ACTA ODONTOLOGICA SCANDINAVICA
2021, VOL. 79, NO. 1, 69–80
https://doi.org/10.1080/00016357.2020.1839673

REVIEW ARTICLE

The efficacy of bio-aerosol reducing procedures used in dentistry: a systematic review

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ABSTRACT

Background and objective: Bio-aerosols, are routinely generated and airborne in clinical dentistry due to the operative instrumentation within an oral environment bathed in salivary organisms. SARS-CoV-2 transmission being responsible for the current pandemic, appears through airborne aerosols and droplets, thus, there has been an intense focus on such aerosol-generating procedures, and their reduction. Hence the objective of this systematic review was to evaluate available data on three major measures: rubber dam application, pre-procedural oral rinse, and high-volume evacuators (HVE) aimed at reducing bio-aerosols.
Method: PubMed via Ovid MEDLINE, EBSCO host, Cochrane Library and Web of Science databases were searched between 01 January 1985 and 30 April 2020.
Results: A total of 156 records in English literature were identified, and 17 clinical studies with 724 patients included in the final analysis. Eligible articles revealed the inadequacy of three principle approaches used in contemporary dental practice to minimize such bio-aerosols, rubber dam application, pre-procedural oral rinses, and HVE. The latter is an extremely effective method to reduce bio-aerosols in dentistry, although no single method can provide blanket cover.
Conclusion: Present systematic review indicates that employing combination strategies of rubber dam, with a pre-procedural antimicrobial oral rinse, and HVE may contain bio-aerosols during operative procedures.

ARTICLE HISTORY
Received 25 June 2020
Revised 10 October 2020
Accepted 12 October 2020

KEYWORDS
Bio-aerosol; reduction; dentistry; procedures; rubber dam application

Introduction

Aerosols can be natural, such as fog, mist, dust, or anthropogenic – created by humans or animals when they speak, sneeze, or cough, for instance. On the other hand, bio-aerosols are aerosols consisting of particles/droplets with live microorganisms [1,2].

Although there are conflicting reports in the literature on the size of the aerosols and how long they are airborne, early researchers have classified particles <100 µm in diameter as aerosols, and those >100 µm as droplets or 'spatter/splatter'. The latter usually falls on to the ground immediately, as and when they are expelled. At the same time, the former can be entrained or suspended in the air for considerable periods depending on the humidity, airflow, and temperature of the environment into which they are expelled – for example, a dental clinic or a hospital ward. Similarly, the large diameter droplets with the microbial laden contaminants can taint surfaces in the immediate vicinity and spread a few metres, yet again depending on the ambient conditions such as the airflow [3].

Humans produce bio-aerosols by talking, breathing, sneezing, or coughing [1,4,5], depending on the infectious status of a person, and these may contain fungi, bacteria, or viruses. On the other hand, mechanical devices such as clinic/hospital ventilation systems, air rotors with coolant water spray, used in dentistry may spread bio-aerosols equally efficiently, and engineering strategies need to be implemented to minimize or eliminate the spread [6,7].

It is also noteworthy that a number of factors such as virulence, the number of infectious particles, and the pathogenicity of the offending microbes, as well as the host immune response, determine the susceptibility of acquiring an infectious agent via a bio-aerosol [8–10].

Compared to the population at large, healthcare workers (HCWs) run a higher risk of acquiring respiratory pathogens by virtue of their profession. This was clearly shown in the SARS epidemic, which led to numerous deaths of HCWs [11] and in the current COVID-19 pandemic, where HCWs have disproportionately succumbed to the disease [12]. Thus far, there has been no mortality amongst dental HCWs due to COVID-19, however, they are considered to be the professional group that has the highest likelihood of acquiring the disease due to bio-aerosol generating dental procedures [13].

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Bio-aerosol generating dental procedures and implications for dentistry

Many interventional procedures are known to aerosolize respiratory secretions in healthcare settings [6,14,15]. Notably, in dentistry, microbial particles are aerosolized by the high-speed handpiece and the accompanying air jet, ultrasonic scaling, air polishing, and air/water syringes [14]. Unless judiciously controlled, these bio-aerosol generating procedures appear to be one of many intrinsic hazards the profession faces, that has been brought into focus by the current COVID-19 pandemic [6]. Thus, in a very early laboratory study, Miller et al. [16] observed that aerosolized microbes generated by high-powered dental drills and periodontal scalers could transmit to around 200 cm distance in the operatory. Indeed, Li and colleagues [17], during the post-SARS era, suggested additional measures for bio-aerosol reduction, and concomitant safe dental practice. These include manual scaling, chemo-chemical caries removal, atraumatic restorative technique, open debridement for periodontal surgeries, rubber dam isolation, use of pre-procedure oral rinses, general ventilation, air filtration [13,17].

Although the post-SARS era literature provides useful guidance on aerosol reducing procedures in dentistry, there has been, to our knowledge, no recent systematic review on the reduction of bio-aerosol generation during dental procedures, particularly during the current COVID-19 pandemic. Thus, we aimed to systematically gather evidence of standard precautionary measures which attempt to reduce bio-aerosol transmission in dentistry, and reviewed the contemporaneous data of three such major strategies, (i) pre-procedural antimicrobial mouth rinse, (ii) rubber dam application and (iii) high volume evacuation (HVE), used by profession for this purpose,

Methods

Data sources

An electronic data search of English language manuscripts using Ovid MEDLINE, Web of Science, EBSCO host, and Cochrane Library databases was performed by two investigators (LPS and KSF). Published clinical reports were accessed between 01 January 1985, and 30 April 2020. After screening different electronic databases clinical studies on rubber dam-bio-aerosol; HVE-bio-aerosol; and pre-procedural oral rinse were identified.

