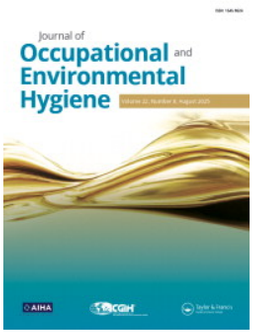

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BRIEF REPORT

Healthcare workers' exposure to aerosolized medications while crushing oral tablets

Erin Tavares, Benjamin Loosley, and Ahlia Shaik

People Safety, Vancouver Coastal Health, Vancouver, Canada

ABSTRACT

Crushing oral tablets can potentially aerosolize active ingredients in the medication and expose healthcare workers to drug particulates. Few studies have quantified aerosolized particulate matter generated during tablet crushing. Inhalation of patient medications can result in negative health effects to the healthcare worker, especially if hazardous medications are being crushed. This study evaluated four different pill crusher and pill container combinations to assess particulate exposure risks and examine whether particulate levels varied depending on the pill crusher, container type, and crushing method. The pill crushers included MAXCRUSH, Silent Knight, and SafeCrush. The MAXCRUSH pill crusher was used with paper pill cups and unit-dose packaging. Factors influencing aerosolized particle generation included the method and intensity of crushing, and the type of pill crusher and container used. An optical particle counter was used to record particle counts in the breathing zone. The highest number of particles was produced when tablets in unit dose packaging were crushed with the MAXCRUSH pill crusher. An aggressive and vigorous procedure significantly increased the number of aerosolized particles generated across devices ($p < 0.001$) except MAXCRUSH with paper pill cups ($p = 0.14$). Most of the aerosolized particulate matter was produced when the crushed tablet was poured from its container into a cup of water. To minimize exposure, recommended control measures include substituting tablet medications with liquid forms, having pills crushed by the pharmacy, using a pill crushing syringe, limiting vigorous pouring of crushed medications from pill containers, and wearing a fit-tested N95 respirator.

KEYWORDS

Aerosolization; medication exposure; nursing; occupational exposure; particulate matter; pill crushing

Introduction

Tablet medications are crushed in a variety of healthcare settings, including hospitals, long-term care facilities, and homecare settings. Medications are primarily crushed for dysphagic patients. Over 50% of long-term care residents are dysphagic (Roberts et al. 2024). Tablets are also often crushed and administered in food for residents who spit out or hide their medication. Residents of long-term care facilities are prescribed more medications compared to seniors living at home, with over 60% taking at least ten different prescription medications (Vogel 2014). In British Columbia, there are approximately 30,000 long-term care residents and over 5,150 nurses working in long-term care facilities (Government of Canada 2023, 2024; Office of the Seniors Advocate British Columbia 2022). However, medication crushing also occurs in geriatric and palliative care wards in hospitals and homecare settings, increasing the number of nurses who are responsible for crushing and administering medications.

Some medications can pose a greater risk to healthcare workers who are exposed to them, even when exposed to small amounts. These medications are often given the designation "hazardous drugs" and include those that are carcinogenic, genotoxic, teratogenic, toxic to organ systems at low doses, capable of causing impaired fertility, or those that resemble existing hazardous drugs in chemical structure or toxicity (NIOSH 2024). Staff exposed to multiple hazardous medications may experience additive or synergistic health effects that have not been previously investigated, the effects of which are not well understood. Hazardous drugs, such as antineoplastic drugs, have been demonstrated to cause acute and chronic health effects in healthcare workers who were occupationally exposed (Cavallo et al. 2005). Symptoms include nausea, dizziness, hair loss, and skin, eye, and mucous membrane irritation (Valanis et al. 1993). The most

CONTACT Erin Tavares erin.tavares@vch.ca People Safety, Vancouver Coastal Health, Vancouver, Canada.

reported chronic health effect is DNA damage, but effects on the liver, kidneys, and hematocytes have also been observed (Zhang et al. 2016). There are no occupational exposure limits for these medications, so exposures should be kept as low as reasonably achievable (ALARA).

