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# Electronic Cigarette use and Blood Pressure endpoints: A Systematic Review

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## Abstract

**Purpose of Review—**E-cigarettes (e-cigs) release toxic chemicals known to increase blood pressure (BP) levels. The effects of e-cigs on BP, however, remain unknown. Studying BP may help characterize potential cardiovascular risks of short- and long-term e-cig use. We summarized published studies on the association of e-cig use with BP endpoints.

**Recent Findings—**Thirteen e-cig trials (12 cross-over designs) and 1 observational study evaluated systolic and diastolic blood pressure (SBP and DBP). All trials included at least one e-cig arm with nicotine, 6 a no-nicotine e-cig arm, and 3 a placebo arm. SBP/DBP increased in most nicotine e-cig arms, in some non-nicotine e-cig arms, and in none of the placebo arms. The observational study followed e-cig users and nonsmokers for 3.5 years with inconsistent findings.

**Summary—**The use of e-cigs with and without nicotine may result in short-term elevations of both SBP and DBP. Prospective studies that investigate the long-term cardiovascular impact of e-cig use are needed.

### Keywords

Blood pressure; Electronic-cigarettes; Hypertension; Nicotine

## Introduction

Hypertension and cigarette smoking are the two leading causes of premature mortality worldwide. In 2017, high systolic blood pressure (SBP) was responsible for 10.4 million deaths, followed by cigarette smoking, responsible for 7.10 million deaths [1, 2]. Early diagnosis and treatment of hyper-tension play a crucial role in preventing clinical cardiovascular events including myocardial infarction and stroke [3••].

Conflict of Interest The authors declare that they have no conflict of interest.

Compliance with Ethical Standards

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

Electronic cigarettes (e-cigs) have been introduced in the market in recent years, promoted in part as a harm reduction strategy for smoking cessation. E-cigs, however, are also being marketed to never smokers and a rapidly increasing number of adolescents and young adults who have never smoked are using e-cigs. In the USA, for instance, e-cigs are the most commonly used tobacco product among youth, with 3.6 million middle and high school students using them in 2020 [4]. It is estimated that around 40% of e-cig users between 18 and 24 years have never smoked cigarettes before [5].

E-cigs are chargeable devices that produce an aerosol from heating an e-liquid with a coil. E-cig aerosols contain aldehydes and other carbonyl derivatives, metals, particulate matter, nicotine, and flavoring compounds [6••]. Chemical components in e-cigs remain unregulated, despite the extension of the FDA regulatory authority to all electronic nicotine delivery systems (ENDS) in 2016 [7]. For the organic and inorganic toxic compounds, there is substantial concern of long-term toxicity derived from the chronic use of these products [8].

Few studies have evaluated the potential effects of e-cigs on hypertension and cardiovascular health, including short-term and long-term effects. To ascertain the evidence and guide future research, in this review, we summarize the available studies on the short-term effects of e-cigs on blood pressure in experimental studies as well as the association between e-cigs and blood pressure endpoints in observational studies. For experimental studies, the comparisons for the short-term effect of e-cig use on blood pressure levels compared to baseline (no use) were reported for tobacco smokers and non-tobacco smokers separately.

## Methods

Research Strategy and Data Abstraction We searched PubMed to find all published studies evaluating the relationship between e-cigarettes and hypertension or blood pressure endpoints using the free text and Medical Subject Headings (MeSH) terms “ Electronic Cigarettes”[MeSH], “Vaping”[MeSH], electronic cigarette*, e cig*, ecig*, vaping, nicotine delivery system, nicotine delivery systems, nicotine inhaler, nicotine inhalers, NICOTROL, smokeless cigarette, smokeless cigarettes, electronic nicotine, nicotine inhalator, vapor device, vapor devices, vapor device, vapor devices, alternative cigarettes, digital cigarettes or vapor smoking and “Hypertension”[MeSH], systolic, diastolic, blood pressure, hypertension, hypertensive, or hypertens*. The search period was from 2003 (when the first e-cigs started to be distributed) through April 2020 with no language restrictions.

A total of 69 publications were found (Fig. 1). We included experimental and observational studies with data on the association of e-cig use with blood pressure endpoints. We excluded animal and in vitro studies, systematic and bibliographic reviews (including the reference lists of the published studies), commentaries, and studies without data on blood pressure end-points, on e-cigs, or on the associations between both. We also excluded studies that exclusively evaluated e-cigs as a harm reduction strategy compared to traditional cigarettes without a comparison to no e-cig and no traditional cigarette use.

