Investigation and Disinfection of Environmental Microbes in Sports Fitness Center

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Abstract

The COVID-19 pandemic shows that indoor air disinfection is extremely important. As early as 2012, Taiwan has released indoor air quality standards, and in 2017 announced the second batch of places that should meet indoor air quality standards including sports and fitness places. In this study, the indoor air quality was monitored in the indoor exercise and fitness center under normal operating conditions of air conditioning and ventilation as well as user flow. Chlorine dioxide and weak acid hypochlorite solutions, and water scrubbing were used to improve the quality of the indoor environment under different operating modes. This study investigated the air quality improvement in terms of bacteria and fungi contamination of the indoor exercise and fitness center under normal operating conditions including air conditioning, ventilation, and user flow. In addition, bacteria contamination and disinfection on sports equipment surface were also examined. Background bacteria and fungi densities in bioaerosols were in the range of 249 ± 65 to 812 ± 111 CFU/m³ and 226 ± 39 to 837 ± 838 CFU/m³ in the indoor air of the fitness center and 370 ± 86 to 953 ± 136 CFU/m³ and 465 ± 108 to $1,734 \pm 580$ CFU/m³ in the outdoor air, respectively. Chlorine dioxide and weak acid hypochlorous water aerosols could remove both bacteria and fungi much better than water scrubbing. Contact time of 15 minutes was sufficient to control both bacteria and fungi to comply with the official air quality standards. User density and carbon dioxide deteriorated both bacteria and fungi disinfection performance whereas temperature was only statistically significant on fungi disinfection. Other factors including relative humidity, airflow velocity, and particulate matters did not have any statistically significant effect on microbial inactivation. Handle of bicycle, dumbbell, and sit-up bench were found to be contaminated with bacteria and *E. coli*. Detected densities for bacteria and *E. coli* on the surface of these sport equipment were in the range of 390 ± 2 to $3,720 \pm 736$ CFU/cm² and 550 ± 70 to $1,080 \pm 114$ CFU/cm², respectively. Microbial densities detected largely depended on the number of users for each specific equipment. Chlorine dioxide and zinc oxide were noticeably better than weak acid hypochlorous water and commercial disinfectant in term of bacteria inactivation whereas all tested disinfectants had comparable effectiveness on *E. coli* disinfection. Targeted microorganisms were sufficiently inactivated within 2 minutes after the application of disinfectant.

1. Introduction

Nowadays, insufficient physical activity is one of the major leading risk factors for death worldwide. World Health Organization (WHO) recommends at least 150 minutes of moderate-intensity physical activity throughout the week (Ramos et al. 2015; WHO 2018) for improving health benefits and improves overall well-being, such as walking, cycling, or sports. However, parks or public spaces particularly in large cities usually have poor air quality due to traffic-related pollution. As a result, people who are living in urban areas prefer to work out in indoor fitness centers to avoid air pollution. Nonetheless, it is not guaranteed that the indoor air quality in the fitness center will always be of high standards as usually perceived by public. It largely depends on building construction, building materials, and type of ventilation together with environmental factors such as natural ventilation, humidity, and temperature. In addition,

number of users and fitness activities also play an important role in the air quality inside the fitness center.

Bacteria and fungi can pose significant risk to human health under fitness center environments. Bacteria can rarely survive and grow on sports equipment under normal conditions. Thus, the main source of bacteria present on the surface of fitness facilities is people who come to exercise (Ramos et al. 2014). On the other hand, most fungal sources are located outdoors, e.g., soil, plants, water bodies, etc. However, the spores can readily penetrate indoor environments by means of human transport and ventilation systems.

