

## Effect of a mechanical ventilation system (exhaust fan) integrated with chlorination on reducing bacterial colonies in dental treatment rooms

*Efektivitas Sistem Ventilasi Mekanik (Exhaust Fan) Terintegrasi Klorinasi untuk Mengurangi Koloni Bakteri di Ruang Perawatan Gigi*

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### ABSTRACT

**Background:** Microbial air contamination (bioaerosols) in dental treatment rooms poses a significant risk for the transmission of Healthcare-Associated Infections, particularly during aerosol-generating procedures. Limited studies have evaluated integrated ventilation and disinfection systems to control airborne bacteria.

**Objective:** This study aimed to evaluate the effectiveness of a mechanical ventilation system (exhaust fan) integrated with calcium hypochlorite disinfection in reducing airborne bacterial colonies.

**Methods:** A quasi-experimental study with a pretest–posttest design was conducted under four conditions: P1 (before ventilation), P2 (after ventilation), P3 (outlet without disinfection), and P4 (outlet with calcium hypochlorite). Air sampling was performed using the settle plate method with five Nutrient Agar plates exposed for 15 minutes at a height of one meter. The exhaust fan was operated for one hour prior to sampling. Each condition was repeated 15 times. Bacterial colonies were quantified and converted into CFU/m<sup>3</sup> using the Omeliansky formula.

**Results:** The baseline bacterial concentration was 211.04 CFU/m<sup>3</sup>. Ventilation significantly reduced bacterial colonies to 100.63 CFU/m<sup>3</sup> ( $p = 0.015$ ). No significant difference was observed between indoor and outlet air ( $p = 0.297$ ). The addition of calcium hypochlorite significantly reduced bacterial colonies to 16.07 CFU/m<sup>3</sup> ( $p < 0.001$ ).

**Conclusion:** Mechanical ventilation reduces airborne bacterial load, and integration with calcium hypochlorite disinfection effectively minimizes microbial contamination before air is released into the environment.

**Keywords:** airborne bacteria, bioaerosol, dental clinic, exhaust ventilation, calcium hypochlorite

### ABSTRAK

**Latar Belakang:** Kontaminasi mikroba udara (bioaerosol) di ruang perawatan gigi merupakan faktor risiko penularan infeksi terkait pelayanan kesehatan, terutama pada prosedur yang menghasilkan aerosol. Studi mengenai integrasi ventilasi dan desinfeksi untuk mengendalikan bakteri udara masih terbatas.

**Tujuan:** Penelitian ini bertujuan mengevaluasi efektivitas sistem ventilasi mekanik (exhaust fan) yang terintegrasi dengan desinfeksi kalsium hipoklorit dalam menurunkan koloni bakteri udara.

**Metode:** Penelitian eksperimen semu dengan desain pretest–posttest dilakukan pada empat kondisi, yaitu P1 (sebelum ventilasi), P2 (setelah ventilasi), P3 (outlet tanpa desinfeksi), dan P4 (outlet dengan kalsium hipoklorit). Pengambilan sampel udara menggunakan metode settle plate dengan lima cawan Nutrient Agar selama 15 menit pada ketinggian satu meter. Exhaust fan dioperasikan selama satu jam sebelum pengambilan sampel. Setiap kondisi diulang 15 kali. Koloni bakteri dihitung dan dikonversi menjadi CFU/m<sup>3</sup> menggunakan rumus Omeliansky.

**Hasil:** Konsentrasi awal bakteri sebesar 211,04 CFU/m<sup>3</sup>. Ventilasi menurunkan koloni bakteri secara signifikan menjadi 100,63 CFU/m<sup>3</sup> ( $p = 0,015$ ). Tidak terdapat perbedaan bermakna antara udara ruangan dan outlet ( $p = 0,297$ ). Penambahan kalsium hipoklorit menurunkan koloni bakteri secara signifikan menjadi 16,07 CFU/m<sup>3</sup> ( $p < 0,001$ ).

**Kesimpulan:** Ventilasi mekanik efektif menurunkan bakteri udara, dan integrasi dengan desinfeksi kalsium hipoklorit mampu meminimalkan kontaminasi mikroba sebelum udara dilepaskan ke lingkungan.

