Medication Crushing and Indoor Air Pollution

LeAnn Elizabeth Guess

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Medication Crushing and Indoor Air Pollution

by

LeAnn Elizabeth Guess

An Honors Capstone

submitted in partial fulfillment of the requirements

for the Honors Diploma

to

The Honors College

of

The University of Alabama in Huntsville

November 13, 2020

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Abstract

**Background:** Particulate matter (PM) is a widespread air pollutant composed of microscopic particles and droplets. Medication crushing is commonly used in healthcare practice when a patient cannot swallow their pills. We hypothesized that particles emitted during the crushing and transferring of crushed medications can become airborne and inhalable and pose a possible health risk. This hypothesis led to an experimental research study that was designed to quantify the particulate matter size distribution that is dispersed in ambient air when medications are crushed.

**Method:** The scenario consisted of sixty trials where medication was crushed near a spectrometer. The team modified a digital adjustable torque wrench and set it to 37 in-lbs. to have consistency among all trials. The experiment was repeated 20 times following three situations: immediate vicinity of the spectrometer, one foot away from the spectrometer, and one foot away from the spectrometer under a fume hood. Two tablets of acetaminophen (325 mg/tablet) were crushed during each trial then transferred and mixed with unsweetened applesauce. The data was collected at different heights to represent an actual crushing method (at face level, a standing height, and under a hood) inside a positive pressure cleanroom. These methods were then repeated in an office space.

**Results:** The spectrometer measured 32 different sizes of particulate matter that ranged from 0.0253 micrometers up to 35 micrometers. The baseline was 0 µg/m³ in the cleanroom and 6600 µg/m³ in the office space. Smaller particles were found across all simulations but no particles larger than 3.515 micrometers were detected. It was concluded that particulate matter is emitted during medication crushing. presence of a fume hood, the risk of inhaling these particles is significantly reduced.

**Conclusion:** The team recommends that healthcare professionals wear proper protective equipment, i.e. a respiratory protective device such as a N95 while crushing underneath a fume hood. This combination of protection is hypothesized to provide the highest level of protection from particulate matter.
**Introduction**

In hospital settings, such as medical units and nursing homes, there is a wide variety of medication administration techniques. Administration of medication types include but are not limited to, intravenous, intramuscular, and oral routes. Medications are absorbed and metabolized differently because of their pharmacokinetics. Pharmacokinetics describes the process of absorption, distribution, metabolism, and excretion of a drug. Some factors that affect pharmacokinetics include a person’s body fat percentage, tolerance to the drug, and which organ directly metabolizes the drug (Le, 2019). Because of pharmacokinetics, certain medications may break down faster or slower depending on their route. Typically, oral drugs have a slower therapeutic effect than intravenous. Some oral medicines have special coatings that delay their breakdown; an example of this would be an enteric coating. This is common for oral tablets that need to be broken down by organs other than the stomach because the enteric coating protects the medication from its high acidity.

Pharmacokinetics continues to play an important role when medication crushing is introduced. Not all tablets can be crushed due to a variety of reasons. For example, if a pill has a protective coating such as an enteric coating, the pill would not be absorbed appropriately if crushed. If absorption begins at the incorrect time, the medication would not be as effective as if taken as prescribed. Crushing pills is relevant in patients who are prescribed oral medications but cannot swallow them correctly; this could be due to a multitude of reasons that could be either physical or psychological. Examples include a person who has suffered from a debilitating stroke that may not be able to swallow due to paralyzed airway muscles and a person with dementia who may not be able to understand that they must swallow their medication. For medications that can be crushed, healthcare providers can crush the pill and deliver it through a feeding tube or mix it into soft foods, such as applesauce. This ensures that the patient receives the medication, and that the medication’s pharmacokinetics are not negatively affected, and the dose will be metabolized therapeutically.
Particulate Matters (PM) in different sizes are micron-sized pollutants that have been shown to be associates with adverse health outcomes. While more commonly found outdoors due to pollutants from car emissions, studies have shown that PM can also be found indoors (Airveda, 2017). Several indoor activities such as cooking, cleaning, vacuuming, exercising may increase the indoor levels of PM. However, there is not enough evidence about whether pill crushing increases levels of PM in medication rooms. Therefore, the team created an experimental research study to find whether particulate matter is emitted when crushing medications, and if so, how healthcare professionals can protect themselves.