Previous studies have investigated the airborne particulate matter that is produced when tablet medications are crushed, but few have compared the amount produced by different pill crushers. Amiri et al. (2023) and Guess (2020) measured airborne particle concentrations across different size fractions when acetaminophen tablets were crushed with a screw-type pill crusher with and without a fume hood. Murahashi et al. (2021, 2022) estimated pharmacists' exposure to drug particulate by measuring the concentrations of drug ingredients in the room's dust. Murahashi et al. (2022) also compared drug exposure between a blade-type pill crusher and the mortar-type SafeCrush pill crusher. Salmon et al. (2013) measured airborne particulates with an aerosol particle counter while using a mortar and pestle to crush medications compared to a pill crusher.

The objectives of this study were to determine whether crushing tablet medication creates an aerosol exposure risk for healthcare workers and whether different pill crusher and container combinations and methods of crushing affected the total amount of generated aerosol. The study also aimed to investigate cumulative exposure risk over the entire pill crushing procedure and whether any steps in the pill crushing procedure posed a greater risk of exposure. These objectives were assessed by measuring aerosolized particles when four different pill crushers and container combinations were used.

Methods

Tylenol Extra Strength 500 mg tablets with an average mass of 0.61 g were crushed on a lab bench in a controlled laboratory setting. Tylenol was selected because it can be obtained without a prescription, is a relatively low-cost medication, and is one of the most common medications crushed in long-term care facilities (Mercovich et al. 2014; Solberg et al. 2021). Three of the most common types of pill crushers used throughout Vancouver Coastal Health Authority were selected and included MAXCRUSH (Figure 1a), Silent Knight (Figure 1b), and SafeCrush (Figure 1c). The MAXCRUSH is a manual pill crusher with an anvil design and buffering mechanism to absorb the crushing force. The Silent Knight is a manual pill crusher that contains two plates that grind the pill as the handle is moved up and down. The SafeCrush is an automatic pill crusher that allows pills to be crushed in an enclosed chamber with the push of a button. One Tylenol tablet was crushed in each trial. To account for differences in medication preparation time between pill crushers, cumulative particle counts are reported to allow for a direct comparison of pill crushing procedures independent of time.

A Lasair III 110 Aerosol Particle Counter (Particle Measuring Systems Inc, Boulder, CO, USA) was used to measure particle counts and has the following particle size channels: 0.1–0.15 µm, 0.15–0.2 µm, 0.2–0.25 µm, 0.25–0.3 µm, 0.3–0.5 µm, 0.5–1.0 µm, 1.0–5.0 µm, $>$ 5.0 µm. The Lasair III uses a laser to count particles and provides raw particle counts each second. The $>$ 5.0 µm channel was selected because elevated background particle counts were observed at the smaller particle channels, greatly decreasing the signal-to-noise ratio. The $>$ 5.0 µm channel best allowed for the determination of particle counts during active pill crushing, removing the crushed medication from the pill crusher, and pouring the crushed medication into a cup of water. The particle counter was calibrated before use and set to a one-second logging interval and a 28.3 L/min flow rate.

A Q-TRAK Indoor Air Quality Meter (Model 7565-X, TSI, Inc., Shoreview, MN, USA) with a TSI VelociCalc 960 Air Velocity Probe was used to measure air flow in the vicinity where the medications were crushed. The pill crushing area was not located near any ventilation inlets or exhausts, and there was negligible vertical or horizontal air movement (less than 0.05 m/s air speed in all directions).

The MAXCRUSH pill crusher was used to crush pills in a paper pill cup (Figure 2a) and pills that had been packaged into unit-dose packaging by the regional pharmacy production center (Figure 2b). Pills crushed in the Silent Knight pill crusher were placed into plastic Silent Knight pouches (Figure 2c). Pills crushed using the SafeCrush electronic system were placed between two compatible plastic cups (Figure 2d). Twenty replicate tests were performed when Tylenol was crushed with each pill crusher and container combination.

