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Application of Cold Atmospheric Plasma to Decrease Biological Contamination on Surfaces of Equipment and Furniture for Indoor Sports Facilities

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Abstract: Recently, air contamination by microorganisms, such as fungi, bacteria, and viruses, has emerged as a critical issue in public health. The purpose of this study was to determine the level of biological contamination on surfaces of equipment and furniture for sports facilities and to evaluate the performance of cold atmospheric plasma (CAP), in reducing biological contamination. Two facilities, including a golf practice center and a table tennis club, were selected. Since all living cells contain adenosine triphosphate (ATP), it is possible to look for changes in ATP levels on the surface as an indication of biological contamination. The ATP levels were measured from surface samples collected from equipment and furniture for sports facilities and expressed as Relative Light Units (RLU). The ATP tests were conducted before and after the application of CAP. In the golf practice center, ATP levels before the application of CAP ranged from 1,853 to 2,793 RLU, well exceeding the guideline of 500 RLU recommended. When CAP was applied, all the values, except one case, decreased to below 500 RLU. The overall reduction of biological contamination, expressed as ATP level, was 80.2%. In the table tennis club, the ATP levels before CAP was applied ranged from 656 to 2,268 RLU, exceeding 500 RLU. When CAP was applied, the values decreased to levels below 574 RLU. The overall reduction of biological contamination in the table tennis club was 65.5%. In both facilities, the overall reductions of ATP levels were extremely significant. ($p < 0.0001$) It is concluded that the cold atmospheric plasma is a useful, promising technique to control biological contamination in sports facilities.

Keywords: Cold Atmospheric Plasma, Sports Facility, Biological Contamination, Surface Contamination

1. Introduction

In 1976, Krueger and Reed reported that small air ions, currently called cold atmospheric plasma (CAP), are biologically active and inhibit the growth of bacteria and fungi on solid media. [1] Plasma is one of the four fundamental states of matter (i.e., solid, liquid, gas, and plasma). The CAP, operating at atmospheric pressure and room temperature, has been shown to safely and effectively treat contaminated surfaces. The efficacy of CAP is due to its many components, such as reactive oxygen and nitrogen species (RONS), which exhibit favorable behavior for biomedical and industrial applications. Biological contamination in air and surface are responsible for numerous cases of hospitalization and deaths which result in an enormous medical, economical, and biological burden. There are several disinfection methods, including heat, liquid disinfection, vapors/gases, and radiation. Each of the currently used decontamination methods has important drawbacks. CAP has entered this field as a novel, efficient, and clean solution for inactivation or killing of microorganisms.

Filipic et al. presented recent developments in this promising field of CAP-mediated virus inactivation, and described the applications and mechanisms of the inactivation. It is particularly important because viral pandemics, such as COVID-19, highlight the need for alternative virus inactivation methods to replace or upgrade existing procedures. [2] Researchers reported biological contamination with fungi, bacteria, and viruses in subway stations, hospitals and university buildings. [3, 4] Efficiencies of CAP against the bacteria, fungi, and viruses have been tested both in laboratory and fields. The efficiencies of reduction or inactivation were highly successful. [5-9] As a sensitive indicator of microbial contamination, surface samples were tested for adenosine triphosphate (ATP) levels. Although there is no universal pass/fail limit of ATP levels, a few researchers recommended ATP levels, 250 RLU, 500 RLU, and 1,000 RLU as guidelines. [10, 11] Temporarily, we chose 500 RLU as a guideline for this paper. The objectives of this study were to determine the degree of biological contamination of equipment and furniture surfaces in sports facilities and to measure the efficiency of CAP for decontamination.

2. Materials and Methods

Two facilities, including an indoor golf practice center and a table tennis club, were selected in this study. Both facilities are located near Seoul, South Korea. The dimensions of the golf practice facility were 25 m long, 11 m wide and 3.7 m high. The dimensions of the table tennis club were 25 m long, 14 m wide and 3.7 m high.

