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Effects of the Air Quality in Equine Stable Environments on the Respiratory Health and Allergy Response of Human Personnel: A Review

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Abstract

Many studies have evaluated the impact of poor stable air quality on equine respiratory health and respiratory illness in horses. Many factors contribute to poor air quality conditions in the equine stable environment, including ventilation rates, humidity levels, presence of noxious gases, rate of fungal spore production, and level of airborne organic and inorganic dust particles. While the implications of poor air quality for equine health are well-documented, far less is known about how air quality impacts human stable personnel. This literature review seeks to evaluate the implications of poor equine stable air quality on the respiratory health and allergic response of human personnel and consider management strategies to mitigate these risks. Management practices that have shown efficacy at reducing the levels of respirable particles and improving air quality include the use of clean, low-dust bedding and hay, turning horses out of the stable for long periods of the day, and ensuring the stable is adequately ventilated. Findings suggest the most common cause of increased respirable airborne particulate matter (APM) in equine stable air is the dispersion of settled dust during daily barn management and cleaning practices. Many of these practices are required to maintain an environment that meets equine health and husbandry needs, so further research is warranted to determine ways of reducing workers' exposure to APM during these activities.

Introduction

Many studies have correlated poor air quality in stabling areas—especially high dust levels—with an increase in respiratory illness occurrence and severity in horses. It has also been found that horses and humans have incredibly similar clinical, pathological, and physiological responses to inhalation of particles that are known to cause respiratory illness. In horses and humans both acute and chronic respiratory reactions have considerable symptom overlap. Both species commonly display clinical signs including coughing, labored breathing, increased mucus secretion, increased white blood cell counts, and bronchitis (Ghio, 2006). Because of the similarities between these species' response to inhalation of particulate matter and the knowledge that in horses these conditions are commonly developed due to poor air quality in stabling areas, it can be assumed that the human stable personnel who are regularly exposed to stable air are at risk for developing respiratory diseases, as seen in horses.

While few studies have been done to date on how the human respiratory system is impacted by exposure to equine stable air quality, pilot studies have been conducted using surveys to track the incidence of respiratory disease and allergy symptoms in stable workers. Studies have also been conducted to determine levels of airborne particulate matter (APM) exposure within equine stable environments, including determining the major components within stable APM that lead to chronic respiratory diseases.

When evaluating the causes of increased respiratory and allergy symptoms of equine stable personnel compared with the general population, there are two major categories of irritants. These are APM and horse allergen. Airborne particulate matter is responsible for respiratory irritation and illnesses such as chronic bronchitis and particulate-based lung damage. There are increased concentrations of APM in stables due to lack of adequate ventilation, high microbe production rates, and dispersion of particles during routine stable activities. For equines diagnosed with respiratory disorders such as recurrent airway obstruction and inflammatory airway disease, the primary management strategy is providing a low-dust environment (Claußen and Hessel, 2017). Adopting a low-dust management strategy is likely beneficial for all equine residents, as well as would decrease the severity, and possibly prevalence, of respiratory disease in human personnel. Horse allergen and dander leads to allergy symptoms in sensitized individuals, such as rhinitis, atopic dermatitis, and asthma. Allergy symptoms are commonly caused by allergic sensitivity to horse dander but can also be triggered in individuals sensitized to mold, plant pollen, or dust, which are prevalent in stable environments.

This review seeks to evaluate the implications of poor stable air quality on the respiratory health and allergic response of human personnel and consider management strategies to mitigate the known risks.

Incidence of Respiratory Disease and Allergic Response in Equine Personnel

Tutluoğlu et al. (2002) sought to determine if exposure to horse hair causes increased allergy symptoms and respiratory inflammation. The study surveyed over one-hundred grooms regarding allergy and respiratory symptoms and health history, and conducted respiratory examinations on participants. Allergic sensitivity to horse hair, asthma, allergic rhinitis, allergic conjunctivitis, and atopic dermatitis were higher in grooms than in the control group. Sensitivity to horse hair was 12.8% in grooms and 4.3% in the control. Prevalence of asthma was 14.4% in grooms and 5.4% in the control. Allergic rhinitis was found in 42.4% of grooms and 18.4% of the control. Rate of allergic conjunctivitis was 35.2% in grooms and 15.2% in control, and atopic dermatitis was seen in 32.8% of grooms and 8% of the control group. 9.6% of grooms also reported worsened symptoms while at work. The study found a 3.75-fold increase in allergic sensitization to horse hair in the grooms and that sensitization to horse hair increases the risk of asthma by 4.53-fold. This data suggests regular exposure to horse hair increases the risk for horse allergy, which in turn increases the risk of developing respiratory conditions. Sensitivity to horse hair, allergic rhinitis, allergic conjunctivitis, and atopic dermatitis were significantly higher in grooms than in the control group, however asthma—while more prevalent in grooms than the control group—was not significantly higher in the grooms (Tutluoğlu et al, 2002). While not all data points were statistically significant, the trend of increased allergy and asthma symptoms in grooms warrants further investigation.

A similar study conducted by Gallagher, et al in 2007 surveyed horse trainers and vegetable growers in New Zealand to evaluate the respiratory health effects of working with horses compared to other types of agricultural work and additionally sought to uncover potential confounding factors. The study found the prevalence of allergies and current asthma was similar for both groups, but the horse trainer group reported a higher incidence of bronchitis and organic dust toxic syndrome/farmer's lung. Interestingly, this study noted higher prevalence of all respiratory disease symptoms in female vegetable growers compared to male growers, but in the horse trainer group gender had no effect. The study also noted full-time horse trainers reported more symptoms than those working less than 40 hours a week, suggesting a positive correlation between increased respiratory and allergic disease and increased exposure (Gallagher et al, 2007). This study's major limitation is that it was a voluntary written survey, and thus there was no physical examination to confirm symptom prevalence. Because the data is only what was reported by each agricultural worker, there is moderate risk of error due to misclassification or erroneous reporting.