For each study, we abstracted the following data: first author and study year, study population (age, sex, traditional cigarettes smoking status, e-cig use), e-cig intervention or pattern of use, e-cig device and e-liquid characteristics, sample size, blood pressure assessment and/or hypertension definition, measure of association, effect estimate, and adjustment for potential confounders. The study findings are summarized for experimental and observational studies separately. For experimental studies, findings related to traditional tobacco cigarettes were excluded.

## Results

A total of 14 studies published between 2012 and 2020 evaluating the relationship between the use of e-cigs and blood pressure endpoints were identified. All the studies recruited healthy participants with no previous hypertension diagnosis. Hypertension was defined as the consistent elevation of SPB and/or DBP above 140 and 80 mmHg, according to previous guidelines [9]. Thirteen were experimental studies and 1 was an observational study [10•]. Four studies were conducted in the USA [11–14], two studies were conducted in Greece [15, 16], Italy [10•,17], and Poland [18, 19], and one study was conducted in Belgium [20], Germany [21], Sweden [22], and the UK [23].

The sample size ranged from 15 [19, 21] to 76 [15] participants. One study included only women [19], one study included only men [23], and other studies included both men and women. The age range was from 20 to 58 years old.

All the experimental studies were randomized controlled trials; 12 of them had a crossover trial design. Three studies recruited exclusively nonsmokers [11–13]. The remaining 10 studies recruited current cigarette smokers, although 2 of those studies recruited occasional smokers of less than 10 cigarettes per month and the median cumulative pack-years was 0.2 [20, 22].

All the experimental studies included at least one e-cig arm with variable concentrations of nicotine that ranged from 11 mg/mL [15] to 50 mg/mL [12] (Table 1). Six studies included a 0% nicotine e-cig arm, eight included a tobacco cigarette arm, and three included a no intervention or placebo arm. Except for one experimental study [16], all the studies described the e-cig characteristics and e-liquid composition (Table 2).

All experimental studies measured systolic and diastolic blood pressure levels at pre-intervention baseline and up to 4 h after the intervention. The washout period between different intervention arms in the crossover studies ranged from 24 h to 1 week.

Three experimental studies were conducted in non-tobacco smokers (Table 3). In the e-cig with nicotine arm, SBP and DBP increased compared to baseline in all studies. Comparing SBP and DBP changes happening in less than an hour post-intervention vs. pre-intervention, the mean SBP/DBP change was + 5/+ 4 mmHg [12] and + 2/+ 4 mmHg [11]. For the no nicotine e-cig arm, the corresponding changes were + 3/+ 2 mmHg [12] and a nonsignificant decline in Cooke et al. Fogt et al. did not provide the baseline SBP/DBP data but reported a significant increase at 40 min after the intervention with a nicotine e-cig arm and no significant changes in either SBP or DBP with the no nicotine e-cig arm. The study by

Cossio et al. reported that between 1 and 2 h of the intervention, SBP/DBP declined, but they were still higher compared to baseline both in the nicotine and non-nicotine e-cig arms.

Ten experimental studies were conducted in smokers (Table 4). All of them included an e-cig arm with nicotine that experienced elevations of SBP and DBP after the intervention compared to baseline. Comparing the SBP and DBP change from baseline vs. after the intervention, immediately after the intervention, the mean SBP/DBP change was + 12/+10 mmHg [20] and + 9.9/+ 8.6 mmHg [22]. At 10 min, the mean SBP/DBP change was + 8.0/+ 7.4 mmHg [22], + 8.9/+6.2 mmHg [17], + 6.6/+ 3.0 mmHg [15], no change/+1.9 mmHg [18], and − 1/no change [23]. And at 20 min, the mean SBP/DBP change was + 5.8/+ 6.8 mmHg [14]. Vlachopoulos et al. did not provide numerical results but reported a significant increase of SBP in this group vs. placebo at 30 min. Franzen et al. graphically reported an increase of SBP and DBP at 40 min. Antoniewicz et al. reported a non-significant mean change of + 2 mmHg for SBP and a significant mean change of + 4.9 mmHg for DBP 2 h after the intervention. Chaumont et al. also reported an increase of SBP and DBP at 2 h that was significant for DBP.

Three studies conducted in smokers included a no nicotine e-cigarette arm, and all three studies found increases in SBP during the intervention. The findings for DBP were variable. The mean SBP/DBP change immediately after the intervention compared to baseline was + 5.2/+ 4.3 mmHg [22] and + 7/+ 5 mmHg [20]. At 10 min, the mean SBP/DBP change was + 2.0/+ 2.5 mmHg [22]. Antoniewicz et al. reported a significant mean change of + 2 mmHg for DBP 2 h after the intervention. Chaumont et al. graphically reported increases of SBP and DBP compared to baseline for 2 h after the intervention. This study included a placebo arm that experienced no significant changes in BP levels. Franzen et al. graphically reported an increase in SBP at 60 min vs baseline that was not statistically significant, and a significant decrease in DBP at 10 and 30 min. All the studies that included a traditional cigarette arm found elevations of SBP and DBP for this group (data not shown). A graphic visualization of the short-term SBP and DBP effects of e-cigarette use with and without nicotine and placebo device in nonsmokers and smokers in the experimental studies is represented in Fig. 2.