**Kata kunci:** bakteri udara, bioaerosol, klinik gigi, ventilasi exhaust, kalsium hipoklorit

## INTRODUCTION

Indoor air quality (IAQ) in healthcare facilities is an integral and critical component of infection prevention and control (IPC) efforts, particularly in reducing the number of nosocomial infections (healthcare-associated infections/HAIs). Poor air quality in hospitals and healthcare facilities can significantly contribute to patient and staff health risks and increase healthcare costs.<sup>1,2</sup>

Dental clinics and practices inherently carry a high risk of cross-infection, which threatens the safety of patients and healthcare workers. This increased risk is due to routine clinical procedures classified as Aerosol-Generating Procedures (AGP), such as the use of ultrasonic scalers, high-speed handpieces, and air-water syringes, which generate large numbers of bioaerosols—particles suspended in the air carrying pathogenic microorganisms from patients' saliva, blood, and plaque. These very small bioaerosol particles (<5  $\mu\text{m}$ ) can remain airborne for hours and penetrate deeper into the respiratory tract, making them a major vector for airborne disease transmission. Microbiological studies have confirmed the presence of potentially nosocomial bacteria, such as *Staphylococcus aureus* and *Klebsiella pneumoniae*, in dental clinic air samples. <sup>$\mu\text{m}^{2-4}$</sup>

Although standard infection control guidelines, such as the use of Personal Protective Equipment (PPE) and high-volume evacuation (HVE) systems, have been shown to significantly reduce aerosol concentrations in the operative area, airborne pathogen transmission remains a significant global challenge, particularly in enclosed environments with suboptimal ventilation. Several systematic reviews have demonstrated limited conclusive data regarding the absolute effectiveness of specific ventilation systems (such as portable HEPA filters or supplemental ultraviolet germicidal irradiation/UVGI) in preventing actual disease transmission in the dental environment, rather than simply reducing airborne contamination. This gap in prevention efficacy drives the need for innovative solutions to mitigate the risk of infection transmission in dental facilities.<sup>5-7</sup>

IAQ control strategies in healthcare facilities are generally divided into static (without activity) and dynamic (with activity) methods. Static methods, such as ultraviolet (UV) irradiation or ozone and sodium hypochlorite fumigation, have proven highly effective in disinfecting rooms and surfaces, with bacterial colony reduction rates reaching 90-92% in a short time. However, these methods have a fundamental limitation: they cannot be operated during clinical activity, when the risk of cross-infection is at its peak. Mechanical

ventilation systems, particularly exhaust systems, are the globally recommended engineering control solution because they allow for the dilution of contaminants and the removal of contaminated air during activity.<sup>8-11</sup>

While effective in reducing indoor contaminants (through dilution and removal), the implementation of conventional exhaust systems creates a new risk gap: contamination of the outdoor environment. The drawn-out air will cause the accumulation of bioaerosols in the exhaust ducts (outlets). This is feared to spread microorganisms isolated from the clinical space to the general environment or other healthcare facilities. Therefore, the current system does not fully solve the problem; it only relocates the threat. Therefore, the use of disinfectants such as chlorine tablets in exhaust ducts is an alternative to increase the efficiency of microbial control. Calcium hypochlorite, the active ingredient in chlorine, is known to have strong oxidative activity through the release of hypochlorous acid (HOCl), which can damage cell membranes and essential components of microorganisms. Several studies have reported that chlorine compounds, particularly in the form of hypochlorous acid (HOCl) or sodium hypochlorite (NaOCl), at certain concentrations can reduce bacterial counts by up to 99–99.99% in a relatively short contact time. In addition, chlorine residue is relatively non-persistent as it degrades into chloride ions and other stable compounds in the environment.<sup>12,13</sup> Thus, the use of chlorine has the potential to be an effective disinfection alternative to reduce bioaerosol contamination before the air is released into the external environment. The primary objective of this study was to test the effectiveness of a mechanical ventilation system integrated with chlorine disinfection in reducing bioaerosol concentrations.

## METHODS

### Study design

This study used a quasi-experimental design with a comparative approach to evaluate the effect of a mechanical ventilation system (exhaust fan) and chlorine disinfection on airborne bacterial concentrations. The study was conducted in the dental health service room of Dr. Rubini Mempawah Regional Hospital from October to November 2025.