In 2009 Mazan et al conducted a questionnaire study comparing the respiratory and nasal irritation symptoms of those with equine exposure to a control group of people with no equine exposure. The test group of people exposed to horses was further divided into those with high exposure and those with low exposure. High exposure was classified as spending more than 10 hours a week in equine stables—most stable personnel were assumed to fall into this category—and low exposure was less than 10 hours a week in the stable—assumed to be comprised of riders and other casual participants. 77% of barn-exposed participants fell in the high exposure category. Significantly more barn-exposed participants reported experiencing respiratory symptoms than no-exposure participants, and significantly more high-exposure participants reported symptoms than low-exposure participants (59% and 26% respectively. 15% of no-exposure participants reported respiratory symptoms). There were fewer reported cases of nasal irritation overall, but the trend was the same with nasal irritation as with respiratory symptoms—39% of the high-exposure group, 17% of the low-exposure group, and 12% of the no-exposure group reported nasal irritation (Mazan et al, 2009). As with the questionnaire study by Gallagher et al (2007), this study relied only on self-reported symptoms, which could differ from the actual prevalence of respiratory and nasal irritation symptoms experienced by each population.

A study by Samadi et al into the exposure of equine stable workers to inhalable dust, endotoxins, and β(1→3)-glucans collected samples from stationary and personnel sampling areas in four different stables during each of the existing shifts at each stable. They found that 90.5% of samples contained endotoxin levels exceeding the Dutch recommended exposure limit, but dust levels collected by the personnel samplers were within the recommended limits. Samples from the morning shift—when the majority of stable chores were carried out—showed the highest levels of exposure to dust, endotoxin, and β(1→3)-glucan. These results also showed significant variation in between-worker and inter-worker dust exposure levels, meaning different times and tasks result in different exposure levels. Even so, it was concluded the high dust, endotoxin, and β(1→3)-glucan exposure posed risk for respiratory inflammation and infection (Samadi et al, 2009).

In addition to stable workers such as grooms who carry out routine tasks and riders who generally spend less time in stables than equine professionals, riding instructors may be exposed to additional risks. Data has indicated riding instructors, who often spend extended periods in indoor riding arenas, are diagnosed with respiratory conditions including chronic bronchitis, asthma, and rhinitis at significantly higher rates than the general population. And, riding instructors who spend the majority of their time teaching indoors reported being affected by chronic bronchitis symptoms at a higher rate compared to instructors who spent the majority of their time teaching in outdoor settings—40% and 26% respectively (Venable, at al. 2016).

Components of Air Quality

Airborne Particulate Matter

The cause of chronic respiratory disease is inflammation in the lower respiratory tract caused by irritation and minor damage that occurs when dust is inhaled (Clements and Pirie, 2007). The term "dust" is used colloquially when referring to any small particles that are seen floating through the air before settling on various surfaces. These airborne particles are more technically referred to as airborne particulate matter (APM) and are comprised of many more components than dust alone. APM is the collective term for any airborne particles and can be further classified as aerosols, bioaerosols, and dust, or, more simply, as inorganic dust and organic dust. Bioaerosols are the particles more commonly referred to as organic dust and are particles released from any living organism (Claußen and Hessel, 2017). Bacterial endotoxin and mold β(1→3)-glucan have been determined to be common in organic dust and have major pro-inflammatory affects. Exposure to endotoxins results in increased incidence of airway inflammation and respiratory diseases including asthma, chronic bronchitis, and organic dust toxic syndrome (Samadi, et. al, 2009). Some organic dusts also have animate properties. Particles with animate properties are living microorganisms such as bacteria, fungi, viruses, and mites (Claußen and Hessel, 2017).

The APM found in equine stable environments is a mix of organic and inorganic materials and commonly has higher concentrations of organic particles—which are a known cause of respiratory disease—than in other environments such as homes and non-agricultural workplaces (Wålinder et al, 2011). In equine stables, bacterial and fungal spores make up a large portion of the respirable particles. These spores are carried on bedding and hay, and can grow on many stable surfaces in the presence of moisture. Elfman et al (2009) found *Streptomyces* was the most common bacteria present in the stable environment. The most common fungal species found were *Cladosporium*, *Alternaria*, and *Aspergillus* which are all major sources of mold spore release and human allergy (Elfman et al, 2009).

Airborne particulate matter can also be classified by size based on diameter. The current standard classification system is based on how each particle size affects the human respiratory tract when inhaled. Smaller particle sizes can penetrate farther into the respiratory tract than particles with larger diameters, thus this system for size classification also provides insight into what portions of the respiratory tract will be affected by a given particle size (Fleming et al, 2008). The inhalable APM fraction contains all particles <100 µm that enter the nose or mouth during inhalation. The extra-thoracic fraction is comprised of particles 100-10µm which penetrate no farther than the larynx. The thoracic fraction contains particles <10 µm. The tracheobronchial fraction contains particles 4-10 µm which penetrate farther than the larynx but generally not all the way to the alveolar sacs—although there is a possibility small numbers of these particles occasionally do make it to the alveolar sacs. Finally, the alveolar permeable fraction, or respirable fraction, are the portion of airborne particles small enough, <5μm, to enter the peripheral airways and cause inflammation (Claußen and Hessel, 2017) (Fleming et al, 2008). The small particles of the respirable portion are the leading cause of particulate-based lung damage (Clements and Pirie, 2007)(Venable et al, 2016).

