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Pandemic Preparedness and Response: A Foldable Tent to Safely Remove Contaminated Dental Aerosols—Clinical Study and Patient Experience

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Abstract: The D-DART (Droplet and Aerosol Reducing Tent) is a foldable design that can be attached to the dental chair to prevent the spread of contaminated dental aerosols. The objective of this study was to evaluate the ability of the D-DART to reduce spread of aerosols generated during dental treatment. Thirty-two patients (sixteen per group) undergoing deep ultrasonic scaling were recruited and randomly allocated to groups D-DART or Control (no D-DART). After 20 min from the start of the treatment, the clinician's face shield and dental chair light were swabbed and the viable microbial load was quantified (ATP bioluminescence analysis, blinded operator). Statistical analyses were performed with Tukey's Honest Test with a level of significance pre-set at 5%. There were significant increases in ATP values obtained from the operator's face shield and dental chair light for the Control compared with baseline (31.3 ± 8.5 and fold increase). There was no significant change in microbial load when the D-DART was used compared with baseline (1.5 ± 0.4 fold increase). The D-DART contained and prevented the spread of aerosols generated during deep scaling procedures.

Keywords: infection control; cross-contamination; saliva; virus; SARS-CoV-2; splatter; COVID-19

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1. Introduction

Since the beginning of the COVID-19 pandemic, there has been much concern about how dental professionals could be infected by patients and thus promote the workplace and community spread of the disease. One of the main concerns for practitioners and policymakers is spray production from rotary dental instrumentation [1]. These fine particles contained in the spray are a mixture of moisture droplets, splatters, and debris that can remain suspended in air for prolonged periods [2]. Dental aerosols contain microorganisms from the mouth and respiratory tract that can contaminate the skin and mucous membranes of the mouth, respiratory passages, and eyes [3–5]. For instance, *Mycobacterium tuberculosis* has been found in aerosol particles generated by a dental handpiece used on patients with active tuberculosis [6]. Notably, bacterial air contamination increases significantly following dental treatments [7,8], and microorganism dissemination can reach up to 60 cm during simple restorative procedures [5].

This concern has been increased further by the identification of the SARS-CoV-2 virus in the saliva of COVID-19-positive patients [9], and several potential scenarios of

transmission of COVID-19 by droplets from talking, coughing, sneezing, and aerosols produced during clinical procedures have been predicted [10,11]. Moreover, the US Bureau of Labor Statistics has placed dentists within the class of workers with the highest high risk of COVID-19 contamination due to their close proximity to individuals, contact with many patients, and risk of exposure to disease [12,13].

This major concern about the potential of COVID-19 transmissibility in dental offices has led authorities in countries such as Australia, Singapore, Italy, and the United Kingdom to restrict (or even impose a complete ban on) aerosol-generating procedures during the COVID-19 pandemic [14]. However, such an extreme measure aimed at protecting the population has also left thousands of people deprived of treatment and businesses without revenue. The magnitude of the health risks, psychological stresses, and financial losses imposed by these bans are impossible to estimate, but they certainly are immense.

During the COVID-19 pandemic, clinicians enhanced their infection control practices and even benefited from digitization (to a limited degree) to keep the clinical staff and patients safe [15,16]. A survey of 614 dental professionals (dentists and oral health therapists) reported increased their use of preoperatory mouthwashes and rubber dams during the pandemic. Moreover, at least 46% of the professionals' survey have changed their habits, reducing the use of aerosol-generating instruments and aerosolization procedures (i.e., ultrasound) [17]. Moreover, international guidance and national guidelines have been deployed to inform clinicians about the best practices (e.g., clinical protocols, disinfection of surfaces, and environmental ventilation) to avoid being infected or promoting the spread of the virus in clinical setups [18]. Although the apocalyptic scenario in which dental offices could become spreaders of the virus has not materialized [15,19], the pandemic has taught us important lessons. For instance, the high global demand for face masks to protect the general population has caused critical disruptions to supply chains along with a temporary shortage of personal protective equipment [20,21]. Prior to the pandemic, this would have been an unimaginable scenario, and the situation has triggered the urgent establishment of new production plants to supply the very basic (and yet much needed) personal protective equipment needed to protect clinicians [22]. In addition, governments, and dental institutions need to develop safety protocols to ensure the safe delivery of dental treatments [23]. It is true that dentistry has overcome many of the challenges imposed by the pandemic, but several of the measures were merely empirical reactions to the unfolding crisis. Moving forward, it is critical to look beyond crisis management to prepare an armamentarium, including scientific and evidence-based guidelines focusing on pandemic preparedness instead of responses to a crisis.

