Original Research Article

High-speed compressed air filtration device: an effective alternative to decrease cross-contamination in dental care

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ABSTRACT

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| **Aims:** To develop and evaluate the effectiveness of a filtration device designed to decrease the microbial load in the air system of the dental chair.  **Methodology:** This experimental, laboratory-based, quantitative study involved the construction of a filtration device using modified high-speed handpieces, rubber gaskets, N95 masks folters, and welding. Sample collection was organized into four groups: Group A - Sterilized distilled water; Group B - High-speed handpiece with a closed water system and the filtration device; Group C - High-speed handpiece with a closed water system without the filtration device; and Group D – The filter from the filtration device after use. Samples were incubated at 37°C for 48 hours, quantified for microbial growth, Gram-stained, and analyzed microscopically.**Results:** No microbial growth was observed in Group A, confirming the sterility of the water. Group B, exhibited an average of 3.33±3.50 colony-forming units (CFU), representing a significant reduction (p<0.05) compared to Group C, which showed substantially higher contamination (32.11±188.36 CFU). The filter in Group D retained microorganisms, with an average growth of 3.00±6.00 CFU, confirming its role in microbial filtration.  **Conclusion:** The filtration device effectively reduced the microbial load in the air system of the dental chair, demonstrating its potential as a biosafety measure to minimize cross-contamination in dental environments. |

*Keywords: Cross Contamination; Air contamination; Microorganisms; Dentistry.*

1. INTRODUCTION

In dentistry, the dental chair serves as fundamental plataform for preventive, therapeutic, and surgical procedures. The integrated devices – including support tray, spittoon, monofocal reflector head, and handpiece holder - are essential for clinical operations and function synergistically with dental interventions(Tonello *et al.*, 2022).

Advancements in dental technology have transformed the dental chair into a sophisticated system, incorporating high-precision instruments such ashandpieces, high-speed drills, ultrasonic scalers, and triple syringes(Hong *et al.*, 2022; José *et al.*, 2005; Monteiro *et al.*, 2018). However, the extensive network of components increases susceptibility to microbial contamination, providing favorable conditions for the proliferation of pathogenic microorganism(Hubar, Pelon e Gardiner, 2002; José *et al.*, 2005).

The water and air systems of the dental chair are indispensable for ensuring adequate cooling, protection, and irrigation during procedures(Li *et al.*, 2020; Spratt *et al.*, 2004). However, failures in the negative suction of handpieces, combined with the intrinsic conditions within the equipment—such as surface texture, the presence of organic and inorganic residues, and a humid microenvironment—facilitate biofilm formation on internal components(Bagga *et al.*, 1984; Hubar, Pelon e Gardiner, 2002).

Several studies have identified a diverse array of pathogenic microorganisms colonizing dental unit systems, with particular emphasis on *Streptococci*, *Staphylococcus spp.*, *Enterococci*, *Pseudomonas aeruginosa*, *Legionella*, and other Gram-negative bacilli(Meriem et al., 2014; Mills, 2000; Pankhurst e Coulter, 2007; Xavier1 et al., 2015). These pathogens pose significant risks to immunocompromised patients, such as individuals with diabetes, transplant recipients, the elderly, and those undergoing cancer treatment(Fotedar e Ganju, 2015; Gusmão e Gusmão, 2013).

To mitigate health risks, the American Dental Association (ADA) established in 2000 that water used in non-surgical dental procedures should not exceed 200 CFU/mL of heterotrophic bacteria(Hubar, Pelon e Gardiner, 2002; Kadaifciler e Cotuk, 2014; Mills, 2000). However, despite increasing evidence of microbial contamination in the air system of dental chairs(Bjerring e Berg, 1986a; Hubar, Pelon e Gardiner, 2002; Walker e Marsh, 2007; Walker et al., 2004), no standardized regulatory limits have been established for microbial load in compressed air used to activate dental handpieces(Bzdęga, Trykowski e Bzdęga, 2007).

Given the limited number of recent studies investigating microbial contamination in dental chair air systens and strategies to mitigate its spread, the present study aimed to develop a prototype filtration device and evaluate its effectiveness in reducing the microbiological load, thereby minimizing cross-contamination in dental settings.