We identified one observational study reporting the association between e-cigarette use and blood pressure endpoints [10•]. This study was a prospective 3.5 years follow-up study with a cohort of 9 daily exclusively e-cig users for more than 3 months and a control group of 12 people naïve to any tobacco products. E-cig users were recruited from a pool of vape shops customers and the control participants were selected from hospital staff at the “Centro per la Prevenzione e Cura del Tabagismo” of the University of Catania, Italy, and matched by age and sex with the e-cig users. One initial and 3 follow-up visits were scheduled until the end of follow-up at 3.5 years. Participants were asked to use their own e-cig devices and were instructed not to vape or consume any caffeine at least 60 min before the BP measurement. A discrete increase in SBP and a discrete decrease of DBP at the end of the follow up period were reported for the e-cig group. The mean change for SBP/DBP at 3 years was + 3/− 3 mmHg for the e-cig group and + 1/− 1 mmHg for the control group. None of the changes was significant during the follow-up period. The study description and results are summarized in (Table 5).

## Discussion

Intervention studies on the short-term effects of e-cig use on blood pressure endpoints showed a consistent increase of blood pressure immediately to several hours after exposure to e-cigs containing nicotine, variable changes after exposure to non-nicotine e-cigs, including significant increases of SBP and/or DBP, and no changes when using a placebo device. The study populations were heterogeneous including tobacco smokers, nonsmokers, or e-cig users. The intervention arms, protocols, and e-cig devices, including their nicotine content and other e-liquid and coil components, varied among studies, representing potential limitations for their comparability.

The short-term increases in SBP and DBP for the nicotine e-cig groups are consistent with previous research attributing these increases to the activation of the sympathetic nervous system mediated by nicotine in the e-cig aerosol [14, 24]. Nicotine stimulates the sympathetic nervous system, producing an increase in heart rate, blood pressure, and myocardial contractility [2, 25]. The sympathetic activation is dependent on plasma levels of nicotine. Some studies, especially those conducted with first generation e-cigs, have shown a lower concentration of plasma nicotine comparing e-cig use to smoking tobacco cigarettes. However, new generations of e-cig devices have increased the amount of nicotine in the aerosol and have enhanced nicotine delivery, resulting in similar plasma concentrations compared to traditional cigarettes [26]. The short-term effects of nicotine on the sympathetic nervous system have been widely studied in tobacco cigarettes [27, 28].

Higher concentrations of urinary cotinine were reported in nicotine e-cig users compared to non-nicotine e-cig users. Fogt et al. reported significantly higher urine cotinine levels in between the group of e-cig users with (30–100 ng/ml) vs. without (0–10 ng/ml) ($p < 0.001$) in a study included in our review [13].

The studies that included a non-nicotine e-cig arm also found increases of blood pressure in the short term, although those increases tended to be smaller compared to those found for nicotine e-cigs. These findings suggest the potential existence of blood pressure elevation mechanisms other than nicotine, mediated by other compounds in the e-cig aerosol. Recent human experimental studies with no nicotine e-cigs have documented an increase in endothelial dysfunction parameters in the short term [22, 29]. The studies in our review that included a placebo arm did not report any significant changes in blood pressure, supporting this hypothesis. Franzen et al. reported a decrease in DBP after the use of no nicotine e-cigs. The authors attribute the decrease in blood pressure to the relaxation caused by the use of a device which supports the finger-mouth coupling mechanism. They stated that this mechanism could have influenced all groups, lowering their expected increase in BP [21].

E-cigarettes aerosol contains a variable concentration of carbonyl derivatives, metals, particulate matter, and flavoring [6••]. The concentration of these substances in the aerosol is variable among devices and the mechanisms by which they could potentially impact the cardiovascular and respiratory system in humans when inhaled have yet not been clearly stablished. Nevertheless, the molecular mechanisms of action of these compounds have been studied in laboratory and animal models as well as in epidemiologic studies.

