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Aerosol generating procedural risks and concomitant mitigation strategies in orthodontics amid COVID-19 pandemic – An updated evidence-based review

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Summary

Importance > The ongoing COVID-19 pandemic has posed unique challenges to orthodontic profession by adversely impacting provision of in-office orthodontic care due to prevailing uncertainty around risks pertaining to splatter and 'aerosol-generating procedures' (AGPs). This review aims to provide an insight into the prevailing and emerging evidence informing potential risks related to splatter and AGPs, and risk mitigation strategies employed for reducing the potential risk of SARS-CoV-2 transmission from dental bioaerosols.

Methods > PubMed, Google Scholar, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, LILACS, WHO COVID-19 databases and preprint databases were searched for eligible English language publications. Citation chasing was undertaken up until the review date of 4 January 2021. Study selection, data extraction and risk of bias assessment was undertaken independently in duplicate, or else by consultation with a third author.

Results > Following filter application and duplicates removed, a total of 13 articles assessing procedural mitigation measures were included. Seven included studies revealed overall low-risk of bias. The overall risk varied from unclear to high for rest of the studies, with the most concerning domains being blinding of the participants and the personnel and blinding of the outcome assessors. Accumulated consensual evidence points towards the use of dental suction devices with wide bore aspirating tips as effective procedural mitigation strategies. Variations in the literature can be observed concerning aerosol transmission associated with water spray use during debonding. Emerging direct evidence consistently supports adjunctive use of pre-procedural povidone-iodine mouthrinse to mitigate direct transmission risk in the orthodontic practice.

Conclusions > A thorough risk assessment concerning AGPs and implementation of consistent and evidence-based procedural mitigation strategies may play an indispensable role in navigating optimal orthodontic practice through unforeseen similar pandemic threats. High-quality robust research focussing on more biologically relevant models of dental bioaerosols in orthodontic settings is warranted.

Introduction

As of late December 2020, the catastrophic outbreak of a highly infectious pneumonia-type respiratory illness "Coronavirus Disease (COVID-19)" caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has infected 79.2 million people and claiming over more than 1.7 million lives worldwide [1]. The constant detection of SARS-CoV-2 in the saliva [2] and in the oral mucosa [3] of infected individuals necessitated placing 'dental health care professionals' (DHCPs) and other medical personnel who perform Aerosol-Generating Procedures (AGPs) in the "very high exposure risk" category.

During these unprecedented turbulent times, global public health regulatory bodies and major orthodontic associations formulated guidelines mandating temporary suspension of routine and elective dental treatment, including orthodontic problems, which usually represent urgencies and not true dental emergencies [4]. Teledentistry involving utilization of professional and personal WhatsApp messenger, telephone, or dental office webpage emerged as a beneficial option for high-quality remote monitoring and management of orthodontic emergencies at home [5]. However, since orthodontic treatment is a long-term process dependent upon the consistent monitoring and adjustment of active appliances throughout treatment, delay in treatment has been reported to be a concerning issue with greater impact on anxiety among patients undergoing orthodontic treatment [6]. Lower levels of anxiety were observed in patients willing to attend an in-office orthodontic appointment than in patients reluctant to or prefer going only in urgency/emergency. In light of the fact that long and continuous scheduled orthodontic care of many patients was abruptly suspended midway, patient's requirements for dental services and orthodontist workload are expected to grow explosively in the post-COVID-19 period.

At a time when vaccine rollout is rekindling the hope amongst the populations, preliminary reports of newly discovered mutant SARS-CoV-2 VOC 202012/01 strain [7] with 56% more transmissibility have fuelled another wave of fear and anxiety due to the impending possibility of larger overburdening epidemic waves. In light of the perceived vulnerability to the coronavirus infection in orthodontic settings, implications for the resumption of routine orthodontic care are enormous and cannot be ignored. In transition to phased recovery, extraordinary efforts to capitalize the opportunity to refocus, retool and reorganize are required for effective resumption of reasonable, evidence-based orthodontic care while at the same time preventing nosocomial spread of infection.

Anticipating increased patient volume and orthodontic treatment needs in the immediate post-COVID period, and considering the possibility of the post-pandemic resurgences as late as 2024 [8], assessment of the risks involved and adoption of consistent procedural mitigation strategies will help mitigate

unprecedented levels of professional uncertainty and anxiety, thereby precluding the risk of sub-optimal practices.

In the past, various mitigation strategies have been reported for containment of orthodontic bioaerosols, however, none have been tested in real-time COVID-19 scenario. Even as Orthodontics have evolved digitally and automated significantly in present digital era, we are still unable to cope up with very high infectivity rates of COVID-19, which is the first reported pandemic of this century, showing repeated resurgences, leading to either frequent lockdown of practices or increasing the morbidity and mortality among populations. In light of the limited evidence-based literature studies in the contemporary pandemic crisis, this critical review aims to provide a consolidated overview/appraisal of the prevailing and emerging evidence informing risks related to particulate-, splatter- and aerosol-generating procedures, and pertinent strategies employed for minimizing unprecedented relative occupational risks while navigating sustainable orthodontic practice through and beyond the pandemic.

Methods

Protocol registration and reporting

The study protocol was registered with the Open Science Framework [9] (<https://doi.org/10.17605/OSF.IO/MWJVX>). The reporting was conducted in accordance with the PRISMA statement for transparent reporting of systematic reviews and meta-analysis [10].

Eligibility criteria

Study methodology/design

In vitro experimental (including those using manikins, phantom heads, modelling studies, etc.) mimicking in vivo dental settings, prospective clinical trial (randomized or non-randomized), reviews (integrative, overview, systematic, narrative, and rapid), and other relevant original research related to aerosol generating procedural mitigation strategies.

Participants

Studies involving routine dental aerosol-generating procedures carried out on mannequins/phantom heads/patients by dentists assisted/not assisted by dental surgery assistant in dental operatory/clinical simulation units. Procedures included ultrasonic scaling performed at pre-, post- and during course of orthodontic treatment, orthodontic fixed appliance bonding, composite removal following debonding, aligners' attachment removal, use of 3-in-1 air-water spray, and tooth extraction under local anaesthesia.

Intervention/comparator

Aerosol Procedural mitigation strategies with the involvement of different levels of dental suction (low, medium and high), water spray, extraoral air filtration/cleaning systems, rubber

dam, antimicrobial coolants, high molecular weight FDA-approved irrigation solutions or simulating alternative.

Outcome

Any outcome pertaining to reduction in:

- microbial contamination levels in bioaerosols;
- concentration and/or count/surface area of contaminated splatter, suspended and settled aerosol particulate in the procedural environment;
- incidence of rate of infection among dental staff and patients.

Exclusion criteria

Non-English language articles, study design not relevant to dental settings, case studies, opinions, perspectives, letter to the editors, commentaries.

Search strategy

A systematic review of literature was performed electronically using PubMed, Google Scholar, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, LILACS and WHO COVID-19 databases. A manual search of eligible articles for inclusion was conducted for any additional potential inclusion and authors of the included papers were contacted when need arose for any clarification on data extraction or data curation. Additionally, to obtain the most up-to-date information, we also searched for unpublished literature in the Open Grey and preprints listed in bioRxiv, medRxiv and SSRN database server. Searches were made up until the review date of 4 January 2021. The search keywords included: "Coronavirus," "COVID-19," "SARS-CoV-2," "2019-nCoV," "transmission," "aerosol", "bonding", "debonding", "composite", "contamination", "infection control", "splatter", "orthodontics", "practice", "polishing", "orthodontic procedure", "risk assessment", "mouthwash", "mouthrinse" and "procedural mitigation". Controlled vocabulary, i.e., MeSH terms, Key words in Title/Abstract [tiab] in various combinations of Boolean terms, AND and OR, were employed during search process. Search was further refined using 'truncation', wild card, proximity adjectives as well as relevant study filters (*supplementary table*).