Ultrafine particles are the portion of APM less than 0.1μm in diameter (Wålinder et al, 2011). Ultrafine particles are of particular concern because they can reach the smallest sections of the respiratory tract and are able to diffuse into the alveoli (Claußen and Hessel, 2017), and therefore are often the cause of particulate-based lung damage (Venable et al, 2016). These smallest particles also remain airborne for longer periods than larger particles and are more efficiently cleared through ventilation than waiting for them to settle (Auger and Moore-Colyer, 2017).

Noxious Gases

While a less common concern than APM, air quality also includes the levels of noxious gases in the air. Noxious gases originate from various natural and anthropogenic sources, including release by animals, the microbial breakdown of manure, and farm equipment and machinery. The most common noxious gas of concern in equine stables is ammonia, but carbon monoxide, carbon dioxide, carbonyl sulfide, and methane are also possible concerns, although unlikely in equine stables which tend to have relatively low stocking densities compared to other livestock facilities (Curtis et al, 1996)(Kwiatkowska-Stenzel et al, 2014).

The human occupational exposure limits for ammonia—established by the American Conference of Governmental Hygienists—are 25ppm over a long, 8-hour period, and 35ppm for short term exposure, which is defined as 10 minutes up to four times per day. The continuous exposure limit for animals—set by the International Commission of Agricultural and Biosystems Engineering—is 20ppm (Curtis et al, 1996). A study by Kwiatkowska-Stenzel et al (2014) evaluating common noxious gases in stables found the levels of all gases tested for were below the acceptable level in a stable performing an effective mucking regime. Ammonia, carbonyl sulfide, and methane levels were greatest at 4:00am, a significant increase from the other samplings occurring at noon and 8:00pm. These increases are likely of natural origin, and the highest concentration of gases with anthropogenic origin occurred at noon—due to the use of equipment with internal combustion engines and heaters during routine stable chores. Air flow was lowest at the 4:00 am sampling, due to the stable doors being closed and all horses being inside overnight, which could account for the increased overnight gas levels. This study did not find a significant difference in noxious gas level with height, although an earlier study by Curtis, et al (1996) found ammonia levels were higher closer to the ground and were decreased with the use of absorbent bedding.

Production of noxious gases is influenced by bedding type and mucking regimen. Fleming, et al (2009) evaluated the gas production associated with three different bedding materials— wheat straw, wood shavings, and wheat straw pellets—and then with three different mucking regimens when bedding material was consistent. When mucking regimen was the same, the wheat straw resulted in the lowest ammonia production which was significantly lower than straw pellets, but not significantly lower than that of wood shavings. When comparing mucking regimens, it was found complete removal and replacement of bedding each day resulted in the highest gas production. The lowest gas production occurred when feces were removed and a small amount of bedding was added daily, and the bedding was entirely removed and replaced every two weeks. A positive correlation was seen between air temperature and ammonia concentration, meaning there were higher ammonia levels recorded at increased air temperatures (Fleming et al, 2009)(Kwiatkowska-Stenzel et al, 2014), and the presence of high dust concentrations can exacerbate the effects of ammonia, as dust particles carry ammonia into the alveolar sacs of the lung (Curtis et al. 1996).

Allergens from Horse Dander

Similar to the cause of chronic respiratory disease, allergic reaction occurs as a result of irritation when a sensitized individual comes into contact with the allergen they are sensitized to. Allergic reaction can occur in many forms and levels of severity, but the most common symptoms occur in the nose, throat, eyes, and skin as a result of immune system overreaction to the allergen (AAAAI, 2021). While stable personnel may experience allergic response from a variety of materials in stables—including mold, hay, seasonal pollen, and dust—another aspect of stable environments that can cause allergic reaction or respiratory inflammation is the presence of horse allergen. While there are a number of known horse allergens—Equ c 1 through Equc c 5—the major horse allergen is Equ c 1 (Liccardi, et al. 2012). Equ c 1 is a lipocalin protein that is found predominantly in horse dander and saliva. Animal allergens are produced in many bodily substances and are excreted through shedding dander and hair and through the secretion of fluids. While lipocalin allergens are the major cause of allergic sensitization and reactions, other known horse allergens—within the albumin category—are a lesser concern but are associated with cross-reactivity between species (Zahradnik and Raulf, 2014).

Exposure to animal allergens is a risk factor to developing sensitization and other allergic diseases such as asthma, rhinitis, and dermatitis. While the presence of animal allergens is universal, the concentration of these allergens varies greatly with location. In addition to direct exposure, these allergens can be carried through the air on dust particles, as well as can be transported on other objects. Equ c 1, along with other lipocalin animal allergens, is easily dispersed through the air and sticks to clothing and other surfaces. These properties make dispersion of the allergen easy, and Equ c 1 has been found in environments well-removed from horse stables. While the allergen can travel various distances from stables, indirect contact generally occurs in concentrations too low to elicit an allergic response, and people in direct contact with horses comprise the majority of those affected by equine allergen (Liccardi et al. 2012)(Zahradnik and Raulf, 2014).