Carbonyl derivatives like formaldehyde, acrolein, or acetaldehyde have been widely documented in exhaled e-cig aerosols in a higher concentration than background breath [30,31•]. These aldehydes are derived from propylene glycol, vegetable glycerin, and some flavorings [32]. Formaldehyde and acrolein cause intracellular oxidative stress and endothelial dysfunction as well as alterations in myocardial contractibility. A recent ex vivo experimental study in cultured endothelial cells has observed that exposure to these aldehydes increases NOX-2 expression which increases the oxidative stress in vascular and brain tissues [33•]. Formaldehyde and acrolein are classified as human carcinogens and long-term effects on coagulation and myocardial remodulation on animal models have been observed after exposure to these toxicants [34, 35].

There are more than 7000 flavorings available in the market; many of them are widely used in e-cigs. These chemicals are safe for ingestion but their inhalation has been associated with respiratory diseases [36]. While their cardiovascular toxicity is not yet well understood, flavoring chemicals have been shown to cause oxidative stress and cytotoxic and proinflammatory effects on endothelial cells in laboratory studies [37]. E-cig aerosol also constitutes a source of variable amount of ultrafine and fine particulate matter [38]. There is a causal association between exposure to particulate matter and hypertension [39]. Ultrafine particulate matter cause direct endothelial dysfunction and increased oxidative stress and prothrombotic activity [38, 40, 41].

Recently published reviews of preclinical and clinical studies assessing cardiovascular risk of e-cigs use cite oxidative stress, inflammation, DNA damage, and abnormal coagulation as potential mechanisms of cardiovascular harm that may be caused by e-cig aerosol compounds. The authors remark the relevance of assessing the role of inhalation of flavoring molecules in cardiovascular health and recommend a cautious use of e-cig until their long term health effects are understood [31•,42••,43].

The endothelium plays a crucial role in vascular homeostasis, regulating the vascular tone, balance between vasodilator and vasoconstrictor factors, smooth muscle proliferation, and inflammatory processes. Vasoactive molecules like nitric oxide (NO), prostacyclins, adenosine, or bradykinin are released by the endothelium [44, 45]. Inflammation, oxidative stress, and ROS production contribute to endothelial dysfunction, which is a precursor of atherosclerosis and cardiovascular risk [45]. Increasing evidence suggests that oxidative stress and endothelial dysfunction also play a role in hypertension development [44, 46]. However, it is still not completely understood whether these processes are causal agents or consequences of hypertension [47, 48].

Besides carbonyl derivatives, flavorings, and particulate matter, the e-liquid and the coil represent sources of exposure to metals [49,50•]. The association between metals and cardiovascular diseases is well known [51–53]. In studies of daily e-cig users, we have estimated that the documented concentrations of metals in the e-cig aerosol is above the recommended guidelines for aerosol samples collected from devices of around half of the participants [50•,54]. The use of e-cigs thus represents an unnecessary source of exposure to metals.

The studies included in our systematic review suggest the short-term effects between e-cig use and elevation of blood pressure endpoints. However, there is a need for prospective studies that assess the long-term consequences on blood pressure elevation and the risk of developing hypertension. There is limited evidence that explain the mechanism of action and long-term outcomes of e-cigarettes use. Moreover, few pro-spective studies are available and additional research is needed to evaluate these long-term effects. In particular, large-scale population studies, which are currently not available, are needed to assess the effects of e-cig use on blood pressure levels outside of the experimental settings.

## Conclusion

This systematic review supports that the use of e-cig with and without nicotine results in short-term elevations of both SBP and DBP. The mechanisms that underlie this relationship are incompletely understood, particularly for e-cigs without nicotine. E-cig aerosol contains several toxic components that increase oxidative stress and endothelial dysfunction in preclinical and laboratory studies. Aldehydes, flavoring molecules, metals, and particulate matter could represent an additional source of oxidative-stress inducing compounds, particularly for non-smokers. While prospective research is needed to evaluate the possible long-term effects of e-cigs on hypertension and cardiovascular risk, the short-term vascular effects support the need to further prevent the initiation of e-cig use, especially in never smokers.

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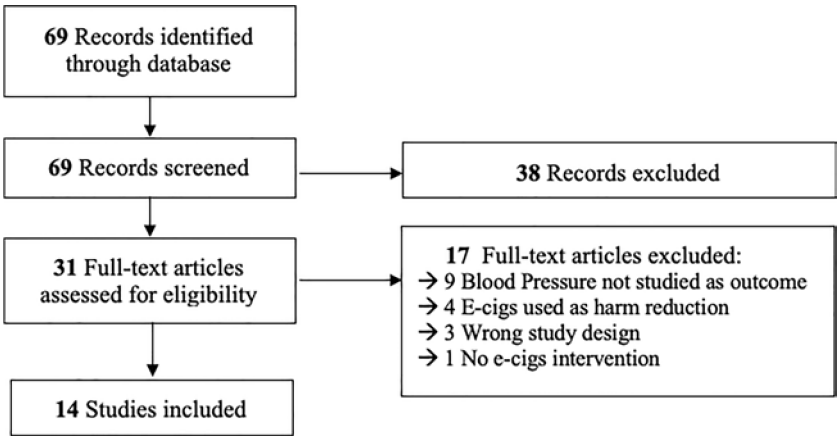