The process of medication preparation was divided into three distinct phases:

1. The "crushing" phase was when the pill was actively being crushed inside a pill-crushing device.

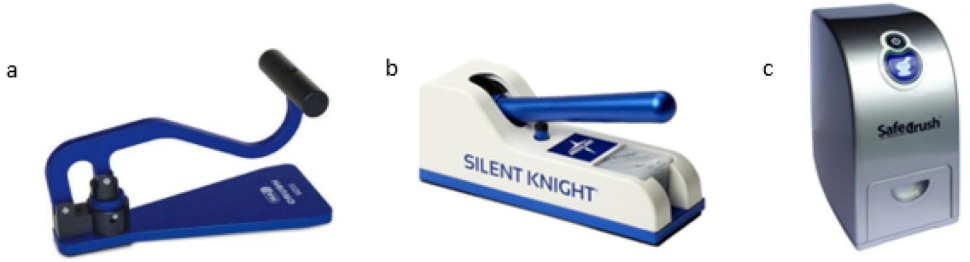

Figure 1. Pill crushers used. (a) MAXCRUSH. (b) Silent Knight. (c) SafeCrush electronic system.

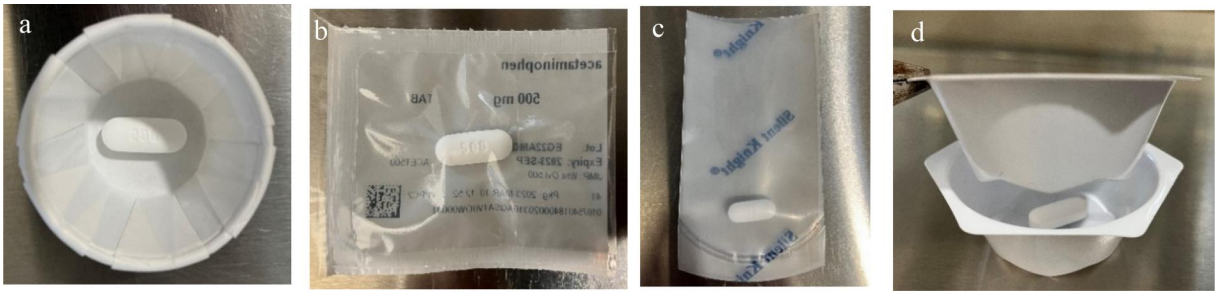

Figure 2. Containers in which the tablets were crushed for each pill crusher. (a) MAXCRUSH pill crusher paper cup. (b) Unit dose packaging where the tablet was crushed with the MAXCRUSH pill crusher while in the packaging. (c) Silent Knight pill pouch. (d) Plastic cups that were used with the SafeCrush electronic system.

2. The "transitioning" phase included the time immediately following crushing until the medication was poured from the pill container. For the pills that were crushed inside unit dose packaging, this included when the pill bag was opened.
3. The "pouring" phase was when the crushed tablet was poured from the pill container into a cup of water at a height parallel with the rim of the cup.

Particle counts were measured under "controlled" and "uncontrolled" conditions:

- "Controlled" conditions involved carefully pouring the crushed medication out of the pill container and not attempting to remove the medication that was left in the container.
- "Uncontrolled" conditions involved applying more force while crushing, vigorously pouring the crushed medication out of the pill container, and attempting to remove the medication from the container by shaking it.

Aerosolized particle counts were measured in the breathing zone. A tube attached to the particle counter inlet was taped at chest height with the tube inlet at a vertical distance of 43 cm above the height of the lab bench surface. The pill was crushed and poured at a horizontal distance of 30 cm from where the tube was positioned. The researcher wore a gown, nitrile gloves, and a fit-tested N95 respirator during all trials. Cumulative particle counts were calculated by summing the particles recorded at each one-second logging interval throughout the test. Particle counts were logged until they returned to baseline levels.

Statistical analysis

Statistical analysis was conducted using R (version 4.2.1, R Foundation for Statistical Computing, Vienna, Austria) and RStudio (version 2024.04.1 + 748, RStudio, PBC, Boston, MA, USA). The non-parametric Kruskal-Wallis Test and Dunn's Test were used to determine statistical significance between the particulate produced by each pill crusher and container combination and statistical significance between the particulate produced during the crushing, transitioning, and pouring phases. The non-parametric Wilcoxon Rank Sum Test was used to determine statistical significance between the particulate produced during the controlled and uncontrolled scenarios for each pill crusher and container combination. A P value of < 0.05 was considered significant.