Global vaccination campaigns have significantly improved the pandemic situation, but the journey has not been smooth due to the uneven worldwide distribution of vaccines, and the emergence of coronavirus variants that have resulted in sharp increases in the number of positive cases and deaths. The scientific community acknowledges that new highly transmissible infections with pandemic potential may arise in the future [24], so public health measures and response actions need to be planned to avoid further sudden disruptions to dental services.

Against this background, we have developed a foldable tent for the containment and safe extraction of aerosols produced during dental treatment. The Dental Droplet and Aerosol Reducing Tent (D-DART, Figure 1) aims to limit, and potentially prevent, the spread and environmental availability of infectious agents from patients potentially infected with pathogens spread via the air, aerosols, and droplets and those who cannot have their treatments deferred.

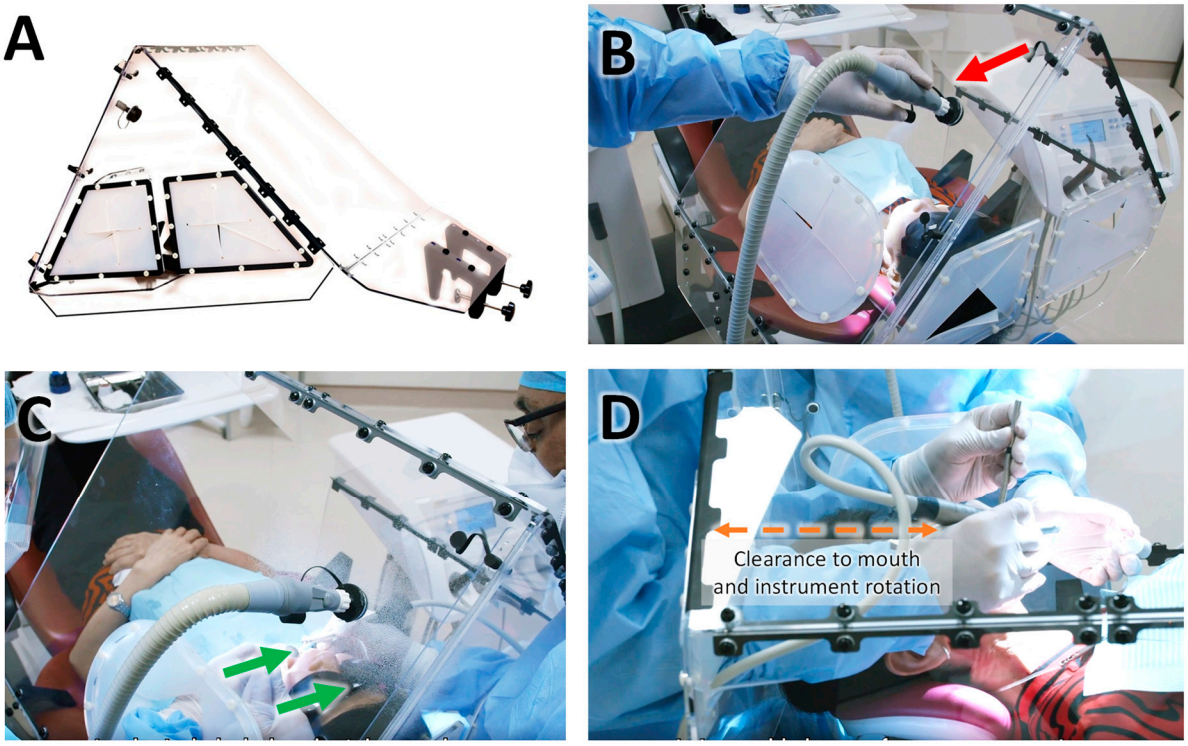

Figure 1. (**A**) D-DART design. (**B**) Dental suction canula attachment to the extraction valve (red arrow). (**C**) Dental aerosols are directed to the extraction valve (green arrows). (**D**) The distances from the back and lateral panels allow for ample movement of the instruments.