**Fig. 1.**
PRISMA flow chart

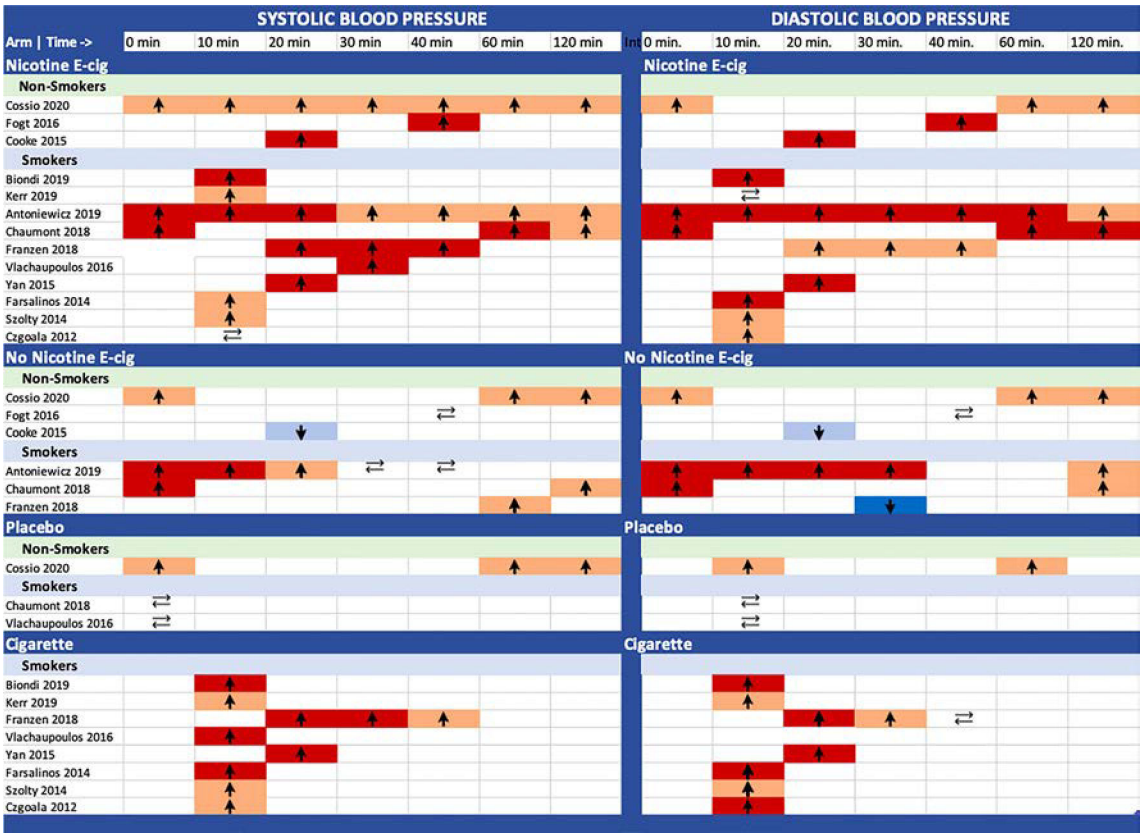


**Fig. 2.**

Summary of the short-term SBP and DBP effects (between 0 and 120 min) of e-cigarette use with and without nicotine and placebo device in nonsmokers and smokers. Arrows indicate if blood pressure increased, decreased or remained the same. Light and dark red reflect nonsignificant and significant increases, light and dark blue reflect nonsignificant and significant decreases, respectively.