### Data source and sampling procedure

The data used is primary data in the form of the number of airborne bacterial colonies. The study population was all microorganisms suspended in the air in the sampling area. The research sample was a bacterial colony that grew on Nutrient Agar (NA) media after incubation. The sampling technique used the settle plate method (open cup) with an exposure time of 15 minutes at a height of approximately 1 meter from the floor. The study consisted of four treatment groups, namely:

P1: indoor air before the exhaust fan is operated

P2: indoor air after the exhaust fan has been operated for 60 minutes

P3: air at the ventilation outlet without disinfection

P4: Air at the ventilation outlet with chlorine disinfection

Each group was repeated 15 times so that the total sample was 60. The number of repetitions has exceeded the minimum requirements based on the Federer formula to increase the statistical power of the study.

### Variables of the study

The independent variables in this study were mechanical ventilation and chlorine disinfection. The dependent variable was the number of airborne bacterial colonies expressed in CFU/m<sup>3</sup>. Control variables included exposure time, growth medium, incubation temperature, and sampling location and altitude.

### Data collection

Air sampling was performed using the settle plate method using five petri dishes filled with Nutrient Agar at each measurement point. In the ventilation treatment group, the

exhaust fan was operated for 60 minutes before sampling to ensure stable air circulation. After 15 minutes of exposure, the media were incubated for 48 hours at 37°C. The number of bacterial colonies was then counted using a colony counter. Each sample represents the average value from five petri dishes.

**Measurement and instruments**

The instruments used in this study included Nutrient Agar media, Petri dishes, colony counters, and an exhaust fan as a mechanical ventilation system. The disinfectant used was a chlorine tablet containing calcium hypochlorite (Ca(OCl)<sub>2</sub>). A total of 5 chlorine tablets were placed in the collection media in the ventilation outlet channel based on the results of preliminary tests to ensure the availability of active chlorine without disrupting air flow. The number of bacterial colonies was expressed in CFU/plate and converted to CFU/m<sup>3</sup> using the Omeliansky empirical formula as follows:

$$N = a \times 10^4 (b \times t)^{-1}$$

Information:

- N = number of microbes (CFU/m<sup>3</sup> air)
- a = number of colonies in the petri dish
- b = surface area of the cup (63.6 cm<sup>2</sup>)
- t = exposure time (minutes)

In this study, chlorine tablets were installed in a collection unit located in the ventilation outlet duct before the air is discharged into the ambient environment. This arrangement ensured that the disinfection process was confined to the exhaust air, preventing direct chlorine exposure to indoor air. Therefore, this intervention did not affect the air quality breathed by patients and healthcare workers in the dental office.

**Ethical considerations**

This research has obtained ethical approval from the Health Research Ethics Commission (KEPK) of the Pontianak Ministry of Health Polytechnic under the number: No. 305/KEPK-PK.PKP/XII/2025. The research does not directly involve human subjects, so informed consent is not required, but it still adheres to the principles of work environment safety.

**Data analysis**

Data were analyzed using statistical software. Normality testing was performed using the Shapiro-Wilk test to determine data distribution. Because some data were not normally distributed, intergroup differences were analyzed using the non-parametric Mann–Whitney U test with a significance level of α = 0.05. Differences were considered significant if the p-value <0.05.

**RESULTS**

The results of bacterial colony measurements in the Dental Health Outpatient Unit of Dr. Rubini Mempawah Regional Hospital are as follows:

**Table 1. Number of Airborne Bacterial Colonies in Each Treatment and Repetition**

Repetition	Number of Air Bacterial Colonies			
	Treatment 1 (P1)	Treatment 2 (P2)	Treatment 3 (P3)	Treatment 4 (P4)
1	19	16	9	1
2	25	11	11	0
3	10	14	8	4
4	15	14	11	0
5	9	13	1	1
6	31	6	1	1
7	11	2	7	3
8	20	16	11	0

Repetition	Number of Air Bacterial Colonies			
	Treatment 1 (P1)	Treatment 2 (P2)	Treatment 3 (P3)	Treatment 4 (P4)
9	10	20	9	1
10	18	7	2	4
11	11	2	3	2
12	54	7	10	3
13	13	3	14	2
14	31	5	1	1
15	25	8	6	0
Mean	20.13	9.60	6.93	1.53
SD	11.98	5.68	4.35	1.41