**Review of Literature**

When selecting appropriate articles, special consideration was taken including specific keywords, inclusion criteria, and exclusion criteria. Databases from which the articles were retrieved from were selected based on their respective genres in the biomedical sciences. The main search engines used was PubMed, a database that accesses MEDLINE articles that is commonly used when requiring medical-focused studies. Keywords used in this database were medication crushing and particulate matter. Due to the narrow scope of this literature review, relevant articles were difficult to collect. Main exclusion criteria limited the articles from being greater than 18 years old and in a non-English language. Specific exclusion criteria limited the articles that did not mention the harmful effects of particulate matter and/or did not reference medication crushing. Inclusion criteria allowed the articles to include a study or research data regarding particulate matter or medication crushing. A total of four articles were referenced.

The first referenced study was conducted in 2018 by Thong et. al (2002) who compared medication loss due to medication crushing. The team tested 24 different crushing devices, which included a mortar and pestle, separate containers, and disposable cups and bags. The drug of choice was paracetamol, a brand name for acetaminophen. A sample size equivalent to 500 mg of paracetamol was collected from 20 tablets and used in all trials. The team concluded that an average medication loss due to crushing and then tapping out the medication into a bag was shown to be 5.8%; however, if the
medication crusher was rinsed twice after being crushed, the amount of medication loss was decreased to 4.2%.

The second study determined that hospital pharmacists who work in drug compounding showed an increase in subjective nasal symptoms. In 2014, researcher Ryoichi Inaba and his team administered a questionnaire to over 500 pharmacists in Japan; this questionnaire asked about subjective symptoms and job environments. The trial group was exposed to drug compounding, a process where pharmacists crush and prepare medications before they are given to a patient at the bedside. A control group was made up of 84 office-based pharmacists who were not involved with drug compounding. The trial group was made up of 495 hospital pharmacists who reported a higher increase in nasal symptoms when compared to the control (Inaba et al., 2014).

The third study by Kienle (2019) focused on hazardous medications and their potential harmful effects to others if not contained appropriately. The study referenced how crushing medications and manipulating medications through drug compounding can lead to contamination and possible injury. Because of this, medications need to be handled in a manner that not only protects the patient but the administrative personnel as well. The study listed a current series of 200 hazardous drugs (HD) and a hierarchy of controls of how to protect oneself from HD. The study gave multiple guidelines on mixing, preparing, and administering HD; this included preparing under vented hoods and using negatively pressurized rooms. The study concluded that personal protective equipment, such as goggles, masks, isolation gowns, and respirators should be used if dealing with any HD (Kienle, 2019).

The fourth study looked at the impact of chronic PM\textsubscript{2.5} exposure and its relations to asthma and COPD mortality rates. An author of this article, Dr. Azita Amiri, was the supervising mentor for this research study so previous knowledge was available. The research team reviewed mortality rates for COPD and prevalence rates for asthma. They specifically studied the impact of PM\textsubscript{2.5} and ozone levels across the southeastern United States during the years between 2005 and 2014. A distributed lag model
was created and showed evidenced of asthma and mortality due to COPD, even at relatively small increases in ambient exposure (<1 μg/m$^3$) (Amiri et al, 2019). This previous study was vital to the research team’s hypothesis since it had previously connected PM$_{2.5}$ and mortality rates. Further research is needed to learn other factors that can increase this risk, including comorbidities and regular exposure to common pollutants.