Screening process and selection of studies

Search was carried out by one single author (RKM). References yielded from the search strategy were imported in Open Science Framework, an online web application for interactive systematic reviews preparation, and duplicates were removed. HS and RKM screened and scored the relevance of the hits independently, based on their title and abstract. Additionally, a reference check of relevant full text articles screened was conducted and included in the flowchart using 'snowballing' sampling.

The shortlisted articles were read and brought to consensus to be included in study by at least two co-authors. In case of any disagreement among the judgement, differences in screen results were resolved by discussion or else independent co-author (PS) decision was taken as final.

Data extraction and management

Pre-piloted standardized forms were utilized for data extraction. A single review author (HS), not blinded to study origin or author identity, extracted the data while all entries were confirmed by a second author (RKM). Specifically, information entries were related to study demographics (year and country of origin), study design, study settings, interventions assessed, technical information for laboratory and clinical studies, method of analysis (instrumentation used) and measures of outcomes.

Risk of bias (ROB) and level of evidence assessment

Assessment of the quality of the papers and ROB were performed using Review Manager 5.3 (Revman 5.3, Copenhagen) [11]. Two authors (RKM and HS) assessed ROB independently and in duplicate, and any disagreements were resolved by mutual discussion or else by consultation with a third author (PS). For all included studies, each of the seven domains/parameters was classified at low (green), unclear (white) and high (red) risk of bias. Overall ROB was also assessed for each included study.

Level of evidence was rated in accordance with the 'Oxford Centre for Evidence-based Medicine' (OCEBM) [12] ranking criteria as follows: level 1 (systematic review of randomized trials), level 2 (randomized trial), level 3 (non-randomized controlled cohort/follow-up study), level 4 (case-series, case-control, or historically controlled studies) and level 5 (mechanism-based reasoning).

Results

Of the total 988 records identified through database searching, a total of 13 articles assessing aerosol procedural mitigation measures were finally included in the qualitative synthesis (PRISMA Flow chart *figure 1*).

Characteristics of included studies

All included studies evaluated the effectiveness of different aerosol procedural mitigation interventions and were published in English language. Majority of the included studies ($n = 9/13$) were published in 2020. Eight studies [13–20] originated from UK alone, two studies [21,22] from USA, one [23] from Belgium and Germany combined, one [24] from Switzerland, and one [25] from Malaysia, UK, Bahrain and Netherlands combined. Of all the studies, nine were in vitro experimental studies [13,15–19,21–23], one controlled clinical trial [20], one Cochrane review [25], one narrative review [24], and one rapid evidence review [14]. Descriptive characteristics including technical details of 13 studies evaluating different procedural mitigation interventions are illustrated in *table 1*. The extracted data exhibited heterogeneity across key characteristics, with regard to the aims, methodology (clinical settings, instrumentation used) and assessed outcomes. A narrative summary of the different procedural mitigation interventions assessed in the studies was undertaken.

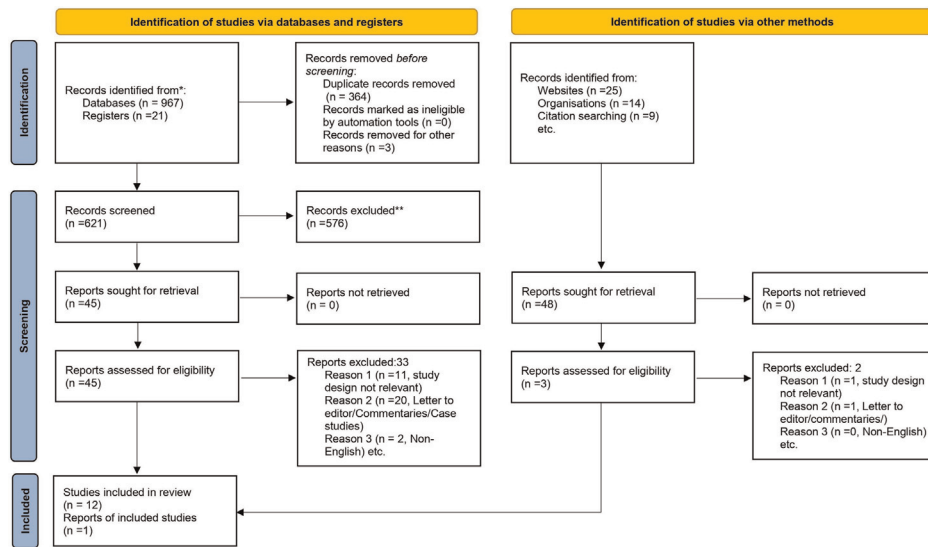


FIGURE 1
Flow-diagram of study selection

TABLE I
Main characteristics of articles (n = 13) evaluating the effectiveness of different procedural mitigation interventions (in alphabetical order) with levels of evidence¹

Author(s)/(Year)/Ref/ Country	Topic of study	Study design/setting	Assessment	Level of evidence ¹
Allison et al. (2020) [13] UK	Evaluating aerosol and splatter following dental procedures: addressing new challenges for oral health care and rehabilitation	In vitro simulation study; open-plan clinical settings with 6.5 ACH, constant temperature, all windows and doors remained closed during experiments; tracer dye method	Effect of dental suction and the presence of an assistant on aerosol and splatter distribution during three clinical procedures (anterior crown preparation, ultrasonic scaling and 3-in-1 spray use); spectrofluorometric analysis	3
Cocic et al. (2020) [23] Belgium, Germany	The effect of water spray on the release of composite nano-dust	In vitro experimental/ laboratory within enclosed 1-m ³ chamber with low particulate background; composite sticks in metal mold	Collection efficiency of water spray on the release of airborne composite particles during composite grinding; ultramorphological and chemical analysis of unfractionated and size fractionated particles by a transmission electron microscope equipped with energy-dispersive X-ray spectroscopy	3
Eliades and Koletsis (2020) [24] Switzerland	Minimizing the aerosol-generating procedures in orthodontics in the era of a pandemic: current evidence on the reduction of hazardous effects for the treatment team and patients	Narrative review	Discussion of aerosol-related hazards and potential mitigating interventions during routine orthodontic practices	5

TABLE I (Continued).