A precise review question was formulated using the PICO framework as follows. Does pre-procedural antimicrobial mouth rinse, rubber dam application, and high volume evacuation (HVE) (I), compared with placebo, no mouth antimicrobial mouth rinse/rubber dam application/use of high volume evacuation (C), results in effective microbial reduction (CFU, colony-forming units or percentage reduction) disseminated via aerosol generated during dental procedures (O), in dental patients (male and female) undergoing the dental procedure? (P). The search keywords and combination of the keywords were systematized according to the PICO model (Table 1).

Outcome

The key finding of the present review was the systematic assessment of the efficacy of preprocedural mouth rinse, rubber dam application, and use of HVE in reducing bio-aerosols generated via dental procedures.

Study selection

Inclusion criteria

Pre-determined inclusion criteria were (1) English language articles; (2) clinical trials; (3) patients undergoing dental procedures (use of high-speed rotary instruments/ultrasonic scalers/air polishers/triple syringe); (4) paediatric and adult patients; (5) country or date enforced no limitations.

Exclusion criteria

The exclusion criteria included: (1) review articles; (2) studies that did not report a pre-post microbial reduction in bio-aerosol; (3) reports presenting incomplete outcome details; (4) recruits (patient) on antibiotics; (5) studies that do not allow extraction of data needed to meet the set study objectives; (6) poster/conference presentation/abstracts, grey literature, and unpublished research information were neither considered nor used.

Electronic data search and analysis

To ensure of systematic and comprehensive method approached, we trailed through the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [18,19]. The search approach employed, and results generated, are presented in Figure 1, and search terms and limits are shown in Table 1.

A three-staged, electronic data search and analysis was carried out. In stage one: the titles and abstracts of all relevant clinical trials meeting our set inclusion criteria were screened. In step two: a full-text review of all the pertinent articles was completed, which yielded a comprehensive account of the data. Through the full-text review of the retrieved literature, the investigators used spreadsheets, ensuring that eligibility criteria were met and the reported outcomes were in alignment with the set study objectives. References of the included clinical trials were checked as a backward-search. In stage-three, the reviewers extracted and assessed the data.

Following the full-text review, specific points linked to the characteristics of each included clinical trial were charted following Cochrane standards, which enabled in classifying the setting, study design, and the country. Additionally, sample size, assessment methods, evaluation time, and study conclusions were comprehensively examined. The identified articles were compiled using a bibliographic software tool, Endnote version 9 (Clarivate Analytics, Philadelphia, PA).

Summary of the characteristics of included clinical trials and the reported results, including the microbial counts generated during dental procedures, are provided in Tables 2–4.

Table 1. Employed search-terms and limits.

