Contributions to Tobacco & Nicotine Research
formerly: Beiträge zur Tabakforschung International
Volume 34 · No. 5 · December 2025
DOI: 10.2478/cttr-2025-0019

Critical Appraisal of Exposure Studies of E-Cigarette Aerosol Generated by High-Powered Devices*

by

Sébastien Soulet[1] *and Roberto A. Sussmann*[2]

[1] *Ingesciences, Cestas, Gironde, France*
[2] *Institute of Physical Sciences, National Autonomous University of Mexico, UNAM, Mexico City, Mexico (on leave from Institute of Nuclear Sciences UNAM, Mexico City)*

SUMMARY

Currently low-powered pods and disposables overwhelmingly dominate consumer preference of vaping products. Yet, despite its marginal usage, third generation high power low resistance (sub-ohm) devices are still used frequently to generate aerosols for assessing the toxicity of vaping aerosols. All these studies operate these devices under the CORESTA Recommended Method 81 protocol or with slight modifications, with airflow rates around 1 L/min. This experimental set up is concerning, since we have published various articles showing that much higher airflow rates (around 10 L/min) are a necessary experimental condition for these devices to generate aerosols that avoid overheating and large production of toxic byproducts. In a previous recent article, we replicated aerosol generation from a high-powered device integrated into a computerized exposure system used to expose in *in vitro* and *in vivo* systems. After careful calibration, we identified the experimental conditions for this device to avoid generating aerosols under an Overheating Regimen that would generate a repellent aerosol for human users. Applying the experimental results of this study, we show in this critical review that all studies using this same device exposed biological systems to overheated and aldehyde-loaded aerosols, with about half of the studies also delivering excessive nicotine concentrations. Some studies reported the presence of carbon monoxide, suggesting evidence of advanced wick pyrolysis. Most of the reviewed studies are irreproducible for failing to provide sufficient information of their aerosol generation procedures. Our results raise questions on the relevance of this literature to assess the risk profile of vaping products. Finally, we provide guidelines to improve the protocols of aerosol generation methodology in emission and exposure studies. [Contrib. Tob. Nicotine Res. 34 (2025) 202–221]

KEYWORDS

Vaping; electronic cigarette; overheating conditions; animal testing, *in vivo*, exposure, puffing protocols.

ZUSAMMENFASSUNG

Derzeit dominieren Pods und Einwegprodukte mit geringer Leistung die Verbraucherpräferenzen bei Vaping-Produkten. Trotz ihrer marginalen Verwendung werden Geräte der dritten Generation mit hoher Leistung und niedrigem Widerstand (Sub-Ohm) jedoch nach wie vor häufig zur Erzeugung von Aerosolen verwendet, um die Toxizität von Vaping-Aerosolen zu bewerten. Alle diese Studien verwenden diese Geräte nach dem CORESTA 81-Protokoll, oder mit geringfügigen Modifikationen, bei Luftdurchflussraten von etwa 1 L/min. Diese Versuchsanordnung ist bedenklich, da wir in verschiedenen Artikeln gezeigt haben, dass viel höhere Luftdurchflussraten (etwa 10 L/min) eine notwendige Versuchsbedingung sind, damit diese Geräte Aerosole erzeugen können, die eine Überhitzung und die

*Received: 11th July 2025 – accepted: 21st October 2025

Bildung großer Mengen toxischer Nebenprodukte vermeiden. In einem kürzlich erschienenen Artikel haben wir die Aerosolerzeugung eines leistungsstarken Geräts nachgebildet, das in ein computergesteuertes Expositionssystem integriert ist, welches zur Exposition von *In vitro*- und *In vivo*-Systemen verwendet wird. Die Versuchsbedingungen für dieses Gerät wurden nach sorgfältiger Kalibrierung ermittelt, um die Erzeugung von Aerosolen unter Überhitzungsbedingungen zu vermeiden, die ein für Konsumenten unangenehmes Aerosol erzeugen würden. Anhand dieser Versuchsergebnisse zeigen wir in unserer kritischen Analyse, dass alle Studien, die genau dieses Produkt verwendeten, überhitzte und mit Aldehyd beladene Aerosole erzeugten, wobei in ungefähr der Hälfte der Studien auch erhöhte Nikotinkonzentrationen beschrieben wurden. Einige Studien berichteten über das Vorkommen von Kohlenmonoxid, was auf eine fortgeschrittene Pyrolyse des Heizelements hindeutet. Die meisten der untersuchten Studien sind nicht reproduzierbar, da sie keine ausreichenden Informationen über ihre Verfahren zur Aerosolerzeugung liefern. Unsere Ergebnisse werfen Fragen zur Relevanz dieser Literatur für die Bewertung des Risikoprofils von Vaping-Produkten auf. Abschließend geben wir Leitlinien zur Verbesserung der Protokolle für die Methodik der Aerosolerzeugung in Emissions- und Expositionsstudien heraus. [Contrib. Tob. Nicotine Res. 34 (2025) 202–221]

RESUME

Actuellement, les pods et dispositifs jetables de faible puissance dominent largement les préférences des consommateurs de produits de vapotage. Pourtant, malgré leur usage marginal, les dispositifs de troisième génération à haute puissance et faible résistance (sub-ohm) sont encore fréquemment utilisés pour générer des aérosols destinés à l'évaluation de la toxicité des émissions de vapotage. Toutes ces études utilisent ces dispositifs selon le protocole CORESTA 81 ou avec de légères modifications, avec des débits d'air d'environ 1 L/min. Cette configuration expérimentale est préoccupante, puisque nous avons publié plusieurs articles montrant que des débits d'air bien plus élevés (autour de 10 L/min) constituent une condition expérimentale nécessaire pour que ces dispositifs génèrent des aérosols évitant la surchauffe et la production importante de sous-produits toxiques.

Dans un article récent, nous avons reproduit la génération d'aérosol à partir d'un dispositif haute puissance intégré dans un système d'exposition informatisé utilisé pour exposer des modèles in vitro et in vivo. Après une calibration minutieuse, nous avons identifié les conditions expérimentales permettant à ce dispositif d'éviter la génération d'aérosols en régime de surchauffe, qui produirait un aérosol répulsif pour les utilisateurs humains. En appliquant les résultats expérimentaux de cette étude, nous montrons dans cette revue critique que toutes les études utilisant ce même dispositif ont exposé des systèmes biologiques à des aérosols surchauffés et chargés en aldéhydes, et qu'environ la moitié d'entre elles ont également délivré des concentrations excessives de nicotine. Certaines études ont rapporté la présence de monoxyde de carbone, suggérant des signes de pyrolyse avancée de la mèche. La plupart des études examinées sont non reproductibles, car elles ne fournissent pas suffisamment d'informations sur leurs procédures de génération d'aérosol.

Nos résultats soulèvent des questions quant à la pertinence de cette littérature pour évaluer le profil de risque des produits du vapotage. Enfin, nous proposons des recommandations visant à améliorer les protocoles de méthodologie de génération d'aérosols dans les études d'émission et d'exposition. [Contrib. Tob. Nicotine Res. 34 (2025) 202–221]

1. INTRODUCTION

There is a widespread consensus that E-cigarettes (ECs) provide smokers a much safer nicotine delivery than combustible cigarettes, thus motivating part of the global public health community to endorse their adoption by smokers as a popular harm reduction product to substitute conventional tobacco cigarettes (CCs) (1, 2) (see opposing stance to this policy in (3)). While users of the devices ("vapers") are exposed to significantly less harmful and potentially harmful compounds (HPHCs), it is still necessary to assess the risks involved in its usage. This is a complex process involving laboratory testing of EC emissions followed by probing biological and medical effects of the inhaled chemicals through preclinical studies (biomarkers, cytotoxicity, animal models) and clinical studies. In particular, *in vitro* and *in vivo* studies (in spite of their known limitations (4–11)), might provide a valuable laboratory evaluation of toxicity from exposure to EC aerosol emissions contributing to the assessment of the safety profile of ECs.

The computerized InExpose equipment, manufactured by SCIREQ (Scireq®, Montreal, QC, Canada) is a valuable tool for the examination of biological and physiological effects of EC aerosol exposure on cell cultures and rodents (12). The InExpose system is coupled with an ECX-JoyeTech E-Vic Mini accessory that is composed of a third-generation tank device (JoyeTech® E-Vic Mini, Shenzhen, China), with its atomizer replaced by a 70-mL custom made tank, incorporating as well instruments for chemical analysis and biological testing of *in vitro* and *in vivo* systems (see description in (13)). EC aerosol is generated as a controller puffs this box mod that SCIREQ supplies by default, operating with a default choice of KangerTech resistances mainly 0.15 Ω (nickel), 0.5 Ω, 1.5 Ω (Kanthal), under power and temperature control modes. The controller can draw rectangular or sinusoidal puff profiles with a maximal instantaneous peak flow of 1.675 L/min, leading to airflow rates around 1–2 L/min for puff duration around 2–4 s (12).

Considering the publicly available information supplied by SCIREQ (12, 13), a recent article (14) examined in the laboratory the general functioning of the aerosol generation process of an accurately constructed simulation of the InExpose equipment described above. This was accomplished by using the same box mod of a Joyetech E Vic Mini, a similar custom made tank and the set of KangerTech coils recommended for its usage in power and temperature control modes (13). The electric calibration revealed meaningful differences between the nominal coil resistance value specified by the retailer and the laboratory measured value (for example, the 0.15 Ω resistance measured 0.2 Ω). Likewise, meaningful differences were found between values of power, voltage and temperature displayed in the instrument panel of the box mod and their corresponding laboratory measured values.

The tests in (14) were conducted by puffing the JoyeTech E-Vic Mini box mod in consecutive blocks, each with a sequentially increasing fixed value of supplied power. This testing determines the power range of the Optimal Regime of operation, defined by a linear relation between the mass of e-liquid vaporized (MEV in mg) and supplied power. As shown in previous research (14–17), the slope of the linear relation MEV *vs* power (W) increases with increasing airflow and defines an increase of thermodynamical efficiency of EC operation (16). The relation MEV *vs* power (W) becomes non-linear, with a very decreased slope (very low efficiency), when the power supply exceeds the range of the Optimal Regime. This results in an Overheating Regime, with inefficient aerosol generation, also marking the onset of an exponential production of carbonyl byproducts (which remain in minute quantities under the Optimal Regime).

In the present review article we rely on the results of the laboratory tests conducted in (14), (summarized in Section 2), but considering only the E-Vic Mini box mod with the OCC 0.15 Ω nickel coil, since the InExpose with this coil and this box mod has been used by at least 31 of the 41 studies that we selected from an extensive literature search (described in Section 3 and listed in Table 1).

One of the main problems we found in most of the 41 studies using the InExpose is the scarcity of the information provided by the authors on the parameters they used to generate EC aerosol with the InExpose - this problem also occurs in numerous other preclinical studies on ECs. In fact, only 14 of the 41 studies using the InExpose provided sufficient information on their aerosol generation parameters to potentially reproduce their results, other 10 provided partial but sufficient information, while 16 provided very incomplete information or just mentioned the usage of the InExpose. This information vacuum on an important technical point renders these studies unreproducible (a serious quality flaw in experimental research) (18, 19).

We evaluated with full detail the aerosol generation in the 14 reproducible studies, reviewing individually 5 of them that provided information on the chemical composition of the aerosols. For this purpose, we consider the information supplied by the authors evaluated with respect to our laboratory tests conducted in (14) (summarized in Section 2) with the OCC 0.15 Ω nickel coil. Our evaluation clearly proves, with full or nearly full certainty, that at least 14 studies of the 41 selected exposed biological systems to EC aerosols (in power and temperature modes) generated under overheating conditions with high levels of carbonyl yields. We argue that there is a high likelihood that the same conclusion applies to at least 17 of the remaining 27 studies. These outcomes follow (as concluded in (14)) from the authors' generating an aerosol under an unrealistic combination of high supplied power and a low airflow around 1 L/min.

Our section-by-section plan is as follows. Section 2 provides a summary of the calibration and functionality tests on the InExpose generating aerosol by the box mod of the E-Vic Mini with the 0.15 Ω coil. In Section 3, we identify a selection of 41 studies from a literature search based on the criteria described in Section 2. The studies are listed in Table 1. Section 4 provides a detailed review of 5 studies in this selection that provided full information on their aerosol generation and quantified yields of aldehyde, nicotine and other byproducts. In Section 5 we gather and discuss the main results of the review. Section 6 summarizes a series of guidelines on aerosol generation procedures for the operation of the InExpose system. The conclusions of the study are outlined in Section 7.

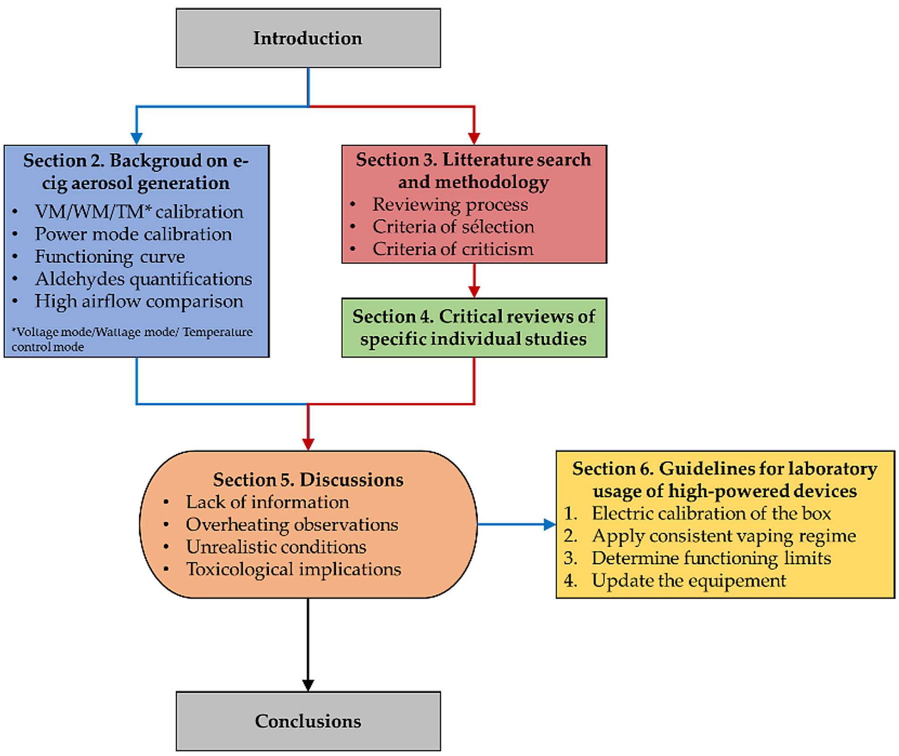

Figure 1. Methodological flow diagram.