Author(s)/(Year)/Ref/ Country	Topic of study	Study design/setting	Assessment	Level of evidence ¹
Hallier et al. (2010) [20] UK	A pilot study of bioaerosol reduction using an air cleaning system during dental procedures	Controlled clinical trial involving 8 patients and 4 procedures; large open multi-chair clinical areas and a single chair closed operator; clinic windows closed and no air conditioning systems or fans, constant room temperature	Assessment of bioaerosols; effectiveness of IQAir System (FlexVac™ ACS) in reducing the size of bioaerosols during cavity preparation using an air rotor, history and oral examination, ultrasonic scaling and tooth extraction under local anaesthesia	3
Holliday et al. (2020) [17] UK	Evaluating dental aerosol and splatter in an open-plan clinic environment: implications for the COVID-19 pandemic	In vitro simulation study involving 6 experiments in open-plan clinic with 3.45 ACH, and 3 experiments in clinical teaching laboratory with 6.5 ACH; clinic windows opened to facilitate cross-ventilation	Contamination assessment using imaging software and spectrofluorometric analysis of settled aerosol; mitigation impact of water spray, two levels of dental suction (low-volume and medium volume) and cross-ventilation	3
Johnston et al. (2009) [18] UK	Quantitative and qualitative analysis of particulate production during simulated clinical orthodontic debonds	In vitro setting: debonding and enamel cleanup on extracted human teeth; Marple Cascade Impactor simulating lung	Qualitative/quantitative analysis of particle size and composition; effects of HVE and face mask	3
Kumbargere Nagraj et al. (2020) [25] Malaysia, UK, Bahrain, Netherlands	Interventions to reduce contaminated aerosols produced during dental procedures for preventing infectious diseases	Cochrane review of randomized controlled trials and controlled clinical trials; closed dental operator	Effectiveness of interventions for minimizing aerosol production and contamination: high volume evacuator; dental isolation combination system (Isolite); saliva ejector; rubber dam; air cleaning system; disinfectants (antimicrobial coolants)	1
Llandro et al. (2020) [16] UK	Evaluating splatter and settled aerosol during orthodontic debonding: implications for the COVID-19 pandemic	In vitro experimental (qualitative) study; positive control (high-speed air-turbine crown preparation with assistant-held dental suction); large-bore medium volume dental suction; 6.5 ACH	Contamination due to splatter and settled aerosol following orthodontic debonding, including removal of composite using a slow speed handpiece with assistant-held dental suction	3
Nulty et al. (2020) [15] UK	A clinical study measuring dental aerosols with and without a high volume extraction device	Comparative clinical simulation study involving 10 procedures; single dental clinic, ventilation turned off (windows closed, no air conditioning and no air purifier running)	Quantitative assessment of PM ₁ , PM _{2.5} and PM ₁₀ aerosol particulate (per unit volume) with and without the use of 'VacStation', an external high volume extraction device; active air sampling using industrial Trotec PC220 particle counter one hour before and after procedures	3
Plog et al. (2020) [22] USA	Reopening dentistry after COVID-19: complete suppression of aerosolization in dental procedures by viscoelastic Medusa Gorgo	In vitro experimental/clinical simulation study	Suppression of aerosolization on rotary drill and Cavitron scaler in dental clinical using high molecular weight FDA-approved polymer additives 2 wt. % polyacrylic acid and 0.8 wt. % xanthan gum; water droplet analysis using Mosaic Particle Tracker	3

TABLE I (Continued).

Author(s)/(Year)/Ref/ Country	Topic of study	Study design/setting	Assessment	Level of evidence ¹
Ravenel et al. (2020) [21] USA	Evaluation of the spatter-reduction effectiveness and aerosol containment of eight dry-field isolation techniques	In vitro experimental study; high-speed handpiece with air-water spray; closed dental operatory with ventilation turned off (air vents sealed)	Effectiveness of eight dry-field isolation methods involving use of HVE, an intraoral evacuator (IsoVac), a 3D-printed rubber dam and HVE with funnel in mitigating PM _{2.5} aerosols	3
Scottish Dental Clinical Effectiveness Programme (SDCEP) Group (2020) [14] UK	Mitigation of aerosol-generating procedures in dentistry: a rapid review, version 1.0; (25 September 2020)	Rapid evidence review based on systematic reviews	Mitigation of dental AGPs and the associated risk of transmission of COVID-19; assessment of evidence certainty using GRADE rating for developing guidance recommendations	1
Shahdad et al. (2020) [19] UK	The efficacy of an extraoral scavenging device on reduction of splatter contamination during dental aerosol-generating procedures: an exploratory study	In vitro experimental study: open clinic vs. closed surgery within a dental hospital setting; centralized air exchange system with HEPA filters with 6 ACH	Splatter detection and associated contamination reduction with concurrent use of four-handed dentistry, rubber dam and extraoral scavenging device	3

ACH: air changes per hour; ACS: air cleaning system; HVE: high volume evacuator; GRADE: Grading of Recommendations, Assessment, Development and Evaluation.

¹Level of evidence rating scheme based on Oxford Centre for Evidence-based Medicine (OCEBM) Levels of Evidence Working Group. "The Oxford Levels of Evidence 2:" Oxford Centre for Evidence-Based Medicine. Available at: <https://www.cebm.ox.ac.uk/resources/levels-of-evidence/ocebml-levels-of-evidence>. [Accessed on 26.12.2020].

Clinical settings

Three studies [13,16,17] used open-plan clinical settings, while three studies [15,18,21] used closed operatory. Two studies [19,20] utilized both single chair closed operatory and open multi-chair clinical set-up. One study [23] was conducted in laboratory within an enclosed chamber under standardized conditions. One experimental study [22] was performed both in laboratory and clinic settings.

Effects of interventions

Different mitigation interventions assessed to reduce contaminated aerosols produced during dental procedures were grouped into eight: high volume suction ($n = 5$ studies) [14,18,19,21,25], medium volume suction ($n = 3$ studies) [13,16,17], low-volume suction/saliva ejectors ($n = 2$ studies) [17,19], water spray ($n = 2$) [17,23], extraoral air filtration/cleaning systems ($n = 4$ studies) [15,19,20,25], rubber dam ($n = 4$ studies) [14,19,21,25], antimicrobial coolants ($n = 2$ studies) [14,25], and dilute aqueous solutions of high molecular weight FDA-approved polymers ($n = 1$ study) [22].

High volume suction (HVS)

Johnston et al. [18] tested the effectiveness of high volume evacuation during simulated orthodontic debonding of metal and ceramic brackets and enamel cleanup procedure on extracted teeth. With suction tip positioned 15 cm away from the central incisor teeth of the models, the authors demonstrated 43.5% and

25% reduction in the detectable particulate concentration during enamel cleanup using slow speed dry tungsten carbide bur and water cooling assisted high-speed tungsten carbide bur, respectively. In one simulation study [19], HVS with 8 mm bore tip has been shown to be an effective adjunct in reducing mean intensity of splatter contamination to dental operator and patients. An experimental study [21] exploring the spatter and aerosol reduction efficiency of eight dry-field isolation techniques revealed statistically significant results with the use of additional/dual HVS lines when compared with positive controls (P -value < 0.0001).

High volume evacuator (HVE) used in conjunction with intraoral evacuator (Iso Vac) was found to be most effective in mitigating splatter. A rapid review performed by 'The Scottish Dental Clinical Effectiveness Programme' (SDCEP) Working Group [14] also recommends the use of HVS as an effective aerosol mitigation strategy, albeit with indirect and very low certainty evidence. On the contrary, a Cochrane review [25] evaluating effectiveness of different procedural interventions to reduce aerosol production and biocontamination during dental procedures found very little confidence in the evidence for the use of HVS in preventing the transmission of infectious diseases.

Medium volume suction (MVS)

In their simulation study, Allison et al. [13] showed that during the procedures involving high-speed air-turbine, ultrasonic scaler and 3-in-1 spray, the use of operator-held dental suction

(flow rate of 6.3 L of water per minute) contributes to 65–75% reduction in fluorescein contamination at distance between 0.5 and 1.5 m. However, reduction in contamination was found to be greater within the first 1 m distance with assistant-held dental suction. Another in vitro simulation study [16] also showed significant decrease in localized settled aerosol and splatter contamination when orthodontic debonding including composite remnant removal procedure was performed with a speed-increasing air motor handpiece at full speed (with no water coolant) in the presence of MVS (with an air flow rate of 105 L/minute). By utilizing MVS (flow rate of 159 L/min of air with 8.2 mm aspirator tip) during experiments involving high-speed air-turbine handpiece, one study [17] also reported 53% contamination reduction within the AGP bay, 81% in adjacent bays/walkway and 83% in distant bays/walkways within open-plan clinical settings.

Low-volume suction (LVS)

The substantial beneficial effects of low-volume dental suction (40 L/min air) with a wide bore aspirating tip in reducing contamination within open-plan clinical settings has been demonstrated by Holliday et al. [17]. The authors observed 49% reduction in fluorescein contamination within the AGP bay, and 82% reduction in adjacent and distant bays/walkway. On the contrary, one study [19] found that in closed operatory, use of saliva ejector alone does not contribute significantly to reduction of contamination by splatter during ultrasonic scaling.