Since adenosine triphosphate (ATP) is an indicator of biological contamination on surfaces of equipment and furniture, the ATP levels on surfaces of various equipment and furniture in sports facilities were measured using a 3M™ Clean-Trace™ Surface ATP test. The test device contains a swab for the collection of a sample from a surface. The swab was pre-moistened with a cationic agent to aid in the collection of samples and the release of ATP from intact cells. Upon activation of the test, the reagent in the cuvette of the test device reacts with the ATP collected on the swab to produce light. The intensity of the light is proportional to the amount of ATP, which shows the degree of biological contamination. The light was measured using a 3M™ Clean-Trace™ NG Luminometer and displayed as the Relative Light Unit (RLU). [12] A field test was performed during a period from October 13, 2023, to October 23, 2023. The RLUs were determined before and after applying CAP to evaluate the efficiency of CAP in reducing biological contamination. After-sampling was performed at least four days after the CAP application. A CAP generator (model Wulute Model TB-700, Shinyoung Air Tech, South Korea) was employed. The percent decrease in biological contamination after applying the CAP generator was calculated using the following equation:

$$\text{Percent Decrease (\%)} = [(RLU_1 - RLU_2)/RLU_1] \times 100$$

Where RLU_1: ATP levels (RLUs) before applying the CAP

RLU_2: ATP levels after (RLUs) after applying CAP

Since the data showed a tendency toward a log normal distribution rather than a normal distribution, we presented the data using a geometric mean (GM) and geometric standard deviation (GSD). To do statistical analysis, including 'analysis of variance' (ANOVA) and a t-test, we converted the original data into log-transformed values using natural logarithms. [13]

3. Results and Discussion

Before and after applying CAP, ATP levels were measured at five sampling points in a golf practice center, as shown in Table 1 and Figure 1. Three samples were collected from three tables located in front of three screens, another one was collected from the surface above a locker in a changing room, and the remaining one sample was collected from a counter desk. The ATP levels before applying CAP ranged from 1,853 to 2,793 RLU with a GM of 2,209 RLU. All of the ATP levels in the normal state well exceeded 500 RLU, the guideline we chose. When the CAP was applied, the ATP levels reduced to a range from 343 to 612 RLU with a GM of 437 RLU. The overall reduction of ATP levels was 80.2%, with a range from 74.4 to 84.6%. All of the percent decreases were statistically significant ($p < 0.01$) and the overall reduction (80.2%) was extremely significant. ($p < 0.0001$) To evaluate whether there is any difference by sample point, an ANOVA test was conducted. The ANOVA result showed there was no significant difference between the ATP values by sampling points. ($p = 0.398$, see Table 2)

Table 1. *ATP Levels Before and After CAP Application by Sample Location in a Golf Practice Center.*

Sampling Point	Before		After		Percent Decrease %	t-value	p-value
	N	ATP, RLU GM* (GSD**)	N	ATP, RLU GM (GSD)			
Table by Screen A	6	2,793 (1.52)	6	430 (1.24)	84.6	5.42	< 0.01
Table by Screen B	6	1,853 (1.26)	6	419 (2.11)	77.4	6.14	< 0.01
Table by Screen C	6	2,056 (1.11)	6	421 (1.73)	79.5	13.44	< 0.01
Changing Room Locker	6	2,391 (1.24)	6	612 (1.25)	74.4	10.73	< 0.01
Counter Table	6	1,980 (2.00)	6	343 (1.09)	82.7	6.15	< 0.01
Overall	30	2,209 (1.38)	30	437 (1.57)	80.2	14.79	< 0.0001

*GM: Geometric Mean, **GSD: Geometric Standard Deviation

Table 2. ANOVA Table for Golf Practice Center.

