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Aerial transmission of the SARS-CoV-2 virus through environmental e-cigarette aerosol: is it plausible?

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Abstract

The plausibility, extent and risk of transmission of SARS-CoV-2 virus through respiratory droplets potentially carried by e-cigarette aerosol (ECA) exhaled by infected vapers are discussed. Taking into account observational data on mouth breathing droplet emission rates as a proxy model for this transmission, droplet diameters should be overwhelmingly in the submicron scale. We predict emission rates of 2-230 droplets per puff horizontally transported 0.5-2 meters towards the exhaled jet for the most typical low intensity puffing form (practiced by 80-90 percent of vapers).Considering that vaping is an intermittent respiratory expiration associated with a short duration exposure and assuming contagion risks to be proportional to the SARS-CoV-2 viral load of emitted droplets, we estimate that vaping represents about 1% added risk with respect to the ever existing risk from continuous rest breathing in indoor spaces with natural ventilation (as a reference, speaking for 6 minutes per hour increases this risk to 44%). With universal wearing of face masks shielding bystanders, the added risks remain negligible in public spaces.

Direct aerial transmission of the SARS-CoV-2 virus borne by respiratory droplets is a fact already acknowledged by the WHO [1] and the CDC [2]. Indirect transmission by smaller droplets (often referred to as 'aerosols') is also proven [3], but its reach and frequency remain controversial [4,5]. The current COVID19 pandemic has intensified the existing scientific interest in the mechanisms of generation, viral transport and respiratory droplet dynamics emitted by different respiratory

activities, such as respiration [6], vocalization [7], coughing [8] and sneezing [9]. In this paper we expand this current body of study by addressing the plausibility of SARS-CoV-2 virus transmission via respiratory droplets borne by e-cigarette aerosol (ECA) exhaled by infected vapers. For a more detailed presentation of the discussion given here, see [10]. The following disclaimer must be issued: this article does not deal with health risks resulting from ECA exposure that are not specifically linked to the transport of respiratory droplets that potentially contain pathogens.

Vaping is characterized by a wide variety of individual styles or topographies that have a range of intensities depending on whether the devices are low or high-powered [11,12,13]. However, we address here the 'mouth-to-lung '(MTL) style, requiring momentary mouth retention of the aerosol bolus prior to lung inhalation, which involves low powered devices and is practiced by the overwhelming majority (80-90%) of vapers [14] (see [10] for a discussion of droplet emission in minority styles and topographies).

Droplets exhaled by an infected vaper would not be just “airborne” as in other respiratory expirations, but would be evolving jointly with a non-biological aerosol (ECA) that is strongly diluted in exhaled air. Hence, considering inhaled ECA droplet numbers [15] and a 90% retention by the respiratory system [16,17], the exhaled respiratory droplets would be accompanying a much larger number (about 10^8-10^9) of submicron ECA droplets composed of propylene glycol (PG), vegetable glycerine (VG), nicotine and water [18].

As there is no experimental research on respiratory droplets assisted by ECA, by looking at current evidence on expiratory activities that can act as proxies for vaping, we need to infer their diameter distributions and emission rates. We therefore need to first quantify the exhaled volume of ECA diluted air that vapers exhale. Cigarette smoking is a helpful proxy for this purpose, as most vapers are either relatively recent ex-smokers or current smokers, often following the style of MTL vaping that resembles the topography of puffing practiced by most cigarette smokers [19,20]. Available evidence [21,22] indicates that smokers exhale a fluid mixture of mainstream smoke and air with a total volume 30-40% greater than the normal tidal resting breathing volume (approximately 700-900 vs. 400-600 cm^3). This rise in volume is the probable product of smoke suction and is also consistent with smoking occupying a higher percentage of vital capacity (approximately 20 % versus 10-15% in rest breathing [21]).

We conclude that is fair to assume this quantity of exhaled fluid volume for vaping, an inference further justified by the fact that it requires higher air flow resistance than smoking [23], though vapers puff for longer periods [11,12,13], thus being able to inhale a comparable (or greater) aerosol mass and puff volume (between 4-10 mg and 20-100 cm^3 [11,12,13]) as smokers by exerting similar effort (similar suction pressure gradient).

Given the lack of empirical evidence, we consider mouth breathing as a useful proxy model to infer respiratory droplet diameters and emission rates by vaping. We estimate vaping-related exhalation velocities to clarify this. A total volume of fluid of 300-1500 cm^3 exhaled in 2-4 seconds through the combined nose/mouth area of 2-3 cm^2 (vaping does not include nose occlusion) induces exhalation speeds of U_0 = 30-250 cm/s. The range of these exhalation velocities is comparable

to that of measured velocities for mouth breathing [24,25], which are below velocities for speaking (3.9 m/s), coughing (6-22 m/s) and sneezing (20-35 m/s) reported in the literature [26,27,28,29,30]. Hence, we can consider the wealth of available data on respiratory droplets from breathing experiments at different levels of inspiration (see review in [6]), with subjects breathing in all cases through mouthpieces and noseclips.