2. material and methods

**2.1 Material**

To conduct this research, an adjustable metal prototype (Figure 1A), referred to as a filtration device, was developed. When attached with the high-speed handpiece and the dental chair hose, this device functioned as a dual water and air filtration barrier.

The filtration device was constructed using the following components: two high-speed handpieces, a rubber gasket, a 3 cm-long metal cannula with a 4 mm diameter, two additional metal cannulas (each 3 cm in length and 2 mm in diameter), welding materials, N95 masks filters, and a male/female screw-on system. The screw-on components measured1 cm in length, with the male screw having 14 mm diameter and the female screw 8 mm diameter. No specific commercial brand was utilized in the fabrication of the device (Figure 1B).

**2.2 Assembly of the device**

The prototype manufacturing process involved modifying two high-speed handpieces by sectioning them at the posterior region, where the water (smaller diameter) and air (larger diameter) passage holes are located in standard dental equipment. Metal cannulas were welded to the corresponding openings, with the larger diameter cannula designated for air flow and the smaller diameter cannula for water filtration.

The larger diameter cannula was welded to the female screw component, while the smaller diameter cannula was positioned laterally and tangentially to the female component. The male component of the device was integrated into the second sectioned high-speed handpiece using a 3 cm-long metal cannula. To ensure proper functionality, the water passage hole in the sectioned handpiece was internally sealed using metal welding. Finally, the assembled device was securely attached to the high-speed handpiece through the screw-on mechanism (Figure 1C).

**Fig 1.** Schematic representation of the filtration device and its assembly process: (A) conceptual design and fabrication steps, (B) final device components, and (C) fully assembled filtration device coupled to the high-speed handpiece.

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**2.3 Sample collection and Microbiological Processing**

The study was structured into four experimental groups: Group A – sterilized distilled water; Group B – activation of the high-speed handpiece equipped with the filtration device and a closed water system; Group C – activation of the high-speed handpiece without the filtration device, using a closed water system; and Group D – analysis of the filtration device’s filter after use. Sample collection was conducted over three weeks in a randomly selected dental care unit within a teaching clinic characterized by a high patient turnover.

To validate the sterility of the distilled water (Group A), 100 µL of sterile water stored in an Erlenmeyer flask was pipetted in triplicate and inoculated onto nutrient agar plates. Additionally, the dental unit’s water reservoir was emptied, disinfected with 70% alcohol, and then refilled with sterilized distilled water. The system was flushed by activating the motor for 10 seconds to expel any residual fluid. In Group B, a pre-sterilized filtration device was coupled to a high-speed handpiece, and an 8 mm diameter sterile N95 mask disc was placed inside the female component of the device. Once assembled, the high-speed handpiece was activated with the water system closed and the air system open, directing the airflow for 5 seconds at a distance of 5 cm from a culture medium plate.

In Group C, a sterilized high-speed handpiece, without the filtration device but with a closed water system and open air system, was connected to the dental chair unit and activated under the same conditions as in Group B (Figure 3).

In Group D, after the use in Group B, the filtration device was carefully disassembled, and the filter was removed using sterile forceps. The exposed surface of the filter was streaked onto the periphery of culture medium plate for microbiological analysis.

All samples were transported under refrigeration to the Microbiology Laboratory for processing. Culture plates were incubated at 37°C in a bacteriological incubator (BOD®) for 48 hours. Bacterial growth was assessed by counting colony-forming units (CFU), and Gram-stained slides were prepared to evaluate staining patterns, morphology, and the arrangement patterns of bacterial groups. A control plate was included in each experiment to ensure the absence of secondary contamination.

2.4 Statistical analysis

Statistical analysis was performed using SPSS Statistics 25® software (SPSS Inc., IBM®). Statistical significance was set at P = 0,05. Since the Shapiro-Wilk normality test indicated a non-normal data distribution, nonparametric tests were applied. The Kruskal-Wallis test was used for group comparisons, followed by Dunn's post hoc test to identify specific differences between groups.

3. results

Visual inspection of the control plates (containing only nutrient agar culture medium) revealed no color changes or microbial growth, confirming the sterility of both the culture medium and the plates.

All groups exhibited macroscopic contamination (Table 1), except for Group A, which further confirmed the sterility of the medium and validated the reliability of the other analyses.