The flow diagram in Figure 1 describes the aims and scope of the present review, serving also as a reading guideline. To read first the reviews of individual studies (green box) please follow red arrows. To begin with aerosol generation tests (blue box) follow blue arrows.

2. BACKGROUND ON THE E-CIG AEROSOL GENERATOR DESIGNED BY SCIREQ

EC emissions required for *in vitro* and *in vivo* testing can be generated by an additional module within the InExpose series of laboratory equipment manufacturer by SCIREQ (Scireq®, Montreal, QC, Canada). This equipment, containing the EXC-JoyeTech E-Vic Mini kit, is composed of a JoyeTech E-Vic Mini mod box (the electronic components) and a third-generation atomizer (Subtank® by KangerTech, Shenzhen, China) modified by a customized tank allowing it to be filled by a maximum of 70 mL of e-liquid.

Although these are originally commercial products, the modification of design, such as the horizontal position of the mod box and their inclusion in another commercial product (the additional module), make SCIREQ responsible for providing appropriate instructions for their use. This module can be connected to another module (a peristaltic pump) allowing simulation of inhalation.

Among the various coils marketed by KangerTech for this atomizer (0.15 Ω, 0.5 Ω, 1.2 Ω and 1.5 Ω), the 0.15 Ω nickel coil was the most frequently found in our search, followed by the 1.5 Ω and the 0.5 Ω coils (0.15 Ω: 72%, 0.5 Ω: 10% and 1.5 Ω: 21%, one reference using the three coils) whereas the 1.2 Ω coil was not used. Each coil was examined in a recent paper (14) and their functioning limits experimentally determined. It is also important to remark that coils are manufactured by Chinese companies for commercial use with varying quality and precision. It is also important to point out that there is no current standardized clearomiser, electric resistance and related settings for laboratory purpose, as there are standard references for e-liquids (20, 21). Thus, appropriate calibration is required to evaluate their repeatability for laboratory purposes and to fully understand and identify their functioning limits. Otherwise, setting up the condition fixed for aerosol generation becomes a random exercise.

As shown in (14), the electric calibration and the characterizations of the energy supplied using the E-Vic VTC box with the organic cotton coil (OCC) 0.15 Ω coil leads to the two following graphs (Figure 2) reporting the real power supplied using the power and the temperature control modes. To facilitate the visualization of the graphs, the gray shaded regions illustrate the range of conditions in both power and temperature control modes that were used in the studies we list in Table 1 (Section 3) and review in Section 4.

As an overall observation, it is necessary to stress from Figure 2 that reported conditions in the reviewed literature in both wattage and temperature control modes lead to an actual measured supplied power that tops between 40 W and 46 W. Additionally, the variations of power supplied through a single puff are lower in wattage mode than in temperature control mode. Figure 3 illustrates the difference between the two modes.

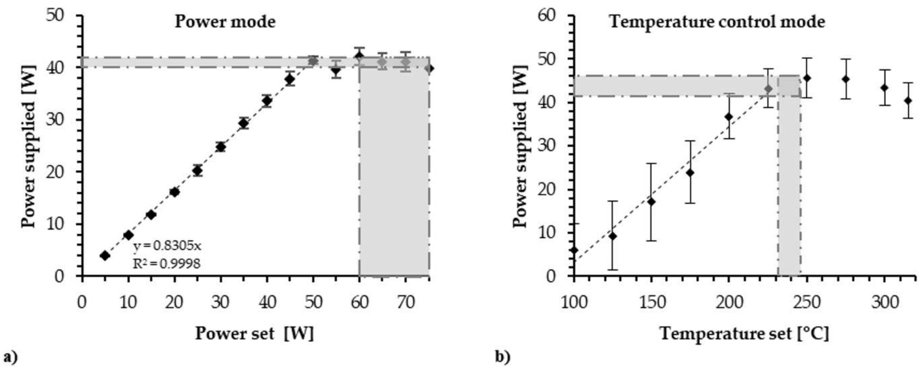

Figure 2. Calibration curve of the E-Vic VTC modes using the OCC 0.15 Ω coil and an airflow rate of 1.1L/min (a) power-controlled mode and b) temperature-controlled mode). Gray boxes illustrate the range of conditions reported in the literature we listed in Table 1 and reviewed in Section 4.

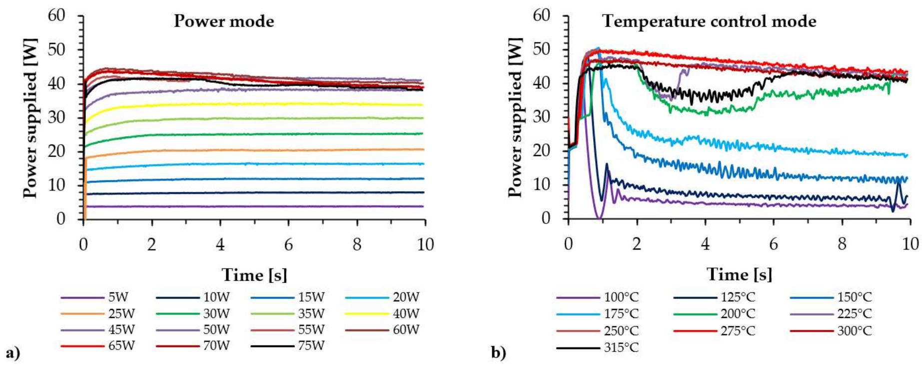

Figure 3. Calibration curve of the E-Vic VTC modes using the OCC 0.15 Ω coil and an airflow rate of 1.1 L/min (a) power-controlled mode and b) temperature-controlled mode).

The main result emerging from Figure 2 is the power profile difference between the two modes: it is almost constant in power-controlled mode, while in temperature-controlled mode it rapidly reaches an initial peak and then decreases to reach a constant power. The signal is also flat in power-controlled mode, while it is fluctuating in temperature-controlled mode. Therefore, the power-controlled mode is more appropriate to assure the experimental repeatability required for laboratory purposes. Figure 2 emphasizes (from the gray shaded regions in Figure 3) the stability of actual supplied power around the range 40–45 W in the conditions used in the reviewed literature, which corresponds (in studies using the temperature-controlled mode) to stable temperatures close to and slightly above 300 °C.

Finally, some articles reported setting up voltage values when generating aerosols with the E-Vic VTC box, which supposedly were voltage values displayed in the device instrument screen, though the authors provide no explanation on how these voltages were determined.

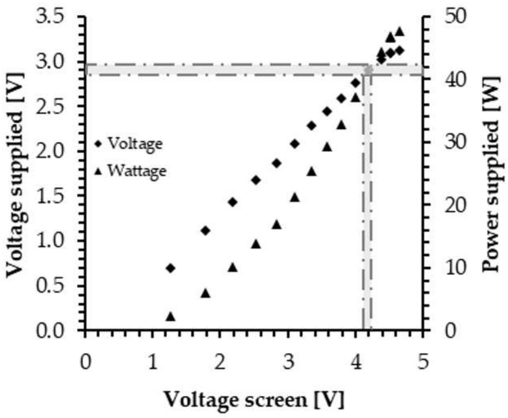

Figure 4. Calibration curve of the E-Vic VTC modes using a 0.20 Ω coil (left y-axis) voltage calibration and (right y-axis) resulting wattage supplied in wattage mode. Gray boxes mark the voltages (4.1 V and 4.2 V) reported by three studies listed in Table 1.

However, we were unable to obtain voltage control from the device screen, so we assessed in the laboratory the power control mode and reported the voltage that should have been displayed on the device screen and compared it with measured voltages and power levels. The results are presented in Figure 3 displaying the simulated screen voltage, together with the supplied voltage and power that were measured.

Under power-controlled mode, we also observed a significant deviation between the voltage displayed in the screen and the measured supplied voltage. For example, with a 0.2 Ω coil, the measured applied voltage is about 32% lower than the one that would appear in the device screen, meaning that 4.2V screen value corresponds to around 2.85 V measured (and corresponds to 41 W measured supplied power).

Through all the conditions reported in our reviewing process, the OCC 0.15 Ω was truly used under close conditions (between 41 W and 46 W supplied).

The consistency between supplied power and airflow rate is a major factor to determine the range of supplied power to achieve an Optimal Regime (14 W–17 W). This efficient aerosol generation occurs when puffing a given device in the supplied power ranges that allow for a linear relation between MEV (mass of e-liquid vaporized) and power, with the width of these power ranges strongly depending on the airflow rate. This is particularly important when puffing a high-powered device, since an insufficient airflow significantly narrows the power range of the Optimal Regime, making it easy in the laboratory to puff the device at power levels above this regime under overheating conditions that do not occur at these power levels under sufficiently high airflows.

Laboratory tests conducted in (14) have determined the Optimal Regime for the E-Vic VTC equipped with the OCC 0.15 Ω coil to extend between 20 W and 63 W under an airflow of 10 L/min (see Figure 5).

As a contrast, under an airflow rate of 1.1 L/min (recommended by the CORESTA puffing regime (21–23) with same device and 0.15 Ω coil led to a significant narrowing of these ranges to 15–30 W.

Supplied power at 30 W (equivalent to 35W set on the screen of the E-Vic VTC box) is the maximal value for the Optimal Regime for the OCC 0.15 Ω coil under the CORESTA puffing regime (21–23) at an airflow rate of 1.1 L/min (Figure 5). At power levels above this value under this airflow overheating conditions initiate, producing the emergence of a gas layer surrounding the wire indicating an ongoing thermal process known as film boiling (17, 24). At this stage, the quantification displayed in Figure 6 reveals an exponential increase of aldehyde yields resulting from glycerol dehydration (14, 17), with the cotton element in the wick possibly becoming pyrolyzed as power keeps increasing.

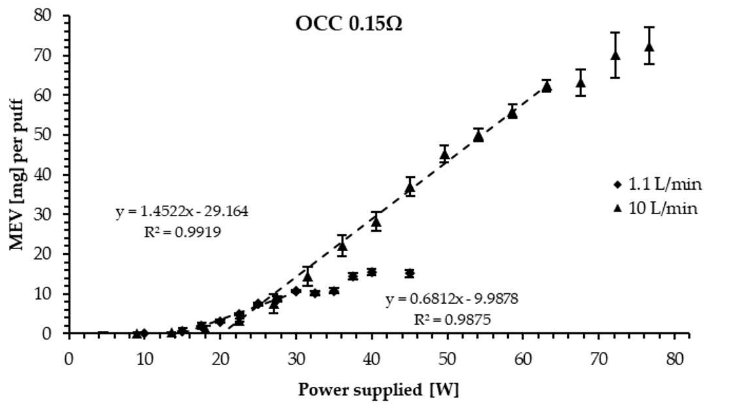

Figure 5. Functioning curves of the OCC 0.15 Ω coil applying 1.1 L/min and 10 L/min.

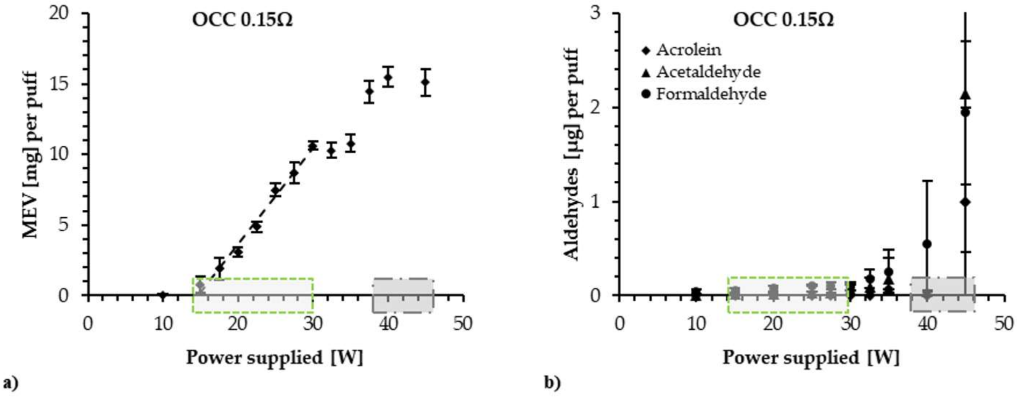

Figure 6 a) Functioning curve of the OCC 0.15 Ω coil and b) the resulting aldehydes released. The green rectangles mark the power range of the Optimal Regime.

This maximal power of 30 W marks an important transition in the assessment of toxicological risks induced by vaping products, a transition that is perceivable by users as a repellent sensation to be avoided (25).

The calibration and functionality test we have presented reveal a major problem: the reviewed studies are using the InExpose with the OCC 0.15 Ω coil at high powers with an inappropriately low CORESTA airflow, which implies an aerosol generation in the Overheating Regime above the power ranges of Optimal Regime. The SCIREQ documentation (12) mentions the controller limited to draw a maximal instantaneous peak flow of 1.675 L/min which is close to CORESTA regime (21–23), an airflow rate that will extremely likely produce overheating conditions even at relatively low powers. This experimental flaw was previously highlighted in two reviews of the literature dealing with the quantification of metals and organic chemicals in the aerosol (18, 19) and is worth highlighting its occurrence also in *in vitro* or *in vivo* articles not necessarily using the SCIREQ. As pointed out in Figure 5, with an appropriate high airflow rate compatible with consumer usage (10 L/min) (26), the reported experimental conditions of the reviewed preclinical studies would have occurred under an Optimal Regime and this criticism would not apply to their aerosol generation procedures. Considering that our calibration tests conducted in (14) and summarized in this section point towards a near certainty that aerosol was generated under overheating conditions in studies using the 0.15 Ω coil, provided by the SCIREQ equipment, we need to identify first all articles citing or referring to "SCIREQ" and then, to identify their reported conditions of aerosol generation. These tasks are described in the following section.