Descriptive analysis of Table 1 includes:

- Average air bacteria count: 20.13 Colonies/Petri disk (211.04 CFU/M3)
- P2 average air bacteria count: 9.60 Colonies/Petri disk (100.63 CFU/M3)
- P3 average air bacteria number: 6.93 Colonies/Petri disk (72.68 CFU/M3)
- P4 average air bacteria count: 1.53 Colonies/Petri disk (16.07 CFU/M3)

Description: P1 Measurement of air bacteria in the room before the exhaust fan is operated, P2 Measurement of air bacteria in the room after the exhaust fan is operated without the addition of chlorine, P3 Measurement of air bacteria in the air coming out of the exhaust fan outlet without disinfection and P4 Measurement of air bacteria in the air coming out of the exhaust fan outlet after passing through media given chlorine tablets. The results of the study showed that the use of exhaust fans in treatment P2 has reduced the concentration of air bacteria to below the indoor air quality standards for health care facilities. However, the addition of chlorine disinfection at the ventilation outlet (P4) was able to reduce the number of air bacteria more significantly so that the potential for the release of microorganisms to the outside environment can be minimized.

The comparison between the average P1 vs P2 shows a decrease of 52.32%, indicating the magnitude of the exhaust fan's effectiveness in reducing the density of bioaerosols in the room. The average P2 vs P3 shows a decrease of 27.78%, or the exhaust fan can move bioaerosols by 72.22%. The average P3 vs P4 shows a decrease of 77.88% as the value of the ability of chlorine tablets (chlorine gas) to reduce the number of airborne bacteria at the outlet.

Data normality test: Each treatment had n=15 samples (considered a small sample, n<50), the researcher used the Shapiro-Wilk Test to test the normality assumption. Since this study had four treatment groups, the general difference analysis could be conducted using the Kruskal–Wallis test. However, the main objective of this study was to evaluate three stages of the ventilation and disinfection process, namely: (1) conditions before and after the exhaust fan was operated (P1 vs P2), (2) the transfer of bioaerosol from indoors to the ventilation outlet (P2 vs P3), and (3) the effectiveness of chlorine disinfection at the ventilation outlet (P3 vs P4). Therefore, a pairwise comparison analysis was conducted using the non-parametric Mann-Whitney U test with a significance level of  $\alpha = 0.05$  (Table 2).

**Table 2. Normality Test Results (Shapiro-Wilk Test)**

Treatment	n	Shapiro-Wilk Statistics (W)	p-value	Decision (at $\alpha=0.05$ )	Interpretation
P1	15	0.852	0.027	H0 is rejected	Abnormal Data
P2	15	0.938	0.395	H0 is accepted	Normal Data
P3	15	0.925	0.252	H0 is accepted	Normal Data
P4	15	0.816	0.007	H0 is rejected	Abnormal Data

In Table 2 above, P1 and P4 show that the data is not normally distributed, so the researcher used a non-parametric statistical test, namely the Mann-Whitney U test.

**Table 3. Mann-Whitney U Statistical Test Results for Comparison of P1 vs P2, P2 vs P3, and P3 vs P4**

Comparison	Null Hypothesis (H0)	U Statistics	p-value (2-tailed)	Decision ( $\alpha=0.05$ )	Interpretation
P1 vs P2	Median(P1)=Median(P2)	53.5	0.015	H0 is rejected	There is a significant difference.
P2 vs P3	Median(P2)=Median(P3)	79.5	0.297	H0 is accepted	There is no significant difference.
P3 vs P4	Median(P3)=Median(P4)	23.5	<0.001	H0 is rejected	There is a significant difference

The Mann-Whitney U statistical test results in Table 3 show a significant difference between the conditions before and after the exhaust fan was operated (P1 vs. P2;  $p = 0.015$ ), indicating that the use of the exhaust fan was effective in reducing the number of airborne bacterial colonies in the dental service room. Comparison between P2 and P3 did not show a statistically significant difference ( $p = 0.297$ ). These results indicate that the concentration of airborne bacteria exiting through the ventilation outlet was relatively similar to the concentration of airborne bacteria in the room after the exhaust fan was operated, so the mechanical ventilation system plays a major role in moving bioaerosols from the room to the exhaust duct. Conversely, the comparison between P3 and P4 showed a very significant difference ( $p < 0.001$ ), indicating that the addition of chlorine tablets to the ventilation outlet was effective in reducing the number of airborne bacterial colonies before the exhaust air was released to the outside environment.