As illustrated in Figure 2, the use of the filtration device attached to the dental chair significantly reduced the microbial load in the air passing through the high-speed handpiece (p < 0.05). The mean CFU count was 3.33 ± 3.50 CFU (95% CI: 1.90–4.77) when the device was used. In contrast, the absence of the filtration device resulted in a markedly higher mean CFU count of 32.11 ± 188.36 (95% CI: 21.56–42.66), demonstrating the device’s efficacy in mitigating airborne microbial contamination. Furthermore, the analysis of the microbial load retained within the filter (Group D) exposed to contaminated air showed a mean CFU count of 3.00 ± 6.00 (95% CI: 1.12–4.88) in the area directly subjected to airflow from the dental equipment, reinforcing the device's filtration capability.

**Fig. 2 –** Microbiological contamination data collected in triplicate over a 3-week period, presented as CFU. Group A showed no contamination, whereas Groups B, C, and D demonstrated varying levels of contamination, as indicated by the CFU counts.

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Macroscopic evaluation of the culture medium plates demonstrated the effectiveness of the filtration device in reducing microbiological contamination (Figure 3). The comparative assessment of CFU counts across the different groups visually reinforces the device’s impact. Notably, the plate representing Group B (filtration device in use) exhibited a significantly lower number of CFUs compared to the plate from Group C, where the device was not utilized.

Fig. 3. Comparison of CFU contamination levels: (A) plate from Group B, where the filtration device was utilized, showing a reduced microbial load; (B) plate from Group C, where no filtration device was used, demonstrating a visibly higher CFU count.

Placa de vidro

Descrição gerada automaticamente com confiança baixa

Microscopic examination, including Gram staining and morphological assessment, identified microorganisms from the genera *Streptococcus sp*., *Staphylococcus sp.*, *Diplococcus sp.*, and *Bacillus sp.*, encompassing both Gram-positive and Gram-negative species (Table 1).

Table 1. Bacterial shapes, arrangements, and types identified in the respective groups over the 3-week analysis period.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Group | Week 1 | | Week 2 | | Week 3 | |
|  | Shape | Gram | Shape | Gram | Shape | Gram |
| A | 0 | 0 | 0 | 0 | 0 | 0 |
| B | *Streptococcus sp.* and *Staphylococcus sp*. | - + | *Staphylococcus sp*. | - + | *Streptococcus sp*. and *Staphylococcus sp.* | + - |
| C | *Staphylococcus sp.* and *Bacillus sp.* | - | *Staphylococcus sp.* and *Bacillus sp.* | - | *Staphylococcus sp.* and *Diplococos sp.* | + |
| D | *Streptococcus sp.* and *Staphylococcus sp.* | - | *Staphylococcus sp.* and *Bacillus sp.* | - | *Staphylococcus sp.* and *Bacillus sp.* | - + |

\*(+) Gram-positive bacteria; (-) Gram-negative bacteria.

4. Discussion

The high microbial diversity and load present in the oral cavity pose a significant risk of cross-contamination in the dental environments, affecting both the external and internal components of equipment used during procedures. Such contamination can occur in public teaching clinics, private practices, and private teaching clinics, as evidenced by the results of this study(José *et al.*, 2005). Cross-contamination originating from dental procedures may compromise the health of immunocompromised patients. Therefore, dental professionals have an ethical, moral, and legal obligation to ensure that procedures adhere to biosafety standards(Gusmão e Gusmão, 2013).

Prophylactic measures against cross-infection should be implemented before the start of dental procedures. Key strategies include replacing dental unit water with filtered and/or distilled water before each treatment, fully draining reservoirs after use to prevent microbial growth and biofilm formation, utilizing anti-reflux valves, following protocols for disinfecting water lines, activating instrument tips for at least 20 seconds before procedures, and regularly replacing protective filters(Dallolio *et al.*, 2014; Hong *et al.*, 2022; Odonnell *et al.*, 2011).

Contamination of the dental equipment’s piping system, particularly the triple syringe and high-speed handpiece, has been previously reported at significant levels(Amancio *et al.*, 2020). Additionally, many water samples obtained from dental chair water systems exceed legal standards set by regulatory safety thresholds, largely due to insufficient disinfection protocols and the use of non-sterile water sources, such as sink water from dental offices (Fotedar e Ganju, 2015; Tonello *et al.*, 2022).