Emenius et al conducted a study to determine the distance of dispersion of horse allergen in air and settled dust, with the goal of determining the accuracy of the recommendation that residential and academic buildings not be placed within 500 meters of a horse stable. This recommendation was made to prevent members of the public with horse allergen sensitivities from being exposed to horse allergen, but in Sweden—where this study was conducted—many buildings have far less than a 500-meter distance to horse stables. The study used a newly developed monoclonal antibody ELISA assay (mAbs) specific to horse allergen to test the level of horse allergen in air samples collected within, just outside of, 12 meters from, and 500 meters from a horse stable. The results showed the level of airborne horse allergen within the stable was more than 500-fold higher than that just outside the stable, and 3,000-fold higher than in air samples collected 12 meters from the stable (Emenius et al, 2001).

The study also tested samples of settled dust collected from sheltered areas at increasing distances outside the stable. These settled dust samples showed a decreasing trend in level of horse allergen present with distance from the stable. There was no horse allergen found in any sample farther than 100 meters from the stable. These findings suggest the dispersion of horse allergen across large distances is limited due to rapid dilution of airborne allergen (Emenius et al, 2001).

Liccardi et al (2012), in a study on the prevalence of horse allergy, noted participants in the study with previous direct contact with horses had a higher production of IgE antibodies against horse serum proteins than participants with indirect exposure or no known exposure. This means the previously exposed individuals were more sensitive to horse dander and had a greater immune reaction following contact with the allergen (AAAAI, 2021). Other possible risk factors for sensitization this study found were family history of allergies, allergic sensitization to other animal lipocalin allergens such as cat or dog allergen, and being of the female sex. The study concluded that sensitization to horse allergen can occur without direct contact due to the prevalence of horse allergen in public spaces and the cross-reactivity of patients who are allergic to other animal lipocalin proteins, such as dog or cat allergens (Liccardi et al, 2012).

There has been speculation that the allergen in horse dander varies by breed and that the Bashkir breed is hypoallergenic. A study evaluating the allergenic composition of dander samples from eight different horse breeds—including the Bashkir horse—determined there were no apparent breed-specific allergens. All dander samples studied contained known horse allergen. This study also found variation in the allergenic compositions of horse dander within a single breed, further confirming there are no breed-specific allergenic components. It was found the Bashkir horse's longer hair length tends to release less dander than is released from breeds with shorter hair length, and the supposed hypoallergenic status is likely due to this lower level of allergen release rather than no presence of allergen (Felix et al, 1996).

Periods of Increased APM

The concentration of airborne particulate matter in a given stable environment is resultant of the rate at which particles are disrupted and released into the air, the size of the stable, and the rate of clearance from the air by ventilation or settling (Curtis et al. 1996).

APM concentrations tend to be higher in the summer, as increased temperatures and humidity stimulates the growth of fungi and bacteria (Witkowska et al, 2012). This is an interesting finding, as stable air quality is generally considered to worsen during the winter months due to reduced ventilation when doors and windows are kept closed. If it is true that more APM is generated during the summer and the increased ventilation rate from keeping doors and windows open for greater periods is able to disperse this increase, then improving ventilation during the winter months may produce much improved conditions, possibly the best all year.

A study by Elfman et al published in 2009 studied the differences in air quality of one stable in summer and winter and sought to determine whether the respiratory system of the stable workers was impacted by seasonal air quality changes. During winter months it is common in cold climates to keep stable windows and doors closed for much of the day in order to raise the internal temperature. While a closed stable can offer a more comfortable environment, keeping windows and doors closed greatly reduces natural ventilation. This study collected air samples from stationary pumps placed just outside stalls at three points in the stable and used pumps attached to the clothing of stable personnel to sample respirable dust in the breathing zone of the workers. These samples were collected over a period of 4-7 hours, beginning at the start of morning stable activity. Most stable chores were completed during the morning shift. Samples of settled particulate were collected by surface sampling the outer wall of three stalls. A questionnaire survey and symptom diary were used to collect information regarding the respiratory health and symptoms experienced by stable personnel, and nasal lavage was used to evaluate activity of eosinophils, neutrophils, and albumin—markers of allergic reaction, rhinitis, and mucous production.

The results of this study indicated that during the summer sampling the air particle load was less than that during winter. Total and respirable APM was relatively low during all times of year, and well within acceptable limits, but was slightly higher during winter. The level of ammonia in summer was just above the occupational limit and the hygienic limit for horses, but ammonia level could not be determined during winter sampling, so the study was unable to find a reference for ammonia level change. While there is no official limit for β-glucan or endotoxin, studies have shown no poor health effects at levels of 20 ng/m^3 and 10 ng/m^3 respectively. In this stable, levels of β-glucan and endotoxin were slightly higher than these levels, but the effect of this concentration on human and animal health is unknown. The results of the survey and nasal lavage sampling found some cases of increased mucous secretion and respiratory inflammation in members of the stable personnel, but the stable under investigation had a high turnover of employees, creating differences in the persons at each sampling time. Due to this, only one employee was present at all three data collections and the data regarding personnel symptoms from surveys and nasal lavage likely does not accurately show changes in an individual's respiratory health and symptoms over time when exposed to the equine stable environment (Elfman et al, 2009).

The most common horse housing structure in the United States is a large, enclosed barn containing multiple stalls, in which many horses share the same airspace. However, Auger and Moore-Colyer suggested the single box stable design, where each horse is housed in a stall separate and has no shared airspace—more common in Britain—can provide improved air quality since the influence of neighboring stalls and stable management activities is removed. Additionally, horses housed in individual stables will be exposed only to the airborne dust generated from their own bedding and forage, while horses with a common airspace will be exposed to dust generated from surrounding stalls which results in an environment with an overall higher dust concentration (Auger and Moore-Colyer, 2017). These findings seem to recommend that future construction of stables following the single box design would be beneficial for respiratory health, although the enclosed stable design is much more practical in colder climates.