Results

The baseline particle counts for particles $> 5.0\,\mu m$ were measured at the beginning of each trial (for all conditions) before medication preparation, with an average count of 1.7 particles per second. Figure 3 compares the cumulative number of particles

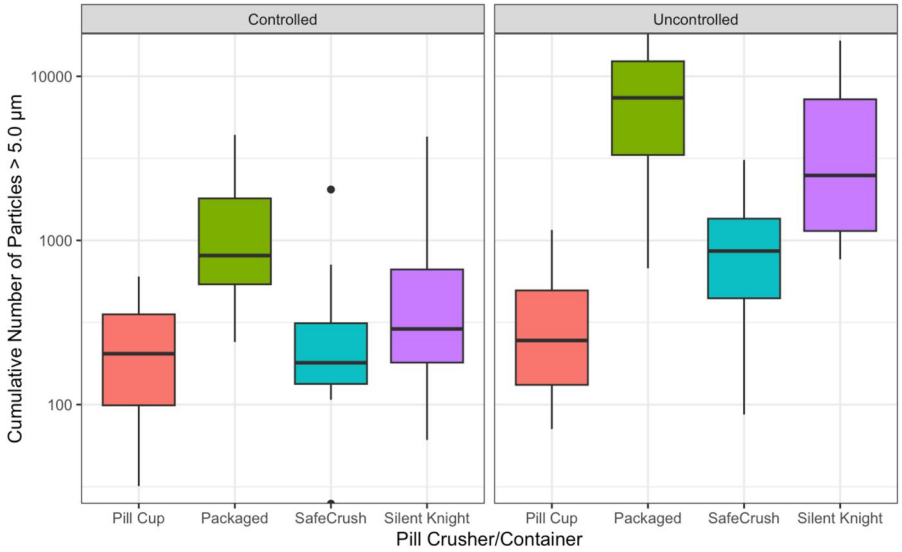

Figure 3. Boxplots of the cumulative number of particles > 5 µm produced in the controlled and uncontrolled scenario when using the MAXCRUSH with paper pill cup (red), MAXCRUSH with unit dose packaging (green), SafeCrush (blue), and Silent Knight (purple) to crush Tylenol, remove it from the pill crusher, and pour it into the cup of water.

> 5.0 µm produced in the "controlled" and "uncontrolled" scenarios by each pill crusher and pill container combination measured over the full procedure (crushing, transitioning, and pouring). The cumulative number of particles > 5.0 µm during the uncontrolled scenario was significantly higher compared to the controlled scenario ($p < 0.001$) for all pill crusher and container combinations except the MAXCRUSH pill crusher with pill cup ($p = 0.14$). Median particle counts were 204 (SD = 163) and 245 (SD = 288) for the controlled and uncontrolled scenarios, respectively, when the MAXCRUSH pill crusher with pill cup was used.

In the controlled scenario, the cumulative number of particles > 5.0 µm was significantly higher when Tylenol was crushed in the unit dose packaging with the MAXCRUSH pill crusher compared to the other pill crusher and container combinations ($p < 0.001$, MAXCRUSH pill crusher with pill cup and SafeCrush pill crusher, $p = 0.028$, Silent Knight pill crusher). Crushing Tylenol in unit dose packaging with the MAXCRUSH pill crusher also produced the highest cumulative number of particles > 5.0 µm in the uncontrolled scenario (median = 7431, SD = 5600), but it was not significantly greater than the cumulative number of particles > 5.0 µm measured when using the Silent Knight pill crusher (median = 2488, SD = 4539).

Figure 4 displays the cumulative number of particles > 5.0 µm generated in each phase of the procedure for each pill crusher and container combination in both the controlled and uncontrolled scenarios. For nearly all pill crusher and container combinations, the cumulative number of particles > 5.0 µm measured during the pouring phase was significantly higher ($p < 0.001$) than the crushing or transitioning phase. The exception was between the crushing and pouring phases with the MAXCRUSH pill crusher and pill cup in the uncontrolled scenario ($p = 0.16$) and the crushing and pouring phases with the Silent Knight pill crusher in the controlled scenario ($p = 0.72$).