According to the National Institute of Occupational Safety and Health (NIOSH) of the US and the American Conference of Governmental Industrial Health (ACGIH), the total number of bioaerosol particles in indoor environments should not exceed 1,000 CFU/m³, while the total culturable count for bacteria should be no higher than 500 CFU/m³ (ACGIH 1989; AIHA 1996). Furthermore, the Environmental Protection Administration (EPA) of Taiwan has stated that, for indoor public spaces, the bacteria intensity should be not higher than 1,500 CFU/m³, while the fungi concentration should not exceed 1,000 CFU/m³ (EPA Taiwan 2014). Unfortunately, Taiwan lies in a subtropical zone where the climate is generally warm and humid all year round. This type of climate is highly conducive to the breeding and spreading of bioaerosols (Tsai and Liu 2009). Moreover, recent spread of COVID-19 worldwide shows that indoor air disinfection is extremely important and necessary.

Various types of chemical disinfectants can be used against microorganisms including glutaraldehyde, formaldehyde, and chlorhexidine (McDonnell and Russell 1999). However, potentially toxic, corrosive, or volatile problems have to be concerned in case of wide public application. Effective disinfectants without side effect or with low toxicity should be considered in such case.

Chlorine dioxide (ClO₂) can be used as an oxidizing agent or disinfectant. It is a very powerful oxidizer that effectively eliminates pathogenic microorganisms including fungi, bacteria, and viruses. As a disinfectant and pesticide, it is mainly applied in a liquid form (Lenntech B.V. 2020). Weak acid hypochlorous water (WAHW), the most widely used disinfectant with good antimicrobial activity, can also be used as well. WAHW is environmentally friendly since it is unaffected by water hardness (Rutala and Weber 1997). Likewise, antibacterial activity of zinc oxide (ZnO) has received significant interest worldwide (Sirelkhatim et al. 2015).

In this study, ClO₂, WAHW, ZnO, commercial disinfectant and water (scrubbing effect) were used to determine their microorganism disinfection effectiveness in bioaerosols present in the fitness center. The evaluation covers indoor air quality and sports equipment. For indoor air disinfection, three different fitness user numbers were investigated, i.e., 10 people, 5 people, and no people exercising. Environmental factors including temperature, relative humidity, and airflow velocity were measured and maintained steadily. In all cases, the solution was applied using EP606 aerosol devices (GAO-SHUO Corporation, Taiwan) for 60 minutes after the exercise period. Bacteria and fungi remaining in the aerosols were

periodically monitored and compared. For sports equipment, the solution of disinfectant was used to clean the contact surface after each the exercise session. Bacteria and *Escherichia coli* (*E. coli*) remaining on the surface were periodically monitored and compared.

2. Materials And Methods

This study was conducted in the fitness center at Chia-Nan University of Pharmacy and Science in Taiwan. This study consists of two parts: (1) determination of bacteria and fungi existence in the indoor air and (2) determination of bacteria and *E. coli* existence on the surface of sports equipment, both before and after treatment with various disinfection means. The details of the experimental procedure are described in the sections below.

2.1 Study Area

Sampling was undertaken in a 332 m³ bicycle room in a fitness center of Chia Nan University of Pharmacy and Science in Tainan, Taiwan. Sampling was taken at six locations, including five locations inside and one location outside the bicycle room as shown in Figure 1.

2.2 Disinfection Method

Several substances including ClO₂, WAHW, ZnO, commercial disinfectant (Savlon, ITC Limited), and water (via wet scrubbing effect) were applied in this study in order to disinfect or remove indicating microorganisms. For bioaerosol study, ClO₂, WAHW, and water were used. As described above, the bicycle room volume is 332 m³. To satisfy the 8-h Time Weighted Average (TWA) maximum exposure limit of 0.3 mg/m³ for ClO₂ (OSHA 2020), ClO₂ disinfection in the bicycle room was performed using 400 mL ClO₂ solutions (at 250 mg/L). No maximum exposure limit is prescribed for WAHW disinfection nor water for wet scrubbing. Nonetheless, in order to control the amount of aerosols being introduced into the studied boundary, the rates of WAHW (at 250 mg/L) and water aerosolization were similar to those of ClO₂. The Two EP606 aerosol devices (GAO-SHUO Corporation, Taiwan) placed at two different locations in the bicycle room were switched on just after the termination of all exercise activities and all users had left the room, and continued for 60 minutes.