Water spray

The report of one laboratory study [23] on the effect of water spray on the release of composite nanoparticles, revealed that in spite of large particle size distribution observed during composite grinding, concomitant use of water spray during composite grinding significantly reduces the number of released nanoparticles and may mitigate exposure to airborne composite dust. One clinical simulation study [17] performed in open-plan clinics demonstrated that the dilution effect of dental water spray results in reduced fluorescein contamination to negligible or very low levels, especially in distant bays situated at or greater than 5 m distance.

Extraoral air filtration/cleaning systems

A controlled clinical study [20] evaluated effectiveness of an air cleaning system in reducing potentially hazardous bioaerosols generated during dental AGPs and non-AGPs involving history and intraoral examination, ultrasonic scaling, cavity preparation using a high-speed dental handpiece and tooth extraction under local anaesthesia. The authors found statistically significant reduction in bioaerosol levels with the air cleaning system in operation during dental procedures involving cavity preparation ($P = 0.018$), ultrasonic scaling ($P = 0.027$) and tooth extraction ($P = 0.036$) [20]. A recent in vitro study [15] demonstrated significant decrease in suspended $PM_{2.5}$ - and PM_{10} -sized aerosol particulate count with the use of a VacStation, a high volume

extraction device, comprising of multi-level filtration system (HEPA, high-fibre cotton filter, activated carbon, $KMnO_4$, ceramic filter, 2nd HEPA 13) and UV-C light, during procedures involving use of three-in-one air-water syringe, micromotor high-speed, air-turbine high-speed, slow speed and ultrasonic handpieces. However, the reduction in PM_1 sized particulate count was found to be statistically insignificant for the three-in-one procedure [15]. The efficacy of extraoral scavenger device (EOS) when used in conjunction with rubber dam and HVE has also been demonstrated in a recent in vitro experimental study [19]. With the use of EOS, the authors found 75%, 33% and 76% reduction in the mean intensity of contamination of operatory sites, clinician, and assistant, respectively. EOS was also found to be effective in reducing the frequency of contamination by 20% in the operatory sites. A Cochrane review by Kumbargere Nagraj et al. [25] found the evidence for the use of air cleaning system to be of very low certainty.

Rubber dam (RD)

It has been reported in one simulation study [19] that use of rubber dam in closed operatory is an effective primary mitigating strategy, showing significant decrease in the number of contaminated sites along with greater reduction observed in the mean and maximum intensity of contamination of operatory, clinician and assistant. The outcomes were assessed during the labial veneer and cavity preparation on anterior and posterior teeth, respectively using high-speed air-turbine handpiece with irrigation from the water line. One study [21] used 3D-printed internally irrigated rubber dam frame attached to high and low speed suction line and found that rubber dam exhibits greater effectiveness in reducing splatter contamination when used in conjunction with additional HVS line. It was also observed that 3D-RD + HVS ($P = 0.0469$) allows more effective $PM_{2.5}$ aerosol mitigation when compared to positive control, i.e., high-speed handpiece with no suction ($P < 0.0001$), and with outcome, i.e., $PM_{2.5}$ concentration showing similarity to the negative control i.e., ambient air quality ($P > 0.05$). One study [25] by Cochrane group found very low certainty of evidence with regard to the use of rubber dam as an effective mitigation measure. Concurring with findings of the Cochrane review on one hand, but also considering the substantial benefits outweighing harms, SDCEP Working Group [14] recommended the use of rubber dam to reduce the potential SARS-CoV-2 transmission risks associated with dental AGPs.

Antimicrobial coolants

A Cochrane review [25] showed very low certainty and inconclusive evidence for effectiveness of antimicrobial coolants. In view of the safety concerns regarding possible risk of irritation, allergic reaction or anaphylaxis, alteration of the normal oral microbiota or tooth staining (as observed with chlorhexidine), the SDCEP Working Group [14] does not recommend use of antimicrobial coolants for the purpose of reducing the potential

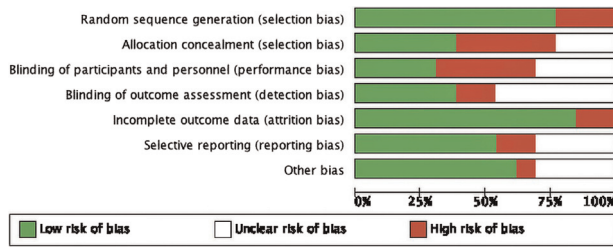


FIGURE 2 Risk of bias graph showing percentage representation of each risk of bias domain/parameter assessed across all included studies

risk of SARS-CoV-2 transmission. The authors also concluded that possible harms of antimicrobial coolants limit their feasibility of use and compromise generalized acceptability.

High molecular weight irrigation solutions

Based on the rheological behaviour of fluids, a laboratory and clinical simulation study [22] recommends capitalizing the beneficial shear-thinning behaviour exhibited by high molecular weight polymer (non-Newtonian liquids) solutions with shear viscosity greater than that of water. The authors demonstrated that by using dilute aqueous solutions of hydrogel (0.8 wt. % xanthan gum) or polymer (2 wt. % polyacrylic acid) instead of water, physicochemical properties of the dental irrigation solution can be altered and prevention of aerosolization during scaling and rotary instrumentation can be achieved by virtue of enhanced viscoelastic forces, thereby preventing droplet detachment.

Measures of outcome assessment

Outcome of aerosol mitigation interventions assessed by:

- measurement of reduction in contamination levels in bioaerosols using agar-based sampler (impactor-based air sampler) in colony forming units (CFU) per unit volume [20];
- measurement of reduction in concentration ($\mu\text{g}/\text{m}^3$ or mg/m^3)/count of suspended aerosol particulate in the procedural environment using optical particle counter [15,21], Personal Data Ram pDr-1200 real-time active air sampler [18] and scanning mobility particle sizer spectrometer [23];
- surface area measurement (mm^2) of fluorescein dyed splatter, and quantitative fluorescence assessment of splatter and settled aerosol fractions in relative fluorescence units (RFU) [13,16,17];
- rheological characterization and tracking analysis of self-thinning threads of high molecular weight polymers [22].

Instrumentation used to attain the assessed outcomes

Different methods were used:

- fluorescence photography and subsequent image analysis using ImageJ software, accompanied by spectrofluorometric analysis in 3 studies [13,16,17];

- active air sampling employing air suction pump connected to blood agar plates in one study [20];
- optical particle counter device based on multi-angle, laser-scattering detection in two studies [15,21];
- transmission electron microscope equipped with energy-dispersive X-ray spectroscopy (TEM-EDS) in one study [23];
- scanning electron microscopy (SEM) and energy-dispersive x-ray (EDX) analysis in one study [18];
- direct visual inspection method for analysing universal indicator paper under bright operatory lights/light-emitting diode dental curing light in two studies [19,21], and additionally digital image analysis by colour thresholding technique in one study [19];
- Mosaic Particle Tracker (ImageJ), a 2D/3D single-particle tracking tool in one study [22].

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Allison JR, et al. (2020)	-	-	-	+	+	+	+
Cokic SM, et al. (2020)	+		-		+		+
Ellades T and Koletsis D (2020)	-	-	-	-	-	-	-
Haller C, et al. (2010)	-	-	+		+		
Holliday IR, et al. (2020)	+	+		+	+	+	+
Johnston NJ, et al. (2009)	+	-			+		+
Kumbargere Nagraj S, et al. (2020)	+	+	+	+	+	+	+
Llandro H, et al. (2020)	+	+	+	+	+	+	+
Nulty A, et al. (2020)	+	-	-	-	+	+	+
Plog J, et al. (2020)	+		-		+		
Ravenel TD, et al. (2020)	+				-	-	-
SDCEP	+	+	+	+	+	+	+
Shahdad S, et al. (2020)	+	+	-		+	+	

FIGURE 3 Risk of bias summary for each included study

Risk of bias (ROB) within included studies/levels of evidence

Overall ROB in the individual studies was assessed to be low, unclear and high considering involvement of more than 50% of the assessed risk domains.