Search strategy for the systematic review of literature on the bio-aerosols and standard dental practice protocol in post-COVID-19 era		
	Search history	
Search (Database/s)	(01 January 1985 and 30 April 2020)	
Cochrane Library databases	Bio-aerosol and rubber dam	(rubber dam OR dental dam) AND (aerosol OR bio-aerosol) AND (bacterial reduction OR microbial reduction) AND (dental operatory OR dental clinic) AND (dry field OR moisture control) AND (saliva OR blood)
	Bio-aerosol and high-volume evacuator (HVE)	(aerosol OR bio-aerosol) AND (extraoral suction OR extra oral evacuator) AND (bacterial reduction OR microbial reduction) AND (dental operatory OR dental clinic) AND (high volume evacuator OR high volume suction) AND (saliva OR blood) AND (evacuators OR suction)
	Bio-aerosol and preprocedural oral rinse	(aerosol OR bio-aerosol) AND (mouth rinse OR oral rinse) AND (mouth wash OR prophylactic mouth wash) AND (dental operatory OR dental clinic) AND (anti-microbial OR antibacterial) AND (anti-viral OR anti-fungal) AND (Chlorhexidine OR CHX OR Essential Oil) AND (Cetylpyridinium chloride OR CPC) AND (scaling OR ultrasonic) AND (high-speed rotary OR high-speed handpiece) AND (microbial reduction OR bacterial reduction) AND (preprocedural oral rinse OR preprocedural mouth rinse)
PubMed via OVID	Bio-aerosol and rubber dam	Heading (MeSH) and text words: (aerosol OR bio-aerosol) AND (rubber dam OR dental dam) AND (bacterial reduction OR microbial reduction) AND (dental operatory OR dental clinic) AND (dry field OR moisture control) AND (saliva OR blood)
	Bio-aerosol and high-volume evacuator (HVE)	Heading (MeSH) and text words: (aerosol OR bio-aerosol) AND (extraoral suction OR extra oral evacuator) AND (bacterial reduction OR microbial reduction) AND (dental operatory OR dental clinic) AND (high volume evacuator OR high volume suction) AND (saliva OR blood) AND (evacuators OR suction) AND (high volume OR low volume)
	Bio-aerosol and preprocedural oral rinse	Heading (MeSH) and text words: (aerosol OR bio-aerosol) AND (mouth rinse OR oral rinse) AND (mouth wash OR prophylactic mouth wash) AND (Chlorhexidine OR CHX OR Essential Oil) AND (Cetylpyridinium chloride OR CPC) AND (scaling OR ultrasonic) AND (high-speed rotary OR high-speed handpiece) AND (dental operatory OR dental clinic) AND (anti-microbial OR antibacterial) AND (anti-viral OR anti-fungal) AND (microbial reduction OR bacterial reduction) AND (preprocedural oral rinse OR preprocedural mouth rinse)
EBSCO host	Bio-aerosol and rubber dam	(aerosol OR bio-aerosol) AND (rubber dam OR dental dam) AND (bacterial reduction OR microbial reduction) AND (dental operatory OR dental clinic) AND (dry field OR moisture control) AND (saliva OR blood)
	Bio-aerosol and high-volume evacuator (HVE)	(aerosol OR bio-aerosol) AND (extraoral suction OR extra oral evacuator) AND (bacterial reduction OR microbial reduction) AND (dental operatory OR dental clinic) AND (high volume evacuator OR high volume suction) AND (saliva OR blood) AND (evacuators OR suction)
	Bio-aerosol and preprocedural oral rinse	(aerosol OR bio-aerosol) AND (Chlorhexidine OR CHX OR Essential Oil) AND (Cetylpyridinium chloride OR CPC) AND (scaling OR ultrasonic) AND (high-speed rotary OR high-speed handpiece) AND (mouth rinse OR oral rinse) AND (mouth wash OR prophylactic mouth wash) AND (dental operatory OR dental clinic) AND (anti-microbial OR antibacterial) AND (anti-viral OR anti-fungal) AND (microbial reduction OR bacterial reduction) AND (preprocedural oral rinse OR preprocedural mouth rinse)
Web of Science	Bio-aerosol and rubber dam	(aerosol OR bio-aerosol) AND (rubber dam OR dental dam) AND (bacterial reduction OR microbial reduction) AND (dental operatory OR dental clinic) AND (dry field OR moisture control) AND (saliva OR blood)
	Bio-aerosol and high-volume evacuator (HVE)	(aerosol OR bio-aerosol) AND (extraoral suction OR extra oral evacuator) AND (bacterial reduction OR microbial reduction) AND (dental operatory OR dental clinic) AND (high volume evacuator OR high volume suction) AND (saliva OR blood) AND (evacuators OR suction)
	Bio-aerosol and preprocedural oral rinse	(aerosol OR bio-aerosol) AND (mouth rinse OR oral rinse) AND (mouth wash OR prophylactic mouth wash) AND (dental operatory OR dental clinic) AND (anti-microbial OR antibacterial) AND (anti-viral OR anti-fungal) AND (microbial reduction OR bacterial reduction) AND (preprocedural oral rinse OR preprocedural mouth rinse) AND (Chlorhexidine OR CHX OR Essential Oil) AND (Cetylpyridinium chloride OR CPC) AND (scaling OR ultrasonic) AND (high-speed rotary OR high-speed handpiece)