For bacterial inactivation on the surface of sports equipment, ClO₂, WAHW, ZnO, and commercial disinfectant (Savlon, ITC Limited) at the concentration of 50, 50, 400, and 400 mg/L were used. The disinfectant mixture was wiped thoroughly on the surface of the sports equipment.

2.3 Air Sample Collection

Air samples were collected in accordance with the NIEA (National Institute of Environmental Analysis) guidelines specified by the Taiwan Environmental Protection Administration (TEPA) (Taiwan EPA 2016; Taiwan EPA 2016b). On each sampling day, indoor air samples were collected before and after the exercise session (either with 5 and 10 users) for 15 and 60 minutes. The samples were collected using a

MAS-100 Eco Microbial Air Sampler (Merck, Germany, 200 L/min) containing in petri dishes with Tryptic Soy Agar (TSA) plates and Malt Extract Agar (MEA) plates for bacteria and fungi enumeration, respectively. Air flow velocity, temperature, relative humidity, PM10, PM7, PM2.5, and PM1 were also measured.

Collection of microbial samples on sports equipment, i.e., bicycle handle, dumbbell, and sit-up bench, was performed before and after cleaning of 2, 5, 10 and 30 minutes. One-cm² surface of the sports equipment was swabbed with a sterilized cotton bud soaked with basal medium. Five random swabs were performed for each sports equipment. The swabbed cotton buds were then further processed for microbial enumeration. To determine the amount of viable microorganisms, the samples were cultivated on petri dishes with plate count agar (PCA) plates for bacteria and chromocult coliform agar plates for *E. coli*.

2.4 Analytical Methods

2.4.1 Measurement of Environmental Factors

The temperature, relative humidity, airflow velocity and carbon dioxide concentration were evaluated by The VelociCalc® Multi-Function Ventilation Meter 9565 (TSI Inc, USA). Light meter pocket (Lutron Electronic, LX-103) was used to measure the illumination in the room. Particulate matter was measured by Handheld Particle Mass Counter (AEROCET 531, Met One Instruments Inc, USA).

2.4.2 Measurement of Disinfectants Concentration

The concentration of chlorine dioxide and hypochlorous acid were determined by using light absorbance measurement by Waterproof Portable Colorimeter (OAKTON Instrument, USA).

2.4.3 Microbiological Analysis

For the bioaerosol bacteria, the TSA plates were incubated at the temperature of 30±1°C for 48±2 hours. Meanwhile, the MEA plates were incubated at 25±1°C for 4±1 day for measurement of bioaerosols fungi. The bacteria and fungi concentrations were then evaluated by counting the colonies formed on the respective agar surfaces.

For microorganism numeration from sports equipment, the initial sample was diluted with Butterfield's phosphate buffered-dilution water (PBS) at the dilution of 1:10, 1:100, 1:1,000 and 1:10,000. After that, appropriate amount of the diluted sampled was dropped into the plate count agar (PCA) or chromocult coliform agar in the petri dishes and then swirled the plate to homogeneously mix the sample and culture medium together. Allow the mixture to solidify and then turn the culture dish upside down. Then the PCA plates were incubated at a temperature of 35±1°C for 48±2 hours. Meanwhile, the chromocult coliform agar plates were incubated at 35±1°C for 48±2 hours for the *E. coli* cultivation. Count the number of colonies on the culture plate and calculate total microbial count in term of CFU/mL (Jaemsri and Rujak 2017).

2.5 Statistical Analysis

The experimental data were analyzed statistically using a commercial SPSS software (IBM SPSS Statistics 22.0). The correlations of the bioaerosols disinfection effectiveness and environmental factors (i.e., the temperature, relative humidity, airflow velocity, carbon dioxide concentration, and particulate matters) were examined by means of a Pearson's correlation analysis ($p < 0.05$).