**Theoretical Framework**

Florence Nightingale, known as the Lady with the Lamp, is known as one of the most important nursing figures in history. She was a vital component in the Crimean War and saved numerous lives by focusing on items such as proper hygiene and sewage disposal (Aravind & Chung, 2010). In her book *Notes on Nursing*, she mentioned how proper ventilation would improve patient care. She suggested keeping windows open and to space out hospital beds to allow increased airflow and improve ventilation (Aravind & Chung, 2010). It was later shown through evidence-based practice that Nightingale was correct in her assumptions; adequate light and ventilation do improve care in hospital stays (Aravind & Chung, 2010). One could hypothesize that Nightingale’s theory concerning ventilation could be applied when crushing pills. If adequate ventilation is not present, patients and healthcare workers could be at higher risk of inhaling particles that could be detrimental to their health.

**Methods**

**Population, Sample and Setting:** The experiment did not involve any individuals except for the research assistant that crushed the medications, so an IRB for human subjects was not required. The scenario was repeated in a positive pressure cleanroom and an ordinary office building, twenty times each at three different proximities of the spectrometer inside the cleanroom and in the office space for a total of 120 trials. PM concentrations were recorded in different sizes, including the following: PM coarse, inhalable, thoracic, PM1, PM2.5, PM4, PM10, and total suspended particles (TSP). These sizes were measured
using GRIMM technology every six seconds. In each simulation, two tablets of acetaminophen (325 mg/tablet) were crushed then mixed with unsweetened applesauce.

**Data Collection:** Data was collected in two separate rooms, a positive-pressurized clean room and a normal office space. A torque wrench was used to keep the same pressure on both pills for every simulation. The research assistant would step into the room or office space area and complete the experiment and would time it. For protection against inhalable particles, the research assistant was donned in full personal protective equipment (PPE): gloves, goggles, gown, mask, and shoe covers. Afterwards the crushing was complete, the assistant would leave the room/office space area for two minutes for any left-over particulate matter to settle and reset the baseline to zero (0) detectable PM. This scenario was repeated 20 times at three different proximities of the spectrometer inside the cleanroom and in the office space for a total of 120 trials.

**Research Design:** This simulation was a type of experimental research. It was completed in a manipulated space where certain variables, such as procedure, pressure, and time, were controlled to investigate the outcome.

**Instruments:**

- **Positive Pressurized Clean Room:** The clean room was a small space that was approximately 8x6 feet. There were two tables, one with a computer and all the spectrometer equipment, and the other with medication, transfer saucers, and the crushing device. The room was pressurized to maintain a higher pressure inside of the clean room than outside of the clean room; this type of pressure is like those found in a medication rooms in hospitals. The pressuring system allowed all particles to stay inside the room so none could escape when entering/exiting the room. This helped enable accurate measurements through the spectrometer.

- **Office Space:** The office space was a part of Dr. Azita Amiri’s office in the University of Alabama in Huntsville Nursing Building. The spectrometer, crushing device, medication, and
transfer saucers were all placed on a table where the experiment was performed. This space was used so the researchers could compare the baseline PM matter of the clean room to learn how much the clean room impacted the presence of inhalable particles.

- **GRIMM 11-D Aerosol Spectrometer and Software:** This device consisted of the spectrometer used to capture particulate matter concentration and the software that was installed into the computer to run and save the data. It reported the amount and size of microns of medication particles that were emitted through crushing.

- **AirAssure PM2.5 Indoor Air Quality Monitor:** This monitor measures the overall quality of the air and how much PM is detected if the amount is over 2.5 microns.

- **Crushing Device:** A generic screw-type pill crusher and an adjustable torque wrench were applied to 37 in-lbs. to crush the medication. The hand-held pill crusher, the Clearwell Mobility Pill Crusher, was modified. A bolt was attached to the top of the pill crusher so the torque wrench could be applied. A holder for the crushing device was also created, which consisted of a wooden frame and large clamps to keep the crusher in place on the table when the wrench was used. This ensured that the same amount of force was used on every pill crush in every simulation.