## DISCUSSION

Effectiveness of exhaust fans in controlling indoor bioaerosols (P1 vs P2): The Mann-Whitney U test results showed a statistically significant difference ( $p=0.015$ ) in the number of airborne bacterial colonies between conditions before the intervention (P1) and after the exhaust fan was activated (P2). This validates the effectiveness of exhaust fans as a primary intervention to reduce the risk of nosocomial infections in dental outpatient units. The theory explains that increasing ventilation rates is a key mechanism to reduce airborne disease transmission. Ventilation functions to: 1) remove or dilute droplets and droplet nuclei containing pathogens, 2) reduce the concentration of bioaerosols, and 3) reduce the risk of exposure to healthcare workers. The review confirmed that the risk of infection decreases as ventilation rates increase due to the dilution effect of contaminated air.<sup>14-17</sup>

Dilution and Extraction Mechanism: Exhaust ventilation (such as exhaust fans) works by creating partial negative pressure in the dental office and continuously diluting the concentration of bioaerosols generated by dental procedures (Aerosol Generating Procedures - AGPs). Research by Sandberg M et al. (2020) confirmed that the air exchange rate (ACH) is a key factor in reducing airborne particles.<sup>18</sup>The significant results in P1 vs P2 indicate that exhaust fans effectively increased local ACH, outperforming natural ventilation mechanisms. Yao G et al. (2025) found that the effectiveness of ventilation in restoring air quality in dental clinics depends on the strategic placement of exhaust fans. In a hospital context, where fresh air is often sourced from corridors, exhaust fans help prevent contaminated air from spreading back to other low-risk areas.<sup>19</sup> Treatment 1 (P1) data were abnormal and had the highest standard deviation ( $s=12.38$ ), indicating an uncontrolled environment. The use of exhaust fans in P2 not only reduced the median colony count but also improved data

consistency ( $s=5.76$ ), reflecting a mechanically controlled environment. The consistent (significant) statistical results in the Mann-Whitney U test further strengthen the conclusion that exhaust fans are a vital tool in post-pandemic aerosol mitigation strategies in dental healthcare facilities.<sup>20</sup>

**Limitations of Pure Extraction Ventilation Design and Secondary Pollution Risk (P2 vs. P3):** A comparison between P2 (room air) and P3 (exhaust fan outlet air without chlorine) showed no statistically significant difference ( $p=0.297$ ). This finding provides important empirical data regarding the risks posed by pure extraction ventilation design. **Exhaust Air Microbial Load:** The absence of significant differences indicates that the air discharged by the exhaust fan has a similar microbial load to indoor air. The median colony count in P3, although lower, is statistically indistinguishable from P2. This is consistent with the exhaust fan's function of simply moving air without processing or cleaning it.<sup>21</sup> In the Hospital context, where there are many units and heavy patient/visitor traffic, the direct release of contaminated air to the outside environment (or roof/plenum area) is a serious infection control issue: Guidelines from ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) strictly limit the discharge of potentially infectious air and require a safe discharge distance from air intakes or public areas.<sup>22-24</sup> Saeedi R, et al. (2021) highlighted that re-entrainment (exhaust air re-entering the building through intake ducts) is a real risk. These findings validate the need to not only remove contaminants from dental rooms but also neutralize them before they are released.<sup>25</sup>

**Exhaust Air Disinfection Innovation and Validation of Chlorine Effectiveness (P3 vs P4):** Comparison between P3 (outlet without chlorine) and P4 (outlet with chlorine) showed a highly statistically significant difference ( $p < 0.001$ ). Treatment 4 (P4) produced the lowest colony count, validating chlorine tablets as an effective exhaust air disinfection agent. **Exhaust Air Chlorination as a Low-Cost Solution:** Exhaust air chlorination is a key and novel finding in this study. The use of calcium hypochlorite (chlorine) utilizes the release of chlorine gas, a chemical disinfectant proven effective in killing microorganisms. This process creates a "disinfection zone" in the exhaust duct without requiring additional electrical energy, making it a practical and economical solution for dental healthcare facilities in developing countries.