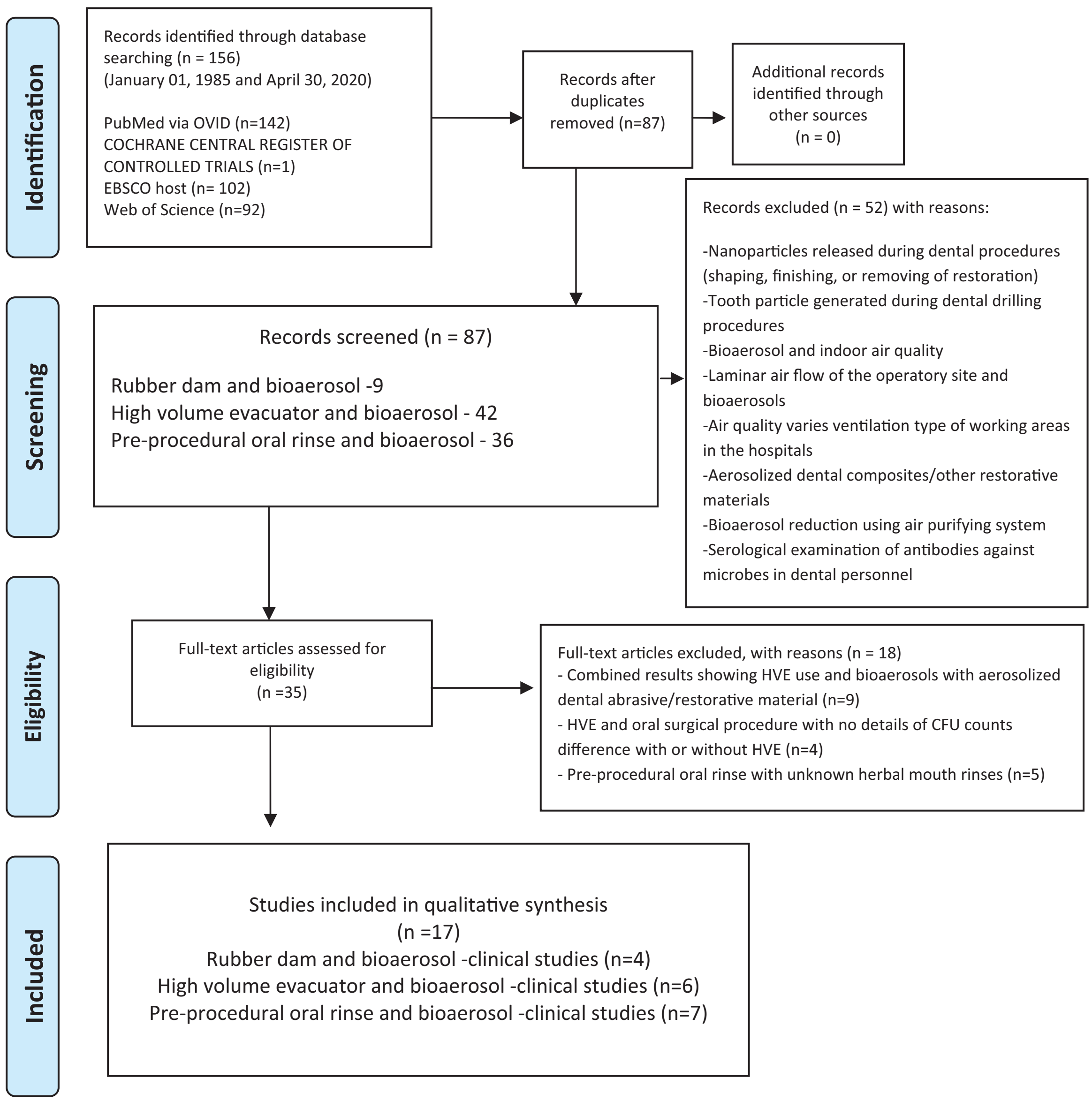

Figure 1. PRISMA flow chart of the literature search and study selection.

Quality assessment and risk of bias

The quality assessment of the eligible clinical studies was performed by two investigators (LPS and KSF) independently. In case, if there was any disagreement, a third or fourth reviewer (CP or BB) were consulted. The Cochrane Collaboration risk of bias assessment tool was used to assess the methodological quality of the study [20]. This included an evaluation of the method of randomization, allocation-concealment, blinding of the outcome assessment, selective reporting, and other sources of biases. Any discrepancies were resolved via mutual agreements reached between the reviewers. The evaluated trials were documented as low, unclear, or high-risk (Table 5). Studies falling under the high-risk of bias were excluded from the present review.

Results and discussion

A total of seventeen clinical studies (rubber dam-bio-aerosol [4]; HVE-bio-aerosol [6]; and pre-procedural oral rinse [7]) were identified from the data search.

Efficacy of rubber dam in reducing bio-aerosol generated during dental procedures

In total, we assessed data from 108 participants (40 paediatric and 68 adults) enrolled in four clinical trials evaluating the efficacy of rubber dam in reducing aerosols. In almost all experimental settings [21–24], bio-aerosols were generated using high and low-speed rotary dental devices during restorative dental procedures. The adjunct use of an air-water syringe and high-speed rotary instrumentation, either with or without a rubber dam, was also examined by Cochran et al. in one study [21]. Their data showed up to 90–98% efficacy of the rubber dam in preventing the spread of bio-aerosol during dental procedures (Table 2). Samaranayake and team [22] also observed an up-to-70% reduction in airborne particles in and around a 1-m diameter of the operational area, consequential to the use of rubber dam; this effect was negligible on cabinetry surfaces located 3 m from the operative site.

In one study, Tag El din and colleagues [23] compared the efficacy of rubber dam with the addition of an oral antimicrobial rinse before the rubber dam application. They reported no significant difference in the organisms reaching a culture plate, placed at a 1-m distance from the operative site, irrespective of the pre-procedural rinse. The reduction in CFUs was 98.8 and 99.4% in the rubber dam group and the antiseptic plus rubber dam group, respectively. Apart from the above, Al Amad and colleagues [24] reported a significant bacterial reduction due to rubber dam use, although the information on colony counts was not presented in their report.

The preceding data from the clinical trials conclusively indicate that rubber dam isolation during operative dental procedures is an effective and efficient bio-aerosol suppressor [21–24]. The significant advantage of the rubber dam application in this context is the reduction of salivary, serum, and blood contamination of aerosol plumes laced with infectious microbes. In the event, the microbial content of the aerosol can only arise from the biofilms on the tooth surfaces exposed during treatment [11], thus significantly impacting the overall dental operatory infection control.

Efficacy of high-volume evacuator (HVE) in reducing bio-aerosol generated during dental procedures

Many dental procedures ranging from routine prophylactic ultrasonic scaling and subgingival restorations to periodontal and oral surgical procedures generate copious bio-aerosols [21,25,26]. This has been a major concern, as these procedures are executed in an intraoral niche copiously laced with voluminous amounts of saliva and blood. Hence, HVE is highly recommended to reduce the bio-contaminants originating from the operative site before it becomes bio-aerosols released into an operatory environment [27].

We evaluated data from 128 patients from four-experimental settings [25,28–30], that assessed the efficacy of HVE in reducing bio-aerosol generation; all four studies were conducted when restorative dental procedures were performed. All the included reports [25,28,29], except for Desarda et al. [30], noted a significant reduction in CFU when HVE was used during several dental procedures. The latter group [30] attributed this divergent observation to the reduced efficacy of the evacuation system they used. In another experimental setting where only two patients were used, Bentley et al. [31] observed an efficient reduction of bio-aerosols when HVE was used in a patient who flossed and brushed before ultrasonic scaling. However, the data quality of this study is weak and somewhat anecdotal due to the low number of enrolled subjects.