The objective of this single-center randomized clinical trial is to test the efficacy of the D-DART to prevent the spread of aerosols and contamination of clinical surfaces. The hypothesis is that the D-DART effectively prevents contamination on surfaces that are close to (operator's face shield) or far from (dental chair light) the source of the contaminated aerosol.

2. Materials and Methods

2.1. Sampling during Standard Dental Treatment

The study was performed by sampling hospital surfaces during patient visits to the National University Centre for Oral Health Singapore (NUCOHS) by evaluating aerosols and splatters produced during ultrasonic scaling. Ethics approval was obtained from the Domain Specific Review Board, National Healthcare Group (NHG DSRB Ref.: 2021/00059). The sample size was calculated based on the study objective to compare the contamination pattern between the experimental group and the control group. With a Cohen's effect size of 1.2 between the experimental group (D-DART) and the control group, a total of 32 subjects (16 subjects per group) was required for the study at 5% statistical significance and 90% statistical power. Informed consent was obtained from all patients. The effect size was selected according to the following reasons: (i) preliminary in vitro data showed promising results that the D-DART was able to contain the aerosols with a large difference compared with the Control; (ii) vaccines were not yet widely available at the time this study was initiated; and (iii) the efficacy of rapid antigen test was not ascertained, and polymerase chain reaction (PCR) testing was prioritized for suspected COVID-19-positive cases at the time this study was initiated. Hence, to avoid unnecessary exposure, risks of clinicians and staff to get infected, and the potential spreading COVID-19 in the population, we opted for an effect size of 1.2.

The exclusion criteria were patients below the legal age of consent or who were unable to give consent; pregnant females; patients who had received antibiotics within 1 month of the time of treatment; and patients with known transmissible infectious diseases. As a pre-treatment standard procedure, patients rinsed their mouths with 10 mL of 0.05%

cetylpyridinium chloride for 1 min. The treatment was performed with only the dentist, patient, and dental assistant present in the room.

Deep ultrasonic scaling was performed on 32 patients randomized 1:1 and receiving the treatment with the D-DART (experimental group) or without (control group). A single operator performed the scaling using a piezoelectric ultrasonic scaler (SiroSonic TL or Dentsply Sirona, Charlotte, NC, USA). Dental unit water was used concurrent with the ultrasonic instruments to achieve cooling. Evacuation was performed by a dental assistant during the treatment using a dental suction (canula diameter 6 mm) and high-volume evacuator (HVE; canula diameter 16 mm) with a suction flow of 300 L/min.

2.2. Swab Collection and ATP Bioluminescence Assessment

The dental chair light and the operator's face shield were the surfaces analyzed. The surfaces were cleaned with 70% alcohol disposable gauze just before the dental procedure. The amount of viable splatter produced during the procedure was assessed by swabbing standardized 5 cm × 10 cm areas of the aforementioned surfaces with sterile cotton swabs (Copan Diagnostic, Murrieta, CA, USA) before and after treatment.

The sole difference between the control and the D-DART group was the static device placed during a dental hygiene four-hands procedure. For the swab analysis, the investigator was blinded to the study groups' allocation. The study's primary outcome was a comparison of the total relative light unit (RLU) counts in two items in the dental environment: the dentist's face shield and the dental chair light. Each swab was placed in a sterile 15-mL tube containing 1 mL sterile PBS and subjected to vigorous agitation for 5 min to elute cells from the swabs. The eluates were subsequently subjected to adenosine triphosphate (ATP) bioluminescence assays.

The ATP assay was used to evaluate the spread of potential contaminants; ATP bioluminescence was measured using the BacTiter-Glo ATP detection reagent (Promega, Madison, WI, USA). An equal volume of the ATP reagent was added to eluates from the cotton swabs and incubated at room temperature for 5 min. The amount of luminescence was determined using a GloMax 20/20 luminometer (Promega, Madison, WI, USA). Contaminating ATP levels, expressed in relative light units (RLUs), were recorded.