3. Results And Discussion

3.1 Bioaerosols in Indoor Air

3.1.1 Initial Concentration of Bioaerosols

The initial concentrations of bacteria and fungi before the disinfection treatment were shown in Table 1. Average temperature, relative humidity, airflow velocity, carbon dioxide, PM1, PM2.5, PM7, and PM10 during the experimental periods were 18.9 to 24.9°C, 62.0% to 80.6%, 0.3 to 1.2 m/min, 398 to 1,298 ppm, 0 to 1.12 mg/m³, 0.001 to 1.170 mg/m³, 0.002 to 1.175 mg/m³, and 0.002 to 1.179 mg/m³, respectively. The magnitude of these environmental factors represents the typical conditions of the indoor air in the fitness center. It is necessary to note that the experiments were conducted at existing conditions and different times; hence, the initial concentrations of bacteria and fungi in each experiment were different. Therefore, the determination of whether an indoor environment is polluted or not is often based on a comparison of bioaerosol concentration in the indoor air with that of outdoors (Zhu et al. 2003). It can be seen that the indoor air tended to contain less bacteria and fungi than the outdoor air; nonetheless, there was no specific correlation. This is possibly due to the bioaerosol filtration effect via air conditioning system of the fitness center and the activities happened prior to the tested session.

Table 1. Initial concentration of bacteria and fungi (mean±SD)

	Indoor			Outdoor		
	ClO ₂	WAHW	Water	ClO ₂	WAHW	Water
Initial concentration of bacteria (CFU/m³)						
0 people	401±179	249±65	308±231	855±41	370±86	613±163
5 people	761±169	470±238	433±172	953±136	616±203	498±124
10 people	715±153	619±259	812±111	765±403	684±591	879±83
Initial concentration of fungi (CFU/m³)						
0 people	226±39	228±53	618±499	1203±603	873±460	1064±139
5 people	837±838	275±212	307±16	1734±580	738±174	908±706
10 people	492±278	255±133	613±319	1220±156	465±108	764±677

3.1.2 Effect of Environmental Factors on Bioaerosols Distribution

Table 2 shows the correlations between the bacteria and fungi colony counts and the environmental factors after the disinfection treatment process. Significant positive correlations were found between the effectiveness of bacteria disinfection and the effectiveness of fungi disinfection ($r = 0.610$, $p < 0.01$). By contrast, significant negative correlations were obtained between the effectiveness of bacteria disinfection and the number of users ($r = -0.584$, $p < 0.05$), carbon dioxide concentration ($r = -0.581$, $p < 0.05$). Significant negative correlations also existed between the effectiveness of fungi disinfection and the number of users ($r = -0.690$, $p < 0.01$), temperature ($r = -0.517$, $p < 0.05$) and carbon dioxide concentration ($r = -0.680$, $p < 0.01$). In other words, the effectiveness of bacteria disinfection increased along with the effectiveness of fungi disinfection but decreased with an increasing number of users and carbon dioxide concentration. Similarly, the effectiveness of fungi disinfection decreased with an increasing number of users, temperature, and carbon dioxide concentration. Other factors including relative humidity, airflow velocity, and particulate matters had no statistically significant impact on both bacteria and fungi inactivation.

3.1.3 Effectiveness of Bioaerosols Disinfection

The effectiveness of bacteria and fungi disinfection by three different methods including ClO₂, WAHW, and water were compared within treatment period of 15 and 60 minutes as shown in Figures 2 and 3, respectively. The results showed that all the methods had the ability to reduce bacteria and fungi present in the aerosols in the indoor air although water scrubbing which served as a control had the lowest capability in both bacteria and fungi removals. Hence, it implies that the removal of bacteria and fungi in the presence of ClO₂ and WAHW was mainly derived from chemical interaction rather than physical phenomenon. The inactivation potential decreased as the number of users increased. It is interesting to

observe that fungi can be inactivated in all treatment scenarios at 15 minutes of contact time but ClO₂ had the highest efficiency. However, the number of fungi noticeably rebounded in the WAHW and water scrubbing treatments at 60 minutes. This regrowth behavior of fungi might be due to the ability of fungi to form spores to protect themselves from inactivation. Another factor might be due to an increase in relative humidity after prolonged aerosolization which could promote the enumeration of fungi (Rajasekar and Balasubramanian 2011). Figures 2 and 3 also illustrate that ClO₂ seemed to be a better fungicide whereas WAHW seemed to be a slightly better bactericide than ClO₂ for long time exposure.