The sterilized and distilled water samples collected for Group A, prior to placement in the equipment reservoir, showed no microbial growth in culture media. This finding confirms that sterilized distilled water is a viable, safe, and low-cost-effective alternative for dental procedures. However, a previous study reported that while sterilized distilled water reduces contamination, it does not enturely prevent biofilm formation within the internal lumen of water systems (Williams *et al.*, 1993).

In Group B, where the high-speed handpiece was activated with the filtration device, culture plates exhibited a significant reduction in microbial load. This result demonstrates the effectiveness of the device, which can be attributed to the presence of an internal filtration barrier. The filter, fabricated from a section of an N95 mask, has a high microbial filtration capacity, as it can block particles with an average diameter of 75 ± 20 nm(He *et al.*, 2013). These findings highlight the potential of the filtration device as a protective measure in dental environments, particularly considering the risk of airborne contamination within dental equipment(Walker e Marsh, 2007).

In Group C, where the filtration device was not used, significant contamination was evident within the tubing. This contamination likely resulted from prior procedures, as the reflux mechanism of the of the high-speed handpiece—also known as negative suction—can allow biological material from the oral cavity to enter the tubing(Castellano Realpe *et al.*, 2020).

The presence of microorganisms in compressed air systems, such as air generated by dental compressors, has been previously documented(Spratt *et al.*, 2004). A study assessing air contamination from the tips of triple syringes (air-water) in various dental offices, confirmed that the air used during dental procedures is frequently contaminated(Bjerring e Berg, 1986; Hubar, Pelon e Gardiner, 2002; Spratt *et al.*, 2004; Walker e Marsh, 2007; Walker *et al.*, 2004). Microbiological analysis in that study revealed colonies of gram-positive cocci, gram-negative diplococci, and tetrads, consistent with the findings of the present research(Bjerring e Berg, 1986a).

Evaluation of the filter's contamination level (Group D) (Group D) showed microbiological growth on culture plates, confirming that the air passing through this region was contaminated. Similarly, a quantitative assessment on microbial contamination in compressed air from an air-water syringe, reported that 23 out of analyzed 99 samples tested positive for contamination, with a predominance of gram-negative cocci and gram-negative diplococci colonies, which were also identified in the present study(Hubar, Pelon e Gardiner, 2002). These findings suggest that contamination within the air system piping may originate from negative suction in the high-speed handpiece after deactivation, allowing the reflux of biological material from the oral cavity into the system.

Despite the promising results, certain limitations of the present study must be acknowledged. First, the filtration device prototype was tested in a single experimental group, limiting the scope of the data and restricting the generalizability of the results. This also limited an evaluation of variables associated with prolonged use. Furthermore, the device requires an external irrigating solution, which may compromise practicality during dental care by necessitating adaptations in the professional's routine. Another limitation is that the prototype was manufactured manually, which affected its aesthetics and finish. Additionally, the device may demand extra effort during dental procedures, potentially challenging its feasibility in routine clinical practice.

Nevertheless, this study highlights the significant advantages of the device in reducing the microbial load within the air system of the dental chair. The device demonstrated effectiveness in mitigating the risk of cross-contamination, offering a promising approach to microbial control in dental environments. This is particularly relevant for immunocompromised patients, who face a higher risk of adverse outcomes from pathogenic exposure. For such individuals, the device represents a valuable protective measure, contributing to safer dental care practices.

Although the study's limitations are notable, the results suggest that the device offers considerable potential for improving biosafety in dental practice. It represents an important step toward the development of technologies aimed at microbiological protection. The application of this device could reinforce safe dental practices, addressing the growing demand for interventions that minimize cross-infection risks, especially in patients with specific immunological vulnerabilities.

5. CONCLUSION

Within the limitations of this study, the developed device proved effective in filtering microorganisms from the dental chair air system when coupled to the high-speed handpiece, reducing cross-contamination during dental procedures. However, further studies are necessary to refine the filtration device, aiming for the total elimination of microorganisms.

Consent

Not applicable

Ethical approval

Not applicable

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