In addition to the drastic decrease in the median, Treatment 4 recorded the lowest Shapiro-Wilk statistic ( $W=0.816$ ) and the lowest standard deviation ( $s=1.58$ ). While not normal (as most values are concentrated around zero), this reflects an extreme level of control and high consistency of results. The near-perfect disinfection rate indicates that environmental variability no longer significantly impacts the measurement results, as the chlorine agent has eliminated most of the microorganisms extracted. Amid post-pandemic cost challenges, such a solution offers an alternative to the expensive technologies (such as UVGI or HEPA filtration in exhaust ducts) suggested by Tzoutzas et al. (2022). This innovation allows dental facilities in hospitals to achieve outdoor environmental safety standards without compromising the budget.<sup>26</sup>

The main advantage of this research lies in its integrated engineering control approach, namely the combination of an exhaust fan and chlorine disinfection of the exhaust air, which not only reduces bioaerosols indoors but also prevents secondary contamination to the outdoor environment. This innovation is simple, low-cost, and easily replicated, making it relevant for healthcare facilities with limited resources. Furthermore, the use of a quasi-experimental design with sufficient repetition and appropriate non-parametric statistical analysis enhances the validity of the research findings.

This study has several limitations. First, bioaerosol measurements were conducted using the settle plate method, which represents passive deposition and does not reflect

real-time aerosol particle concentrations. Second, this study did not identify specific bacterial species, so the system's effectiveness against certain pathogens cannot be confirmed. Third, the study was conducted at a single dental healthcare facility, so generalizing the results to other facilities with different ventilation characteristics and clinical activities requires caution. Furthermore, this study did not measure ventilation parameters such as Air Changes per Hour (ACH) or airflow rate, so a more in-depth quantitative analysis of the relationship between ventilation rate and bioaerosol reduction cannot be conducted.

The findings of this study have important practical and policy implications. Practically, an exhaust fan system combined with chlorine disinfection can be adopted as a prototype for bioaerosol control in dental offices to reduce the risk of nosocomial infections while protecting the surrounding environment. Policy-wise, these results can inform the development of technical guidelines for ventilation and the removal of contaminated air in healthcare facilities, particularly in developing countries. Further research is recommended to test the effectiveness of this system in various types of healthcare facilities, using active aerosol sampling methods, and assess the long-term impacts on environmental safety and worker health. For further research, it is recommended to conduct more comprehensive measurements of ventilation parameters, such as Air Changes per Hour (ACH), airflow velocity, and indoor air circulation patterns. Furthermore, the use of active aerosol sampling methods, such as air samplers or bioaerosol monitors, should be considered to obtain a more accurate picture of bioaerosol concentrations. Further research could also identify specific microorganisms using microbiological or molecular methods and evaluate the effectiveness of ventilation systems and chlorine disinfection against various types of airborne pathogens. Further studies on the safety of chlorine residual exposure in exhaust air, the long-term effectiveness of the system, and its applicability to various types of healthcare facilities are also needed to strengthen the scientific evidence and support wider implementation of this technology.

## CONCLUSION

This study aimed to evaluate the effectiveness of a mechanical ventilation system using exhaust fans and their integration with chlorine disinfection in reducing bioaerosols in dental healthcare facilities. The results showed that the use of exhaust fans significantly reduced the concentration of airborne bacteria in the room through dilution and air extraction mechanisms. However, the air released through the ventilation outlet still contained microorganisms, potentially becoming a source of secondary pollution if released directly into the environment without a disinfection process. The addition of chlorine tablets to the ventilation outlet proved highly effective in reducing the number of bacterial colonies in the exhaust air, thus controlling bioaerosols not only indoors but also in the air released to the outside environment.

Based on these findings, a mechanical ventilation system integrated with chlorine disinfection has the potential to be a simple, effective, and relatively low-cost engineering control alternative for bioaerosol control in dental healthcare facilities, particularly in facilities with limited resources. Further research is recommended to quantitatively measure ventilation parameters such as Air Changes per Hour (ACH), use active aerosol sampling methods, and identify specific types of microorganisms to strengthen the evidence of the effectiveness of ventilation systems and exhaust air disinfection.

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