Seven studies [13–17,19,25] were assessed as having overall low-risk of bias, three studies [18,22,23] as having overall unclear risk of bias, and three studies [20,21,24] having overall high-risk of bias (figures 2 and 3).

Most of the included studies revealed unclear to high-risk of bias. Selection bias for most of the studies was found to be low, considering the adequate baseline similarity of the experimental conditions. Five studies [13,14,16,17,25] exhibited low bias with regard to the blinding of the outcome assessment. Attrition bias was found to be low for all studies, except for two studies [21,24] with incomplete outcome data, whereas risk of reporting bias varied from unclear to low for majority of included studies. Other biases including domains such as industry funding, conflict of interest and ethical approval were assessed to be low to unclear for majority of studies (figures 2 and 3). Regarding the levels of evidence, two studies were rated as having level 1 of evidence, 10 studies as having level 3 and one study as having level 5 of evidence (table 1).

Discussion

We identified 13 studies that evaluated eight different procedural mitigation interventions in this review. Majority of the included studies assessed the outcomes for reduction in concentration, surface area and/or count of contaminated splatter and aerosol particulates in the procedural environment. Only one study presented the results for reduction in microbial (bacterial) contamination levels of aerosols. None of the included studies explored the reduction in infection rate as outcome measure. The qualitative synthesis of evidence was considered in risk assessment, procedural risk mitigation interventions, pre-procedural mouth rinses (PPMRs) and other supplemental mitigation interventions and discussed as below.

Risk assessment considerations

Aerosol and splatter contaminated with saliva and/or blood, being an important potential vector for transmission of SARS-CoV-2 infection in dental surgery has attracted global scrutiny [13]. Given the fact that aerosols and splatter are made up of a spectrum of droplet sizes, and aerosol transmission may occur for presumed droplet infections, the authors contend that the true distinction between the two is somewhat arbitrary and an oversimplification. While the bacterial air contamination during dental procedures has been widely documented [26–28], the effect of this cross-transmission especially involving the air borne viruses is still largely unknown because of the paucity of the studies investigating the relationship between cross-transmission and infection [29].

Categorisation of dental procedures according to aerosol production and concomitant risks

National Health Services (NHS) [30] outlined three COVID-19 care pathways, namely, high, medium and low-risk. Dental care involving non-AGPs has been classified as part of the medium risk pathway, and treatment involving AGPs as part of the high-risk care pathway. Based on the characteristics of the instruments used and assumptions regarding aerosol generation, the SDCEP Working Group [14] also categorized dental procedures into three groups:

- procedures that involve utilization of powered, high velocity instruments requiring water or irrigants for cooling, produce aerosol particles < 5 µm, and require airborne transmission-based precautions, procedural mitigation and fallow time [personal protective equipment (PPE) suitable for AGP] are classified as group A procedures;
- use of powered, low velocity instruments for limited period of time that is unlikely to produce aerosol particles < 5 µm, requiring procedural mitigation such as use of HVE, and routine standard infection control precautions (SICPs) are classed as group B procedures;
- group C procedures include those performed using non-powered instruments wherein splatter, if produced is unlikely to produce aerosol particles < 5 µm, and thus, routine SICPs may suffice.

Evidence pertaining to contamination risks due to procedural aerosol and splatter generation

A rapid evidence review [31] conducted during the early periods of the present outbreak identified weak/inconclusive evidence supporting the creation of infectious aerosols during dental procedures. However, it found moderate evidence that respirable aerosols are produced during ultrasonic scaling and drilling. The evidence base informing risks in relation to AGPs is largely guided by in vitro simulation studies. Aerosolized particles smaller than 10 µm or 2.5 µm, i.e. PM₁₀ and PM_{2.5} particulates produced during removal of metallic brackets, bands, and residual adhesive, are an emerging health concern for the orthodontist because of their propensity to enter the respiratory tract [32]. Moreover, large quantities of particles less than 0.75 µm in mass median aerodynamic diameter (MMAD) are produced during use of high-speed rotary instruments in combination with water cooling [33], which may tend to intensify the risk further during removal of large volume of multiple composite attachments after clear aligner therapy [34].

A sole randomized controlled trial [35] investigating particulate production both quantitatively and qualitatively at debonding and enamel cleanup did not reveal any statistically significant effect of bracket type [metal, ceramic brackets (conventional, adhesive precoat [APC], and APC flash-free)] on the concentration of particulates produced. Greater particulate concentration

was observed with the use of conventional acid etch regimen when compared to the use of self-etching primer regimen.

A recent simulation study conducted within a closed operatory with an air exchange system demonstrated that low concentration of 'very small' (0.08–0.26 μm) and 'small' (0.26–0.9 μm) particulate matter (within inhalable and respirable fractions) is released during standard orthodontic debonding procedure (involving air but no water), albeit for a shorter duration of approximately five minutes. No difference in aerosol levels were observed when debonding was performed without supplementary air coolant. The authors also reported the combined use of 3-in-1 air-water syringe for removal of acid etch during bonding to be a low-risk dental procedure, with no increased tendency for the risk of aerosol release [36].

Based on the assumption that the spherical SARS-CoV-2 virus with diameter varying from about 60 to 140 nm can be carried by any PM₁, PM_{2.5}- or PM₁₀-sized aerosol particulates [37], the implications for the orthodontic practice are enormous and cannot be ignored. It has been observed that concentration of bioaerosol increases significantly immediately within 5 minutes of removal of residual composite following debonding procedures [38]. A systematic review by Zemouri et al. [39] pinpointed the presence of 38 types of microorganisms, including 19 bacteria and 23 fungal species in aerosols generated in dental environment, which may pose a health hazard to certain populations and healthcare workers who are extensively exposed to bioaerosol-generating procedures. A recent clinical study by same group of researchers [40] showed that even though the contamination due to aerosols is mainly low in dental settings, both human- and dental unit waterlines-derived bacterial contamination within 80 cm around the head of the patient is a cause of concern during dental treatment. The authors also observed no increase in bacterial contamination at 1.5 m from the oral cavity. However, considering the smaller size of the viruses and the larger distances travelled, the authors contemplated contamination with viruses at even farther distances from their source.

A real-time clinical study performed in closed dental operatory with natural ventilation settings demonstrated the highest increase (6-fold) of airborne particulates generated during composite grinding and drilling, both with and without the use of water [41]. Ultrasonic scaling contributed to 2.5-fold increased rates of almost all of the measured particles [41]. More recently, within open-plan clinical settings, Allison et al. [13] demonstrated the probability of low cross-infection risk from dental aerosol and splatter during dental procedures involving use of high-speed air-turbine, ultrasonic scaler, and 3-in-1 spray, even at a 4 metres distance from the source. Of all the three procedures assessed, maximum aerosol and splatter generation was observed with high-speed air-turbine, even with assistant-held suction. Higher levels of contamination with 3-in-1 spray procedure was observed at 0.5 m which reduced

significantly beyond 1 m. Llandro et al. [16] reported that orthodontic debonding procedure performed in open-plan clinical settings (with at least 6.5 air changes per hour) with a slow speed handpiece in a dry-field aided by medium volume dental suction tends to produce localized spatter confined to the vicinity of dental chair; however, with a low propensity risk for aerosol generation. Holliday et al. [17] echoed similar findings by demonstrating minimal risk of cross-infection from AGPs in an open-plan clinical setting with following configurations: bays set at ≥ 5 m apart, 1.5 m high lateral bay partition with open fronts with a patient positioned 73 cm above the floor (operator heights 1.67 m–1.87 m) and with 3.45 air changes per hour.