Clements and Pirie (2007) found that the air quality in a given stall is heavily influenced by the air quality of the surrounding stalls and stable areas. It has been shown that employing a low-dust management system in one stall can reduce the overall level of airborne dust in the barn as a whole. However, the opposite effect—the higher dust areas negatively effecting the stall with a low-dust system in place—will remain (Auger and Moore-Colyer, 2017). Airy barns with high ceilings tend to have lower concentrations of air particulate matter within the breathing zones of horses and personnel when compared to barns with shorter ceilings and high solid walls separating each stall, due to increased ventilation throughout the barn and a greater amount of air held within the building which decreases the overall concentration of airborne particles (Claußen and Hessel, 2017).

Monthly observations of airborne fungi in three differing stable designs, each with a different level of openness to the outside, yielded evidence that airborne fungal concentrations are lowest in the autumn. There was no significant difference in concentrations of airborne fungi between the three stable designs, which seems to indicate factors other than stable structure have the largest influence over the presence of airborne molds. It is suggested that focus be placed on management practices to limit dust and mold contamination (Nardoni et al. 2005). Additionally, air quality will be influenced by the quality of air outside the stable, thus the climate and other environmental factors should be considered. Cool and humid climates had less air particulate matter in horses' breathing zones than hot and dry climates, due to humidity reducing the amount of airborne dust both within and outside the stable. (Claußen and Hessel, 2017).

Many of the studies evaluating the levels of airborne and inhalable dust particles throughout the day noticed an increase in airborne respirable dust particles during the periods during and immediately following a number of routine stable management activities. Sweeping aisle ways was found to increase the concentration of beta-glucan, respirable particles, and endotoxins in the breathing zone of stables workers by factor of 4.9, 4.4, and 3.6, respectively. The process of mucking out a stall was seen to increase the level of respirable dust in that stall by a factor of 19 and increased the level of respirable dust in an adjacent stall by a factor of 9 (Claußen and Hessel, 2017). Levels of ammonia gas in the air similarly increases during the mucking out process (Flemming et al, 2009).

Samadi et al noted the majority of stable cleaning tasks were performed during the morning shifts, fewer cleaning tasks were performed during the afternoon shift, and an overnight shift was mainly observational and few or no cleaning tasks were carried out. Because of this distribution of tasks, the workers during the morning shift were exposed to greater levels of APM than those working the later shifts. In this study it was determined the task of sweeping increased the stable worker's dust exposure by a factor of up to 4.9 (Samadi et al, 2009). Wetting the aisleways before sweeping is one recommended practice to reduce the level of dust released during sweeping, in addition to keeping doors and windows open during periods of high stable activity (Claußen and Hessel, 2017).

Equine jobs other than as a trainer or stable worker also have high dust exposure levels. Samadi et al (2009) found the work zone of a farriery contained high dust levels. Although these dusts were low in endotoxin and β(1→3)-glucan, likely due to the dust containing higher percentages of inorganic components (metal) than organic components.

Contrary to the studies mentioned above, Gallagher et al (2007) suggested the activities most associated with elevated risk of bronchitis or other respiratory disease include feeding powder supplements, spreading hay, and grinding oats. This study did not find the mucking out process or use of different bedding types increased risk of respiratory disease.

Mitigation Through Management

Ventilation and Air Exchange Rate

Curtis et al (1996) found the rate of clearance for all airborne particle sizes being measured was more efficient in a high ventilation environment than in a low ventilation environment. Most equine stables rely on natural ventilation, which is the flow of air through openings in the stable walls and roof generated by air pressure differences and temperature differences on the interior and exterior of the stable. Openings through which air flows include openings designed expressly for ventilation purposes—such as doors, windows, and vents—as well as smaller openings such as cracks between boards on stable walls and around doorframes (Claußen and Hessel, 2017). One way to improve stable air quality is through the installation of mechanical ventilation systems. These systems are designed to improve indoor air quality by using fans to increase the air exchange rate so that airborne particles are removed more efficiently than if relying on natural ventilation alone (Curtis et al, 1996). The amount of air changes per hour (ac/hr) required for sufficient clearance of APM and humidity varies by stable due to variance in the production and release of airborne particles, humidity, and noxious gases, as well as the size of the stable which influences overall concentration of APM (Claußen and Hessel, 2017).

The installation of a mechanical ventilation system does not guarantee improved air quality, and care must be taken to ensure the system is set at an air flow rate to allow adequate APM removal without producing excessive exchange rates that could cause the resuspension of settled particles. High air exchange rates resulted in an increase of the APM concentration in a stable during periods of stall cleaning activity, which is suspected to have occurred from the increased air flow dispersing the APM generated from stall cleaning into the air throughout the stable rather than the increased APM staying near the site of activity—in this case the individual stalls. Although total APM concentration was increased during these periods of activity, the concentration returned to pre-activity concentrations more rapidly compared to the facility under a natural ventilation system (Claußen and Hessel, 2017). Not only does this reinforce the findings that increased air exchange rate carries away more APM than lower air exchange rates, but it also suggests that APM remaining suspended and being carried out of the stable may be a more efficient way of removing APM from the stable environment than a combination of lower air exchange rates and settling.