Discussion

All pill crushing procedures were found to aerosolize oral tablet medication. This result is in accordance with previous studies (Amiri et al. 2023). The greatest cumulative number of particles > 5.0 µm was generated by the MAXCRUSH pill crusher with unit dose packaging, followed by the Silent Knight, SafeCrush, and MAXCRUSH with pill cup in both the controlled and uncontrolled scenarios (Figure 3). If medications were crushed in a controlled manner, there did not appear to be a single pill crushing system that was better at reducing aerosolized particles than any other. In terms of equipment, the most important choice appeared to be the use of a dedicated pill crushing container and not to crush medications in unit dose packaging.

For the MAXCRUSH with unit dose packaging, Silent Knight, and SafeCrush pill crusher and container combinations, significantly greater particle counts were produced in the uncontrolled scenario compared to the controlled scenario. This indicates that the method by which a pill is crushed and poured

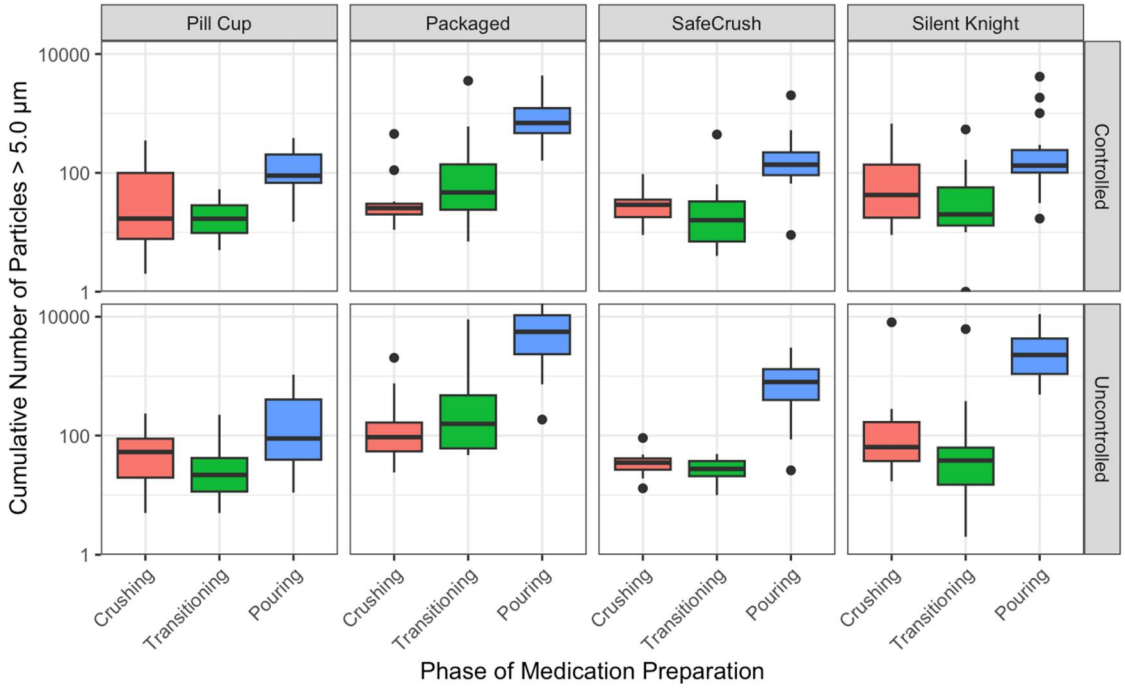

Figure 4. Boxplots of the cumulative number of particles > 5 µm produced in the controlled and uncontrolled scenarios during the crushing (red), transitioning (green), and pouring (blue) phases for each pill crusher and container combination.

affects the number of aerosolized particles produced. Other studies have also found that individual differences in crushing techniques could affect drug exposure (Murahashi et al. 2021, 2022). Development of safe work procedures for medication crushing should emphasize the importance of careful crushing and pouring techniques to minimize the generation of aerosolized particles through agitation.