The use of high-speed rotary instruments is common during minor oral surgical procedures, with the simultaneous production of splatter and aerosols [26,32]. In an elegant study Ishihama et al. have demonstrated 'blood mist' carrying potential infectious pathogens in the air of the operatory [32] and the efficacy of an extra-oral evacuator close to the surgical site, that leads to an immediate reduction of this air plume. In one of the most extensive studies, to date, on the latter subject Yamada and colleagues [33] reviewed data from 281 patients who underwent oral surgery as well as therapeutic and prophylactic procedures. They tested HVE efficacy, using filters at two differing distances (50 cm and 100 cm) from the patients' mouth. Not surprisingly, they observed that the combined use of two extraoral evacuators was more effective in reducing bio-aerosol, particularly during third molar surgeries. This was even when the second evacuator was placed 100 cm from the patients' mouth.

Another factor that affects the efficacy of the HVE is the distance between the operative site and the suction tip of the evacuator. Two studies [26,32] had documented that HVE, when applied close to the surgical site, was significantly better in obviating visible microbial-laden saliva, blood, and water sprays and spatter produced during dental procedures.

The foregoing conclusively demonstrates the efficacy of HVE in reducing bio-aerosols in the clinic environment, and such efficiency is determined by the suction strength of the appliance [27,32], the proximity of the HVE to the operating site, and the number of HVE used.

Efficacy of a pre-procedural oral rinse in reducing bio-aerosol generated during dental procedures

In total, the database comprised 128 patients, and the bacterial content of the dental aerosols generated through ultrasonic scaling and air polishing procedures, either with or without pre-procedural oral rinsing.

Three major and most popular antiseptics used for pre-procedural oral rinses are chlorhexidine gluconate (CHX), cetyl pyridinium chloride (CPC), and essential oils, and this practice has been shown to reduce bio-aerosols significantly [34–39]. Indeed, chlorhexidine and essential oils are effective antiseptics in reducing the load of both the planktonic organisms suspended in saliva, and those residing within biofilms, either on mucosal or tooth surfaces [6,40–42].

The vast majority, six of seven experimental settings [34–39], mainly randomized controlled trials indicated a significant bacterial reduction after pre-procedural rinsing with either CHX, CPC, or essential oils. One study [43], however, was an exception, as it reported increased numbers as well as bacterial diversity with preprocedural CHX oral rinses, during debonding of orthodontic-brackets using a low-speed handpiece.

Although a rubber dam can be applied for many operative procedures, it not a realistic option for some treatment modalities such as crown preparations, subgingival restorations, and full mouth prophylaxis with ultrasonic scaling. The

Table 2. Included studies (efficacy of rubber dam isolation and bio-aerosol).

Study	Population, No. of patients (*n*)	Study type	Country	Dental procedure	Aerosol-method of assessment	Summary microbial reduction with and without rubber dam (mean CFU)	Outcome
Cochran et al. [21]	Adults patients (16)	Case control	USA	(1) The rotary dental instrument with and without rubber dam. during restorative procedures (placement of amalgam and composite resin restorations). (2) Rotary dental instrument and air–water syringe with and without rubber dam. The microbial collection was done during handpiece and air–water syringe spray	Case: Microbial collection on the four culture dishes that were attached to the dental operating light positioned perpendicular to 24 inches away from the patients' mouth Another petri dish containing the same kind of agar placed on the patients' napkin 6-7 inches in front of the patients' chin. Controls: consisted of sets of four dishes attached to the dental light. A petri dish on the bracket table, all exposed to the air	With the rubber dam: 0.3 ± 0.2 (98%) Without the rubber dam: 13 ± 0.3	(1) Statistically significant reduction in microorganisms with the use of the rubber dam – 70 to 88% (2) Statistically significant decrease in microbes with the use of the rubber dam- 95 to 99% Overall, 90 to 98% of all data combined
Samaranayake et al. [22]	Paediatric patients (20)	RCT	UK	The rotary dental instrument with and without rubber dam	Blood agar plate positioned at 1m, 2m and 3m distances near the headrest area	With the rubber dam: 88% reduction at − 1 m from the headrest 72% reduction at 2 m from the headrest 0 % – No reduction at 3 m from the headrest	A highly significant ($p = 0.001$) reduction in bacterial contamination with rubber dam isolation A reduction in bacterial aerosols was most considerable at 1 m from the headrest
Tag El-Din et al. [23]	Paediatric patients (20)	RCT	Egypt	Rotary instrument (air-turbine-driven handpiece) Standard restorative procedures performed under rubber dam isolation Standard procedures without rubber dam isolation Use of chlorhexidine mouth rinse 30 min before the procedure Use of chlorhexidine mouth rinse before application of the rubber dam	Four blood agar culture plates placed equidistantly from the child's head One each on the chest left and right sides, and behind the patient. Another two plates placed at 1 and 2 m from the headrest of the dental chair, respectively	With the rubber dam: 7.9 ± 2.8 Rubber dam + Antiseptic mouth rinse: 5.9 ± 2.0 Without the rubber dam: 19.5 ± 5.8	The bacterial reduction was 98.8% at 1 m when the rubber dam was used. The bacterial reduction increased when antiseptic mouth rinse was used before rubber dam application The reduction in CFUs at one m were 98.8, 73.8, and 99.4% in the rubber dam group, the antiseptic group, and the antiseptic with rubber dam group, respectively. The highest bacterial contamination was on the agar plates positioned on the patient's chest
Al-Amad et al. [24]	Adult patients (52)	RCT	UAE	The rotary dental instrument with and without rubber dam, during the standard restorative dental procedure	Fifty-two unused (autoclaved) cotton-polyester scarves (head covers). Cotton swabs moistened with sterile normal saline for sample collection	With the rubber dam: NA Without the rubber dam: NA	Statistically significant bacterial reduction (mean CFU= 1.67 ± 2.03) using a rubber dam ($p = .009$)

Table 3. Included studies (efficacy of high-volume evacuation – HVE, and bio-aerosol).