**Table 1**

Experimental studies: population age, biological gender, smoking status at baseline, number of participants, and intervention arms

| Author/year | Country | Age, y Mean (SD) | % Men | % cigarette smokers | % naive e-cig users | N | Cross-over study | Intervention arms | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Cigarette | Nicotine e-cig | 0% nicotine e-cig | Placeb |
| Cossio 2020 | United States | 24 (3) | 50% | 0% | 100% | 16 | X | | X | X | X |
| Biondi-Zoccai 2019 | Italy | 35 (13) | 30% | 100% | NR% | 20 | X | X | X | | |
| Kerr 2018 | United Kingdom | 31.6 (10.5) | 100% | 100% | 100% | 20 | X | X | X | | |
| Antoniewicz 2019 | Sweden | 26 (3) | 40% | 100% | NR | 17 | X | | X | X | |
| Chaumont 2018 | Belgium | 23 (0.4) | 72% | 100% | NR | 25 | X | | X | X | X |
| Franzen 2018 | Germany | 22.9 (3.5) | 33% | 100% | 0% | 15 | X | X | X | X | |
| Fogt 2016 | United States | 23.1 (2.5) | 50% | 0% | 100% | 20 | X | | X | X | |
| Vlachaupoulos, 2016 | Greece | 30 (8) | NR | 100% | NR | 24 | X | X | X | | X |
| Cooke 2015 | United States | 23 (1) | 50% | 0% | 100% | 20 | X | | X | X | |
| Yan 2015 | United States | 38.7(11) | 48% | 100% | 0% | 23 | X | X | X | | |
| Szolty 2014 | Poland | 23 (2) | 0% | 100% | 0% | 15 | X | X | | | |
| Farsalinos 2014 | Greece | 35 (5) | 90% | 100% | NR | 76 | | X | | | |
| Czogala 2012 | Poland | 34.9 (15.3) | 50% | 100% | 100% | 42 | X | X | | | |

**Table 2**

E-cigarette device and e-liquid characteristics

| Author, year | e-cig devices | e-liquid | Nicotine content in mg/mL |
|---|---|---|---|
| Cossio, 2020 | Cirrus 3, white cloud cigarette | Menthol flavor clear draw | 50 |
| Biondi-Zoccai, 2019 | Blu Pro, Fontem, Netherlands | e-liquid details not described | 16 |
| Kerr, 2019 | 2nd generation e-cig. 1300 mAh variable voltage rechargeable battery, a tank and an atomizer (SmokeMax; Groove Trading Ltd., Glasgow, UK) | Tobacco flavored (Pillbox38 UK Ltd., Totally Wicked, Blackburn, UK) | 18 |
| Antoniewicz, 2019 | 3rd generation e-cigarette (eVic-VT, Shenzhen Joyetech Co., Ltd., China). Temperature 230 °C, effect 32 W, resistance 0.20 ω). dual-coil nickel atomizer | 49.4% propylene glycol, 44.4% vegetable glycerin, and 5% ethanol without any added flavorings (Valeo laboratories GmbH, Germany) | 19 |
| Chaumont, 2018 | Last-generation high-power vaping device with popular and commercially available parts in USA (Smoke©, Shenzen, China). 60 W. 0.4 Ω dual coils | 50% propylene glycol and 50% glycerin pharmaceutical grade (Fagron©, Waregem, Belgium) | 19 (Nicobrand©, Coleraine, UK) |
| Franzen, 2018 | DIPSE, eGo-T CE4 vaporizer third generation, (SSR Produkt GmbH & Co KG, Oldenburg, Germany). 3.3 V, 1.5 Ω, and 7.26 W | 55% propylene glycol and 35% glycerin, tobacco flavor | 24 |
| Fogt, 2016 | Green Smart Living, Salt Lake City, UT) | e-liquid (details not described?) | 18 |
| Vlachaupoulos, 2016 | NR. | NR. | NR |
| Cooke, 2015 | Green Smart Living (Salt Lake City, UT) and Clean Electronic cigarettes (details not described) | e-liquid (details not described) | 18 |
| Yan, 2015 | Blu e-cigs, sold in retail outlets across the USA in both disposable and re-useable forms. | 3 e-liquid formulations: A and C: 75% vegetable glycerin. B and E: 50% vegetable glycerin 20% propylene glycol. D: 75% vegetable glycerin | A, B, C: 24<br>D: 16 |
| Szoltysek-Boldys, 2014 | e-Go, Clearomizer Crystal 2 with coil, 2.4 Ω, voltage battery 900 mAh, 3.4 V | e-liquid details not described | 24 |
| Farsalinos, 2014 | 2nd generation eGo-T battery (Nobacco Athens, Greece) with an eGo-C atomiser (Alter Ego Athens, Greece). 650-mAh rechargeable lithium battery, 3.5 V | α -propylene glycol or 1,2-propanediol > 60%, linalool (3,7-dimethylocta-1, 6-dien-3-ol) < 5%, tobacco essence (< 5%), and methyl vanillin (4-hydroxy-3-methoxybenzaldehyde) at < 1% | 11 |
| Czogala, 2012 | Mild M2001 (1st generation) | e-liquid details not described | 14 |
| Polosa, 2014 | Use of personal devices. Assorted eGo products. Advanced and standard refillable. Provari, Innokin, Joyetech, eVIC, Avatar Puff | e-liquid details not described | 9–12 ($n$ = 4)<br>16–18($n$ = 5) |