Source of Variation	Sum of Squares	d.f.	Mean Squares	F-statistics	p-value
Between Sample Locations	0.655	4	0.164	1.058	0.398
Within Sample Locations	3.872	25	0.155		
Total	4.527	29			

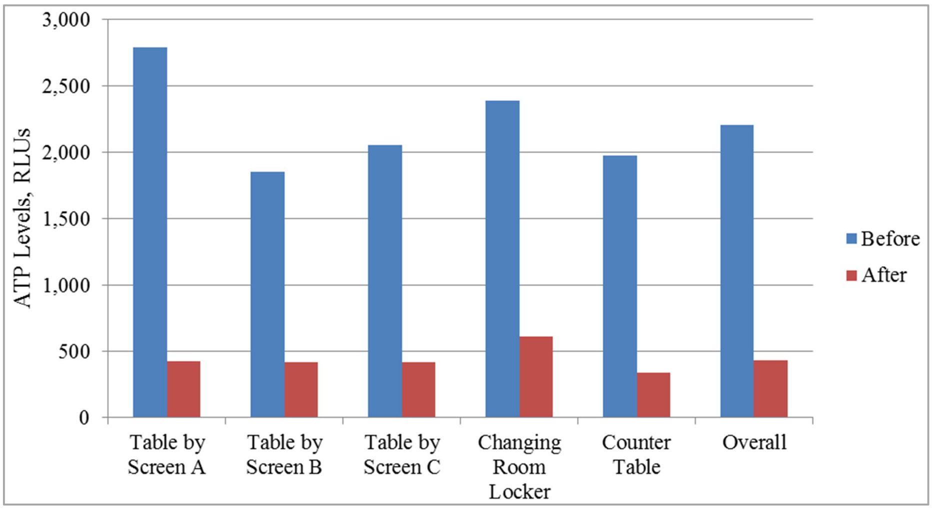

Figure 1. ATP Levels Before and After CAP Application by Sample Location in a Golf Practice Center.

Table 3 and Figure 2 present ATP levels measured before and after the application of CAP at five sampling points in a table tennis club. Samples were collected from a changing room door handle, a changing room chair, two ping pong tables, and an entry door handle. Prior to applying the CAP, all ATP levels exceeded 500 RLU, ranging from 656 to 2,268 RLU with a GM of 1,023 RLU. After the CAP application, ATP levels ranged from 280 to 574 RLU with a GM of 353 RLU. With the exception of samples taken from table tennis table A, all average ATP values were below 500 RLU. The ANOVA test indicated no significant difference between the five sampling points. (p = 0.068, see Table 4).

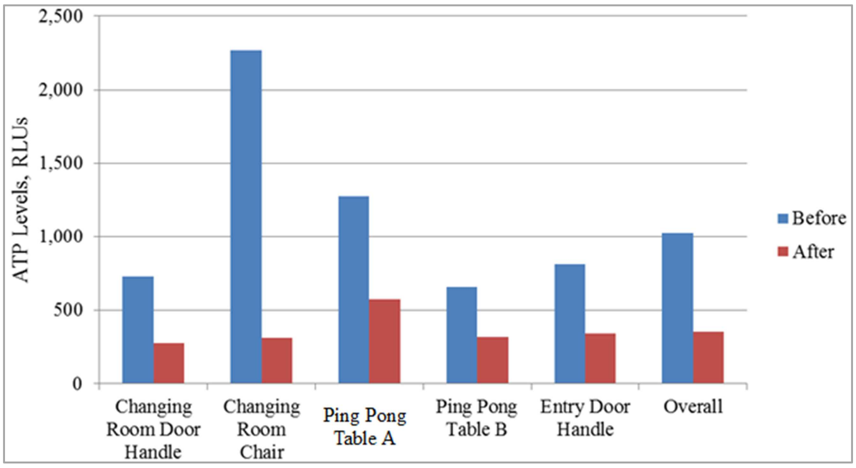

Figure 2. ATP Levels Before and After Application of Cold Atmospheric Plasma by Sample Location in a Table Tennis Club.

Table 3. ATP Levels Before and After CAP Application by Sample Location in a Table Tennis Club.