- **XPert Filtered Balance Systems Fume Hood:** It was a standard fume hood with a HEPA filter that created local ventilation to protect from and limit exposure to hazardous fumes. It was used to determine if this type of ventilation affected the amount of inhalable PM in the clean room and office space.

- **Apple Sauce:** A generic brand, no sugar added applesauce was used for all simulations. Approximately 2 ounces were used for each medication transfer.

- **Transfer Saucers:** After the medication was crushed in the crushing device, it was then transferred to a two-inch plastic dish where apple sauce was previously placed. The crushed medication powder and apple sauce were mixed. Each transfer saucer was cleaned with acetone to be reused for further trials.
• **Pill Cups:** A generic brand plastic pill cup was used to bring in the two tablets of acetaminophen into the clean room/office space. This allowed the research assistant to keep conformity across all trials and introduce as limited PM as possible.

**Procedures**

**Clean Room Procedures**

1. The clean room is entered to ensure that a journal and pencil was in the room, the spectrometer and air quality monitor were working appropriately, the crushing device and scale are in place, and the positive pressure ventilation is working. After this is complete, the room is exited to allow the room to return to baseline PM (0 PM).

2. Outside of the clean room, twenty pill cups were laid out on a table. Two 325 mg acetaminophen pills were then added to each cup. Twenty transfer saucers were then placed on the table with 2 oz. of applesauce placed in each saucer.

3. The researcher then entered the room in full PPE, taking note of the time entered. The researcher brought the pill cup with acetaminophen, the transfer saucer with the apple sauce, and a plastic spoon. The door to the clean room was shut and the experiment began.

4. The pills were weighed and recorded in the journal. The pills were then crushed in the crushing device; the torque wrench was turned three times. After the third turn, the top crusher was opened and the crushed medication was emptied back into the pill cup.

5. Once the crushed medication was in the pill cup, the medication was then mixed into the applesauce in the transfer saucer.

6. Once this was completed, the pill cup, transfer saucers, and the researcher left the room for two minutes. During these two minutes, the researcher rinsed off the pill cup, transfer saucer, and spoon with water and acetone.
7. These procedures were completed at three different vicinities to the spectrometer, twenty times each: immediate vicinity of the spectrometer, one foot away from the spectrometer, and one foot away from the spectrometer under a fume hood for a total of 60 trials in the clean room.

**Office Room Procedures**

1. The spectrometer, crushing device, and air quality monitor are placed on one side of a table in the office space.

2. On the other side of the table the scale, all twenty of the pill cups and transfer saucers were placed. As stated in the clean room procedures, two acetaminophen tablets were added to the pill cups and 2 oz. of no sugar added apple sauce was added to the transfer saucers.

3. The research assistant started the simulation by weighing the cups in the pill cup. Once recorded in the journal, the pills were then crushed in the same way as they were in the clean room.

4. After the pills were crushed, the crushed medication was then transferred to applesauce in the transfer saucer.

5. Once this was completed, the simulation ended.

6. The researcher waited two minutes before the next trial. During these two minutes, the researcher rinsed off the pill cup, transfer saucer, and spoon with water and acetone.

7. These procedures were completed at three different vicinities to the spectrometer, twenty times each: immediate vicinity of the spectrometer, one foot away from the spectrometer, and one foot away from the spectrometer under a fume hood for a total of 60 trials in the office space.

**Results**

After data analysis, it was found that PM is emitted when crushing medications. This is shown in Figure 1, Figure 2, and Figure 3. Figure 1 depicts TSP (total suspended particulate matter) across all sixty clean room trials and Figure 2 depicts TSP across all sixty office space trials. While the cleanroom reduced particulate exposure more than the office space, it is evident that using a fume hood is best practice. When used in combination, using a fume hood in the clean room provided the least exposure.
The data was recorded in GRIMM software and transferred to an external drive. It was then uploaded to Microsoft Excel where the full analysis took place. In the cleanroom, the spectrometer detected numerous zeros in place when there were no activities, and this was considered the baseline PM. To ease synthesizing, the baseline data were removed so only detected particulate matter concentration would be used. This means that measurements were removed from the samples. Figures 1 and 2 show the TSP in the clean room and office space at the three different distances from the spectrometer. Figure 3 shows the TSP for all three distances combined for office space and clean room. This figure illustrates explicitly how the cleanroom particulate matter emission is significantly lower than the office space.