*NR.*, not reported

**Table 3**

Experimental studies in non-smokers, intervention description, groups and results for SBP and DBP

| Author, year | Intervention Description / Washout | Groups | Results for SBP (group mean (SD)) in mmHg | Results for DBP (group mean (SD)) in mmHg |
|---|---|---|---|---|
| Cossio, 2020 | 3 cycles of one product use: 18 e-cig puffs at 20s interval / 48 h | Nico, e-cig (50 mg/mL)<br>No nico. e-cig<br>Placebo | (Baseline/immediately post/1 h/2 h):<br>Nico e-cig:119(10)/124(10)/121(10)/121(9)<br>No nico. e-cig:115(8)/118(10)/120(8)/119(10)<br>Placebo: 117(6)/119(8)/120(7)/120(7) | (Baseline/immediately post/1 h/2 h):<br>Nico. e-cig: 69(4)/73(5)/71(6)/70(5)<br>No nico. e-cig: 66(4)/68(5)/70(5)/68(5)<br>Placebo: 68(3)/68(6)/71(6)/69(5) |
| Fogt, 2016 | 2 cycles of one product use: 20 e-cig puffs in 10 min/L week | Nico. e-cig (18 mg/mL)<br>No nico. e-cig | (Baseline/40mins)<br>Nico. e-cig: NR/112.1(6.8) $p = 0.04$<br>No nico. e-cig: NR/115.8(8) | (Baseline/40mins)<br>Nico. e-cig: NR/76.6(6) p = 0.04<br>No nico. e-eig: NR/73.6(8.3) |
| Cooke, 2015 | 2 cycles of one product use: 20 e-cig puffs in 10 min/L week | Nico. e-cig (18 mg/mL)<br>No nico e-cig | (Change pre-post 20 mins)<br>Nico. e-cig: 2 $p = 0.03$<br>No nico. e-cig: −2 | (Change pre-post 20 mins)<br>Nico. e-cig: 4 $p = 0.001$<br>No nico. e-cig: −2 |

*Nico.*, nicotine

**Table 4**

Experimental studies in smokers, intervention description, groups and results for SBP and DBP