According to Ishihara et al. (2017), the hypochlorous acid in aqueous solution is unstable against ultraviolet (UV) light, sunshine, air contact, and elevated temperature (≥ 25 °C); hence, ClO₂ seems to be a better choice for bioaerosol disinfection. As shown in Table 1, bacteria and fungi disinfection effectiveness were not related to treatment time; hence, disinfecting the fitness room for 15 minutes after usage is a more appropriate option that can reduce both treatment time and cost. Within the ranges obtained during the experimental period, other compositions in the room including temperature, relative humidity, air flow velocity, PM10, PM7, PM2.5, and PM1 had no statistically significant effect on bacteria and fungi disinfection.

The results from this study showed that the effectiveness both of bacteria and fungi disinfection decreased with an increasing number of users, time, temperature, and carbon dioxide concentration. It was found that ClO₂ seemed to be the most appropriate selection for bacteria and fungi control in the bioaerosols under the studied conditions. This is because ClO₂ is a very powerful oxidizer that effectively eliminates pathogenic microorganisms including fungi, bacteria, and viruses (Lenntech B.V. 2020). Findings from this study are in agreement with several other studies using ClO₂ to control the amount of bioaerosols in indoor air including student cafeterias (Hsu et al. 2014), library (Hsu et al. 2015); and pet shop (Lu et al. 2018). These studies recommended that treatment with ClO₂ is an efficient way of compliance with the Taiwan EPA guidelines for indoor air quality. Nonetheless, this study found that airflow velocity had no significant effect on both bacteria and fungi removal which contrasts with the observations from Hsu, et al. (2014) and Lu, et al. (2018) who found that a higher air velocity was helpful for spreading the disinfectants through indoor space as well as to enhance disinfection efficiency accordingly. This might be because the minimum airflow rate of 0.3 m/min detected in this study was already sufficient enough to thoroughly spread the disinfectant solution in the room space. The results confirmed that ClO₂ disinfection could sufficiently suppress the numbers of bacteria and fungi present in the bioaerosols to comply with the Taiwan EPA guidelines for the indoor air quality.

3.2 Bioaerosols on Sports Equipment

3.2.1 Initial Concentration of Microorganisms

Table 3 shows the initial concentrations of bacteria and *E. coli* before cleaning the sports equipment. The initial concentrations of bacteria and *E. coli* were different among each experiment because it is based on the number of people who exercised with the specific equipment namely bicycle handle, dumbbell, and

sit-up bench in the fitness center prior to the testing period. It is necessary to note that the experiments were conducted at existing conditions and at different times.

Table 3. Initial concentration of bacteria and *E. coli* on sports equipment (mean±SD)

	ClO ₂	WAHW	ZnO	Commercial disinfectant
Initial concentration of bacteria (CFU/cm²)				
Bicycle handle	756±278	390±2	3720±736	1132±430
Dumbbell	684±232	1070±144	1596±418	860±260
Sit-up bench	820±28	816±210	840±566	1486±234
Initial concentration of <i>E. coli</i> (CFU/cm²)				
Bicycle handle	990±146	1080±114	628±266	550±70
Dumbbell	786±50	700±28	732±118	1002±224
Sit-up bench	866±94	802±286	960±170	910±14