Mouthpieces and noseclips are standard instruments in breathing experiments. This is not necessarily a downside since vaping requires oral inhalation through a mouthpiece by suction (but not nose occlusion that occurs by wearing noseclips). We have therefore reviewed the available literature[31,32,33] that discusses the effects of these tools on breathing parameters. Although oral inhalation with a mouthpiece and a noseclip increases tidal volume and inhalation/exhalation times for factors close to 20% above rest breathing values, these effects virtually cease when nasal breathing is not blocked[33], even if, as is the case with vaping, subjects are kept breathing orally via a mouthpiece (and smoking). This would indicate a volume of exhaled fluid similar to the volume of rest breathing tidal volume (400-600 cm^3) for vaping, but the studies examining the effects of mouthpieces and noseclips did not consider aerosol suction that occurs in vaping. Therefore, our estimate of exhaled fluid volume due to vaping is approximately comparable to that showing a rise of exhaled fluid volume in studies using mouthpieces and noseclips on respiratory droplets from mouth breathing.

Experimental breathing data (see study in [6,10]) can therefore be used as a valid proxy for estimating droplet emissions for vaping, resulting in an average rate of emissions of between 2 and 230 droplets per puff, mainly in the submicron range. In respiratory studies, this rate of emission is comparable to droplet numbers and sizes found for tidal volumes similar to resting breathing.

Since both ECA and respiratory droplets are in the submicron range, they exert negligible influence on the flow dynamics of the carrier fluid. In other words: exhaled ECA is a “single phased” fluid flow [34] in which ECA droplets act approximately as molecular contaminants that can serve as tracers to visualize the respiratory air flow (because of their optical properties [35]). In fact, usage of tracer gases and aerosols with fine and hyper fine particles like ECA is a standard technique to visualize respiratory flows [36].

After the exhaled tidal volume and numbers and diameters of respiratory droplets to be borne by the exhaled ECA have been inferred, we continue to estimate the direct exposure distance. We model ECA flow as a puff with a starting turbulent jet with finite fluid injection (finite exhalation time) [37,38,39] to estimate how far respiratory droplets can be carried by exhaled ECA. The dynamical model yields a range of 0.5-2.0 meters for horizontal transport of (ECA and respiratory) droplets (see detailed discussion in [10]). Once the injection has stopped, the jet evolves into an unstable puff that is rapidly disrupted by turbulent mixing with entrained surrounding air [37], with submicron droplets (ECA and respiratory) being subsequently carried and dispersed by air currents, thereby enhancing the possible risk of indirect contagion.

We consider (see [10]) a condensed version of the dose-response exponential risk model proposed by Buonanno, Morawska and Stabile (BMS) to evaluate the risk of indirect contagion [40,41]. Our goal is to estimate the relative risk of

indoor vaping, an intermittent expiratory operation, with respect to (and in direct contrast with) rest breathing, which is an inevitable continuous expiratory activity that can be regarded as a " control case " scenario. For speaking and coughing, which are often episodic and sporadic behaviors, the same risk relation with respect to this " control case " can be calculated.

Assuming that the submicron respiratory droplets have been spread uniformly and considering recent data used by BMS on SARS-CoV-2 viral load and other infection parameters, as well as their data on droplet size and emission rates, we evaluate these relative risks for a home and restaurant scenarios (12 and 3 hours total exposure) with natural and mechanical ventilation. The resulting values of added risks computed in [10] with respect to the control case are:

- 1% for vaping (160 daily puffs)
- 44 % for continuous speaking 10 % of time (6 minutes every hour), up to 90 % for speaking 40 % of time (20 minutes every hour)
- over 260 % for coughing 30 times per hour.

Last but not least, we comment on the possibility of chemical interaction between respiratory droplets and PG and VG vapors, the main chemical compounds of the gas phase of ECA. These compounds are glycols whose bactericidal and virucidal properties [42,43] and aerial disinfectant effects have been laboratory tested on various pathogens (mostly bacteria) [44,45,46]. However in the unpredictable and sporadic conditions of practical vaping, the highly idealized conditions and PG concentrations in which these disinfectant experiments were performed could hardly be applicable. Nevertheless, experimentally checking the disinfectant properties of PG on the SARS-CoV-2 virus should be worthwhile and useful.