2.3. Patient Experience and Feedback Survey

Patients' experiences and feedback were sought after the treatment through a self-administered questionnaire. Patients from both study groups were asked to rate their treatment experience using a 5-point Likert scale (1: strongly agree, 2: agree, 3: undecided, 4: disagree, and 5: strongly disagree).

2.4. Statistical Analysis

Descriptive statistics were performed to summarize the information collected (median and interquartile range (IQR) for quantitative data and frequency and percentage for qualitative data). To compare the contamination patterns between the control group (without the D-DART) and the experimental group (with the D-DART), the Mann–Whitney U test was conducted to determine whether the differences were statistically significant. The statistical significance level was set at p-value < 0.05.

3. Results

The ATP values (in RLUs) on the surfaces of the operator's face shield and dental chair light were determined before and after deep ultrasonic scaling (Table 1) for the control and D-DART groups. Before treatment, the ATP values for both surfaces were similar (less than 2000 RLU, $p > 0.05$) for both groups. However, after treatment, the ATP values median (IQR) on the operator's face shield in the control group [15,574 (43,630)] and the D-DART group [1964 (1049)] were significantly different ($p < 0.05$), whereas no statistical significant difference ($p > 0.05$) was observed on the dental chair light between the control [2645 (1107)] and D-DART groups [2115 (729)]. Notably, the ATP values after the treatment increased by

88% (1888 to 15,574) in the control group as compared to a 1% increase (1945 to 1964) in the D-DART group on the operator's face shield.

Table 1. Changes in the ATP value during dental treatment (* means $p < 0.05$).

	Control		Dental Dart		
	Median	**(IQR)**	**Median**	**(IQR)**	***p*-Value**
Operator's face shield					
Before Treatment (RLU)	1888	(653)	1945	(610)	0.735
After Treatment (RLU)	15,574	(43,630)	1964	(1049)	0.002 *
Difference (RLU)	14,097	(42,538)	211	(568)	0.001 *
Dental chair light					
Before Treatment (RLU)	1714	(555)	2000	(682)	0.122
After Treatment (RLU)	2645	(1107)	2115	(729)	0.346
Difference (RLU)	692	(966)	292	(659)	0.065

Figure 2 shows the maximum contamination on the operator's face shield with a 31.9 ± 0.60-fold increase in viability in the Control, in contrast to a 1.5 ± 0.04-fold increase when the D-DART was used. There was a 1.5 ± 0.05-fold increase in the dental chair light surface after the treatment for both Control and the D-DART groups.