Depending on the size, PM has the risk of being inhaled. Figures 4, 5, and 6 depict how particles between 0.737 µg/m³ and greater have the capability of moving into the airway of healthcare professionals when crushing medications. While the amount of inhalable particulate matter is minuscule when compared to TSP, it is important to recognize that it is evident since researchers do not know the extent of damage these particles can cause.

**Limitations**

There were several limitations to this study. The team only used one medication due to time and monetary constraints. While acetaminophen was ideal for the study, there are hundreds of other prescription medications that can be crushed. These medications could not be used since the team did not have access to them. The study was conducted in a cleanroom, which is different from an actual medication room, where the ventilation varies, and the baseline PM levels are different. Therefore, this study's results might be further from the PM levels during crushing in a medication room.

**Discussion**

Since an increase was found in PM concentration, there is potential that nurses are at risk for inhaling particulates at a microscopic level that could be damaging to their health. The research team found that medication crushing in a cleanroom, especially when utilizing a fume hood, can reduce the
levels of inhalable particles. Due to the lack of other research in this field, the researchers recommend conducting a similar study in a compounding pharmacy. This study would allow healthcare professionals to discover if crushing various of different medications increases their chances of inhaling particles. It is best for healthcare workers, pharmacists, and nurses to consider the risks of crushing medicines as it has the capability of impacting their respiratory health. Going forward, nurses should weight the benefits of protecting themselves when crushing medications for their patients.

**Implications to Nursing Practice**

Since healthcare workers crush medications, this research study is vital because the exposure to PM could have adverse effects on their health. Although an official evidence-based guideline has not been created, possible particulate matter exposure can be prevented in many ways. Firstly, the medication should be crushed away from the face. This includes, but is not limited to, when placing the medicines inside the crusher, the act of crushing the medication, and transferring the medication. This should be done at a substantial distance away from the nose and throat area. Secondly, wearing proper protective equipment, such as gloves and a mask, could also decrease exposure. These two methods combined could dramatically reduce the risk of exposure to possible PM$_{2.5}$.

Another option would be to use a crusher that crushes with the medication inside a disposable bag. Afterward, the medication could then be distributed to the patient via tube feeding or mixed with food. With more potent drugs, such antineoplastics, it could be recommended to crush in a separate area away from other staff and patients with complete PPE. A designated area could be used only for crushing medications; this could be a special area, a negatively pressurized room with HEPA air filters, or the use of a fume hood.
Conclusion

The team researched whether PM is emitted when crushing medications in various circumstances. The trials were completed in a clean room and office space with three different vicinities near the spectrometer: face level, near, and under a fume hood. It was concluded that PM$_{2.5}$ emitted from medication crushing has the potential to be inhaled. These risks are dramatically increased when the subject is not in a positive-pressured clean room or crushing underneath a fume hood. Research concerning these risks needs to be taken a step further in determining the extent of these risks since it is unknown what the inhalation of these particles does to the body over time.

Dissemination of Scholarly Work

The student was unable to present at the 2020 Research Horizon’s Day due to the COVID19 pandemic. The student did present at the Research or Creative Experience for Undergraduates (RCEU) Poster Presentation in September of 2019 and received an award for First Place in the Honors College as depicted in Figure 7.
References


Figures

**Figure 1:** Total Particulate Matter Measured by a Spectrometer in a Clean Room Environment Organized by Particulate Matter Size

- Elevated Crash Cart
- Fume Hood
- Close Up

Figure 1 depicts TSP in the clean room at the three different vicinities to the spectrometer: close up, at a standing height (the team used an elevated crash cart) and under a fume hood. PPM is plotted against the mean particulate size in micrometers. This figure proves that the fume hood significantly decreased the risk of inhalable TSP.