There are clear drawbacks to the studies that we have done. By extrapolating from available data on droplet sizes and emission rates of cigarette smoking and mouth breathing taken as proxies, we inferred estimates for droplet emissions via ECA. Although these figures are consistent with ECA's physical and chemical properties, and/or the relationship between vaping and these proxies, actual experimental and observational studies still need to confirm them.

We accept that our fluid dynamic modeling of exhaled ECA is idealized, but we claim that the calculation of direct exposure distances from a single vaper in still air under natural ventilation is acceptable and necessary. Advanced theoretical and computational methods of fluid mechanics (see for example [47]) would be sufficient to estimate indirect exposure by studying droplet dynamics under more realistic conditions (a ventilation regime and integrating the effects of turbulent air mixing and thermal convection). Rather, we examined indirect exposure through a simplified exponential risk model based on the rates of expired viral load through various respiratory activities of actual SARS-CoV-2 data. This simplistic risk model is also idealized, but it fulfills our objective to provide a rough estimation of the relative risks of indirect exposure to vaping (as an intermittent expiration) with regards to the continuous rest breathing control scenario. We assume that this simplistic approach captures the necessary risk information to direct preventive policies, but in a future

study, a more elaborate and complete approach should be tried (see [10] and references cited therein).

As commented before, an interesting feature resulting from a possible respiratory droplet transport by vaping is the possibility of actually visualizing a potentially risky respiratory airflow. This has an important psychological dimension that is absent in other expiratory activities that cannot be visualized (speaking, singing, coughing, sneezing) but are also potentially carrying infective droplets. Thus, bystanders able to visualize ECA as a respiratory flow would be able to position themselves at appropriate safe distances for direct exposure (1-2 meters), approximately equal to the recommended distances of social separation. Visualization of respiratory flow will also make it clear that direct exposure risk distances apply only in the direction of the exhaled plane, with only indirect exposure risk to individuals put in other directions (and not wearing face masks). Nevertheless it is prudent to maintain 2 meters of separation from everyone vaping if you don't wear a face mask.

In indoor or socially shared spaces where there is no universal wearing of face masks, vaping will add only a minuscule additional risk (1%) to those risks already existing from continuous breathing or talking. Face masks worn by infected persons offer fairly effective protection against contamination by infected persons, but wearing them also provides bystanders reasonably good protection from emissions from people infected who are not wearing a face mask [48].

Universal wearing of face masks obviously implies a dramatic reduction of any level of the current baseline risk for continuous breathing (more so for talking). It can be argued that vaping requires the temporary removal of a face mask and will therefore raise the risk of exposure in an indoor setting where everyone wears a face mask. If face mask wearing is universal, this risk change would be inconsequential because it would be offset by the fact that the same face masks would shield others from droplet emissions produced in these short intermittent mask-free vaping episodes .

Further, we remark that eating and drinking (like vaping) also require face masks removal, but breathing emissions due to these brief face mask removal episodes to drink, eat or vape, or even to take a brief rest from wearing the mask, would only imply for bystanders (already protected for wearing face masks) to tolerate a small rate of droplet emission only for a very short time. Since face masks are not 100% efficient in blocking droplets and usage cannot be rigidly maintained and enforced 100 % of time in shared spaces, this tolerance is necessary for civilized coexistence. In the specific case of vaping it implies a tolerance of mask-free periods that would be of shorter duration than those for eating or drinking: likely no longer than 10 seconds roughly 10-15 times per hour (being free from this exposure for the remaining 600-1400 breaths by the vaper in the same hour).

It is true that vaping can pose risks not relevant to aerial transmission, such as face-to-face or mask contamination or sharing or tampering with a device inserted in the mouth, but the same risks are present while drinking or eating (and are tolerated or tackled by hygiene prevention). The same tolerance and courtesy offered to people drinking or eating should be granted to vapers, most of whom prefer to avoid smoking and remain smoke-free (or at least to smoke less).

The risk for direct and indirect COVID-19 contagion from indoor vaping expirations does exist and must be taken into consideration. However, this risk must be put in its proper context with reference to the criteria of exposure that define vaping and other expiratory practices. Therefore, as far as defense against the SARS-CoV-2 virus is concerned, vaping does not require specific additional interventions in a home scenario or in shared social spaces, other than those already suggested for the general population: social distance and face masks. Vapers should be advised to be alert to the worries and fears of non-vapers when sharing indoor spaces or dwellings or when close to other citizens, and for safety measures to use low-powered devices for low intensity vaping. Vapers, however, deserve the same sensitivity, courtesy and tolerance as well.

Competing interests

R.A.S. declares no competing interests.

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