Wålinder et al (2011) studied the use of a mechanical ventilation system to improve stable air quality and the related symptoms of airway inflammation in horses and humans. In this study winter air quality was evaluated before and after a mechanical ventilation system was installed. This ventilation system increased the air exchange rate to a minimum of 400 L/s in cold weather and a maximum of 2,200 L/s in warm weather. The results of winter air quality readings were also compared to the summer air quality within the stable before the ventilation system was installed—assumed the season of best natural ventilation and air quality. The results showed a reduction in CO_2 and ammonia. There was also a winter reduction of ultrafine particles and horse allergen, although the level of these were lowest in the summer prior to installation. Total dust level was not significantly changed, and respirable dust level actually increased slightly with the addition of the ventilation system, from winter and summer values of 100 µg /m^3 and 70 µg /m^3, respectively, prior to installation and a winter value following installation of 130 µg /m^3. There was also an increase in fungi following the installation. Following installation, reduced mucous production was seen in the horses, suggesting a positive effect, but two of the 14 horses exhibited increased respiratory inflammation. There was no difference in the respiratory health of the human personnel or riders under either ventilation system (Wålinder et al, 2011). These results suggest an improvement in winter air quality with the addition of the mechanical ventilation system, but not all aspects of air quality were improved and there is possibility the overall improvement is negligible as it relates to lessened respiratory inflammation.

Claußen and Hessel report a similar study that introduced a mechanical ventilation system set at an exchange rate of at least 1,440-1,980 m^3/hr. The results of this study showed a 32.5% reduction of airborne ultrafine particles, and, most significantly, 84.72%, 98.73%, and 97.73% reductions, respectively, of airborne horse allergen, bacteria collected from stable surfaces, and fungus collected from stable surfaces. This large reduction in surface microorganisms was thought to be due to reduced humidity in the stable—as excess humidity was carried out by the increased air exchange rate—leading to a reduction in microorganism growth on stable surfaces. (Claußen and Hessel, 2017).

Soaking Hay

In addition to barn design, there are many management practices that have shown success in reducing APM. These practices often correspond to the stable components and activities that tend to increase the incidence of APM, one such being the feeding of hay. Some studies suggest feeding haylage instead of dry hay to reduce respirable dust concentration, but the practice of feeding horses haylage or silage is uncommon in the United States. Hay tends to have a higher level of contamination by microorganisms, such as bacteria and fungi, than does haylage or silage. This is due to the higher pH of the fermented forages, which retards microbial growth (Claußen and Hessel, 2017). Clements and Pirie's (2007) findings suggest immersed and soaked hay contains less respirable dust, and thus suggest feeding immersed or soaked hay as an alternative to feeding haylage.

Clements and Pirie (2007) evaluated the respirable dust concentration in hay that had been briefly immersed in water compared to hay that had been soaked for 16 hours. Both methods loaded the hay into a hay net prior to immersion or soaking and fed from the hay net. They found a statistically higher mean respirable dust concentration in dry hay compared to immersed or soaked hay, and a significantly higher maximum respirable dust concentration in dry hay than immersed hay. There was no statistical significance between mean respirable dust concentration in immersed and soaked hay, or between maximum respirable dust concentration of soaked hay compared to dry or immersed hay. These findings suggest feeding hay that has been fully immersed in water for a short period of time is the best way to reduce respirable dust concentration, when compared to feeding hay dry or after hours of soaking. This is doubly beneficial when compared to feeding soaked hay, because the longer hay is soaked the less nutritive value it will hold (Clements and Pirie, 2007).

Steaming hay, an alternative to soaking which works in the same fashion, has been shown to reduce airborne respirable dust and viable microorganisms by over 99% (Auger and Moore-Colyer, 2017). While this resulting decrease in airborne particle release had a positive effect on air quality and the respiratory health of stable inhabitants, costs of the equipment and labor required to steam hay is not economically feasible for most equine stabling businesses. The specialized equipment required for steaming is itself expensive, and only small batches of hay can be steamed at once, making steaming hay a labor intensive process. Steaming may be feasible for small operations, but soaking hay is a more common and cost-effective alternative. There has been research into options for steaming full square haybales, but these studies found unequal distribution of steam throughout the bales led to a lesser reduction in APM released and increased mold contamination than when hay was steamed in batches. Additionally, the process of steaming entire bales increased the amount of bacterial growth in the hay by over 100% (Claußen and Hessel, 2017).

The conditions under which hay is stored also contribute to the amount of particulate matter present in the hay, and thus affects the possibility of airborne particulate matter being released. Long periods of storage between harvest and feeding out can increase the concentration of particulate matter due to further drying of the hay itself, risk of increased microorganism growth, and from airborne particles present in the storage area settling on the hay (Claußen and Hessel, 2017). To avoid these increases in risk of particle generation hay should be fed in a first in, first out fashion, ensuring older hay is not kept in storage for extended periods while newer hay is loaded in front of that hay.

Additionally, only the minimum amount of hay necessary for management efficiency should be stored in the equine stabling area. It is suggested only that which is needed for 2-3 days should be kept in the stabling area. And, hay should never be stored in lofts above the animals. Keeping large amounts of forage or bedding in the stabling area has been shown to increase the level of airborne particulate matter in the stable (Clements and Pirie, 2007).

Bedding Material

A study conducted in 2008 investigated which bedding materials create the most improved air conditions in equine stable environments by comparing the level and particle size of airborne particulate matter associated with wheat straw, wood shavings, hemp shives, linen shives, straw pellets and shredded paper bedding materials under laboratory conditions. This study also evaluated wood shavings, wheat straw, and straw pellets under actual stable conditions. The laboratory tests showed the shives—both hemp and linen—produced the highest airborne particle load. The load from these materials was 100% greater than that of wood shavings, 200% greater than that of straw, and 700% greater than that of straw pellets—from which the least APM load was produced. In the stable environment tests, straw pellets were again found to generate the least airborne particles. It should be noted that straw was strewn each day, while the shavings and straw pellets were allowed to form a mattress and were not re-strewn during the course of data collection. This leaves the question whether an increase in airborne particles would be seen in the shavings and straw pellet bedding if additional material was added daily (Fleming et al, 2008).