The pouring phase resulted in the highest level of aerosolized particles generated for all pill crusher and container combinations in both controlled and uncontrolled scenarios (Figure 4). This result is consistent with other studies that found that while tablets were crushed, there were limited amounts of drug particulate measured, but large amounts were measured when the crushed powder was poured (Maeda et al. 2016; Murahashi et al. 2022). Pouring from plastic packaging (unit dose packaging and Silent Knight pouches) generated the highest counts of airborne particulates. This is likely because the crushed tablet sticks to the packaging, resulting in more effort and agitation to remove the full dose of medication. This indicates that the container inside which the medication is crushed and how the crushed medication is poured from the container have the largest impact on the amount of airborne particulate generated. In addition, if some of the crushed tablet was left in the container, this could result in patients not receiving their full medication dose.

Limitations

Limitations of this study include that the medications were crushed in a controlled laboratory setting with no air inlet or exhaust near the pill crushing area. In an acute or long-term care facility, healthcare workers often crush medications on their medication cart, which could result in ventilation impacting the movement of airborne particles if an air inlet or exhaust is nearby. Particle counts were measured rather than drug ingredient concentrations. Tablet medications are composed of various ingredients besides active drug ingredients, including diluents, binders, and glidants (Ubhe and Gedam 2020). The inactive ingredients present in Tylenol Extra Strength include cellulose, corn starch, Hypromellose, magnesium stearate, polyethylene glycol, sodium starch glycolate, and water. It is unknown how much of the aerosolized particulate contained active drug ingredients. Cumulative particle counts were reported instead of particle concentrations to account for the time variance between different pill crushers and recommend controls to reduce total exposure risk across procedures.

Conclusion

In conclusion, the results of this study showed that crushing tablet medication creates an aerosol exposure risk for healthcare workers. The cumulative airborne

particle counts generated differ significantly between pill crushing devices, and the aerosol generated increases if the medication is crushed and poured vigorously compared to a careful manner. Pouring the crushed medication into the food or beverage generated the most particulate and posed the greatest risk of exposure. It is prudent to assume that crushing all medications with any device will produce some level of exposure risk, which should be mitigated using the hierarchy of controls. Future research will focus on collecting particulate data while healthcare workers crush tablet medications in clinical settings.

Recommendations

The hierarchy of controls should be utilized to reduce healthcare workers' exposure to particulates when crushing tablet medications. Five recommendations can be made to help reduce healthcare worker exposure to aerosolized medications:

1. Substitute solid medications for liquid medications, if possible. This would reduce the number of solid medications nurses would be required to crush, which would reduce their exposures to associated airborne particulate matter. Eliminating the need for crushing medication can also save time and reduce the risk of musculoskeletal injury.
2. If possible, have pharmacy staff crush and prepare oral medication for patient administration. Pharmacies are often outfitted with superior engineering controls, such as dust removers, and have more rigorous cleaning schedules compared to a nursing medication preparation area. This can help reduce the overall risk of work exposure and environmental contamination. In addition, pharmacies may be more apt to automate the task, reducing the risk of musculoskeletal injuries from repetitive manual crushing.
3. Consider using devices that eliminate the pouring step from the pill crushing procedure. For example, pill crushing syringes allow the pill to be ground up inside the syringe while the end of the syringe is capped. Once crushed, water can be drawn up to dissolve the crushed tablet, which can then be added to the patient's food or beverage and administered.
4. Develop safe work procedures and train workers on the importance of minimizing the generation of drug aerosols by:
    a. Crushing tablets in a controlled and cautious manner,
    b. Minimizing the amount of shaking and agitation during the pouring of crushed medications,
    c. Avoiding crushing medications inside unit dose packaging.
5. Wear a fit-tested N95 respirator when crushing and pouring tablet medications, especially when handling hazardous medications, since this study has demonstrated that there is a risk of particulate exposure when using each of these pill crushers. In the absence of fit-tested respirators, medical masks have been shown to reduce aerosol inhalation exposure while crushing medication by over 90% (Murahashi et al. 2021, 2022).

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

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