In a recent systematic review, Innes et al. [42] proposed a hierarchy of contamination risk from different procedures, wherein procedures such as ultrasonic scaling, high-speed air rotor, air-water syringe (air only or air/water together), air polishing, extractions using motorised handpieces were classified as high-risk; use of slow speed handpieces, prophylaxis with pumice and extractions as being moderate risk; and use of water only with air-water syringe and hand scaling as low-risk procedures. However, the authors found significant gaps in the evidence, variable quality and low sensitivity of measures to be few limiting factors in deriving robust conclusions pertaining to all aspects of contamination for different procedures.

Based on available evidence on effectiveness of PPE and prevalence of asymptomatic patients, Ren et al. [43] reported very low annualized risk of 0.008% for DHCP of contracting COVID-19 from asymptomatic patients. The inherent risk estimate was found to be highly age-dependent, with risks almost approaching zero under the age of 40 years. Although not directly validated in COVID19 scenario, but by extension from studies of H1N1 viruses, authors also postulated that properly fitted N95 masks will also demonstrate at least similar filtration efficiency against SARS-CoV-2 which has a diameter of approx. 125 nm, which is larger in size than the H1N1 virus.

A recent mathematical modelling study [44] utilized a modified version of the Wells-Riley equation for estimating the transmission probability for airborne infectious diseases in dental clinics. The researchers found the highest probability of transmission to be for measles virus (100%), coronaviruses (99.4%), influenza virus (89.4%), and *M. tuberculosis* (84.0%). The transmission probability was found to be strongly influenced by following factors in decreasing order: indoor air quality/ventilation (CO₂ level in the dental clinic), infective potential of the patient, and level of respiratory protection from use of medical face mask. Potential transmission risks from symptomatic infectious patients harbouring viral airborne pathogens such as measles virus and coronaviruses was found to be higher in disease-endemic areas. On the contrary, owing to lower microbial load in patients with low infectivity, the authors expected decreased probability of transmission (less than 20%) from asymptomatic or presymptomatic carriers [44].

Procedural risk mitigation interventions

Various risk reduction interventions that have been consistently recommended include the following [45,46]:

- avoiding or restricting aerosol-generating procedures whenever possible;
- avoiding the use of high-speed dental handpieces, air-water syringe and ultrasonic scalers;
- limited scheduling of patients;
- limiting the number of HCP during procedure;
- using rubber dams and HVE during AGPs;
- utilization of the 4-handed or 6-handed cooperation technique;
- avoiding intraoral radiographs like IOPA or occlusal views that can stimulate gag reflexes and induce coughing;
- one source recommends using handpieces with anti-retractable valves.

Since AGPs can create a risk for airborne transmission of droplet nuclei, less than 5 micrometres in size, emergency AGPs in suspected/confirmed cases should be performed in negative pressure/Airborne Infection Isolation Rooms (AIIRs).

Considering any duration of exposure while performing AGPs to be prolonged, US Centres for Disease Control and Prevention recommends shorter duration of treatment appointments, particularly first post-quarantine appointments.

Evidence base pertaining to procedural mitigation strategies

The importance of routine use of enhanced PPE for the operator, assistant, and patient has been frequently highlighted by several researchers. Guo et al. [47] recommend strict adherence to a 2-before and 3-after hand hygiene guideline, use of appropriate PPE, and proper donning-doffing sequence during orthodontic practice. For every single non-AGPs such as photograph taking, impression taking, digital oral scanning and x-ray examination, basic clinical PPE, i.e., level II constituting disposable surgical cap, medical protective mask (N95), work clothes, disposable surgical clothing, disposable latex gloves, goggles or face shield if necessary and waterproof boot covers have been recommended for all orthodontic staff. However, considering propensity of high transmission risk for AGPs [48], it has been recommended to use highest level of barrier protection equipment (level III) involving the use of a disposable surgical cap, filtering half masks (N95/FFP2/FFP3/P2 or equivalent mask, or powered air-purifying respirators, elastomeric respirators), working clothes, protective goggles or face shield, disposable latex gloves or nitrile gloves, hooded disposable medical isolation gown and waterproof boot covers [47,48]. However, hazards of constant exposure of orthodontists to aerosolized composite dust during the debonding procedure underline the need for adoption of additional prophylactic measures for minimizing the health risk for the patients and dental personnel in orthodontic practice [49].

During composite residue removal following debonding of metal brackets under laboratory conditions, use of a slow speed rotary handpiece and a spiral fluted tungsten carbide bur in a dry-field supplemented with the use of a HVE held close to the patient's mouth has been shown to be effective in reducing production of aerosolized composite dust by 43.5%. Fluid resistant surgical mask was found to be most effective in reducing exposure to respirable particles, by up to 96% [18]. Lately, similar findings have also been reported by Din et al. [36], although authors contemplated inadequate protection offered by surgical masks against close range aerosol transmission of SARS-CoV-2 infection. Even though the contamination observed on the mask is of very low clinical significance when compared to the contamination of the operator and assistant's legs, adjunctive use of visor has been suggested as an additional protective measure against splatter produced during debonding, especially if masks are used on a sessional basis [16].

On the other hand, Cokic et al. [23] demonstrated that the use of water spray targeted directly to the carbide-composite interface during slow speed handpiece reduction of bulk composite results in significant reduction (approx. one-half) in the amount of smaller airborne particulates (less than 0.1 µm in diameter). Additionally, it has been theorized that the debonding efficiency improves with the use of water spray because of faster advancement of the bur into the substrate and decreased demand for heavy load application in practice, thereby resulting in reduced operating time and time of bioaerosol generation [24]. Considering viral load to be an important element of infectivity, dilution of the aerosol contaminants from the water spray of dental instruments may result in greater likelihood of reduced infective potential [17].

Dental suction systems represent indispensable interventions that prevent escape of contaminated aerosols from the mouth and the immediate operating site. In accordance with BS EN ISO 10637 standards, HTM 2022 [50] outlined following classification of dental vacuum/suction systems based on air volume flow rates:

- high volume suction units, comprising of an intraoral suction device with a wide bore aspirating tip of at least 8 mm in diameter attached to an evacuation system, with an air intake of more than 250 L/min at each cannula connector of the largest bore operating hose;
 - medium volume suction, with an air intake between 90 and 250 L/min at the cannula connector;
 - low-volume systems, with an air intake less than 90 L/min.
- High volume suction, representing a third layer of defence [27], has been shown to considerably reduce dispersion of aerosols from the immediate procedural site by more than 90% [28]. A recent Cochrane review [25] provides no clear indication that high volume suction reduces the SARS-CoV-2 transmission risk associated with dental AGPs. Citing risk of bias resulting from variability in the devices used for high volume suction, sparse

information on the level of suction applied in included studies, small sample sizes with wide confidence intervals, indirectness and imprecision of evidence extrapolated from trials measuring reduction in bacterial load in aerosols rather than viral contamination, the authors found the quality of evidence supporting the use of high volume suction to be of very low certainty. Nevertheless, considering the insignificant risk of harm from the use of high volume suction, GRADE rapid review by the SDCEP Group [14] provided a consensus in the favour of use of high volume suction for mitigating transmission risks associated with dental AGPs.