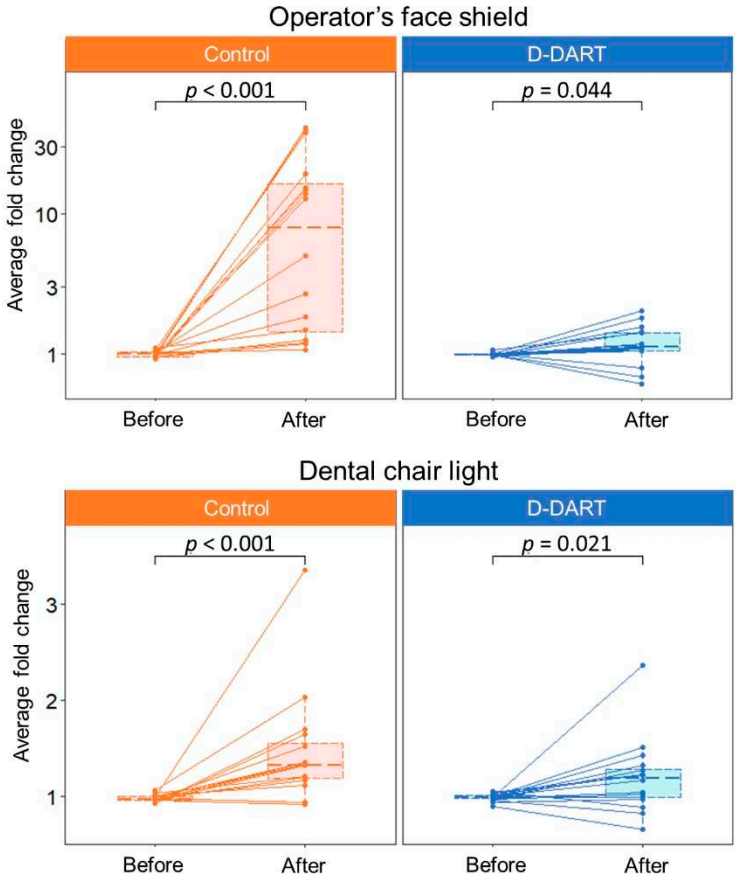

Figure 2. Contamination on the operator's face shield and dental chair light before and after treatment without (orange, Control) or with the D-DART (blue). The D-DART was able to prevent the surface contamination of the face shield by aerosolized particles.

A qualitative analysis of the patients' experiences is shown in Figure 3. Statistical analyses for the feedback survey showed no statistically significant differences in treatment comfort level, noise level, and ease of communication with the dentist among patients

treated with or without the D-DART. Notably, all the patients in the D-DART group agreed that droplets and aerosols can spread disease, and 76% agreed that the treatment with the D-DART was comfortable.

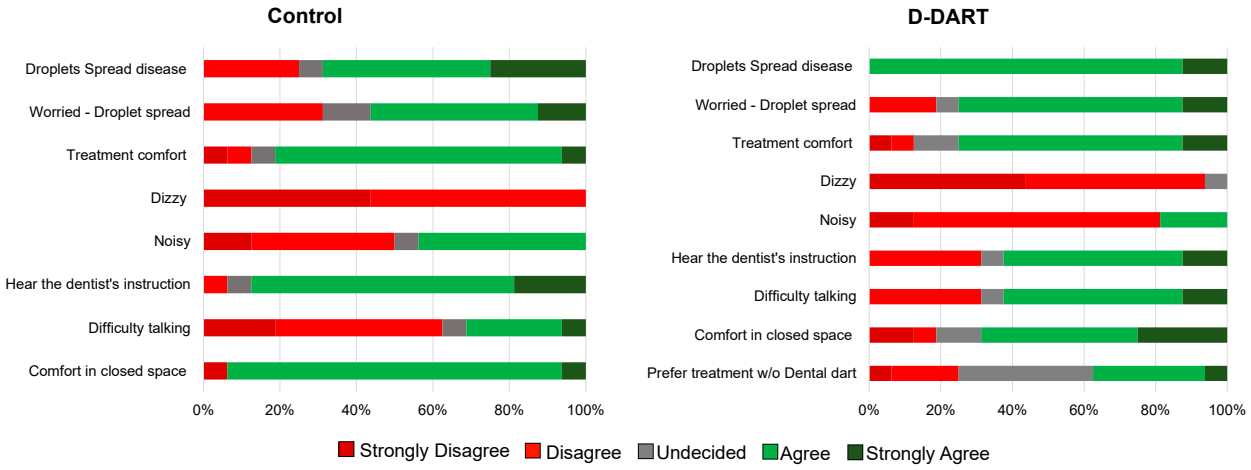

Figure 3. Patient feedback. No major discomfort was reported by most patients treated with the D-DART.

4. Discussion

The COVID-19 crisis has strained patients, health professionals, and systems worldwide. Given the uncertainties and fluid pandemic situation, policymakers have often implemented strict measures to protect professionals and the general population from the disease, thereby compromising access to treatments and jeopardizing the processes and finances of healthcare systems and businesses [14]. The international community acknowledges that other pandemic scenarios will emerge in the future [24], and it is important to develop guidelines and tools that can protect the population and maintain business continuity amidst any evolving crisis. This is particularly important for dentistry since the saliva and aerosols generated during its procedures may carry different infectious agents that can impact the health of dentists, clinical staff, and patients alike [5–8,12,13].

The hypothesis was accepted, as the D-DART was able to prevent the spread of contaminated aerosols from reaching the face shield and dental chair light. The purpose of the D-DART is to contain and extract aerosols during dental procedures. Hence, it was designed as a clear adjustable tented shield held together by 3D-printed fiber-reinforced nylon hinges that provides folding capabilities for sterilization and storage. The D-DART can be installed by a single operator who adjusts the C-clamps with self-adjusting pads that allow the design to fit dental chairs of different sizes.