Study	Population, No. of patients (*n*)	Study type	Country	Dental procedure	Aerosol-method of assessment	Summary microbial reduction with and without high volume evacuation (HVE) (mean CFU)	Outcome
Efficacy of High-volume evacuation and bio-aerosol							
King et al. [28]	Adults patients (12)	*In vivo* (Split mouth design)	USA	Ultrasonic scaling for 5-min with the aerosol reduction device Ultrasonic scaling for 5-min without the aerosol reduction device	Samples were collected on blood agar plates placed 6 inches from the subject's mouth	With HVE 2.6 ± 3.6 Without HVE 45.1 ± 28.9 Low CFU count on the *face shield* with or without HVE	Significantly higher reduction in the quantity of mean colony forming units (CFUs) with HVE However, no significant differences in the number of CFUs found on the investigator's *face shield* due to operators' position at 9 am and 12 pm operating position
Muzzin et al. [29]	Adults patients (30)	*In vivo*	USA	All subjects underwent two min of air polishing. With the aerosol reduction device on one side of the mouth Without the aerosol reduction device on the opposite side	Microbial samples were collected on blood agar plates positioned 12 inches from the subject's mouth One plate blood agar plate attached to the face mask	With HVE 20.10 ± 53.90 Without HVE 148.00 ± 145.00 HVE + Face mask 8.80 ± 15.10 CFUs Without HVE + Face mask 40.90 ± 33.80 CFUs	Air polisher without HVE generated a significantly higher number of CFUs on the face mask plate
Timmerman et al. [32]	Adults patients (06)	*In vivo*	Netherland	Ultrasonic scaler with either high-volume evacuation (HVE) or conventional dental suction (CDS) 17 treatment sessions, consisting of a 40-min episode	Two plates (blood agar) placed at 40 cm for 5 min After 20 min, the procedure was repeated. Two plates (blood agar) placed at 150 cm for 20 min. This was followed by exposure to two new Petri dishes for the rest of the session. The plates were cultured aerobically and anaerobically for 3 and 7 days, respectively.	Mean CFU before treatment never exceeded 0.6 colonies per plate. At 40 cm, the mean CFU, at 40 mins, was 8.0 for HVE and 17.0 for CDS. The mean CFU at 150 cm at 40 mins was 8.1 with HVE and 10.3 with the CDS The use of a high-volume evacuator may, however, help to minimise risks of microbial air contamination	HVE Mean Aerobic microbes 0.9 (1.3) Mean Anaerobic microbes 1.1 (1.2) CDS (conventional dental suction) Mean Aerobic microbes 1.0 (1.2) Mean Anaerobic microbes 3.3 (2.7)
Desarda et al. [30]	Adults patients (80)	*In vivo*	India	Piezoelectric ultrasonic scaling with or without high-volume evacuator. Nutrient agar plate placed on patient's chest at 20 inches and another plate was set at 12 inches on the dental assistant side	Scaling was carried out for 10 min Nutrient agar plates (4) were exposed for 20 min for microbial sampling	With HVE: 12.14 ± 1.93 Without HVE: 11.08 ± 2.25	There found no statistically significant differences in colony-forming units (CFU) with and without high-volume suction placed at 12 and 20-inches from the oral cavity

(*continued*)

Table 3. Continued.

Study	Population, No. of patients (n)	Study type	Country	Dental procedure	Aerosol-method of assessment	Summary microbial reduction with and without high volume evacuation (HVE) (mean CFU)	Outcome
Bio-aerosol reduction-Efficacy of HVE + standard oral hygiene (tooth brushing, flossing)							
Bentley et al. [31]	Adult patient (2)	*In vivo*	USA	Restorative procedure using handpiece and high-volume evacuator for 30 min Ultrasonic scaling with conventional salivary ejector for 30 min	Blood agar plates were placed with on the six spokes of the headrest extension device at 12 and 24 inches from patients' mouth Also, on operators face mask, disposable gowns, head caps.	Colonies of alpha-hemolytic streptococci High-volume evacuation during all the restorative procedures shows negligible bacterial counts reaching plates at 24 inches from the mouth Higher bacterial counts inpatient, who did not brush, or floss for 24 h compared to the second patient who had brushed and flossed before treatment	High-volume evacuation and preoperative toothbrushing and flossing may reduce bacterial contamination and dissemination
Efficacy of High-volume evacuation and bio-aerosol							
Yamada et al. [33]	Adult patients (281) At 50 cm single evacuator (n = 102) At 100 cm (n =124) At 100 cm double evacuator ($n = 55$)	*In vivo*	Japan	At 50 cm and 100 cm from the mouth of the patient with single HVE: Third molar surgery Full-crown preparation, Inlay cavity (Black Class II) preparation, Scaling with an ultrasonic scaler At 100 cm from the mouth of the patient with two HVE: Third molar surgery	Test filter	At 50 cm from patients' mouth ($n = 102$) with single HVE: Third molar surgery 92% (12/13) Full-crown preparation 70% (21/30) Inlay cavity (Black Class II) preparation 35% (9/26) Ultrasonic scaling 33% (11/33) At 100 cm from the patient's mouth ($n = 124$) with single HVE: Third molar surgery 90% (35/39) Full-crown preparation, 48% (15/31) Inlay cavity (Black Class II) 29% (6/21), Ultrasonic scaling 12% (4/33) At 100 cm from the patient's mouth ($n = 55$) with two HVE: Bio-aerosol decreased significantly from 90% (35/39) to 60% (33/55)	Extraoral evacuators are effective in reducing contaminated aerosols during dental procedures