**Figure 2:** Total Particulate Matter Measured by a Spectrometer in an Office Room Environment Organized by Particulate Matter Size

- Elevated Crash Cart
- Fume Hood
- Close Up

Figure 2 depicts TSP in the office space at the three different vicinities to the spectrometer: close up, at a standing height (the team used an elevated crash cart) and under a fume hood. PPM is plotted against the mean particulate size in micrometers. This figure proves that the fume hood significantly decreased the risk of inhalable TSP.
Figure 3. Total Particulate Matter Measured by a Spectrometer Organized by Particulate Matter Size - Comparison of Clean Room Environment versus Office Space Environment

Figure 3 compares the TSP in the clean room to the office space. PPM is plotted against the mean particulate size in micrometers. This figure proves how the clean room causes a significant decrease in TSP when compared to the office space.

Figure 4. Total Particulate Matter Measured by a Spectrometer in a Clean Room Environment Organized by Particulate Matter Size Channel

Figure 4. Represents inhalable, thoracic, and respirable particles from the cleanroom that were collected at the three different vicinities to the spectrometer: close up, at a standing height (the team used an elevated crash cart) and under a fume hood. PPM is plotted against the mean particulate size in micrometers. This figure proves that when concerning particles that can move into a healthcare worker’s airway, the fume hood provides the best protection in the clean room setting.
Figure 5 represents inhalable, thoracic, and respirable particles from the cleanroom that were collected at the three different vicinities to the spectrometer: close up, at a standing height (the team used an elevated crash cart) and under a fume hood. This figure proves that when concerning particles that can move into a healthcare worker’s airway, the fume hood provides the best protection in an office room setting.

Figure 6 represents the combined data depicted in Figures 4 and 5. It proves that when comparing the cleanroom to the office space, the clean room has a significantly decreased exposure to inhalable, thoracic, and respirable particulate matter. When considering TSP, the clean room also has a significant difference.
Medication Crushing and Particulate Matter Concentration

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Introduction

- Previous studies have shown significant relationships between particulate matter (PM) and respiratory/cardiovascular diseases
- Medication crushing is commonly conducted by healthcare workers when a patient has trouble swallowing or is mentally incapacitated
- We hypothesized that particles emitted during medication crushing can become airborne and inhalable
- This hypothesis led to an experimental research study that was designed to quantify the PM concentration that is dispersed in indoor air when medications are crushed

Methods

- A simulation consisting of crushing medication and transferring it was created
- The simulation was repeated in a positive pressure cleanroom and an ordinary office building, ten times each
- PM concentrations in different sizes, including PM coarse, inhalable, thoracic, PM1, PM2.5, PM4, PM10, and total suspended particles (TSP), were measured using Grimm technology every six seconds
- In each simulation, two tablets of acetaminophen (325 mg/tablet) were crushed then mixed with unsweetened applesauce
- To crush the medication, a generic screw-type pill crusher and a digital, adjustable torque wrench applied to 37 in. lbs. were used in all trials to maintain consistency

Results

- Ten simulations were run in a row in one hour, each for 4-6 minutes
- Figure 1 and 2 show the concentration of different sizes of PM in one hour, during the time ten simulations were run, in the office area and cleanroom, respectively. As shown in the graphs during the simulation the levels of PM concentrations were increased with a higher raise in office area.

Impact and Conclusion

- Since an increase was found in PM concentration, this data shows that nurses are at risk for inhaling particulates at a microscopic level that could be damaging to their health.
- Medication crushing in a cleanroom can reduce the levels of inhalable particles.

Acknowledgements
Dr. Don Gregory, Ph.D. College of Science, Physics and Astronomy

Figure 7 is a digital copy of the poster used in the HCR Poster Presentation that won First Place for Honors College.