3. LITERATURE SEARCH AND SELECTION METHODOLOGY

3.1 Selection methodology

We had to follow an atypical process for searching the literature, since we aimed at searching for papers whose experiments relied on specific aerosol generation conditions (explained in Section 2), a background material that is only mentioned and/or described in the materials and methods section of each article. Google Scholar appeared to be the most appropriate search engine for this purpose, since it can look for specific words inside the articles. However, filtering the search output must be done by hand because Google Scholar lacks an inbuilt capacity to filter the information. To illustrate our approach, we provide below a flow chart of a step-by-step description of the criteria applied to filter the articles. The search query we used as input (Google Scholar 11/29/2023) was "(electronic cigarette(s) OR electronic-cigarette(s) OR e-cigarette(s) OR e-cigarettes OR vaping OR "Electronic Nicotine Delivery System") AND "SCIREQ". The results were extracted and after suppression of duplicates the list was finally composed of 263 references.

- The first step was to remove abstracts of conferences, reviews, books, thesis or other reports.
- The next step was identifying (by title) and removing them from the list articles not dealing with tobacco products (heated or combusted), since the Google Search does not restrict the titles, and many selected articles failed this search criterion even if the term "electronic cigarette" was mentioned in their introduction
- We removed from the list articles that did not contain keywords linked to vaping.
- At this point in the selection all papers mentioned the SCIREQ equipment, but it was not evident that they used its exposure chamber or the aerosol generator. We had to look manually in each article to find the specific equipment or instrument that was used, removing those articles that did not use the SCIREQ manufactured aerosol generation equipment.
- Once completing the above-mentioned selection, the final step was to select for more specific conditions of aerosol generation, since the SCIREQ equipment has been used with several EC devices that are outside the scope of our review, such as Juul® or Blu® pods.

However, as previously explained, aerosol generation conditions are often ill described, with authors often providing incomplete and/or missing information (18, 19). Since we are searching for experiments conducted with the 0.15 Ω coil at high powers, we extracted articles that contained basic descriptive terms of the device, which at least would allow for a suspicion of our targeted usage, such as "third generation device" or "ECX E-Vic VTC", the name of the device marketed by SCIREQ. At this step, we also kept articles containing the term "device" but providing no further information.

Additionally, the Subtank uses several coils that are available, and we also assumed that not all the testing conditions should be under an Overheating Regime.

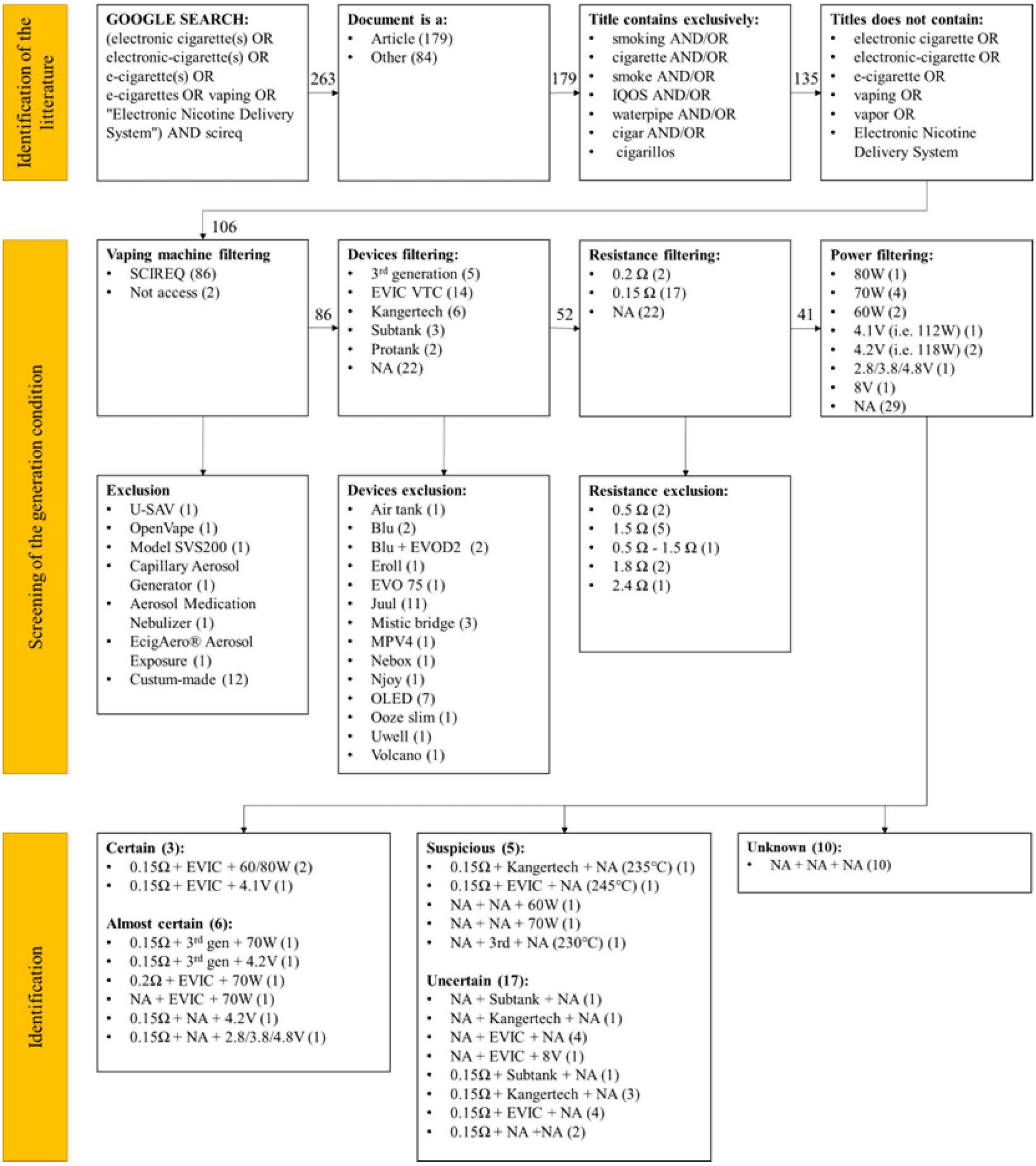

Figure 7. Prisma chart associated with our literature search (see Section 3).

So we applied a filter based on the electric resistance, selecting articles mentioning the 0.15 Ω or 0.2 Ω coils. We suspect that articles reporting a 0.2 Ω coil were really using a 0.15 Ω coil rounded to 0.2 Ω, since SCIREQ mainly provides three coils with resistances: 0.15 Ω, 0.5 Ω and 1.5 Ω (12, 13).
The last step in filtering the literature is linked to the power supplied. In most of the articles, this fundamental information was missing. Figure 7 displays the PRISMA chart associated with the literature search we have described.

3.2 Results of the literature search

The resulting 41 papers that met the search criteria previously described are classified in Table 1. Aerosol generation parameters of the 41 revised studies using the InExpose. Power tested as declared by authors allegedly from display in the instrument screen of the box mod.
Six articles used nicotine concentrations above 30 mg/mL, 14 studies between 20 mg/mL and 30 mg/mL, 9 studies between 10 mg/mL and 20 mg/mL, 12 studies between 3 mg/mL and 10 mg/mL, while 11 studies did not use nicotine.

In 20 articles nicotine concentrations above the Tobacco Product Directive requirement of 20 mg/mL were reported. We have a high level of confidence in our ability to identify aerosol generation conditions in experimental aerosol generation procedures that are potentially associated with overheating, as described in Section 2.

- "Certain" means that the device, coil and power or voltage were fully identified.
- "Almost certain" means that one item of information was not clearly described or was missing, but the available information is sufficient to evaluate aerosol generation.
- "Suspicious" means incomplete minimal information that is insufficient to fully assess aerosol generation conditions. However, based on the significant similarity in experimental design and the materials and methods between these studies and the fact that operating the InExpose requires training, all of which makes it likely that the authors followed the aerosol generation procedures of the "almost certain" and "certain" categories stated above.
- "Uncertain" means that information is so restricted that it prevents the discussion of aerosol generation conditions. In all cases the usage of InExpose or the term "SCIREQ" is mentioned, but there is no information on supplied power, and the device is at best partially identified. As argued in the previous point, it is very likely that complete information might have led to the same operating conditions as studies with more information.
- "Unknown" means a complete lack of information on aerosol generation parameters (either the device, the coil and supplied power, only the SCIREQ equipment is mentioned). In this case, aerosol generation conditions are unknown, which renders the studies completely irreproducible.

In the 41 studies listed in Table 1, we can immediately identify the first top-down 14 studies ("Certain", "Almost Certain" and "Suspicious") that provided at least basic information on their aerosol generation procedures. The lack of information on one parameter (for example power or coil resistance) can be reasonably inferred by the remaining parameters and the constraints from the usage of the InExpose (also from the similarity of the studies). Of the remaining 27 studies, the 16 ("Uncertain") provided even less information, but their mention of terms such as "E-Vic", or "0.15 Ω coil", or "KangerTech" is sufficient to infer that they followed similar aerosol methodology as the first 14 studies, which is consistent with the usage of the InExpose, as explained in the instruction video in (13). The remaining 10 studies (marked "Unknown") lack even minimal information and thus inference on their methodology becomes much more difficult. Consequently, these studies are completely non- reproducible (a serious methodological flaw).

4. CRITICAL REVIEWS OF SPECIFIC INDIVIDUAL STUDIES USING THE INEXPOSE SYSTEM

The protocol described by NOËL *et al.* (13) explains the experimental procedures to operate the InExpose and it has likely been a methodological guideline in the studies using this equipment that we list in Table 1. Of the 41 studies, 9 provided sufficient information on their aerosol generation parameters. Of these 9 studies, only 5 (27, 29, 31, 34, 35) conducted a chemical analysis of the aerosols injected on the exposure chamber. We regard the description of aerosol generation in these 5 studies as representative of (at least) the overwhelming majority of the 41 studies listed in Table 1.

4.1 Study by NOËL et al. (2020)

The authors (35) considered three coil resistances (0.15, 0.5 and 1.5 Ω) and three nominal voltages (2.8, 3.8 and 4. V) in the quantification of nicotine and the main aldehydes (formaldehyde, acetaldehyde, acrolein). They reported a significant increase in aldehyde yields while puffing the 0.15 Ω coil with various voltages. Airflow rate was 1.1 L/min. Aldehyde yields were low for 2.8 V (comparable to those obtained with the 1.5 Ω coil). However, rising the voltage to 3.8 V and then to 4.8 V in the 0.15 Ω coil produced an abrupt increase of these yields, reaching respectively 136, 273, 232 times the yields measured with respect to the 1.5 Ω coil using the Butter-flavour e-liquid.

The large increase of aldehyde yields for the voltages 3.8 V and 4.8 V and the 0.15 Ω coil bears evidence of an aerosol generated under an Overheating Regime. This fact follows from the results of our voltage calibration test displayed in Figures 4 (with Figures 2 and 3 as reference), showing that 3.8 V and 4.8 V correspond to values of measured power of 38 W and 44 W, which are clearly above the upper end (above 30 W) of the Optimal Regime (Figure 4), well into the Overheating Regime for 1.1 L/min airflow. As a contrast, measured supplied power is in the Optimal Regime (below 30 W) for 2.8 V with 0.15 Ω and for all tested voltages with the 1.5 Ω coil.

Another problematic issue with NOËL *et al.* is the excessively high nicotine concentration of 36 mg/mL in e-liquids puffed with the high-powered E-Vic Mini box (see Table 1). We comment on this issue in Section 5.2. The authors justify this as an effort to "mimic nicotine exposure by heavy smokers", but this combination of high nicotine with high power strongly misrepresents consumer usage in which high nicotine levels are used with low powered devices. This fact emerges from observations carried out by SOULE *et al.* (67), who found a strong correlation between high-powered devices (even at 30 W) and low nicotine concentrations (below 6 mg/mL). Besides this point, such high nicotine levels also produce an unrealistic overexposure to nicotine, in *in vitro* and *in vivo* systems. This problem is shared by other studies that we review further ahead (29, 31).

4.2 Study by CAHILL et al. (2022)

The study by CAHILL *et al.* (31) likely used the same cinnamon fireball flavoured e-liquid (reported as 50/50 PG/VG). The authors used the same device and puffing protocols as (35), but supplied only 4.2 V, which corresponds to 40 W–45 W measured power (see Figure 4). Therefore, CAHILL *et al.* also generated aerosol under certain overheating conditions. The authors report yields of 0.021 µg and 0.386 µg per puff, respectively for formaldehyde and acetaldehyde. Although these levels are lower than those of (35), they signal very likely overheating conditions, since formaldehyde mass yield is always higher than that of acetaldehyde under optimal conditions.

Table 1. Aerosol generation parameters of the 41 revised studies using the InExpose. Power tested as declared by authors allegedly from display in the instrument screen of the box mod. Six articles used nicotine concentrations above 30 mg/mL, 14 studies between 20 mg/mL and 30 mg/mL, 9 studies between 10 mg/mL and 20 mg/mL, 12 studies between 3 mg/mL and 10 mg/mL, while 11 studies did not use nicotine. In 20 articles nicotine concentrations above the Tobacco Product Directive requirement of 20 mg/mL were reported.