Table 4. Pre-procedural oral rinse and aerosol.

Study	Population, No. of patients (*n*)	Study type	Country	Dental Procedure	Aerosol-method of assessment	Microbial Assay	Summary microbial reduction with and without pre-oral rinse	Outcome
Fine et al. [34]	Adults patients (18)	Double-blind, controlled, cross-over, clinical study	USA	A 10-min ultrasonic scaling Antiseptic mouthwash (EO) or a control (20 ml) for 30 s	Aerosolized bacteria were collected on a sterile filter. Filter was Incubated on trypticase soy agar, aerobically at 37 °C for 24 to 72 h. Counting the colony-forming units (CFU)	Counting of total CFU with a dissecting microscope	EO: reduction of 1.23 CFU (log-transformed) Placebo: reduction of 0.18 CFU (log transformed) Difference between groups: EO: reduced 1.05 more CFU (log-transformed)	Rinsing with the antiseptic mouthwash (EO) produced a 94.1% reduction in CFUs
Fine et al. [35]	Adults patients (18)	Double-blind, controlled, cross-over, clinical study	USA	Full-mouth dental prophylaxis with ultrasonic scaler for 5 min Antiseptic mouthwash (EO) or a control	Aerosolized bacteria were collected on a sterile filter. positioned in front of the participant's mouth at a distance of 2 inches Counting the colony-forming units (CFU)	Counting of total CFU with a dissecting microscope	EO: reduction of 1.19 CFU (log-transformed) Placebo: reduction of 0.17 CFU (log transformed) Difference between groups: EO: reduced 1.02 more CFU (log-transformed)	Pre-procedural rinsing with an antiseptic (EO) significantly reduce the level of viable bacteria in an aerosol produced via ultrasonic scaling 40 min later
Logothetis et al. [36]	Adults patients (18)	RCT	USA	Air polish device for 3 min Antiseptic mouthwash (EO) and (CHX) or a control	Mask of the operator and at 2, 3, 5, 6, and 9 feet from a reference point (patient's head) Culture grown on eight blood agar plates Counting the colony-forming units (CFU)	Anaerobic culture Counting of total CFU with colony counter	CHX versus control, 93.10% reduction EO versus control, 1% reduction	Pre-rinse with CHX can effectively reduce most of the bacterial aerosols generated via the use of the air-polishing device, Pre-rinse reduces Aerosol as far as 9 feet from the patients' head
Klyn et al. [37]	Adults patients (15)	RCT	USA	Full-mouth dental prophylaxis with ultrasonic scaler for 5 min Antiseptic mouthwash (CHX vs. control)	Bio-aerosols were collected on four blood agar plates. Three agar plates were placed at 6 inches from the oral cavity, One agar plate was placed 2 feet from the oral cavity	Counting of CFU	CHX versus control, 51.43% reduction	The use of preoperative CHX mouth rinse reduces the dissemination of bacteria
Feres et al. [38]	Adults patients (60)	RCT	Brazil	Full-mouth dental prophylaxis with ultrasonic scaler for 10 min Antiseptic mouthwash (CHX) and (CPC) or a control	Bio-aerosols were collected on five blood agar plates: Three on the support board, One on the participant's chest One on the clinician's forehead	Checkerboard DNA-DNA hybridisation (40 species) Anaerobic culture: counting of CFU with colony counter	CHX versus water, 70% microbial reduction CPC versus water, 68% microbial reduction CHX versus no-rinse, 78% microbial reduction CPC versus no-rinse, 77% microbial reduction	Mouth rinses containing 0.12% CHX and 0.05% CPC are equally effective in reducing the levels of spatter containing microbes generated during ultrasonic scaling
Dawson et al. [43]	Adults patients (18)	RCT	UK	Low-speed handpiece Antiseptic mouthwash (CHX) and a control (water)	Petri dish with anaerobe agar The extension tube was positioned at the level of the patient's mouth at a distance of 30 cm	Anaerobic culture Polymerase chain reaction (PCR) using universal primer) for total bacterial count	CXH versus no-rinse, a 77% increase CHX versus water, a 25.3% increase	The use of preprocedural 0.2% CHX mouth rinse increases in the numbers and diversity of airborne microbes
Retamel-Valdez et al. [39]	Adults patients (60)	RCT	Brazil	Full-mouth dental prophylaxis using ultrasonic scaler for 10 min	Bio-aerosols were collected on five agar plates: Three on the support board, One on the participant's chest, and One on the clinician's forehead	Anaerobic culture: counting of CFU with colony counter Checkerboard DNA-DNA hybridisation (40 species)	CXH versus no-rinse: 77% reduction CPC versus no-rinse: 70% reduction CHX versus water: 70% reduction CPC versus water, 61% reduction	Preprocedural mouth rinse with CHX and CPC was effective in reducing microbial species

CHX: chlorhexidine; CFU: colony-forming units; CPC: cetylpyridinium chloride; EO: essential oil.