Throughout the above study, the straw bedding contained the highest concentration of microorganisms, although the highest concentration of mold was found in the straw pellets. All materials tested showed an increase in airborne particle generation during routine stable activities such as mucking out, sweeping, and feeding. This increase was significantly greater for straw than the other bedding materials, and the airborne particles released from the straw bedding remained in the air longer than that from the other materials. This confirms previous findings that bedding horses on shavings produces lower levels of airborne particles and fungal spore growth than straw bedding (Fleming et al, 2008).

In 1996 Curtis et al compared paper bedding to straw bedding, both observed under high and low ventilation conditions. They found paper produced a much lower concentration of particulate matter than straw. In fact, the paper bedding in the low ventilation environment produced significantly less particulate matter than straw in either the low or high ventilation environments.

A correlation has been shown between increased displacement of bedding material during a given mucking system and the level of APM released. Mucking systems where stalls are completely mucked out—all bedding removed daily along with urine and fecal matter—or daily removal of urine and fecal matter were shown to generate higher concentrations of APM than a mattress mucking system in which bedding was added daily but no manure was removed. Because in all three of these systems bedding was added daily, the additional displacement of bedding from mucking out—either completely or only manure removal—led to higher APM generation (Claußen and Hessel, 2017). While mucking systems should be designed with the reduction of APM release in mind, additional effects on equine health from forgoing daily removal of fecal matter and urine were not studied and warrant consideration before the adoption of a mattress mucking system is established.

Changes in bedding material and mucking regimen can also be used in addition to changes in other management practices to form holistic management systems designed to limit release of APM in stable environments. Woods et al (1993) compared a “conventional” management system—straw bedding and feeding obviously dusty hay, with daily amounts of hay and straw stored in front of stalls—to a recommended, low-dust management system—wood shavings and pelleted feed (no hay fed) and no shavings or hay stored in the barn. Switching from the high-dust conventional system to the recommended low-dust system reduced the total airborne dust concentration by 54%. The recommended system was also correlated with a reduction in aeroallergens, although in both systems the recorded aeroallergen concentrations were at levels that trigger asthma and allergy reactions in humans. In both management systems the amount of total dust in the air was greatly reduced over night, when there was no stable activity, but the level of respirable dust did not. This confirms larger particles settle throughout the night, but smaller particles remain in the air for much longer periods and rely on adequate ventilation to be cleared (Woods et al, 1993).

When four different forage and bedding combinations—steamed hay and shavings, dry hay and shavings, haylage and straw, and dry hay and straw—in two differing stable designs—American-style barn and individual box stables—were compared, all other management strategies being the same, the straw and dry hay combination produced significantly higher concentrations of airborne respirable dust that the other strategies. The shavings and steamed hay combination produced the least airborne respirable dust in both stable types and had the least variation in dust production values (Auger and Moore-Colyer, 2017).

Growth of bacteria and other microbes in stable environments creates an increased risk of respiratory infection—from the inhalation of airborne microbes—and disease transmission. Microorganism growth is more rapid in humid environments, and ventilation that adequately removes excess moisture from the air within the stable is one major strategy to reduce microorganism growth. Straw bedding has also been found to have higher levels of microbial contamination than wood shavings or paper. Wood of the *Pinacea* family, the most common wood shaving type for equine bedding, has natural antibacterial properties which can reduce the growth of bacteria on bedding, and subsequently reduce the incidence and transmission of disease. Wood shavings were found containing significantly fewer bacterial colony counts than hemp or straw bedding after inoculation with common bacteria and incubation. Wood shavings were also the most absorbent bedding type tested in this study (Yarnell et al 2016).

APM in Indoor Arenas

Indoor riding arenas pose additional challenges to providing equine professionals and horses environments conducive to good respiratory health. Indoor arenas are often poorly ventilated spaces with high concentrations of airborne particulate matter which increase during the periods when horses are being worked—the periods during which equine professionals and riders will be in the arena (Venable et al 2016). The APM of indoor riding arenas is often high in mold and fungal spores. Inhaled fungal spores can increase allergies in stable personnel. This is especially true concerning *Aspergillus* and *Penicillium*, which have particle diameters within the respirable range (Nardoni et al, 2005). Because arenas are used for athletic practice, horses and riders are generally breathing more often and more deeply when in these environments, so maintaining good air quality in these spaces is critical to prevent respiratory inflammation. There are many factors influencing the level of APM in arenas and APM concentrations in these spaces has shown large variance. A few of the factors to consider are the type of riding activity being performed, activity that occurred just prior to a rider entering the arena, the footing type, footing moisture level, location of arena in relation to other stable buildings, and level of arena maintenance (Claußen and Hessel, 2017).

The activity being performed has a large influence on the amount of particulate matter that is released from the footing as it is disturbed by the horse's footfalls. Dispersal of APM is greatest when training at the trot or gallop, and the effects are amplified—leading to a greater concentration of APM—when there are multiple horses working in the arena at one time. Similarly, APM concentrations are highest when horses are being worked in the arena and are lowest after long periods of no arena activity (Claußen and Hessel, 2017).