	Reference	Nicotine (mg/mL)	PG/VG	Device	Coil (Ω)	Power tested (W)	Airflow (L/min)
	(27)	0 and 6	50/50	EVIC	0.15	80	2.00
Certain	(28)	0 and 18	60/30 10% w	EVIC	0.15	112 (4.1 V)	3
	(29)	30 and 36	30/70 and 40/60	E-Vic and pods	0.15	60 (3 V)	1.10
	(30)	50	50/50	3rd	0.15	70	1.05
	(31)	36	50/50	3rd	0.15	118 (4.2 V)	1.10
Almost certain	(32)	20	30/70	EVIC	0.2	70	1.40
	(33)	20	50/50	EVIC	0.2	70	2.00
	(34)	12 and 18	Varied	E-Vic and pods	0.15	118 (4.2V)	1.00
	(35)	36	Varied	E-Vic and pods	0.15; 0.5; 1.5	2.8; 3.8; 4.8 V	1.10
	(36)	NA	30/70	Kangertech	0.15	235 °C	1.27
	(10)	24	55/45	EVIC	0.15	245 °C	NA
Suspicious	(37)	0	50/50	NA	NA	60	1.22
	(38)	24	50/50	NA	NA	70	1.05
	(39)	24	50/50	3rd	NA	230 °C	NA (9 s)
	(40)	24	50/50	Subtank	NA	NA	NA (10 s)
	(41)	0 and 18	NA	KangerTech	NA	NA	1.10
	(42)	50	NA	EVIC	NA	NA	NA
	(43)	50	NA	EVIC	NA	NA	NA
	(44)	0 and 25	100/0	EVIC	0.15	NA	1.27
	(45)	18	50/50	EVIC	NA	NA	1.10
	(46)	0 and 6	70/30	Subtank	0.15	NA	NA
	(47)	0 and 25	NA	Kangertech	0.15	NA	1.27
Uncertain	(48)	NA	100/0	EVIC	0.15	70 (230 °C)	1.00
	(49)	0 and 18	55/35 10% w	EVIC	NA	NA	NA
	(50)	0	50/50	KangerTech	0.15	NA	1.02
	(51)	0, 25, 33	Varied	Kangertech	0.15	NA	1.27
	(52)	NA	50/50	EVIC	0.15	NA	3.06
	(53)	25	100/0	EVIC	0.15	NA	1.4
	(54)	25	50/50	NA	0.15	NA	1.27
	(55)	25	50/50	NA	0.15	NA	1.27
	(56)	12	50/50	EVIC	NA	NA (8V)	NA (3 s)
	(57)	24	50/50	NA	NA	NA	NA
	(58)	6, 14, 18, 24	50/50 80/20	NA	NA	NA	NA
	(59)	NA	30/70	NA	NA	NA	NA
	(60)	0	NA	NA	NA	NA	NA
Unknown	(61)	0	70/30	NA	NA	NA	4.20
	(62)	24	50/50	NA	NA	NA	NA
	(63)	20	50/50	NA	NA	NA	NA
	(64)	4% of liquid	Varied	NA	NA	NA	2.00
	(65)	0 and 4% mass	50/50	NA	NA	NA	1.10
	(66)	20	30/70	NA	NA	NA	1.40

Theoretically, the dehydration reaction leads to the formation of formaldehyde and to vinyl alcohol, which itself rearranges to into acetaldehyde (68, 69). This explains why acetaldehyde levels cannot be higher than formaldehyde levels under optimal conditions (a situation mainly observed in the literature). However, acetaldehyde is also released by the pyrolysis of the cellulose (70) suggesting that the reported extra acetaldehyde was released under overheating conditions, which led to the pyrolysis of the wick.

The study exhibits other minor irregularities: the authors claim that 0.165 mg/puff of e-liquid was vaporized but the "mg" unit they used is almost certainly erroneous, since even a low power device like the Juul vaporizes at least 1 mg of e-liquid per puff (71). The e-liquids had 3.3% nicotine concentration, which is also unrealistic for usage in a high-powered device nicotine concentration (67) as commented before on NOËL *et al.* (35).

4.3 Study by NOËL and GHOSH (2022)

The authors (34) examined the impact of e-liquid composition in testing *in vitro* systems, with the same aerosol generation parameters as CAHILL *et al.*: the 0.15 Ω coil with 4.2 V (40 W measured, see Figures 2, 3 and 4) and 1 L/min airflow.

As a preliminary step of their investigation, the authors generated aerosols from non-commercial e-liquids only composed of PG and VG. The study quantified around 7 µg of formaldehyde (333 times higher than (31)) and above 2 µg of acetaldehyde (5 times higher than (30)). When commenting on these high yields the authors claim that the aerosols "were not produced under 'dry puff' conditions", a statement that without further explanation must be regarded as merely an assumption, probably based on e-liquid not being depleted. However, having used the same experimental set up as (35) and having obtained similar aldehyde yields, clearly points to overheating conditions, which can occur without e- liquid depletion.
The authors then used commercial e-liquids with their most common PG/VG ratio and two nicotine concentrations: a 70/30 strawberry flavoured e-liquid, a 50/50 Catalan cream flavoured e-liquid and a 30/70 vanilla flavoured e-liquid with 12 or 18 mg/mL of nicotine concentration. Of the 6 tested conditions, two (Vanilla 12 and Catalan cream 18) produced significant quantities of formaldehyde (above 3 µg/puff). Two others produced significant quantities of acetaldehyde, higher than formaldehyde (strawberry 12 and strawberry 18) and the two last combinations (Vanilla 18 and Catalan cream with 12 mg/mL) are too low for comparison.
Finally, the authors also tested pod devices. While pods are out of the scope of our present review, the comparison between fourth generation and third generation devices is interesting, as the tested e-liquids have close solvent composition (at least the solvents themselves are the same). Removing the Puff bar OMG 5% nicotine salt which is suspicious regarding the other results, a rough approximation leads to 0.01 µg of formaldehyde released for 2 mg of e-liquid vaporized (MEV) per puff (5ng of formaldehyde per mg of e-liquid vaporized). Without providing the MEV that results from the non-commercial e- liquid, the ratio of yields cannot be investigated. However, reaching 7 µg of formaldehyde by puff suggests that 1400 mg of e-liquid per puff was vaporized (assuming the same ratio and indirectly the same condition). This enormous ratio suggests possible conditions significantly hotter than usual for the tested pods. Since vaporization occurs under the same conditions in high-powered devices and pods under an optimal vaping regime, this suggests a high likelihood that overheated aerosol was also generated by the fourth-generation pods.

4.4 Study by PINKSTON et al. (2023)

The authors (29) also used an airflow rate of 1.1 L/min and the Joyetech E-Vic Mini VTC mod with 0.15 Ω coil with 3 V. No justification was provided for setting this voltage, which would correspond to 60 W from Ohm's law, though our calibration tests (Figure 2, Figure 3 and Figure 4 in Section 2) determine that it corresponds to measured 30 W (the upper limit of the Optimal Regime). The tank was filled with a Crème-Brûlée flavoured e-liquid (30/70 PG/VG and 30 mg/mL of nicotine) or a Menthol flavoured e-liquid (40/60 PG/VG and 36 mg/mL of nicotine). Cells were exposed to both flavoured e-liquids during 1h on one day but an additional experiment was done with Crème Brûlée where the protocol was replicated during three consecutive days.
Both flavoured aerosols were generated and chemically characterized. Nicotine yields were around 0.028 µg/puff with the Menthol flavoured e-liquid (40PG/60VG) and 0.026 µg/puff for the Crème-Brûlée one (30PG/70VG). Formaldehyde, acetaldehyde and acrolein were quantified respectively at around 2.6 µg/puff, 1 µg/puff and 0.02 µg/puff for the menthol e-liquid and very high levels of 13 µg/puff, 4 µg/puff and 9 µg/puff of acrolein for the Crème-Brûlée flavoured e-liquid.
High levels of aldehydes are not expected at 30 W (calibrated power from 3 V), a power level marking the onset of the overheating region (see Figure 5 and (14)). Nicotine levels were also excessive for a sub-ohm device.

4.5 Study by MUTHUMALAGE and RAHMAN (2023)

The authors (27) used the 0.15 Ω coil at 220 °C or 80 W, which also corresponds to overheating conditions characterized by measured values of 45 W and close to 300 °C (Figures 2, 3 and 4). They tested two commercial e-liquids containing menthol or tobacco flavour with 0 or 6 mg/mL of nicotine and one laboratory liquid with 1:1 PG/VG ratio. Interestingly, each flavoured liquid was chemically analyzed in both liquid and vapor phase. The resulting lists were compared for each phase. Of the 98 compounds found in the tobacco liquid, 33 were also available in the 91 ones detected in the menthol liquid. However, in the aerosol, 82 compounds are common and only 2 and 7 are specific to the tobacco and menthol liquids, respectively.
The authors did not examine the comparison between the e-liquid and the aerosol. The tobacco flavour had only one common compound (ethane, 1,1,1-trichloro-) in both analyses, whereas in the menthol case there are four (ethane, 1,1,1-trichloro-; α and β-pinene; acetaldehyde). The high quantified levels of some compounds (ethanol) in the aerosol but not in the liquid suggests problems in the e-liquid analysis, as well as the formation of byproducts during the vaporization, such as acrolein resulting from glycerol degradation. It should be noted that the absence of formaldehyde and acetaldehyde, with the quantification of the propionaldehyde, raises questions on the methodology used to sample or to analyse the aerosol.
Of the 82 molecules found in the aerosol from both liquids, 35 contain chlorine atoms, 4 contain bromine atoms (1,2-dibromoethane, bromofluorobenzene, bromomethane and bromoform) and 1 contains sulfur (carbon disulfide). The list of compounds in both liquids does not show the presence of Br and S, while chlorine (Cl) is only present in one molecule (ethane, 1,1,1-trichloro-). Based on the points argued before, the quantification of chlorine molecules raise concern on the possible availability of sucralose in the e-liquids (a molecule that is difficult to measure using Gas Chromatography Mass Spectrometry (GC-MS) due to its low volatility). This sweetener is documented for its pyrolysis and the releasing of chlorinated byproducts and for enhancing overheating conditions due to its caramelization on the coil. The lack of information on the specific commercial e-liquids that were analyzed prevents a deeper investigation on these inconsistencies.
Finally, the authors used passive sensors to evaluate the air quality in the mouse exposure chamber, measuring carbon monoxide (CO) and Volatile Organic Compounds (VOCs). Carbon monoxide was quantified in the five experiments from 0.5 ppm, using e-liquid containing menthol and nicotine, to 33 ppm only using PG/VG mixture. These average values limit the interpretation of the measurements. Indeed, the concentrations are real-time values, and the curves would have probably shown abrupt change in some of these concen-

trations (assumption made based on the deviations equivalent to the average values in CO). Besides the presence of these quantified values, the presence of CO is a clear indication of cotton pyrolysis and supports the conclusion that the aerosol was generated under overheating conditions.

5. DISCUSSIONS

We have conducted a review of studies focused on the effects of exposure of *in vitro* and *in vivo* systems using the EC aerosol generator additional module of the InExpose system with a 0.15 Ω coil and airflows around 1 L/min. An extensive literature search based on the device information produced 41 studies listed in Table 1 which highlight many experimental issues.

5.1 Lack of information on aerosol generating procedures

While the 41 selected studies provide detailed information on the characteristics of cell lines and rodents and on the methodology of biological and toxicological procedures, most of the studies failed to provide sufficient information on their aerosol generating procedures. As discussed in Sections 2 and 3 and depicted in Table 1, only 9 studies provide sufficient information to analyze their aerosol generation with full or almost full certainty (the ones denoted as "certain" and "almost certain"). Six studies (the "suspicious") provided minimal sufficient information. The remaining 27 articles failed in providing this information at different levels, with 10 of them providing no information besides having used the InExpose.

Since these studies are focused on the effects on biological systems from aerosol exposure, the generation of the aerosols constitutes an important technical issue that must be fully described in their Materials and Methods section. The vacuum of information on aerosol generation procedures renders these studies unreproducible and/or impossible to replicate, a serious methodological flaw in experimental research that certainly hinders the quality of these studies, irrespective of the possible impeccable quality of the biological procedures. Evidently, we cannot claim full certainty in our evaluation of aerosol generation in the 27 studies that provided insufficient information. Hence, we only reviewed (Section 4) in detail 5 studies that provided this information in full, also reporting aldehyde yields and nicotine concentrations. However, given the thematic similarities of all the studies listed in Table 1 and the common usage of the InExpose that requires training and a learning curve to operate, we can claim with high likelihood that the 16 studies that reported the 0.15 Ω coil and usage of SCIREQ equipment followed the methodology of the 14 studies that did provide at least a minimally acceptable degree of this information (which includes the 5 studies reviewed individually). Besides the 10 irreproducible studies with practically no information, in at least 31 of the 41 selected studies we have sufficient direct and indirect evaluation elements to assert that cell lines and rodents were exposed to overheated and aldehyde loaded aerosols, generated by the combination of high power with low airflow and low resistance, a combination that is also at odds with consumer usage of these devices for the 'direct to lung' inhalation.

5.2 Excessive nicotine concentrations

Three studies (29–31) generated aerosol from e-liquids with high nicotine concentrations (30, 36 and 50 mg/mL). The authors justify this as an effort to "mimic nicotine exposure by heavy smokers", but this combination of high nicotine with high power strongly misrepresents consumer usage in which high nicotine levels are used with low powered devices. This fact emerges from observations carried out by SOULE *et al.* (67), who found a strong correlation between high-powered devices (even at 30 W) and low nicotine concentrations below 6 mg/mL. Besides this point, such high nicotine levels also produce an unrealistic overexposure to nicotine in *in vitro* and *in vivo* systems.

5.3 High levels of aldehydes

The high levels of quantified aldehydes found in (29, 34, 35) supports the main criticism of the present literature review: overheating accompanied with an exponential production of aldehydes occurs when puffing a high-powered device like the E-Vic Mini with a 0.15 Ω coil with an airflow of 1.1 L/min (see Figure 6). The authors of (29, 34, 35) reported yields that (at least) signal early stages of the overheating conditions (masses above 1 or 2 μg per puff), with higher levels (7–8 μg per puff) denoting more advanced stages of overheating that can be associated with the onset of highly energetic pyrolysis close to ignition, a highly likely development supported by levels of acetaldehyde comparable or higher than formaldehyde. To highlight overheating conditions, it is useful to compare these high aldehyde yields with the formaldehyde yields from the Juul in (29). The Juul released 5 ng of formaldehyde per mg of e-liquid vaporized, hence the same ratio of mass per puff means that 7 μg of formaldehyde would have to be generated by 1.400 mg of e-liquid by puff (assuming indirectly the same condition), an enormous e-liquid quantity that questions the conditions used in these studies to generate the aerosol. Table 2 summarizes the aldehydes results graphically extracted from each reference.