| Author, year | Intervention | Groups | Results for SBP (group mean (SD)) | Results for DBP (group mean (SD)) |
|---|---|---|---|---|
| Biondi-Zoccai, 2019 | 6 cycles of one product use: 9 e-cig puffs/1 week washout | Nico. e-cig (16 mg/mL) | (Baseline/10 min):<br>Nico e-cig: 121.7(6.5)/130.6(6.5) $p < 0.001$ | (Baseline/10 min):<br>Nico e-cig: 72.2(4.4)/78.4(4.8) $p < 0.001$ |
| Kerr, 2019 | 2 cycles of 1 product use: 15 e-cig puffs/24 h washout | Nico. e-cig (18 mg/mL) | (Baseline/10 min):<br>Nico. e-cig: 124(12)/123(11) NS | (Baseline/10 min):<br>Nico. e-cig: 80(11)/80(10) NS |
| Antoniewicz, 2019 | 2 cycles of one product use: 30 e-cig puffs in 30 min/1 week washout | Nico. e-cig (19 mg/mL)<br>No nico. e-cig | (Baseline/0 min/10 min/20 min/30 min/2 h/4 h):<br>Nico. e-cig: 109.4(9.5)/119.3(9.5)$p < 0.05$/117.4(13)$p < 0.05$/113.7(10.3)NS/114.5(12)NS/111.1(10.1)NS/109.1(9.5)NS<br>No nico. e-cig: 109.3(10.3)/114.5(13.2) $p < 0.05$/111.2(16.1)$p < 0.05$/109.3(15.5)NS/108.8(15.4)NS/109(10.2)NS/108.8(11.7)NS | (Baseline/0 min/10 min/20 min/30min/2 h/4 h):<br>Nico. e-cig: 70.3(5.7/78.9(5.9) $p < 0.05$/77.7(6.6)$p < 0.05$/76.5(6.6) $p < 0.05$/74.9(5.8)$p < 0.05$/72.6(5.4)NS<br>No Nico. e-cig: 70.2(5.8)/74.5(6.9)$p < 0.05$/72.7(82)$p < 0.05$/71.1(8.1)$p < 0.05$/72.2(8)$p < 0.05$/72(6.5)NS/69.8 (6.6) NS |
| Chaumont, 2018 | 3 cycles of one product use. 25 puffs at 30 s interval: e-cig or placebo (e-cig turned off under supervision)/washout NR | Nico. e-cig (19 mg/mL)<br>No Nico. e-cig<br>Placebo | (Baseline during exposure/60 min/120 min):<br>Nico. e-cig: 109(1)/121(2)$p < 0.001$/$p < 0.05$/NS<br>No Nico. e-cig 111(2)/118(5)$p < 0.001$/NS/NS<br>Placebo: NS | (Baseline/during exposure/60 min/120 min):<br>Nico. e-cig: 68(1)/78(2)$p < 0.001$/$p < 0.05$/$p < 0.05$<br>No nico. e-cig: 68(1)/73(2)$p < 0.001$/NS/NS<br>Placebo: NS |
| Franzen, 2018 | 3 cycles of one product use. 10 e-cig puffs at 30s interval/48 h washout | Nico. e-cig (24 mg/mL)<br>No Nico. e-cig | (Baseline/ 15 min/30 min/40 min):<br>Nico e-cig Mean (SD)NR/increase p < 0.05/increase p < 0.05/increase p < 005<br>No nico. e-cig no change NS | (Baseline/15 min/30 min/40 min):<br>Nico.e-cig: mean (SD)NR/increase NS/increaseNS/increase NS<br>No nico. e-cig: decreased DBP ($p < 0.05$) at 30 min |
| Vlachaupoulos, 2016 | 4 cycles of one product use. 5 min e-cig. 30 min e-cig. 60 min placebo/washout NR | Nico. e-cig<br>Placebo | e-cig vs sham at 5 and 30 min $p < 0.05$ | NR |
| Yan, 2015 | 2 cycles of one product use. 50 puffs at 30s intervals e-cig or free use for 1 h/washout NR | Nico. e-cig (2.4%) A, B, C (1.6%) D, E | Mean (SD) change (baseline/20 min):<br>A-B-C: 1.1 (11.1) NS-2.8 (11.3) NS-4.0 (10.0) NS<br>D-E: 5.8 (10.0) $p = 0.02$–3.8 (10.7)$p = 0.10$ | Mean (SD) change (baseline/20 min):<br>A-B-C: 6.8 (6.7)$p < 0.001$–6.8 (6.5) $p < 0.001$–3.2 (7.3) $p < 0.05$<br>D-E: 6.8 (3.8)$p < 0.001$–6.8 (7.1) $p < 0.001$ |
| Farsalinos, 2014 | one product free use for 7 min/washout NR | Nico. e-cig (11 mg/mL) | Mean (SD) change (baseline/10 min):<br>Nico. e-cig: 0.7 (4.6) NS | Mean (SD) change (baseline/10 min):<br>Nico. e-cig: 3.0 (3.6) $p < 0.001$ |
| Czogała, 2012 | cycles of one product use ad lib/1 week washout | Nico. e-cig (14 mg/mL) | (Baseline/post-intervention):<br>Nico. e-cig: 122.6(11.4) / 122.5 (12.6) NS | (Baseline/post-intervention):<br>Nico. e-cig: 76.7(9.5)/78.6(10.8) NS |
| Szolty, 2014 | Cycles of one product use. 15 puffs e-cigarette/1 day washout | Nico. e-eig (24 mg/mL) | Both cigarette and e-cig showed a small increase in SBP, DBP but it was not significant | |

*Nico.*, nicotine. *NS.*, nonsignificant. *NR.*, non-reported

*Curr Hypertens Rep*. Author manuscript; available in PMC 2024 February 15.

**Table 5**

Polosa et al., epidemiological study description and results

| Author, year | Study design | Population | Mean Age (SD) | %Men | Nicotine levels | Blood pressure measures | Results for SBP (baseline/1/2/3 years) | Results for DBP (baseline/1/2/3 years) |
|---|---|---|---|---|---|---|---|---|
| Polosa, 2017 | Prospective cohort (3.5 years follow-up) | Daily e-cig users ($n$ = 9) and never smokers (controls) ($n$ = 12) | e-cig users/ controls 26.6 (6.0)/27.8 (5.2) years | 66% | 0% ($n$ = 3)<br>0.9–1.2% ($n$ = 4)<br>1.6–1.8% ($n$ = 2) | 2 SBP/DBP measures in seated position after 5 min of rest at baseline and follow-up visits at 1, 2, and 3 years | e-cig 115(9)/116(5)/ 114(9)/118(10)<br>controls: 117(9)/117(10)/ 116(10)/116(9)<br>$p$ value effect between groups = 0.82 | e-cig: 79(6)/78(4)/73(9)/ 76(8)<br>controls: 74(9)/76(6)/ 75(9)/73(9)<br>$p$ value effect between groups = 0.50 |