Sampling Point	Before N	Before ATP, RLU GM* (GSD**)	After N	After ATP, RLU GM (GSD)	Percent Decrease %	t-value	p-value
Changing Room Door Handle	6	727 (1.58)	6	280 (1.96)	58.2	3.46	< 0.01
Changing Room Chair	6	2,268 (1.78)	6	312 (1.57)	87.1	6.62	< 0.01
Ping Pong Table A	6	1,275 (2.95)	6	574 (1.49)	55.0	3.78	< 0.01
Ping Pong Table B	6	656 (1.34)	6	317 (1.70)	48.8	1.65	> 0.01
Entry Door Handle	6	813 (2.11)	6	344 (1.68)	63.0	2.32	< 0.05
Overall	30	1,023 (2.20)	30	353 (1.73)	65.5	6.06	< 0.0001

*GM: Geometric Mean, **GSD: Geometric Standard Deviation

***Table 4.** ANOVA Table for Table Tennis Club.*

Source of Variation	Sum of Squares	d.f.	Mean Squares	F-statistics	p-value
Between Sample Locations	6.297	4	1.574	2.505	0.068
Within Sample Locations	15.708	25	0.628		
Total	22.005	29			

Van Arkel et al. conducted a total of 960 ATP measurements in 9 hospitals on 32 hospital wards, with a range of 60 to 120 measurements per hospital. The median RLU-value was 568 (range: 3–277,586) and 37.7% of the measurements exceeded 1,000 RLU. [14] Guo et al. conducted a study to test the presence of coronavirus, SARS-CoV-2, on surface in an intensive care unit (ICU) and general coronavirus ward at Huoshenshan Hospital. They found that the virus was detected on various objects in both ICU and general wards with the highest rates of positivity from objects came from computer mice (75%), and followed by trash cans (60%) and bed handrails (43%) in the ICU and doorknobs (8.3%) in the general ward. [15] Chen et al. also reported that the coronavirus (SARS-CoV-2) remained viable on various surfaces for several hours. They applied the CAP technique to inactivate SARS-CoV-2 on surfaces such as plastic, metal, cardboard, basketball composite leather, football leather, and baseball leather. The results showed that CAP has the potential to be a safe and effective method to prevent virus transmission from a wide range of surfaces that are frequently touched by humans. [16]

4. Conclusions

As an indicator of biological contamination on equipment and furniture surfaces, we measured ATP levels from surface samples before and after the application of CAP. The surfaces of sports facility equipment and furniture were found to be severely contaminated with an excess of microorganisms, including fungi, bacteria, and viruses, surpassing the recommended guidelines. To address this issue, a new technique called cold atmospheric plasma (CAP), was introduced and applied to reduce biological contamination on these surfaces. The results showed a significant decrease in biological contamination, with reductions of 80.2% at an indoor golf practice center and 65.5% at a table tennis club. These findings demonstrate the promising potential of CAP as a technique for controlling biological contamination. Further research on the safety of the CAP technique is recommended. In addition, more field studies on the decontamination efficiency of the CAP in hospitals and nursing homes are needed.

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Krueger A., Reed, E Biological Impact of Small Air Ions. *Science.* 1976, 24; 193(4259), 1209-13. doi: 10.1126/science.959834.

[2] Filipić, A., Gutierrez-Aguirre, I., Primc, G., Mozetič, M., Dobnik, D. Cold Plasma, a New Hope in the Field of Virus Inactivation. *Trends Biotechnol.* 2020, 38(11), 1278-1291. doi: 10.1016/j.tibtech.2020.04.003.

[3] Cho, J., Min, K., Paik, N. Temporal Variation of Airborne Fungi Concentrations and Related Factors in Subway Stations in Seoul, Korea. *International Journal of Hygiene and Environmental Health.* 2006, 209(3), 249-55. doi: 10.1016/j.ijheh.2005.10.001. Epub 2006 Jan 10. PMID: 16410055.

[4] Park, D., Yeom, J., Lee, W., Lee, K. Assessment of the Levels of Airborne Bacteria, Gram-Negative Bacteria, and Fungi in Hospital Lobbies. *International Journal of Environmental Research and Public Health.* 2013, 10, 541-555. doi: 10.3390/ijerph10020541.