Table 5. Risk of bias of the included studies.

Study	Selection bias Baseline characteristics similarity/ appropriate control selection	Selection bias Allocation concealment	Selection bias Randomisation	Performance bias Blinding of Researchers	Detection bias Blinding of outcome assessors	Reporting bias Selective outcome reporting	Incomplete outcome data
Rubber dam-Bio-aerosol							
Cochran et al. [21]	+	+	?	+	?	+	+
Samaranayake et al. [22]	+	+	?	+	?	+	+
Tag El-Din et al. [23]	+	?	+	–	?	+	+
Al-Amad et al. [24]	+	?	?	?	?	–	+
High volume evacuator (HVE)-Bio-aerosol							
Bentley et al. [31]	+	+	–	+	?	+	+
King et al. [28]	+	?	?	?	?	+	+
Muzzin et al. [29]	+	?	?	?	?	+	+
Timmerman et al. [32]	+	?	+	?	+	+	+
Yamada et al. [33]	+	+	+	+	?	+	+
Desarda et al. [30]	+	?	+	?	?	+	?
Pre-procedural mouth rinse-Bio-aerosol							
Fine et al. [34]	+	?	?	+	+	+	+
Fine et al. [35]	+	?	?	+	+	+	+
Logothetis et al. [36]	+	+	?	–	–	+	+
Klyn et al. [37]	?	?	?	?	?	+	+
Feres et al. [38]	?	?	?	+	+	+	+
Dawson et al. [43]	–	?	–	+	+	?	?
Retamel-Valdez et al. [39]	+	?	+	+	+	+	?

Risk of bias legends: '+': low risk; '–': high risk; '?': un-clear risk.

latter method, in particular, is notorious in the literature as an intense, aerosol, and spatter-producing intervention [44,45]. Hence it is not surprising that a vast majority of the clinical investigations we reviewed appertained to this interventional procedure [34–39,43]. These randomized controlled trials (RCT) unequivocally imply that a preprocedural antimicrobial oral rinse efficaciously reduces the number of viable microbes during substantial aerosol-generating procedures such as ultrasonic scaling [34–39]. Nevertheless, a few of these reports had inherent weaknesses. For instance, we noted imprecise information on the allocation concealment, which may lead to inflated estimates of the treatment effect [46]. Moreover, for valid estimates of the effect size of the intervention in RCTs, blinding of the participants and assessors is crucial [47,48]. Yet, the following information was presented only by Fine et al., in their two studies [34,35].

Which bio-aerosol mitigating method is superior?

Infective pathogens suspended and entrained in the air can be a source of many infectious diseases [1,32]. Researchers in almost all of the preceding reviewed studies determined that a significant reduction in bacteria-laden aerosols could be achieved by the three major interventional procedures discussed, *viz*. rubber dam application, HVE, and preprocedural oral rinses.

Nevertheless, almost all of these workers arrived at this conclusion using the traditional bacteriological culture plate exposure detection methods, which provides an incomplete view of the airborne microbial load. There is, for instance, virtually no data in the literature on the aerosol dissemination of other constituents of the oral microbiome such as fungi, and above all viruses. As the quality of the currently available data on bio-aerosols in dentistry are rather scanty, and wanting, further, rigorously controlled, multi-centre studies to address this important issue of containing contagious broad-spectrum bacterial, fungal, and viral infections that appear to pose a constant infection transmission threat in the dental operatory. It is anticipated that the advent of novel molecular analytical techniques such as next-generation sequencing could redress the situation and shed some light on the all-important viral dissemination that may be associated with dental interventional procedures.

Taken together, there is inadequate data to state the superiority of one method above the others in reducing the generation of bio-aerosols during dental procedures, as all procedures discussed above lead to varying degrees of bio-aerosol reduction. In clinical terms, therefore, judicious selection of one or more methods by the clinician depending on the operative procedure in question is critically important. Nevertheless, HVE must be a compulsory requirement during almost all dental procedures. Additionally, the role of extraneous strategies such as engineering controls of the air evacuation processes of the surgery (not discussed here) that are equally important in the reduction of bio-aerosols in the dental clinic environment should be borne in mind when addressing this issue.

Conclusion

Bio-aerosols are generated in clinical dentistry during multiple interventional procedures. The current review summarises three major approaches used in contemporary dental practice to minimize such bio-aerosols, rubber dam application, pre-procedural oral rinses and HVE.

Altogether our review of a total of 17 clinical studies indicates that HVE is an obligatory requirement to reduce bio-aerosols in dentistry, while rubber dam application and pre-procedural oral rinses must be utilized when opportune. Since all three bio-aerosol reducing measures contribute to reducing airborne bacterial microbes generated during aerosol producing procedures in dentistry.

Acknowledgements

Professor Samaranayake gratefully acknowledges the Thammasat University of Thailand for the award of a Bualuang ASEAN Chair Professorship to support this research.

Author contributions

LPS, together with KSF and CP performed data collation analysis and drafting the manuscript. BB assisted in manuscript writing and editing. All four authors reviewed and agreed on the final version of the review to be published and are responsible for all aspects of the work.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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