5.4 Presence of carbon monoxide

The quantification of CO by MUTHUMALAGE *et al.* (27) is an important outcome supporting the main criticism presented in this review. Also, they systematically quantified CO inside the exposure chamber and the maximal level reached 66 times higher than those of the lowest experiment. To assess the toxicological relevance of these outcomes on biological systems, we remark that they constitute a clear signal of advanced overheating through energetic pyrolysis in the onset of oxidizing processes acting on the cotton element of the wick (and its subsequent structures) (74). The presence of CO also means that other cotton byproducts must have been also released, thus polluting the aerosol generated and increasing its toxicity. The literature on cotton pyrolysis shows that during various stages of pyrolysis the cellulose (in the wick) releases highly toxic furans and polycyclic aromatic hydrocarbons (PAHs). In fact, the results of previously published articles that looked at CO in vaping aerosols highlight a high-correlation with excessive supplied power with an insufficient airflow (i.e. conditions above the power ranges of the Optimal Regime) (72, 73, 75).

Table 2. Summary of the aldehydes quantified in the five articles reviewed. Values were graphically determined. Numbers in parentheses denote number of tests per flavor.

Reference	Conditions	Aldehyde [µg] / puff		
		Acrolein	Acet-aldehyde	Form-aldehyde
(35)	But(1) (2.8 V)	0.05	0.05	0.08
	But(1) (3.8 V)	3.5	15	3.5
	But(1) (4.8 V)	9.5	16	8
	Cin(2) (2.8 V)	NA	0.17	0.10
	Cin(2) (3.8 V)	NA	0.33	0.18
	Cin(2) (4.8 V)	NA	0.39	0.02
(31)	Cin(2) (4.2 V)	NA	0.386	0.021
(29)	Men(3) (3 V)	0.02	0.1	2.5
	CB(4) (3 V)	10	4	13
(27)	Tob(5) (80 W)	3.5	3.1	NA
	Men(3) (80 W)	150	150	NA
(34)	30/70 (4.2 V)	0.8	0.7	3
	50/50 (4.2 V)	0.15	3	7
	70/30 (4.2 V)	0.9	2	7
	Str(6.12) (4.2 V)	0.01	0.6	NA
	Str(6.18) (4.2 V)	0.01	0.7	NA
	Van(7.12) (4.2 V)	1.3	0.8	3.5
	Van(7.18) (4.2 V)	0.1	0.1	0.05
	Cat(8.12) (4.2 V)	0.2	0.2	NA
	Cat(8.18) (4.2V)	0.5	2	7

[1] Butter liquid; [2] Cinnamon fireball flavour; [3] Menthol; [4] Crème Brulée; [5] Tobacco flavour; [6] Strawberry flavour; [7] Vanilla flavour; [8]

5.5 Air dilution of the aerosol

The EC aerosol puffed by the box of the E-Vic Mini is transported by a pump at an airflow of 2 L/min to the exposure chamber through a tubular conduct. It is well known from filtration and sampling in aerosol physics that this transport involves, besides air dilution of the generated aerosol, modifications of its particle/gas partition, mostly affecting the particulates (liquid droplets) with larger diameters that either impact or settle on the conduct walls or (depending on environmental variables) might coagulate, condense or evaporate. However, this air dilution and aerosol physics phenomena will not remove nor decrease the toxicity levels of an aerosol generated under overheating conditions. An empiric proof of this is furnished by Muthumalage and Rahman (27), who found high levels of CO and VOCs in their chemical analysis of the aerosol in the exposure chamber (after its passage through the conducts).

5.6 Toxicological implications

Considering the results of our own laboratory tests summarized in Section 2 (published in (14)) and our review of 5 individual studies in Section 4, it is clear that overheating conditions increases the toxicity of the generated aerosol as specified by high levels of aldehyde yields and signals of energetic pyrolysis of the organic wick material (specially CO). Therefore, it is not surprising that deleterious effects in cellular physiology were detected in cells and animal tissues resulting (at least in part) from the molecular presence of these toxic byproducts.

The study by Muthumalage and Rahman (27) that quantified concentrations of CO and VOCs of similar magnitude provides an illustrative example of how inappropriate laboratory conditions that lead to overheating can induce misleading physiological effects. As recounted in their Figure 9, summarizing the altered proteins in lung tissue, these authors report that a pure solvent PGVG mixture leads to the highest number of altered proteins (around 240 proteins). Adding tobacco flavour leads to 156 alterations with 88 in common with those of the PGVG mixture. Adding nicotine leads to 118 alterations with 52 in common with both PGVG only and tobacco flavour. PGVG exposure has the highest overheating condition observable with the maximal CO followed by the tobacco + nicotine and the tobacco experiments.

Applying the same reasoning to menthol liquids leads to 174 alterations and 107 alterations without and with nicotine where 49 and 51 are in common with PGVG alterations. The reductions in common alterations with PGVG compared to tobacco experiments can be due to lower overheating conditions, which is observable by the CO concentrations closer to 0 ppm in menthol experiments whereas it is above 15 ppm in tobacco experiments. Despite it can be a coincidence, the absence of a PGVG testing under normal conditions means that the contribution of abnormal testing and flavouring agent or nicotine adding in the alteration process cannot be investigated.

5.7 Insufficient awareness of consumer patterns

The JoyeTech® E-Vic Mini was released in 2015 as one of the early devices allowing for a temperature-controlled mode. Currently, this device is difficult to find and its usage is marginal. This follows from the evolution of consumer patterns. Between 2015 and 2019 usage of third generation tank devices became very popular, including devices operating at high power (> 30 W) with sub-ohm resistances (< 1 Ω).The demographic study by Jiang *et al.* (76) shows the market evolution of third generation devices in the USA between 2015 and 2019. These devices are subdivided in "tanks" and "mods", with "mods" describing the bulky devices that are used at high power settings. While tanks became very popular, reaching in 2017 over 70% of preferences in all ages, their usage declined to 30–35% in 2019, "mods" have remained low in preference for all ages, decreasing in the period 2015 to 2019 to 6.3% (youth) and 9.5% (young adults). It is very likely that these percentages of "mod" usage are currently even smaller with usage of low powered devices, including cartridge-based pods and disposables, becoming dominant. Preference of low powered devices is even more marked among adolescents and young adults (77, 78).

Given these developments in consumer preferences, it becomes hard to justify the usage of a device like the E-Vic Mini in current preclinical studies that aim to assess the toxicological profile of generic EC aerosols. At best, if such toxicological assessment is conducted under appropriate laboratory conditions, it will be only applicable to a reduced minority of consumers (which can still be useful).At worse, an assessment based on inappropriate laboratory conditions (high power with insufficient airflow) unrepresentative of consumer usage is necessarily misleading and has little utility to all consumers and stakeholders.

Usage in the laboratory of any arbitrary combination of e-liquids, coils and devices does not necessarily qualify as testing under "normal" conditions simply because all these combinations are commercially available. The case in point that we have stressed in the present review is laboratory usage of high-powered devices (for example operating well above 30 W). This testing cannot be justified as normal usage under any arbitrary airflow or nicotine levels simply because devices and e-liquids with these characteristics are available to consumers in the vaping market (by the same token, driving at 160 km/h or faster cannot be regarded as generic "normal driving", simply because such high speeds are accessible in many commercial automobiles). For laboratory testing of high-powered sub-ohm devices to be objective and useful, authors must acknowledge their representative and overwhelming majority usage with low nicotine concentrations and deep inhalation (i.e., large airflow) needed to cool and condense efficiently the air diluted aerosol (up to 50 mg/puff) in large puff volumes (~ 500 mL) produced by such devices (whose design with wide mouthpieces to minimize air resistance is consistent with this usage).

It would be very useful and would enhance the quality of pre-clinical research to pay more attention to consumer behavior. Consumer patterns are not only reported in consumer forums and magazines (79) and in peer reviewed publications sampling social network films (80), but are described by manuals elaborated by manufacturers and they are also reported in published peer reviewed literature (16, 81, 82), including observational studies (67). The different ways different devices are used can also be understood as a result of the trial and error self-training guided by sensorial effects that vary from user to user, but practically all users conduct this self-training when they begin vaping. A naïve user may try inhaling a powerful device as if puffing a Juul and will receive a hot and unpleasant aerosol, since the low airflow appropriate for a Juul is insufficient to evacuate and cool the large amount of vaporized e-liquid. But users learn and adapt.

5.8 Misunderstanding on "dry puffs" and "normalizing" abnormal usage

When reporting high aldehyde yields, NÖEL and GHOSH (34) comment that the aerosols "were not produced under 'dry puff' conditions" presumably because the e-liquid in the InExpose tank was not depleted. Therefore, these authors mistakenly assumed that the aldehyde yields occurred under normal usage conditions without a dry puff. This comment reveals misunderstanding in the assumption that the repellent "dry puff" phenomenon is only tied to a single event marked by the depletion of e-liquid in the atomizer, thus normal usage occurs as long as e-liquid is not depleted. The same misconception was expressed by BEARD *et al.* (83) who also puffed a high-powered device with insufficient airflow to examine cytotoxicity from "dry hits". These authors classified as normal "standard vaping" all usage without e-liquid depletion. These assessments by NÖEL and GHOSH (34) and BEARD *et al.* (83) fail to understand that e-liquid depletion only marks the endpoint of an overheating process characterized by critical thermal phenomena such as film boiling, when the coil temperature goes above the boiling point of the liquid mixture (24). This endpoint is the advanced manifestation of overheating and is unequivocally accompanied by energetic pyrolysis of the organic material of the wick and rapid increase of thermal degradation byproducts.

BEARD *et al.* (83) argued that abnormal vaping conditions should also be studied. We fully agree, abnormal and critical conditions are researched in many issues, for example simulating automobile accidents at high velocities in order to improve safety measures. However, this type of simulations or experiments should not convey (not even hint) the notion that the tests somehow describe "standard"driving conditions. The same applies to cytotoxicity tests on dry puff conditions. High toxicity levels from overheating conditions need to be investigated to improve our knowledge on this phenomenon and to achieve a comprehensive perspective of vaping products. However, studying these conditions is misleading without an explicit acknowledgement that they are abnormal and deviate from normal consumer usage.

Just as automobile drivers recognize an unpleasant risk of excessively high velocities, there is solid peer reviewed published observational evidence that users perceive sensorially the onset of overheating well before e-liquid depletion. The organoleptic experiments by VISSER *et al.* (25) proved that increasing pyrolysis is perceived by users in gradual progressive stages, increasing from 0 (no perception) to 1 (full dry hit), a perception that was correlated to results of laboratory testing (even with filled tank). Another clear signal of overheating of aerosol generated by the InExpose is in the introductory video in NOËL Table (13), showing the initially colorless e-liquid before the experiment became brownish at the end. This brownish color is a clear signal of compounds produced by cotton pyrolysis (84).

5.9 Comparison with effects from cigarette smoke

The overwhelming majority of users of ECs (vapers) are currently still adult smokers replacing cigarettes with the much safer nicotine deliver through the EC aerosol not generated by combustion. Therefore, the comparison with cigarette smoke is still highly desirable for toxicological and preclinicalstudies to best contribute to advance public health goals.

A low priority in comparison with tobacco smoke can be based on the broad scientific consensus already existent that supports harm reduction for adult smokers who switch to vaping. An additional argument supporting this low priority follows from the surge of vaping among teenagers and young adults who have never smoked (or have smoked very infrequently). An assessment of these arguments is beyond the scope of the present review, but even if taking them at face value, given the overwhelming preference of adolescents and young adults for low powered devices (77, 78), there is no justification or public health benefit in assessing EC aerosol toxicity under inappropriate laboratory conditions and/or testing high-powered devices whose usage has become marginal.

While the authors can argue that using outdated devices in preclinical studies is inevitable, since these studies are expensive and require a long time frame, from assuring sufficient grant funding, to preparing the materials and analyzing the outcomes. However, this claim is not consistent with the fact that the consumers shift to low powered devices was already in full swing when most of the studies we reviewed were published: only 9 were published between 2016 and 2020, 6 in 2021, while 20 (50% of the studies) were published in 2022 and 2023 (10 each year). Therefore, this delay of publication really applies only (at most) to 15 studies published before 2022 (and to only one of the 5 studies reviewed individually).

5.10 Limitations

The present review is evidently limited by the various degrees of insufficiency in providing information on aerosol generating procedures in 27 of the 41 selected studies. As argued in Section 5.2, this vacuum of information leads to various degrees of uncertainty in assessing the generation of EC aerosols under overheating conditions in these 27 studies. However, in 17 of these 27 studies there is sufficient indirect evidence to infer these conditions. Another limitation (common to all research on ECs) is the difficulty of considering the full effect of the wide diversity and of individual usage patterns of the devices, further complicated by the rapid changes in vaping technology and of the regulatory landscape, as well as the capacity of users to modify behavior to adapt to all these developments. Nevertheless, in dealing with complexity there is no better option than to resort to the best assessment from general tendencies supported by observation and by solid theoretical and experimental facts.

6. GUIDELINES FOR LABORATORY USAGE OF HIGH-POWERED DEVICES

We believe that the InExpose and the SCIREQ equipment are valuable tools for preclinical assessment of ECs. Hence, we would like this review to contribute to its improvement and better use by researchers, not only those using it or considering its future usage, but researchers in preclinical assessment of ECs in general. Therefore, we provide in this section, a series of guidelines that concretely aim at correcting the problems we have spotted in using the InExpose with high-powered vaping devices.