Saliva ejectors or conventional low-volume dental suction, by virtue of their usefulness in providing a clear operating field and comfortability when compared to HVE devices, are routinely preferred in clinical practice. However, concomitant use of saliva ejectors and HVE devices held properly in close proximity (at a distance of approximately 6 mm to 15 mm) to the procedure have been shown to be more effective in reducing bacterial contamination when compared to the saliva ejectors used alone [51]. Recently, a proof-of concept clinical study involving real-time ultrasonic scaling and mock procedure performed using high-speed handpiece with a diamond bur, demonstrated that combined use of saliva ejector and high-speed suction during the procedures resulted in minimal increase in the level of aerosol with size smaller than 10 μm . Adjunctive use of extraoral high volume suction further contributed to significantly reduced aerosol levels to below the baseline level [52]. Emerging evidence [21] also points towards effective mitigation of $\text{PM}_{2.5}$ aerosols with combination of experimental set-ups involving funnel devices, 3D-printed devices (rubber dam frame) and dual HVE lines.

It has been observed that few studies [18-20] utilizing high volume dental suction reported the level of suction as 'high' without actually measuring the rate of suction (air flow rate) in real-time. Similar observations have also been made by Holliday et al. who furthermore demonstrated that use of medium (159 L/min air) volume or even low-volume (40 L/min air) dental suction with a wide bore aspiration tip, especially in open-plan clinical settings, contributes significantly to distant contamination reduction by virtue of easy removal/elimination of smaller lighter droplets (aerosol) [17]. Within the AGP bay itself, dental suction exhibits moderate protective effects against local contamination caused predominantly by large droplets or high velocity small droplets. Based on the insignificant little difference observed in the reductions of close and distant contamination between low and medium volume suction, the authors concluded that the substantial beneficial effects of dental suction are observed at low threshold levels, thus obviating the need for high volume suction with 250 L/min air flow rate. Similarly, effectiveness of medium volume suction in reducing cross-infection from splatter has also been documented by Allison et al. [13] Extraoral Air Filtration/Cleaning

System has been shown to be effective in significantly reducing the mean bacterial aerosols and aerosol particulate count (PM_{10} , $\text{PM}_{2.5}$ and PM_{10} -sized) generated during dental procedures [15,20,21], thereby indicating its vital role in the treatment of medically compromised individuals in specialist dental facilities [20]. Of the four included studies evaluating the efficacy of rubber dam, three studies [14,19,21] recommend the routine use of rubber dam to maximise risk mitigation during AGPs. Likewise, a rapid review by the National Services Scotland Short Life Working Group [53] under the aegis of NHS, also showed that rubber dam may reduce bacterial air contamination by approximately 70% at two metres from the source, albeit with limited evidence. Use of rubber dam in orthodontics was first reported to secure pharyngeal airway from aspiration of a radiolucent ceramic fragment during conventional debonding of fixed appliance ceramic brackets. However, being highly operator sensitive, rubber dam has limited practical implications in discipline of orthodontics where multiple teeth are being treated.

From the perspective of targeting the source of aerosol generation, Plog et al. [22] demonstrated that by alteration of physicochemical properties of the irrigation solution, droplet formation can be suppressed at the generating source level without altering flow behaviour in the supply line of standard dental chairs. Utilization of two-part irrigation solution including water and FDA-approved high molecular weight viscoelastic polymers such as polyacrylic acid and xanthan gum has been proposed as a useful control measure for reducing or completely eliminating droplet formation by rotary and ultrasonic instruments, although its effectiveness and reliability remains to be tested in real-time clinical scenario. Moreover, at the source level, utilization of slow speed handpiece instead of fast handpiece [36], four-handed dentistry, and ultrasonic scalers operated at 70% speed instead of 100% speed [19] have been recommended for minimizing exposure to splatter during dental cleaning at bonding, bracket repositioning, and debonding visits.

A recent Cochrane review [25] of 16 studies with 425 participants, evaluated the role of different interventions such as HVE, rubber dam, dental isolation combination system, ACS and antimicrobial coolants (chlorhexidine, cinnamon extract coolant or povidone-iodine) in reducing contaminated aerosols produced during dental procedures for preventing infectious diseases. The authors found that the evidence of the beneficial effects from the interventions is of very low certainty, thereby necessitating high-quality RCTs with standardized interventions and focussing on direct biologically relevant outcome measurements such as viable particles in small sized aerosol particulates to draw a more conclusive real-life evidence. The researchers reported colony forming units as the only outcome measure and acknowledged the unfeasibility of measuring the infection rates which can be assessed only during an epidemic [25]. However,

the escalated burden that the highly contagious coronavirus pandemic has put on healthcare systems all over the world necessitated focusing and utilization of all resources for prevention and treatment, thereby rendering the conduct of split-mouth design studies requiring a necessary two-week wash-out period practically unfeasible during such unprecedented turbulent times.

Risk of bias assessed across the cumulative evidence revealed overall low-risk of bias for seven studies [13–17,19,25], while the overall risk varied from unclear to high for rest of the included studies [18,20–24]. Selection bias for most of the studies was found to be low, considering the adequate baseline similarity of the experimental conditions. Majority of the studies also exhibited low attrition bias. However, the most concerning domains were blinding of the participants and the personnel and blinding of the outcome assessors.

Bonding and debonding-specific mitigation strategies

Low viscosity or liquid gel based conventional acid-etching formulations need to be prioritized because of the advantages of reduced spatter production and diminished working times. By virtue of their chemical interaction and adherence with enamel surface, self-etching primer and glass-ionomer cements may offer a feasible substitute to classic adhesives and conventional light-cured counterparts, thereby reducing the associated risk of aerosol production with rinsing application during bonding procedures [24]. Mussel biomimetic based bonding primers such as L-3,4-dihydroxyphenylalanine (L-DOPA), exhibiting enhanced adhesion potential both in dry and wet conditions, have been proposed to be a promising alternative to conventional bonding strategies by precluding the need for prior enamel conditioning, and also facilitating effortless debonding and enamel cleanup posttreatment [24].

Based on the feasibility, other recommended substitutes for widely used material grinding protocols include [49]: avoiding large-scale composite attachment use for aligner therapy by restricting utilization of company pre-set attachment grips; appropriate case selection for low-scale attachment-aligner orthodontic therapy; and, targeting a carefully selected bracket-to-adhesive interface that would eliminate composite remnants at debonding or induce a cohesive resin fraction of the bulk of the composite upon debonding thereby facilitating remnant removal with a hand scaler without use of an air-turbine or micromotor handpiece. From a bisphenol A (BPA)-linked toxicity mitigation perspective, capitalization of the beneficial effects of triethyleneglycol dimethacrylate, urethane dimethacrylate, and cycloaliphatic dimethacrylate-based aliphatic co-monomers may help prevent elicitation of potential xenoestrogenic effects associated with BPA diglycidyl dimethacrylate compounds in aerosolized dust at the debonding stage [24].

Non-aerosol-generating procedures (non-AGP) alternative protocols

These include use of conventional glass-ionomer (GIC) or resin modified (RMGIC) for banding; use of Weingart or Birdbeak pliers and HVE for removal of adhesive from the fixed retainer wire; employing removable retainers (for retention regime) which can be fabricated over the remnants of a broken fixed retainer; and, using bands/bypassing the debonded tooth/using dead coil or sleeve on the wire/using sectional wires mesial to the debonded tooth in cases requiring repair of brackets mid treatment [54]. Use of intraoral scans/digital impressions rather than traditional alginate impressions should be considered to reduce the risk of cross-infection. Hand instruments such as Mitchell's trimmers or hand scalers may be employed for adhesive removal on incisor teeth, and band/adhesive removing pliers may be considered for residue removal only for posterior teeth. Caution should be exercised to prevent gouging off the enamel surface during adhesive removal and to avoid damage/fracture to the posterior occlusal restorations by placing a cotton wool roll on the occlusal surface before applying any force with the pliers. Any small composite remnants are likely to be lost over time with toothbrushing [54].