3.2.2 Factors Affecting Microbial Inactivation on Sports Equipment

Table 4 shows the correlations between the bacteria and *E. coli* disinfection and the related factors. Significant positive correlations were found between the effectiveness of bacteria disinfection and the effectiveness of *E. coli* disinfection ($r = 0.437$, $p < 0.01$) and types of equipment ($r = 0.446$, $p < 0.01$). Significant positive correlations also existed between the effectiveness of *E. coli* disinfection and types of equipment ($r = 0.396$, $p < 0.01$). In other words, the effectiveness of bacteria and *E. coli* disinfection depends on the surface characteristics of sports equipment. Sports equipment selected in this study had different surface characteristics: (1) the handles of bicycle is soft with foam-like surface, (2) the dumbbell is steel and has a rough surface and (3) the sit-up bench is covered with leather and has smooth surface. Other factors including time and types of the disinfectants had no statistically significant impact on both bacteria and *E. coli* inactivation.

Table 4. Correlations between inactivation effectiveness and environmental factors on sports equipment

	% efficiency on bacteria disinfection	% efficiency on <i>E. coli</i> disinfection	Types of Equipment	Disinfectant
% efficiency on <i>E. coli</i> disinfection	0.437**			
Equipment	0.446**	0.396**		
Disinfectant	0.092	0.009	0.000	
Time	-0.097	0.040	0.000	0.000
** Correlation is significant at the 0.01 level (2-tailed).				

3.2.3 Effectiveness of Bacteria and *E. Coli* Disinfection

Figures 4 and 5 show the efficiency of the four disinfectants in reducing bacteria and *E. coli* present on the sports equipment surface after applying for 2, 5, 10 and 30 minutes. The results show that all the disinfectants are highly effective in reducing bacteria and *E. coli* present on sports equipment (about 66.8-95.4%) even within a short period of time after application (2 minutes).

Figures 4(a) and 5(a) show that chlorine dioxide is highly effective in reducing bacteria and *E. coli* present on sports equipment (81.0-93.9%). It can be seen that ClO_2 could remove bacteria and *E. coli* immediately after 2 minutes of application. Therefore, users can use this equipment straightaway after disinfection without a long-waiting period. According to Cho, et al. (2017), chlorine dioxide (ClO_2) has emerged as an alternative because it has better antimicrobial effectiveness with a higher solubility, shorter response time, and wider pH range. Moreover, the inactivation effectiveness of ClO_2 on both bacteria and *E. coli* was not significantly affected by surface characteristic variation among the sports equipment. Hence, it can be used as a common disinfectant for all equipment in the fitness center. WAHW appeared to be less slightly effective in bacteria and *E. coli* inactivation than ClO_2 as illustrated in Figures 4(b) and 5(b). Required contact time for WAHW seemed to be 10 minutes which was much longer than those of ClO_2 . This observation is in agreement with the studies of Block and Rowan (2020) and Quan, et al. (2017) who stated that hypochlorous acid required at least 10 minutes of contact time to be effective for antimicrobials.

Zinc oxide is highly effective in reducing bacteria all of sports equipment as shown in Figures 4(c) and 5(c). However, it is more effective in reducing *E. coli* on bicycle handle and sit-up bench than dumbbell. Comparing to ClO_2 and WAHW, it was found that ZnO has a slightly better performance on bacteria and *E. coli* disinfection.

Commercial disinfectant could inactivate bacteria and *E. coli* on sit-up bench better than bicycle handle and dumbbell as shown in Figures 4(d) and 5(d). The commercial disinfectant seems to be suitable for the sports equipment which has smooth surface like sit-up bench rather than rough surface as in the case of bicycle handle and dumbbell.

In summary, all disinfectants could remove bacteria and *E. coli* immediately after application. although the highest disinfection efficiency occurred at different contact times. Nonetheless, it implies that users can use these equipment straight-away after disinfection without a long waiting period. Chlorine dioxide and ZnO had comparable inactivation effectiveness regardless of sports equipment and surface roughness as shown in Figure 4(a) and 4(c), respectively. It is interesting to observe that WAHW and commercial disinfectant could disinfect total bacteria on the sit-up bench slightly better than handles of the bicycle and dumbbell which had rougher surface as shown in the Figure 4(b) and 4(d), respectively. The results also demonstrated that the effectiveness of disinfectants somehow depends on the surface characteristics of sports equipment as well.