- The first recommendation for improving the InExpose is to perform preliminary calibration (or to recommend users to do it on their own) of the E-Vic Mini. This calibration is necessary and useful, since aerosol is bound to be generated by the box mod of this commercial device equipped with low-cost commercial coils, all of which lack the required manufacturing quality for laboratory purpose.
- The next recommendation concerns the airflow rate. The same calibration tests conducted with the E-Vic Mini box for the airflow rate of 1.1 L/min were also conducted in (14) with an airflow rate of 10 L/min. For this airflow screen and measured values are well calibrated for much wider ranges of power up to 63 W and temperature up to 300 °C (these values are consistent with the functional limits displayed in Figure 5). Comparing the calibration tests in the two airflow rates (1.1 L/min and 10 L/min) clearly highlights an important problematic issue in experiments using the InExpose: the E-Vic Mini is much more efficient, and its screen values are much more reliable when it is puffed at 10 L/min. This increased efficiency and reliability is consistent with the design of this device for 'Direct to Lung' vaping (low air resistance and large puff volumes).
- Therefore, we recommend SCIREQ to instruct users of the InExpose to avoid generating aerosols with the E-Vic Mini at high power levels (marked in the screen) with the low airflow limited by the maximal instantaneous peak flow of 1.675 L/min, which leads to airflow rates around 1–2 L/min for puff duration around 2–4 s. In case there is no other option but to puff the E-Vic Mini with this reduced airflow, users should be instructed to avoid coils with low resistance and/or to puff the device with sub-ohm coils at low powers below screen values of 35 W (below 30 W measured) that keep the device operating within the Optimal Regime and with diminished aldehyde yields (see Figure 5 and Figure 6).
- To generate aerosols with the E-Vic Mini or any other sub-ohm device with low resistance at high power settings SCIREQ should modify the pump controller to allow for airflow rates of up to 10 L/min and inform the users of the equipment to puff the devices at this airflow. Otherwise, the generated aerosol will be in the Overheating Regime. Modifying the controller to allow for much higher airflow rates would make the experiments with the InExpose and E-Vic Mini (or any other sub-ohm device) consistent with consumer usage of such device for the "Direct to Lung" puffing style. It would also be able to generate an aerosol without overheating and with minute aldehyde and toxin production.
- However, the E-Vic Mini is an outdated mod device released in 2015, so if SCIREQ continues the usage of sub-ohm devices it might as well replace this device with a more updated one. However, the main question to ponder in the end is why considering high-powered sub-ohm devices preclinical studies, when their usage is not representative of consumer preferences that have currently shifted overwhelmingly to low powered devices and disposables.

7. CONCLUSION

We have conducted a literature review focused on the aerosol generation procedures in 41 studies that used the InExpose, a modular part of a computerized equipment manufactured by SCIREQ (Scireq®, Montreal, QC, Canada), to examine the effects in biological systems (cell lines and rodents) exposed to EC aerosol. The InExpose has the capacity to generate EC aerosol from any vaping device but uses as default configuration the box mod of a third-generation device (JoyeTech® E-Vic Mini) equipped with a variety of coils and puffed at airflows limited by a maximal instantaneous peak flow of 1.675 L/min (1–2 L/min with 2–4 s puffs). The 41 reviewed articles listed in Table 1 were selected in Section 3 from an extensive literature search focused on usage of the InExpose to generate EC aerosol with the E-Vic Mini equipped with a 0.15 Ω coil.

To evaluate aerosol generation procedures, we consulted the publicly available information supplied by SCIREQ (12, 13) and conducted electric calibration of the E-Vic Mini and its parts, as well as functionality tests that replicate as best as possible the functioning of the InExpose (see (14) and a summary in Section 2). For the airflow rate of 1.1 L/min consistent with the InExpose allowed airflows, our functionality test showed an Optimal Regime of efficient aerosol production in the range 15–30 W, with overheating conditions and exponential aldehyde production for power levels above 30 W (Figure 5 and Figure 6). The calibration tests (Section 2) showed that above 40–45 W threshold, significant differences arise between values of power, voltage and temperature displayed in the instrument screen of the E-Vic

Mini with respect to values measured in the laboratory. We then compared the aerosol generation parameters reported (from the instrument screen) in the 14 studies that provided (at least) a minimal level of information (the "certain", "almost certain" and "suspicious" in Table 1). The 14 studies with sufficient information reported instrument screen values of 70–80 W, 3–4.8 V and temperatures of 200–250 °C, which once referred to the laboratory measurements in the calibration tests (Figures 2, 3 and 4), and the functional curves (Figure 5 and Figure 6) make it clear that these values correspond to aerosols generated under overheating conditions.

Of the 14 studies that provided minimally acceptable information on their aerosol generation procedures, we selected for an individual review (Section 4) 5 studies (27, 29, 31, 34, 35) that provided a full description of aerosol generation and quantified aldehydes, nicotine and other byproducts. Of the remaining 27, 10 studies merely reported usage of the InExpose or mentioned "SCIREQ" (these are the "unknown" in Table 1). Since aerosol generation is very relevant to assess studies of exposure to EC aerosols, this information vacuum on such a key technical point renders these 27 studies as basically non-reproducible or impossible to replicate. This is a serious methodological flaw in studies conducting experimental research, which hinders their quality and relevance, even if the implementation of the biological procedures was impeccable. This is also a serious flaw of a peer reviewing process in the journals that published this research with reviewers and editors not aware of this important technical issue.

Evidently, we cannot claim full certainty on the evaluation of aerosol generating procedures of the 27 studies that failed to provide sufficient information. However, there is a high likelihood that the criticism of the 14 studies that provided information also applies to them. All 27 studies that lack information mention "SCIREQ" or "InExpose" and 16 of them mention or hint minimal details, such as usage of a third-generation device or the 0.15 Ω coil. Also, the usage of the InExpose is not a trivial matter, it is not a low-cost equipment, and it requires training and a learning curve to operate it. Therefore, it is extremely likely that authors had to resort to available information to operate the equipment, either following the methods of previous studies using it, requesting technical advice from SCIREQ or learning from the introductory video by NÖEL *et al*. (13). All these options should have led, at least in most cases, to the aerosol generation configuration that we have reviewed and criticized.

The problematic puffing of 1–2 L/min a sub-ohm high-powered device, like the E-Vic Mini with insufficient airflow, with 0.15 Ω coil reveals that authors of the reviewed studies have been oblivious and unaware of the overwhelming consumer usage of sub-ohm devices for Direct to Lung vaping that involves a deep inhalation of large aerosol volumes. This consumer usage is not only stressed in consumer magazines but also recommended by manufacturers and in peer reviewed observational studies (see references in Section 5.8). The usage of these devices with high airflows is supported by their design and by physical arguments: high-powered devices have wide mouthpieces (low air resistance) to facilitate the deep inhalation (large airflow) necessary to achieve a sufficient forced convection to condense and cool the large amount of vaporized e-liquid produced by high-powered operation (16, 81, 82). In the individual reviews of the 5 studies in Section 4 we also found other problematic issues that contradict consumer usage, such as using the E-Vic Mini with e-liquids containing high nicotine concentrations (above 20 mg/mL and up to 50 mg/mL).

However, such concentrations delivered through the large puff volumes of sub-ohm devices would involve such an excessive yield of inhaled nicotine (the equivalent of a full cigarette in one puff) that would be intolerable even to heavy smokers (more so for 25-g mice). In fact, consumers only use these high levels with nicotine salts in low powered devices (refillable, cartridge-based or disposables) (67).

We also found the misconception that identifies the dry puff phenomenon as a single event marked by e-liquid depletion, thus claiming that "normal" vaping conditions occur as long as the e-liquid is not depleted. This is mistaken, the dry puff is the end point of an Overheating Regime that initiates when e-liquid is not depleted and is characterized by a critical thermal process: film boiling (17, 24). However, users recognize sensorially the development of this process before the e-liquid depletes (25).

While research under abnormal, critical or exceptional conditions like a dry puff is legitimate and necessary to achieve a full knowledge of vaping, this does not justify the systematic usage of high-power devices puffed with low airflow rate in toxicological studies (not only the ones we reviewed here), with most authors failing to stress the abnormality of this experimental set up. It is unacceptable to justify testing under these conditions without stressing their abnormality simply because users have commercial access to devices and e-liquids that allow them. It is worrying that this failure to acknowledge abnormality might normalize overheating conditions as representative usage in toxicology studies, with a possible undesired consequence of producing a doubtful consensus based on unrealistic experimental results that overstate the risks from vaping but will have limited utility to assess its risks under normal consumption patterns (18, 19).

Demographic trends since 2018 show a tendency evolving towards an overwhelming majority consumer usage of low powered devices (starter kits, refillable and cartridge-based pods, disposables), with usage of high-powered sub-ohm "mods" increasingly becoming marginal, used only by dedicated minority niches of vaping hobbyists (more so with the JoyeTech E-Vic Mini, which was released in 2015 and is now outdated and hard to find in vaping retailers). This shift in consumer preferences questions the utility of using sub-ohm devices to generate aerosol in tests and preclinical experiments to assess a generic EC risk profile.

Finally, we regard the InExpose and the SCIREQ equipment as valuable tools to examine the effects of ECs in biological systems, hence we provide also (Section 6) a series of guidelines based on the results of the present review that we believe can contribute to enhance its operational quality and might serve also to all preclinical research on ECs.

AUTHOR CONTRIBUTIONS:

For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, S.S. and R.A.S.; methodology, S.S. and R.A.S.; software, S.S. and R.A.S.; validation, S.S. and R.A.S.; formal analysis, S.S.

and R.A.S.; investigation, S.S. and R.A.S.; resources, S.S.; data curation, S.S. and R.A.S.; writing original draft preparation, S.S. and R.A.S.; writing review and editing, S.S. and R.A.S.; visualization, S.S. and R.A.S.; supervision, S.S. and R.A.S.; project administration, S.S. and R.A.S.; funding acquisition, Y.Y.
All authors have read and agreed to the published version of the manuscript.

FUNDING:

The author(s) declare that no financial support was received for the research and authorship of this article.

INSTITUTIONAL REVIEW BOARD STATEMENT:

Not applicable.

INFORMED CONSENT STATEMENT:

Not applicable.

DATA AVAILABILITY STATEMENT:

No new data were created or analyzed in this study. Data sharing is not applicable to this article.

CONFLICTS OF INTEREST:

Dr. Soulet is employed by Ingésciences, a private company conducting research and quality control on vapor products without receiving any funding from the vapor industry and without promoting or selling these products. Ingésciences has received public funding from the Nouvelle Aquitaine region. Dr. Soulet has no affiliation with advocacy groups and declares this transparently. Dr. Sussman declares no conflict of interest.

REFERENCES

1. Balfour, D.J.K., N.L. Benowitz, S.M. Colby, D.K. Hatsukami, H.A. Lando, S.J. Leischow, C. Lerman, R.J. Mermelstein, R. Niaura, K.A. Perkins, O.F. Pomerleau, N.A. Rigotti, G.E. Swan, K.E. Warner, and R. West: Balancing Consideration of the Risks and Benefits of E-Cigarettes; Am. J. Public Health 111 (2021) 1661–1672. DOI: 10.2105/ajph.2021.306416
2. McNeill, A., E. Simonavičius, L. Brose, E. Taylor, K. East, E. Zuikova, R. Calder, and D. Robson: Nicotine Vaping in England: An Evidence Update Including Health Risks and Perceptions, 2022. A Report Commissioned by the Office for Health Improvement and Disparities; Office for Health Improvement and Disparities, London, UK, September 29, 2022, Available at: https://assets.publishing.service.gov.uk/media/633469fc8fa8f5066d28e1a2/Nicotine-vaping-in-England-2022-report.pdf.
3. Bals, R., J. Boyd, S. Esposito, R. Foronjy, Pieter S. Hiemstra, C.A. Jiménez-Ruiz, P. Katsaounou, A. Lindberg, C. Metz, W. Schober, A. Spira, and F. Blasi: Electronic Cigarettes: A Task Force Report From the European Respiratory Society; Eur. Resp. J. 53 (2019) 1801151. DOI: 10.1183/13993003.01151-2018
4. Seok, J., H.S. Warren, A.G. Cuenca, M.N. Mindrinos, H.V. Baker, W. Xu, D.R. Richards, G.P. McDonald-Smith, H. Gao, L. Hennessy, C.C. Finnerty, C.M. López, S. Honari, E.E. Moore, J.P. Minei, J. Cuschieri, P.E. Bankey, J.L. Johnson, J. Sperry, A.B. Nathens*, et al.*: Genomic Responses in Mouse Models Poorly Mimic Human Inflammatory Diseases; Proc. Natl. Acad. Sci. 110 (2013) 3507–3512. DOI: 10.1073/pnas.1222878110
5. Bracken, M.B.: Why Animal Studies Are Often Poor Predictors of Human Reactions to Exposure; J. R. Soc. Med. 102 (2009) 120–122.
DOI: 10.1258/jrsm.2008.08k033
6. van der Worp, H.B., D.W. Howells, E.S. Sena, M.J. Porritt, S. Rewell, V. O´Collins, and M.R. Macleod: Can Animal Models of Disease Reliably Inform Human Studies?; PLoS Med. 7 (2010) e1000245.
DOI: 10.1371/journal.pmed.1000245
7. Mak, I.W., N. Evaniew, and M. Ghert: Lost in Translation: Animal Models and Clinical Trials in Cancer Treatment; Am. J. Transl. Res. 6 (2014) 114–118.
8. Li Volti, G., R. Polosa, and M. Caruso: Assessment of E-Cigarette Impact on Smokers: The Importance of Experimental Conditions Relevant to Human Consumption; Proc. Natl. Acad. Sci. 115 (2018) E3073-E3074.
DOI: 10.1073/pnas.1801967115
9. Pound, P. and M. Ritskes-Hoitinga: Is It Possible to Overcome Issues of External Validity in Preclinical Animal Research? Why Most Animal Models Are Bound to Fail; J. Transl. Med. 16 (2018) 304.
DOI: 10.1186/s12967-018-1678-1
10. Wetendorf, M., L.T. Randall, M.T. Lemma, S.H. Hurr, J.B. Pawlak, R. Tarran, C.M. Doerschuk, and K.M. Caron: E-Cigarette Exposure Delays Implantation and Causes Reduced Weight Gain in Female Offspring Exposed in Utero; J. Endocr. Soc. 3 (2019) 1907–1916.
DOI: 10.1210/js.2019-00216
11. Smart, D.J. and G. Phillips: Collecting E-Cigarette Aerosols for *in vitro* Applications: A Survey of the Biomedical Literature and Opportunities to Increase the Value of Submerged Cell Culture-Based Assessments; J. Appl. Toxicol. 41 (2021) 161–174.
DOI: 10.1002/jat.4064
12. SCIREQ: E-Cigarette & Vaping; 2023. Available at: https://www.scireq.com/applications/e-cigarette-vaping/ (accessed November 2025)
13. Noël, A., C.M. Verret, A.L. Penn, F. Hasan, S. Lomnicki, J. Morse, A. Robichaud, and A.L. Penn: Generation of Electronic Cigarette Aerosol by a Third-Generation Machine-Vaping Device: Application to Toxicological Studies; J. Vis. Exp. 138 (2018) e58095. DOI: 10.3791/58095
14. Soulet, S., L. Constans, and V. Quinty: Physical and Chemical Characterizations of a Reference E-Cigarette Used in Animal Testing; Sci. Rep. 13 (2023) 16624. DOI: 10.1038/s41598-023-43733-3
15. Soulet, S.E., M. Duquesne, J. Toutain, C. Pairaud, and H.E. Lalo: Influence of Coil Power Ranges on the E-Liquid Consumption in Vaping Devices; Int. J.