[5] Paik, N., Heo, S., Lee, I. Inactivation of Indoor Airborne Fungi Using Cold Atmospheric Pressure Plasma. J Korean Soc Occup Environ Hyg. 2019, 29(3), 351-357. doi: org/10.15269/JKSOEH.2019.29.3.351.

[6] Kim, K., Paik, N., Kim, Y., Yoo, K. Bactericidal Efficacy of Non-thermal DBD Plasma on Staphylococcus aureus and Escherichia coli. J Korean Soc Occup Environ Hyg. 2018, 28(1), 61-79. doi: org/10.15269/JKSOEH.2018.28.1.61.

[7] Lee, N., Park, S., Kim, J., Kim, K., Kim, D. Inactivation Efficacy of a Non-thermal Atmospheric Pressure Plasma Generator against Mycobacterium tuberculosis. *Korean J Healthc Assoc Infect Control Prev.* 2018, 23(2), 80-85. doi: org/10.14192/kjhaicp.2018.23.2.80.

[8] Son, E., Kim, Y., Paik, N., Lee, I., Kim, E., Park, H., Lee, J. Effect of Non-Thermal Dielectric Barrier Discharge Plasma by Air Volume against Mycobacterium tuberculosis. *J Korean Soc Occup Environ Hyg. 2019, 29(3), 414-419.* doi: org/10.15269/JKSOEH.2019.29.3.414.

[9] Xia, T., Kleinheksel, A., Lee, E., Qiao, Z., Wigginton, K., Clack, H. Inactivation of airborne viruses using a packed bed non-thermal plasma reactor. *J. Phys. D: Appl. Phys.* 2019, 52, 255201 (12pp). doi: org/10.1088/1361-6463/ab1466.

[10] Lewis, T., Griffith, C., Gallo, M., Weinbren, M. A modified ATP Benchmark for Evaluating the Cleaning of Some Hospital Environmental Surface. *Journal of Hospital Infection.* 2008, 69(2), 156-63. doi: 10.1016/j.jhin.2008.03.013.

[11] Nante N, Ceriale E, Messina G, Lenzi, D., Manzi, P. Effectiveness of ATP bioluminescence to assess hospital cleaning: a review. The Journal of Preventive Medicine and Hygiene. 2017. https://doi-org-ssl.libproxy.snu.ac.kr/10.15167/2421-248/jpmh2017.58.2.549

[12] 3M Science. Setting Pass/Fail Limits for the 3M™ Clean-Trace™ Hygiene Monitoring and Management System. clean-trace-setting-pass-fail-limits-pdf-lm1-implementation.pdf

[13] American Industrial Hygiene Association. IHSTAT™ (macro-free version). 2023.

[14] Van Arkel, A., Willemsen, I., Kilsdonk-Bode, L., Vlamings-Wagenaars, S., Van Oudheusden, A., De Waegemaeker, P., Leroux-Roels, I., Verelst, M., Maas, E., Van Oosten, A., Willemse, P., Van Asselen, E., Klomp-Berens, E., Franssen, K., Van Cauwenberg, E., Schweitzer, V., Kluytmans, J.. ATP measurement as an objective method to measure environmental contamination in 9 hospitals in the Dutch/Belgian border area. Antimicrob Resist Infect Control. 2020; 9: 77. doi: 10.1186/s13756-020-00730-9.

[15] Guo, Z., Wang, Z., Zhang, S., Li, X., Li, L., Li, C., Cui, Y., Fu, R., Dong, Y., Chi, X., Zhang, M., Liu, K., Cao, C., Liu, B., Zhang, K., Gao, Y., Lu, B., Chen, W. Aerosol and Surface Distribution of Severe Acute Respiratory Syndrome Coronavirus 2 in Hospital Wards, Wuhan, China, 2020. Emerging Infectious Diseases. 2020, 26(7), 1586–1591. doi: 10.3201/eid2607.200885.

[16] Chen, Z., Garcia, Jr., G., Arumugaswami, V., Wirz, R. Cold Atmospheric Plasma for SARS-CoV-2 Inactivation. Phys of Fluids. 2020, 32(11), 111702. doi: 10.1063/5.0031332.