The *E. coli* disinfection of all disinfectants are quite comparable although the commercial disinfectant showed noticeable less effectiveness on the handles of the bicycle as shown in Figure 5. Coupled with the findings from bioaerosol disinfection as reported earlier, ClO_2 seems to be a better

choice for sanitizing the sports equipment since it was also found to be highly efficient for bioaerosol disinfection as well. Although ZnO and commercial disinfectant were effective for surface disinfection, they are not appropriate nor recommended to apply aurally for bioaerosol disinfection.

It is important to note that this study was carried out during the time of COVID-19 pandemic so the number of users in the fitness center had decreased drastically from normal period. According to Kalogerakis, et al. (2005), the most important source of airborne bacteria is the presence of people who come to exercise. Particular activities like talking, sneezing, coughing, walking, washing and toilet flushing can generate airborne biological particulate matter. Therefore, the initial concentrations of bacteria detected in this study were not as high as it should be under normal condition. Nonetheless, the effectiveness of each disinfectant on targeted microorganisms is still valid and can be further applied for normal condition with certain modifications.

4. Conclusions

This study investigated the effectiveness of bioaerosol disinfection in a fitness room after usage by using ClO_2 , WAHW, and water. Targeted microorganisms were bacteria and fungi. The results revealed that ClO_2 was more effective on fungi inactivation whereas WAHW was better for bacteria disinfection. Water scrubbing had the least efficiency as expected. Number of users statistically diminished the bacteria and fungi removal efficiencies of all tested schemes. According to the outcomes, disinfecting the air in the fitness room by ClO_2 aerosolization for 15 minutes after usage seems to be the most appropriate option for both bacteria and fungi control in bioaerosols in order to improve the air quality in the indoor

environment and human health. For microorganisms on sports equipment control, it was found that ClO₂ and ZnO were noticeably better disinfectants than WAHW and commercial disinfectant in term of bacteria inactivation whereas all chemicals had comparable effectiveness on *E. coli* disinfection. Targeted microorganisms were effectively inactivated in 2 minutes after application. Concerning on overall disinfection performance of both bioaerosols and surface of sports equipment, ClO₂ was found to be the most appropriate and effective disinfectant.

Declarations

Ethics Approval and consent to participate

Not applicable

Consent for Publication

Not applicable

Availability of data and materials

All data generated, used and analyzed during this study are included in this article.

Competing Interests

The authors declare that they do not have competing interests.

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Authors' Contribution

MCL conceptualized and designed the study, secured the funding of the research, planned the research activities. He is the Corresponding Author.

NB contributed to the conceptualization and design of the study, supervised the implementation of the research activities and mentored the other members of the research group.

SY and FJL performed the experiments and data collection and initial analysis of the data. Prepared the initial draft of the manuscript.

LMB performed some analysis of the data, reviewed, edited and critically revised the manuscript.

All Authors read and approved the final manuscript for submission.

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Tables

Due to technical limitations, table 2 is only available as a download in the Supplemental Files section.

Figures

Figure 1

Floor plans of sampling areas: (a) Total area; (b) Bicycle room. (★= sample location; ▲= disinfecting aerosol applying location).

Figure 2

Effectiveness of bacteria disinfection (a) after 15 minutes; (b) after 60 minutes.

(a)

(b)

Figure 3

Effectiveness of fungi disinfection (a) after 15 minutes; (b) after 60 minutes.

(a) Chlorine dioxide

(b) WAHW

(c) Zinc oxide

(d) Commercial disinfectant

Figure 4

Effectiveness of bacteria disinfection after cleaning by four disinfectants.

Figure 5

Effectiveness of E. coli disinfection after cleaning by four disinfectants.

Supplementary Files

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- [Table2.jpg](#)