Environ. Res. Public Health 15 (2018) 1853.
DOI: 10.3390/ijerph15091853
16. Soulet, S., M. Duquesne, J. Toutain, C. Pairaud, and M. Mercury: Impact of Vaping Regimens on Electronic Cigarette Efficiency; Int. J. Environ. Res. Public Health 16 (2019) 4753. DOI: 10.3390/ijerph16234753
17. Talih, S., R. Salman, E. Karam, M. El-Hourani, R. El-Hage, N. Karaoghlanian, A. El-Hellani, N. Saliba, and A. Shihadeh: Hot Wires and Film Boiling: Another Look at Carbonyl Formation in Electronic Cigarettes; Chem. Res. Toxicol. 33 (2020) 2172–2180.
DOI: 10.1021/acs.chemrestox.0c00196
18. Soulet, S. and R.A. Sussman: Critical Review of the Recent Literature on Organic Byproducts in E-Cigarette Aerosol Emissions; Toxics 10 (2022) 714.
DOI: 10.3390/toxics10120714
19. Soulet, S. and R.A. Sussman: A Critical Review of Recent Literature on Metal Contents in E-Cigarette Aerosol; Toxics 10 (2022) 510.
DOI: 10.3390/toxics10090510
20. European Committee for Standardization (CEN): EN 17375:2020 - Electronic Cigarettes and E-Liquids - Reference E-Liquids; CEN, Bruxelles, Belgium; First Edition, 2020.
21. AFNOR: XP D90-300-3 – Cigarettes Électroniques et E-Liquides - Partie 3: Exigences et Méthodes D'Essais Relatives aux Émissions [Electronic Cigarettes and E-Liquids - Part 3 : Requirements and Test Methods for Emissions]; AFNOR, Saint-Denis, France, 2016. Available at: https://www.boutique.afnor.org/fr-fr/norme/xp-d903003/cigarettes-electroniques-et-eliquides-partie-3-exigences-et-methodes-dessai/fa186224/1595 (accessed November 2025)
22. Cooperation Centre for Scientific Research Relative to Tobacco (CORESTA): CORESTA Recommended Method No. 81 – Routine Analytical Machine for E-Cigarette Aerosol Generation and Collection – Definitions and Standard Conditions; CORESTA, Paris, France, 2015. Available at: https://www.coresta.org/routine-analytical-machine-e-cigarette-aerosol-generation-and-collection-definitions-and-standard (accessed November 2025)
23. International Organization for Standardization (ISO): ISO 20768:2018 - Vapour Products — Routine Analytical Vaping Machine — Definitions and Standard Conditions; ISO, Geneva, Switzerland, 2018. Available at: https://www.iso.org/standard/69019.html (accessed November 2025)
24. Soulet, S. and C. Casile: Thermal Engineering of Electronic Cigarettes; Case Stud. Therm. Eng. 51 (2023) 103512. DOI: 10.1016/j.csite.2023.103512
25. Visser, W.F., E.J.Z. Krüsemann, W.N.M. Klerx, K. Boer, N. Weibolt, and R. Talhout: Improving the Analysis of E-Cigarette Emissions: Detecting Human "Dry Puff" Conditions in a Laboratory as Validated by a Panel of Experienced Vapers; Int. J. Environ. Res. Public Health 18 (2021) 11520. DOI: 10.3390/ijerph182111520
26. Hiler, M., N. Karaoghlanian, S. Talih, S. Maloney, A. Breland, A. Shihadeh, and T. Eissenberg: Effects of Electronic Cigarette Heating Coil Resistance and Liquid Nicotine Concentration on User Nicotine Delivery, Heart Rate, Subjective Effects, Puff Topography, and Liquid Consumption; Exp. Clin. Psychopharmacol. 28 (2020) 527–539. DOI: 10.1037/pha0000337
27. Muthumalage, T. and I. Rahman: Pulmonary Immune Response Regulation, Genotoxicity, and Metabolic Reprogramming by Menthol- and Tobacco-Flavored E-Cigarette Exposures in Mice; Toxicol. Sci. 193 (2023) 146–165. DOI: 10.1093/toxsci/kfad033
28. Roxlau, E.T., O. Pak, S. Hadzic, C.F. Garcia-Castro, M. Gredic, C.Y. Wu, J. Schaffer, B. Selvakumar, A. Pichl, D. Spiegelberg, J. Deutscher, M. Bednorz, K. Schafer, S. Kraut, D. Kosanovic, E.M. Zeidan, B. Kojonazarov, S. Herold, I. Strielkov, A. Guenther, et al.: Nicotine Promotes E-Cigarette Vapour-Induced Lung Inflammation and Structural Alterations; Eur. Respir. J. 61 (2023) 2200951. DOI: 10.1183/13993003.00951-2022
29. Pinkston, R., A.L. Penn, and A. Noel: Increased Oxidative Stress Responses in Murine Macrophages Exposed at the Air-Liquid Interface to Third- and Fourth-Generation Electronic Nicotine Delivery System (ENDS) Aerosols; Toxicol. Rep. 11 (2023) 40–57.
DOI: 10.1016/j.toxrep.2023.06.008
30. Martinez, J.D., M. Easwaran, D. Ramirez, and E. Erickson-DiRenzo: Effects of Electronic (E)-Cigarette Vapor and Cigarette Smoke in Cultured Vocal Fold Fibroblasts; Laryngoscope 133 (2023) 139–146.
DOI: 10.1002/lary.30073
31. Cahill, K.M., M.R. Gartia, S. Sahu, S.R. Bergeron, L.M. Heffernan, D.B. Paulsen, A.L. Penn, and A. Noël: In Utero Exposure to Electronic-Cigarette Aerosols Decreases Lung Fibrillar Collagen Content, Increases Newtonian Resistance and Induces Sex-Specific Molecular Signatures in Neonatal Mice; Toxicol. Res. 38 (2022) 205–224. DOI: 10.1007/s43188-021-00103-3
32. Song, M.-A., J.Y. Kim, M.W. Gorr, R.A. Miller, M. Karpurapu, J. Nguyen, D. Patel, K.J. Archer, N. Pabla, P.G. Shields, L.E. Wold, J.W. Christman, and S. Chung: Sex-Specific Lung Inflammation and Mitochondrial Damage in a Model of Electronic Cigarette Exposure in Asthma; Am. J. Physiol. Lung Cell Mol. Physiol. 325 (2023) L568–L579. DOI: 10.1152/ajplung.00033.2023
33. Aslaner, D.M., O. Alghothani, T.A. Saldana, K.G. Ezell, M.D. Yallourakis, D.M. MacKenzie, R.A. Miller, L.E. Wold, and M.W. Gorr: E-Cigarette Vapor Exposure in Utero Causes Long-Term Pulmonary Effects in Offspring; Am. J. Physiol. Lung Cell Mol. Physiol. 323 (2022) L676–L682. DOI: 10.1152/ajplung.00233.2022
34. Noël, A. and A. Ghosh: Carbonyl Profiles of Electronic Nicotine Delivery System (ENDS) Aerosols Reflect Both the Chemical Composition and the Numbers of E-Liquid Ingredients — Focus on the in Vitro Toxicity of Strawberry and Vanilla Flavors; Int. J. Environ. Res. Public Health 19 (2022) 16774.
DOI: 10.3390/ijerph192416774
35. Noël, A., E. Hossain, Z. Perveen, H. Zaman, and A.L. Penn: Sub-Ohm Vaping Increases the Levels of Carbonyls, is Cytotoxic, and Alters Gene Expression in Human Bronchial Epithelial Cells Exposed at the Air-Liquid Interface; Respir. Res. 21 (2020) 305.
DOI: 10.1186/s12931-020-01571-1
36. Jarrell, Z.R., M.R. Smith, X. He, M. Orr, D.P. Jones, and Y.-M. Go: Firsthand and Secondhand Exposure Levels of Maltol-Flavored Electronic Nicotine Delivery System Vapors Disrupt Amino Acid Metabolism; Toxicol. Sci. 182 (2021) 70–81. DOI: 10.1093/toxsci/kfab051
37. Goto, S., R.M.H. Grange, R. Pinciroli, I.A. Rosales, R.

Li, S.L. Boerboom, K.F. Ostrom, E. Marutani, H.V. Wanderley, A. Bagchi, R.B. Colvin, L. Berra, O. Minaeva, L.E. Goldstein, R. Malhotra, W.M. Zapol, F. Ichinose, and B. Yu: Electronic Cigarette Vaping with Aged Coils Causes Acute Lung Injury in Mice; Arch. Toxicol. 96 (2022) 3363–3371.
DOI: 10.1007/s00204-022-03388-x