High-speed air-turbine and ultrasonic scalers are devices able to generate aerosol during ordinary dental procedures. Recently, dental air water spray (3-in-1: air, water, and air + water) has been shown to generate aerosols [25]. The clinician's full-face shield becomes heavily contaminated during aerosol-generating procedures [25,26]. Several studies have shown this phenomenon using bacterial cultures that do not consider non-bacterial sources of contamination.

Herein, we have employed the adenosine triphosphate (ATP) assay, which can also quantify ATP, a key molecule in the metabolism of both mammalian and bacterial cells. ATP quantification has been suggested as a monitoring protocol to determine the extent of contamination generated during aerosol-generating procedures in dental clinics [27]. Our results have shown a significant 10-fold increase in ATP value on the face shield after the dental procedure. Notably, the D-DART was able to prevent such contamination, and the contamination levels of the face shield before and after the treatment were statistically similar (Figure 2 and Table 1).

Notably, the air contamination increases with the procedure length, spreading from 1 to 4 m away from the patient's mouth and remaining suspended for 20 to 90 min after a procedure has finished [25,28,29]. Hence, the D-DART design includes an extraction valve that can be connected to one of the suction units in the dental chair, and this allows for the safe removal of contaminated air from the tent, directing it to the scavenging system. This extraction valve prevented the environmental spread, as there were virtually no changes in RLU quantification from samples obtained from the dental chair light before and after the treatment (Figure 2 and Table 1).

Several administrative and engineering controls have been developed to prevent the spread of microorganisms via aerosols and to protect clinical staff [30]. Although the solutions tried often show acceptable levels of contamination containment, we were unable to determine the patient's opinions and feelings about being treated with such designs. Hence, we have interviewed all the patients that participated in our research to obtain user feedback that will guide design optimization. Overall, patients did not report any major discomfort or concern related to the treatment with the D-DART (Figure 3). Interestingly, patients treated with the D-DART were more aware and concerned about the potential spread of diseases via droplets. We believe that this increased consciousness is a collateral effect of being treated in a new device that is purposely designed to prevent the spread of aerosols. Notably, more than 75% of the patients treated with the D-DART did not feel uncomfortable or dizzy and were able to properly communicate with the clinician.

Despite the promising results, this work has limitations. For instance, it was performed as a single-center clinical trial due to different restrictions experienced by institutions during the most critical periods in the COVID-19 pandemic. Likewise, the D-DART was tested with patients undergoing deep ultrasonic scaling only. More studies, such as a multi-center clinical trial or testing its ability to allow for emergency tooth extraction, are needed to provide external validity to support the widespread adoption of the D-DART for pandemic preparedness and response.

5. Conclusions

Several potential scenarios of the transmission of several diseases (including COVID-19) by droplets via talking, coughing, sneezing, and aerosols produced during clinical procedures are predictable. Concerns regarding the rapid spread of COVID-19 have become even more critical in dentistry since the oropharyngeal airway and droplets have been confirmed as routes for infection. Hence, the pandemic has severely disrupted dental and healthcare services and created a transient global shortage of basic personal protective equipment.

The D-DART has been developed as an engineering control to contain and safely extract the aerosols generated during dental treatment. The results show that the D-DART can effectively contain and extract aerosols via an extraction valve and therefore protect clinicians from direct exposure to aerosols. Moreover, it prevents the spread of microorganisms and viruses onto clinical surfaces, hence decreasing the chances of potential infections and cross-contamination in clinics. The design can be used broadly to protect clinical staff when patients test positive for COVID-19 or other critical transmissible infectious diseases. Likewise, it can create a safer environment and decrease the anxiety and psychological distress imposed by highly infectious diseases on all parties involved in the dental clinical setting.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Domain Specific Review Board, National Healthcare Group (NHG DSRB Ref.: 2021/00059).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author, GS, upon reasonable request.

Conflicts of Interest: Design certificates have been issued to VR, MSG, FB, and S in Singapore, and patent applications have been filed in Brazil, China, Indonesia, Europe, and the United States.

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