The footing type and moisture content is another crucial factor in limiting the release of APM, especially molds, in riding arenas and studies evaluating differences in APM concentrations with the use of different footing materials have been undertaken. A study by Rapp et al (cited by Claußen and Hessel, 2017) found sand, rubber, and crushed foam footing types produced the lowest concentrations of organic airborne particles. A mixture of sand and wood shavings was found to be ideal because the majority of particles measured from the sand were of a diameter and weight too great for suspension and produced only low levels of APM. Leather and pure wood shavings released the greatest amounts of mold spores (Claußen and Hessel, 2017). It should be noted, however, that this study only evaluated the organic particles (mold) released from each footing type tested. If inorganic particle generation had been tested, sand may not have been determined as the lowest source of total APM. Additionally, effects of inorganic materials from the crushed foam and carpet fiber footing types on the respiratory system is unknown. It is likely that small fibers could become lodged in the lungs, potentially permanently, so further studies into the airborne particle release and effects of particle inhalation when using these footing types is warranted (Claußen and Hessel, 2017).

In 2016, Venable et al studied changes in APM when a layer of crumb rubber was applied over an existing sand footing. They found a significant decrease in APM when crumb rubber was applied over the sand. Crumb rubber depths of 1.5" and 3" were tested, however there was no significant APM reduction with the increased crumb rubber depth. It was concluded the application of crumb rubber footing overtop existing sand arenas could provide an option for improving APM concentrations in riding arenas, and the air quality improvement will not further improve with a greater depth of crumb rubber (Venable et al, 2016).

The moisture content of arena footing greatly influences the generation of APM. Dry footing allows horses' hooves to sink deeper into the material, which leads to disturbance and dispersion of greater amounts of material than when horses are worked on moist footing. In arenas where the footing has been watered less footing is disturbed and fewer particles enter the air. There is no significant difference in APM release from footing at the optimum moisture level and footing saturated over the optimum level (Claußen and Hessel, 2017).

It has also been found that the air in indoor riding arenas that are directly connected to stabling areas contains a higher concentration of APM than unconnected indoor arenas (Claußen and Hessel, 2017). This is due to APM moving from the stabling area into the riding arena, especially during the periods of high APM-producing stable activity. It has been found that the concentration of airborne mold in a connected arena when the doors separating the arena from the stable are kept open increases by 385.29% during mucking out and increases by 2,752.94% when bedding is being refilled (Claußen and Hessel, 2017). These major increases illustrate the importance of keeping doors connecting indoor arenas directly to the stable closed during routine stable cleaning to prevent the flow of air with a heavy load of APM into the arena. Conversely, it is likely the increased APM concentration in connected arenas when horses are being worked increases the APM in the stable. Additionally, regular cleaning of riding arena surfaces improves the air quality of arenas and reduces the number of mold colonies by over 60% (Claußen and Hessel, 2017).

Conclusion

While much of the literature currently available on the topic of how human personal are affected by the air quality in equine stable environments is based on preliminary investigations, all studies have shown a trend toward increase in symptoms of allergic reaction and chronic respiratory disease in those employed in equine stables when compared to those working in sectors without equine exposure. This suggested increase in incidence and severity of chronic respiratory disease and allergy symptoms warrants continued consideration and further investigation with increased depth and variable controls. Because many of the available pilot studies relied on surveys, which had possibility for error due to the risk of participants over- or understating symptoms, a logical next step would be to continue research utilizing more physical examinations of participants to record present symptoms and symptom severity in greater detail, and to limit the risk of misidentified symptoms.

Another major challenge many studies faced was high employee turnover rates making it impossible to collect data on the effects of long-term equine stable exposure. Future studies looking specifically at the incidence of chronic respiratory disease symptoms and allergy symptoms in equine professionals who have been working in the industry for five or more years could help fill in this knowledge gap.

In addition to expanding what is known about the incidence of these conditions, it is paramount to begin finding practical ways equine professionals can limit their exposure to the airborne particulate matter and allergens present in equine stable air that can lead to these diseases. There have been a few suggestions put forward, but as of yet no research into the efficacy of any given method. As discussed in depth in this review, improving air quality through methods conventionally used to improve air quality for the treatment of respiratory disease in horses have been shown to improve air quality throughout the stable and improve the respiratory function of both horses and humans.

Arguably the largest challenge is determining how to limit stable workers' exposure to APM during routine chores and activities. Gallagher et al (2007) included in their survey of horse trainers and vegetable farmers a question of whether any breathing protection was used during work, especially during high dust hazard activities. The responses indicated breathing protection was commonly used by vegetable growers, but was not commonly used by horse trainers. Because research indicates working in equine stables can lead to respiratory disease predominantly from the inhalation of dust and other airborne particles, the use of breathing protection should be considered by stable workers especially during activities associated with high levels of dust displacement and further research on the use and effectiveness of breathing protection by stable workers is warranted. Curtis et al (1996) encouraged the use of face masks during stall cleaning to protect stable personnel against increased airborne dust and ammonia released during mucking out, but there have been no studies yet published evaluating the efficacy of such measures. With the increase in familiarity and use of face masks during the COVID-19 pandemic, equine personnel may now be more likely to wear breathing protection during work and participate in studies on this question.

In addition to answering the questions this review leaves, similar studies on equine stable personnel could also enhance studies in other disciplines. Mazan et al (2009) mentioned "the role of airborne molds in respiratory disease remains debatable in human medicine" and therefore stable environments—where mold spore levels are high—could provide an ideal setting to further research the effects of individual molds and other individual APM components on human health. Additionally, there is not currently a threshold value established for airborne particle concentrations in equine stables (Fleming et al, 2008). As more studies are carried out evaluating the impact of aspects of stable air quality on horses and humans, it would be beneficial to utilize the results to aid in the development of threshold occupational exposure values to further protect those regularly exposed to such environments.

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