38. Eden, M.J., Y.M. Farra, J. Matz, C. Bellini, and J.M. Oakes: Pharmacological and Physiological Response in Apoe-/- Mice Exposed to Cigarette Smoke or E-Cigarette Aerosols; Inhal. Toxicol. 34 (2022) 260–274.
DOI: 10.1080/08958378.2022.2086948
39. Mulorz, J., J.M. Spin, P. Mulorz, M.U. Wagenhäuser, A. Deng, K. Mattern, Y.H. Rhee, K. Toyama, M. Adam, H. Schelzig, L. Maegdefessel, and P.S. Tsao: E-Cigarette Exposure Augments Murine Abdominal Aortic Aneurysm Development: Role of Chil1; Cardiovasc. Res. 119 (2023) 867–878. DOI: 10.1093/cvr/cvac173
40. Shi, H.L., X.M. Fan, A. Horton, S.T. Haller, D.J. Kennedy, I.T. Schiefer, L. Dworkin, C.J. Cooper, and J. Tian: The Effect of Electronic-Cigarette Vaping on Cardiac Function and Angiogenesis in Mice; Sci. Rep. 9 (2019) 4085. DOI: 10.1038/s41598-019-40847-5
41. Naidu, V., A.A. Zeki, and P. Sharma: Sex Differences in the Induction of Angiotensin Converting Enzyme 2 (ACE-2) in Mouse Lungs after E-Cigarette Vapor Exposure and Its Relevance to COVID-19; J. Invest. Med. 69 (2021) 954–961. DOI: 10.1136/jim-2020-001768
42. Han, H., M. Meister, G. Peng, Y. Yuan, J. Qiao, J.J. Yang, Z.R. Liu, and X. Ji: Inhalation of Nicotine-Containing Electronic Cigarette Vapor Exacerbates the Features of COPD by Inducing Ferroptosis in βENac-Overexpressing Mice; Front. Immunol. 15 (2024) 1429946. DOI: 10.3389/fimmu.2024.1429946
43. Han, H., G. Peng, M. Meister, H. Yao, J.J. Yang, M.-H. Zou, Z.-R. Liu, and X. Ji: Electronic Cigarette Exposure Enhances Lung Inflammatory and Fibrotic Responses in COPD Mice; Front. Pharmacol. 12 (2021) 726586.
DOI: 10.3389/fphar.2021.726586
44. Wang, Q., I.K. Sundar, D. Li, J.H. Lucas, T. Muthumalage, S.R. McDonough, and I. Rahman: E-Cigarette-Induced Pulmonary Inflammation and Dysregulated Repair Are Mediated by nAChR 7 Receptor: Role of nAChR α7 in SARS-CoV-2 Covid-19 ACE2 Receptor Regulation; Respir. Res. 21 (2020) 154.
DOI: 10.1186/s12931-020-01396-y
45. Noël, A., S. Yilmaz, T. Farrow, M. Schexnayder, O. Eickelberg, and T. Jelesijevic: Sex-Specific Alterations of the Lung Transcriptome at Birth in Mouse Offspring Prenatally Exposed to Vanilla-Flavored E-Cigarette Aerosols and Enhanced Susceptibility to Asthma; Int. J. Environ. Res. Public Health 20 (2023) 3710.
DOI: 10.3390/ijerph20043710
46. Sharma, A., J. Lee, A.G. Fonseca, A. Moshensky, T. Kothari, I.M. Sayed, S.R. Ibeawuchi, R.F. Pranadinata, J. Ear, D. Sahoo, L.E. Crotty-Alexander, P. Ghosh, and S. Das: E-Cigarettes Compromise the Gut Barrier and Trigger Inflammation; iScience 24 (2021) 102035.
DOI: 10.1016/j.isci.2021.102035
47. Wang, J., T. Zhang, C.J. Johnston, S.Y. Kim, M.J. Gaffrey, D. Chalupa, G. Feng, W.J. Qian, M.D. McGraw, and C. Ansong: Protein Thiol Oxidation in the Rat Lung Following E-Cigarette Exposure; Redox Biol. 37 (2020) 101758. DOI: 10.1016/j.redox.2020.101758
48. Wang, Q., N.A. Khan, T. Muthumalage, G.R. Lawyer, S.R. McDonough, T.-D. Chuang, M. Gong, I.K. Sundar, V.K. Rehan, and I. Rahman: Dysregulated Repair and Inflammatory Responses by E-Cigarette-Derived Inhaled Nicotine and Humectant Propylene Glycol in a Sex-Dependent Manner in Mouse Lung; FASEB BioAdv. 1 (2019) 609–623. DOI: 10.1096/fba.2019-00048
49. Wang, F., S. Hadzic, E.T. Roxlau, B. Fuehler, A. Janise-Libawski, T. Wimmer, B. Lei, S.-W. Li, N. Weissmann, and K. Stieger: Retinal Tissue Develops an Inflammatory Reaction to Tobacco Smoke and Electronic Cigarette Vapor in Mice; J. Mol. Med. 99 (2021) 1459–1469. DOI: 10.1007/s00109-021-02108-9
50. Lamb, T., T. Muthumalage, J. Meehan-Atrash, and I. Rahman: Nose-Only Exposure to Cherry- and Tobacco-Flavored E-Cigarettes Induced Lung Inflammation in Mice in a Sex-Dependent Manner; Toxics 10 (2022) 471.
DOI: 10.3390/toxics10080471
51. Day, N.J., J. Wang, C.J. Johnston, S.Y. Kim, H.M. Olson, E.L. House, I.K. Attah, G.C. Clair, W.J. Qian, and M.D. McGraw: Rat Bronchoalveolar Lavage Proteome Changes Following E-Cigarette Aerosol Exposures; Am. J. Physiol. Lung Cell. Mol. Physiol. 324 (2023) L571–l583. DOI: 10.1152/ajplung.00016.2023
52. Lamb, T. and I. Rahman: Pro-Inflammatory Effects of Aerosols from E-Cigarette-Derived Flavoring Chemicals on Murine Macrophages; Toxicol. Rep. 10 (2023) 431–435. DOI: 10.1016/j.toxrep.2023.04.003
53. Khan, N.A., S. Yogeswaran, Q. Wang, T. Muthumalage, I.K. Sundar, and I. Rahman: Waterpipe Smoke and E-Cigarette Vapor Differentially Affect Circadian Molecular Clock Gene Expression in Mouse Lungs; PLoS ONE 14 (2019) e0211645.
DOI: 10.1371/journal.pone.0211645
54. Hinds, D.M., H.J. Nick, T.M. Vallin, L.A. Bloomquist, S. Christeson, P.E. Bratcher, E.H. Cooper, J.T. Brinton, A. Bosco-Lauth, and C.W. White: Acute Vaping in a Golden Syrian Hamster Causes Inflammatory Response Transcriptomic Changes; Am. J. Physiol. Lung Cell. Mol. Physiol. 323 (2022) L525–L535.
DOI: 10.1152/ajplung.00162.2022
55. Hinds, D.M., H.J. Nick, T.M. Vallin, L.A. Bloomquist, S. Christeson, P.E. Bratcher, E.H. Cooper, J.T. Brinton, A. Bosco-Lauth, and C.W. White: Acute Vaping of a Golden Syrian Hamster Is Feasible and Leads to Nicotine-Dependent Respiratory Tract Inflammation; bioRxiv (2022) 2022.2005.2020.492852.
DOI: 10.1101/2022.05.20.492852
56. Meister, M.L. and R.G. Feresin: Blackberry Consumption Protects against E-Cigarette-Induced Vascular Oxidative Stress in Mice; Food Funct. 14 (2023) 10709-10730.
DOI: 10.1039/D3FO02217J
57. Huynh, D., J. Huang, L.T.T. Le, D. Liu, C. Liu, K. Pham, and H. Wang: Electronic Cigarettes Promotes the Lung Colonization of Human Breast Cancer in Nod-Scid-Gamma Mice; Int. J. Clin. Exp. Pathol. 13 (2020) 2075–2081.
58. Hwang, J.H., M. Lyes, K. Sladewski, S. Enany, E. McEachern, D.P. Mathew, S. Das, A. Moshensky, S. Bapat, D.T. Pride, W.M. Ongkeko, and L.E. Crotty Alexander: Electronic Cigarette Inhalation Alters Innate Immunity and Airway Cytokines While Increasing the

Virulence of Colonizing Bacteria; J. Mol. Med. 94 (2016) 667–679. DOI: 10.1007/s00109-016-1378-3
59. Lechasseur, A., É. Jubinville, J. Routhier, J.-C. Bérubé, M. Hamel-Auger, M. Talbot, J. Lamothe, S. Aubin, M.-È. Paré, M.-J. Beaulieu, Y. Bossé, C. Duchaine, and M.C. Morissette: Exposure to Electronic Cigarette Vapors Affects Pulmonary and Systemic Expression of Circadian Molecular Clock Genes; Physiol. Rep. 5 (2017) e13440. DOI: 10.14814/phy2.13440
60. Muthumalage, T., M. Prinz, K.O. Ansah, J. Gerloff, I.K. Sundar, and I. Rahman: Inflammatory and Oxidative Responses Induced by Exposure to Commonly Used E-Cigarette Flavoring Chemicals and Flavored E-Liquids without Nicotine; Front. Physiol. 8 (2017) 1130. DOI: 10.3389/fphys.2017.01130
61. Lechasseur, A., C.A. Huppé, M. Talbot, J. Routhier, S. Aubin, M.J. Beaulieu, C. Duchaine, D. Marsolais, and M.C. Morissette: Exposure to Nicotine-Free and Flavor-Free E-Cigarette Vapors Modifies the Pulmonary Response to Tobacco Cigarette Smoke in Female Mice; Am. J. Physiol. Lung Cell. Mol. Physiol. 319 (2020) L717–L727. DOI: 10.1152/ajplung.00037.2020
62. Zeng, Z., W. Chen, A. Moshensky, R. Khan, L. Crotty-Alexander, L.B. Ware, C.M. Aldaz, J.R. Jacobson, S.M. Dudek, V. Natarajan, R.F. Machado, and S. Singla: Cigarette Smoke and Nicotine-Containing E-Cigarette Vapor Downregulate Lung Wwox Expression Which is Associated with Increased Severity of Murine Ards; bioRxiv (2020) DOI: 10.1101/2020.07.13.200832
63. Neczypor, E.W., T.A. Saldaña, M.J. Mears, D.M. Aslaner, Y.H. Escobar, M.W. Gorr, and L.E. Wold: E-Cigarette Aerosol Reduces Left Ventricular Function in Adolescent Mice; Circulation 145 (2022) 868–870. DOI: 10.1161/circulationaha.121.057613
64. Xu, Z., Y. Tian, A.-X. Li, J. Tang, X.-Y. Jing, C. Deng, Z. Mo, J. Wang, J. Lai, X. Liu, X. Guo, T. Li, S. Li, L. Wang, Z. Lu, Z. Chen, and X.-a. Liu: Menthol Flavor in E-Cigarette Vapor Modulates Social Behavior Correlated with Central and Peripheral Changes of Immuno-metabolic Signalings; Front. Mol. Neurosci. 5 (2022) 800406. DOI: 10.3389/fnmol.2022.800406
65. Han, Y., Z. Xu, Z. Mo, H. Huang, Z. Wu, X. Jiang, Y. Tian, L. Wang, P. Wei, Z. Chen, and X.-A. Liu: MiceVAPORDot: A Novel Automated Approach for High-Throughput Behavioral Characterization During E-Cigarette Exposure in Mice; bioRxiv (2023) 2023.2010.2027.564133. DOI: 10.1101/2023.10.27.564133
66. Song, M.A., L.E. Wold, D.M. Aslaner, K.J. Archer, D. Patel, H. Jeon, D. Chung, P.G. Shields, J.W. Christman, and S. Chung: Long-Term Impact of Daily E-Cigarette Exposure on the Lungs of Asthmatic Mice; Nicotine Tob. Res. 25 (2023) 1904–1908. DOI: 10.1093/ntr/ntad100
67. Soule, E.K., S. Mayne, W. Snipes, E.K. Do, T. Theall, C. Höchsmann, S. Talih, C.K. Martin, T. Eissenberg, and B.F. Fuemmeler: Electronic Cigarette Nicotine Flux, Nicotine Yield, and Particulate Matter Emissions: Impact of Device and Liquid Heterogeneity; Nicotine Tob. Res. 25 (2022) 412–420. DOI: 10.1093/ntr/ntac196
68. Nimlos, M.R., S.J. Blanksby, X. Qian, M.E. Himmel, and D.K. Johnson: Mechanisms of Glycerol Dehydration; J. Phys. Chem. A 110 (2006) 6145–6156. DOI: 10.1021/jp060597q
69. Laino, T., C. Tuma, P. Moor, E. Martin, S. Stolz, and A. Curioni: Mechanisms of Propylene Glycol and Triacetin Pyrolysis; J. Phys. Chem. A 116 (2012) 4602–4609. DOI: 10.1021/jp300997d
70. Wang, Q., H. Song, S. Pan, N. Dong, X. Wang, and S. Sun: Initial Pyrolysis Mechanism and Product Formation of Cellulose: An Experimental and Density Functional Theory(DFT) Study; Sci. Rep. 10 (2020) 3626. DOI: 10.1038/s41598-020-60095-2
71. Talih, S., R. Salman, R. El-Hage, E. Karam, N. Karaoghlanian, A. El-Hellani, N. Saliba, and A. Shihadeh: Characteristics and Toxicant Emissions of JUUL Electronic Cigarettes; Tob. Control 28 (2019) 678–680. DOI: 10.1136/tobaccocontrol-2018-054616
72. Casebolt, R., S.J. Cook, A. Islas, A. Brown, K. Castle, and D.D. Dutcher: Carbon Monoxide Concentration in Mainstream E-Cigarette Emissions Measured with Diode Laser Spectroscopy; Tob. Control 29 (2020) 652–655. DOI: 10.1136/tobaccocontrol-2019-055078
73. El-Hellani, A., S. Al-Moussawi, R. El-Hage, S. Talih, R. Salman, A. Shihadeh, and N.A. Saliba: Carbon Monoxide and Small Hydrocarbon Emissions from Sub-Ohm Electronic Cigarettes; Chem. Res. Toxicol. 32 (2019) 312–317. DOI: 10.1021/acs.chemrestox.8b00324
74. Collard, F.-X. and J. Blin: A Review on Pyrolysis of Biomass Constituents: Mechanisms and Composition of the Products Obtained from the Conversion of Cellulose, Hemicelluloses and Lignin; Renew. Sustain. Energy Rev. 38 (2014) 594–608. DOI: 10.1016/j.rser.2014.06.013
75. Son, Y., C. Bhattarai, V. Samburova, and A. Khlystov: Carbonyls and Carbon Monoxide Emissions from Electronic Cigarettes Affected by Device Type and Use Patterns; Int. J. Environ. Res. Public Health 17 (2020) 2767. DOI: 10.3390/ijerph17082767
76. Jiang, N., S. Xu, L. Li, C.M. Cleland, and R.S. Niaura: Use of Electronic Nicotine Delivery System (ENDS) Devices among U.S. Youth and Adults: Findings from the Population Assessment of Tobacco and Health Study Waves 1–5; Addict. Behav. 139 (2023) 107588. DOI: 10.1016/j.addbeh.2022.107588
77. Selya, A., S. Shiffman, and M.J. Hannon: Youth Patterns of Use of Electronic Nicotine Delivery Systems (ENDS), Population Assessment of Tobacco and Health (PATH) Waves 4–5.5; Addict. Behav. 145 (2023) 107783. DOI: 10.1016/j.addbeh.2023.107783
78. Tattan-Birch, H., S.E. Jackson, L. Kock, M. Dockrell, and J. Brown: Rapid Growth in Disposable E-Cigarette Vaping Among Young Adults in Great Britain from 2021 to 2022: A Repeat Cross-Sectional Survey; Addiction 118 (2023) 382–386. DOI: https://doi.org/10.1111/add.16044
79. Vaping360: Vaping 101: How to Take a Proper Inhale; 2023. Available at: https://vaping360.com/learn/what-is-vaping-how-to-vape/ (accessed November 2025)
80. McAdam, K., A. Warrington, A. Hughes, D. Adams, J. Margham, C. Vas, P. Davis, S. Costigan, and C. Proctor: Use of Social Media to Establish Vapers Puffing Behaviour: Findings and Implications for Laboratory Evaluation of E-Cigarette Emissions; Regul. Toxicol. Pharmacol. 107 (2019) 104423. DOI: 10.1016/j.yrtph.2019.104423
81. Soulet, S., M. Duquesne, C. Pairaud, and J. Toutain: Highlighting Specific Features to Reduce Chemical and Thermal Risks of Electronic Cigarette Use Through a

Technical Classification of Devices; Appl. Sci. 11 (2021) 5254. DOI: 10.3390/app11115254
82. Floyd, E., S. Greenlee, T. Oni, B. Sadhasivam, and L. Queimado: The Effect of Flow Rate on a Third-Generation Sub-Ohm Tank Electronic Nicotine Delivery System-Comparison of CORESTA Flow Rates to More Realistic Flow Rates; Int. J. Environ. Res. Public Health 18 (2021) 7535. DOI: 10.3390/ijerph18147535
83. Beard, J.M., C. Collom, J.Y. Liu, P. Obiako, R.M. Strongin, J. Zavala, and C.M. Sayes: In vitro Toxicity and Chemical Analysis of E-Cigarette Aerosol Produced Amid Dry Hitting; Toxicology 506 (2024) 153865. DOI: 10.1016/j.tox.2024.153865
84. Zhang, X.-S., G.-X. Yang, H. Jiang, W.-J. Liu, and H.-S. Ding: Mass Production of Chemicals from Biomass-Derived Oil by Directly Atmospheric Distillation Coupled with Co-Pyrolysis; Sci. Rep. 3 (2013) 1120. DOI: 10.1038/srep01120

Corresponding author:

Sébastien Soulet, Ph.D.
Ingésciences
Cestas, Gironde
France
E-Mail: sebastien.soulet@ingesciences.fr