Pre-procedural mouth rinses (PPMRs)

In light of the high viral load being reported in the oropharynx of asymptomatic patients with SARS-CoV-2 infection [55], use of mouth rinses such as 0.2% povidone-iodine (PVP-I), 1% hydrogen peroxide, 0.12% chlorhexidine (CHX), essential oils and 0.05% cetylpyridinium chloride (CPC) have been recommended to reduce microbial load in spatter and dental aerosols [56]. In September 2020, Carrouel et al. [57] critically reviewed the scholarly literature demonstrating the antiviral activity of reagents in different mouth rinses and stressed the need for further clinical research to substantiate their recommendation as an effective mitigation measure in dental healthcare settings. A recently conducted sole RCT by Seneviratne et al. [58] found that rinsing with 0.075% CPC and 0.5% PVP-I for 30 seconds decreases the salivary SARS-CoV-2 levels within 5 minutes of use, with virucidal effects lasting up to 6 hours. Although not directly validated in COVID-19 settings, a first of its kind large-scale systematic review with network meta-analysis [59] demonstrated tempered CHX 0.2% at 47 °C to be an effective pre-procedural intervention for the reduction of aerosol-related bacterial load in dental practice.

Another recent unpublished in vitro study [60] examined the potential cytotoxic effect of four commercially available mouth rinses separately to ensure that antiviral activity was not attributed to mouth rinse-induced cytotoxicity. Higher concentrations of Listerine and 0.12% CHX exhibited potent antiviral effects without cytotoxicity, whereas colgate peroxy (1.5% w/v hydrogen peroxide), and 10% PVP-I exhibited cytotoxicity associated antiviral potential.

However, citing low certainty evidence of effectiveness of PPMRs due to risk of bias and indirectness, SDCEP group [14] does not strongly recommend their use to reduce the potential risk of SARS-CoV-2 transmission associated with dental AGPs [14]. Moreover, the group also argue that only the dental professionals and possibly other patients attending the surgery may benefit from the use of mouth rinse rather than the patient using the mouth rinse. It also recommends obtaining a valid patient consent before using PPMR.

PVP-I, a broad-spectrum antimicrobial being used for six decades, exhibits good tolerability and well-established safety profile without any propensity/predisposition for dental discolouration, oral mucosa irritation or taste disturbances [61]. An unpublished experimental study [62] showed that under the acidic environment, PVP-I by virtue of its low pH itself acts as an etchant and undergoes dissolution, thereby aiding in elimination of trapped strains within short time. However, considering the possibility of dental corrosion attributed to its low pH, judicious and supervised use of PVP-I has been recommended. Nevertheless, taking cognizance of the recent emerging direct scientific evidence demonstrating the *in vitro* and *in vivo* efficacy of oxidative agents such as PVP-I, it seems justifiable to recommend the innocuous use of PVP-I as a viable strategy for interrupting transmission of oxidative stress-vulnerable SARS-CoV-2 virus [58,63–66]. One can follow the Kirk-Bailey et al. [67] recommendations regarding use of 9 mL of 0.5% PVP-I as a mouthwash and nasal spray, both for the patient, and for the clinical staff repeated 2–3 hourly, up to 4 times a day if multiple patients are seen.

Supplemental mitigation interventions

With evidence pointing towards viability of SARS-CoV-2 virus for up to 3 hours in aerosol and having an estimated median half-life of 1.1 hours in air, 5.6 hours on stainless steel and 6.8 hours on plastic surfaces [68], implementation of strict air quality control and surface disinfection protocol after every patient is indispensable to reduce the risk of transmission.

Various recommended preventive engineering control measures include the following [69]: ensuring adequate natural ventilation of the operatory and waiting area with new air, allowing air flow from the clean area into the less clean area by placement of supply-air vents in reception or corridor area and return-air vents in the waiting area or rear of the patient operatory, or portable high efficiency particulate air (HEPA) filtration units placed adjacent to the patient's chair, but not behind the dental healthcare personnel.

NHS [30] recommends use of properly directed extractor fans (not towards doors), fixed-split and portable air conditioning (without recirculation) without incorporated humidifiers.

Surface inactivation of SARS-CoV-2 can be achieved by standard disinfection methods involving the use of 70–80% ethanol (minimum 1-minute exposure time), 0.5% hydrogen peroxide,

and freshly prepared 0.1% (1 g/L) sodium hypochlorite at 2–3-hour intervals [47]. A fallow period or minimum post AGP downtime of 10 minutes has been recommended to allow for settling of larger droplets before initiation of environmental cleaning [17].

Sterilization and disinfection of orthodontic armamentarium can be achieved by employing steam autoclave sterilization preferably for pliers, archwires and miniscrews; high-level chemical disinfection or cold sterilization using 2% glutaraldehyde or 0.25% peracetic acid for heat-sensitive items such as orthodontic markers; ultrasound bath and thermal disinfection. Heat-automated high-level disinfection using washer-disinfector may be employed for decontamination of photographic retractors. Flushing dental unit water lines for at least 2 minutes at patient intervals or sucking about 1 L of 1% sodium hypochlorite through the suction line at the end of the day reduces the risk of cross-contamination [69].

As for the waste management, clinical waste should be disposed of as standard regulated category B (UN3291) waste and should be segregated in double-layer yellow leak-resistant clinical waste bags (with a "gooseneck" knot) [69].

Strengths and limitations

With more than a year into pandemic and knowledge about the coronavirus still evolving, this article is the first comprehensive report of evidence synthesis from the latest relevant emerging literature on effectiveness of aerosol procedural mitigation interventions in orthodontic practice amid ongoing COVID-19 pandemic.

As for the limitations, majority of the studies have been conducted as laboratory and clinical simulation experiments in varied settings with none directly investigating the pathogenicity in terms of direct viral load, risk of cross-transmission and its mitigation in real-time clinical settings. Nevertheless, taking cognizance of the unknown role of potential asymptomatic transmission from a high proportion of orthodontic children patient population [70], extrapolation to real-time orthodontic settings may not be considered unfeasible or unrealistic.

Conclusion

The present article collated and systematically reviewed prevailing and emerging evidence informing risks related to splatter and AGPs, and pertinent strategies employed for minimizing the risk of aerosolized based spread of COVID-19 infection in orthodontic settings amid and beyond the pandemic. The accumulated evidence suggests that in addition to well-resourced PPE, the evaluated interventions, namely high-, medium- and low-volume dental suction, external air cleaning systems and pre-procedural mouth rinses in conjunction with engineering control measures might play an indispensable role in mitigating risk of transmission in orthodontic settings.

In view of the prodigious fluid situation posed by the COVID-19 pandemic, all patients with respiratory pathogens are potentially infectious. Considering the sparse knowledge about the level of viral load within dental bioaerosols and the infectivity of these on one hand, and also taking cognizance of the potential inhalational risk posed by even short-lived and low particulate concentration of 'small' and 'very small' suspended and settled aerosol particulates during orthodontic treatment procedures on the other hand, it seems reasonable to adhere to enhanced levels of mitigation strategies in orthodontic practice as discussed above. This may help dispel unprecedented levels of professional anxiety and facilitate delivery of optimal orthodontic care through unforeseen similar future pandemic outbreaks. Additional high-quality robust research focussing on more biologically relevant models of dental bioaerosols in real-time

orthodontic settings is warranted to help provide real support to optimum and safe conduct of orthodontic practice.

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Supplementary data

Supplementary data associated with this article can be found, in the online version, at <https://doi.org/10.1016/j.ortho.2021.05.004>.

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