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Supplemental Material

Metal/Metalloid Levels in Electronic Cigarette Liquids, Aerosols, and Human Biosamples: A Systematic Review

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*The study by Song et al. (2018) measured chromium but did not report the levels. Other missing metal/metalloids in other studies were not measured. The unit of nicotine was mg/ml. Arsenic and cadmium were measured by Flora et al. (2016) but not showed in the Figure due to the high LOQ. NR: not reported.

Figure S2. Mean metal/metalloid levels in aerosol samples (ng/puff) collected from e-cigarette devices.

*The study by Goniewicz et al. (2014) measured chromium and manganese levels and the study by Palazzolo et al. (2017) measured cadmium, manganese, and lead levels. Other missing metal/metalloids in other studies were not measured. The unit of nicotine was mg/ml. NR: not reported.

Additional File- Excel Document

Search Strategies

Search Strategy A (Developed by DZ, ANA, and MH)

PubMed (N=254):

((("electronic nicotine delivery systems"[MeSH Terms] OR ("electronic"[All Fields] AND "nicotine"[All Fields] AND "delivery"[All Fields] AND "systems"[All Fields]) OR "electronic nicotine delivery systems"[All Fields] OR "e cigarette"[All Fields]) OR ("electronic nicotine delivery systems"[MeSH Terms] OR ("electronic"[All Fields] AND "nicotine"[All Fields] AND "delivery"[All Fields] AND "systems"[All Fields]) OR "electronic nicotine delivery systems"[All Fields] OR "e cigarettes"[All Fields]) OR ("electronic nicotine delivery systems"[MeSH Terms] OR ("electronic"[All Fields] AND "nicotine"[All Fields] AND "delivery"[All Fields] AND "systems"[All Fields]) OR "electronic nicotine delivery systems"[All Fields] OR ("electronic"[All Fields] AND "cigarette"[All Fields]) OR "electronic cigarette"[All Fields]) OR ("electronic nicotine delivery systems"[MeSH Terms] OR ("electronic"[All Fields] AND "nicotine"[All Fields] AND "delivery"[All Fields] AND "systems"[All Fields]) OR "electronic nicotine delivery systems"[All Fields] OR ("electronic"[All Fields] AND "cigarettes"[All Fields]) OR "electronic cigarettes"[All Fields]) OR ("electronic nicotine delivery systems"[MeSH Terms] OR ("electronic"[All Fields] AND "nicotine"[All Fields] AND "delivery"[All Fields] AND "systems"[All Fields]) OR "electronic nicotine delivery systems"[All Fields] OR "e cig"[All Fields]) OR ecig[All Fields] OR ecigs[All Fields] OR (("nicotine"[MeSH Terms] OR "nicotine"[All Fields]) AND ("delivery, obstetric"[MeSH Terms] OR ("delivery"[All Fields] AND "obstetric"[All Fields]) OR "obstetric delivery"[All Fields] OR "delivery"[All Fields])) OR (("nicotine"[MeSH Terms] OR "nicotine"[All Fields]) AND ("equipment and supplies"[MeSH Terms] OR ("equipment"[All Fields] AND "supplies"[All Fields]) OR "equipment and supplies"[All Fields] OR "device"[All Fields])) OR (("electronics"[MeSH Terms] OR "electronics"[All Fields] OR "electronic"[All Fields]) AND ("nicotine"[MeSH Terms] OR "nicotine"[All Fields]) AND ("delivery, obstetric"[MeSH Terms] OR ("delivery"[All Fields] AND "obstetric"[All Fields]) OR "obstetric delivery"[All Fields] OR "delivery"[All Fields])) OR (("electronics"[MeSH Terms] OR "electronics"[All Fields] OR "electronic"[All Fields]) AND ("nicotine"[MeSH Terms] OR "nicotine"[All Fields]) AND ("equipment and supplies"[MeSH Terms] OR ("equipment"[All Fields] AND "supplies"[All Fields]) OR "equipment and supplies"[All Fields] OR "device"[All Fields])) OR ("vaping"[MeSH Terms] OR "vaping"[All Fields] OR "vape"[All Fields] OR "electronic nicotine delivery systems"[MeSH Terms] OR ("electronic"[All Fields] AND "nicotine"[All Fields] AND "delivery"[All Fields] AND "systems"[All Fields]) OR "electronic nicotine delivery systems"[All Fields]) OR ("vaping"[MeSH Terms] OR "vaping"[All Fields] OR e-liquid[All Fields]) AND (("metals"[MeSH Terms] OR "metals"[All Fields]) OR ("metals"[MeSH Terms] OR "metals"[All Fields] OR "metal"[All Fields]) OR metallic[All Fields] OR metalloid[All Fields] OR ("aluminium"[All Fields] OR "aluminum"[MeSH Terms] OR "aluminum"[All Fields]) OR ("arsenic"[MeSH Terms] OR "arsenic"[All Fields]) OR ("cadmium"[MeSH Terms] OR "cadmium"[All Fields]) OR ("chromium"[MeSH Terms] OR "chromium"[All Fields]) OR ("cobalt"[MeSH Terms] OR "cobalt"[All Fields]) OR ("copper"[MeSH Terms] OR "copper"[All Fields]) OR ("iron"[MeSH Terms] OR "iron"[All Fields]) OR ("manganese"[MeSH Terms] OR "manganese"[All Fields]) OR ("nickel"[MeSH Terms] OR "nickel"[All Fields]) OR ("Physician's Bull"[Journal] OR "pb"[All Fields]) OR ("tin"[MeSH Terms] OR "tin"[All Fields]) OR ("zinc"[MeSH Terms] OR "zinc"[All Fields]))

Web of Science (n=264):

TOPIC: (((((((((((((e-cigarette OR e-cigarettes) OR electronic cigarette) OR electronic cigarettes) OR e-cig) OR ecog) OR ecogs) OR nicotine delivery) OR nicotine device) OR electronic nicotine delivery) OR electronic nicotine device) OR vape) OR vaping) OR e-liquid) AND (((((((((((((metals OR metal) OR metallic) OR metalloid) OR aluminum) OR arsenic) OR cadmium) OR chromium) OR cobalt) OR copper) OR iron) OR manganese) OR nickel) OR Pb) OR tin) OR zinc))

Embase (n=210):

(((((('e cigarette'/exp OR 'e cigarette' OR 'e cigarettes'/exp OR 'e cigarettes' OR electronic) AND ('cigarette'/exp OR cigarette) OR electronic) AND cigarettes OR 'e cig' OR ecig OR ecigs OR 'nicotine'/exp OR nicotine) AND ('delivery'/exp OR delivery) OR 'nicotine'/exp OR nicotine) AND ('device'/exp OR device) OR electronic) AND ('nicotine'/exp OR nicotine) AND ('delivery'/exp OR delivery) OR electronic) AND ('nicotine'/exp OR nicotine) AND ('device'/exp OR device) OR vape OR 'vaping'/exp OR vaping OR 'e liquid') AND ('metals'/exp OR metals OR 'metal'/exp OR metal OR metallic OR 'metalloid'/exp OR metalloid OR 'aluminum'/exp OR aluminum OR 'arsenic'/exp OR arsenic OR 'cadmium'/exp OR cadmium OR 'chromium'/exp OR chromium OR 'cobalt'/exp OR cobalt OR 'copper'/exp OR copper OR 'iron'/exp OR iron OR 'manganese'/exp OR manganese OR 'nickel'/exp OR nickel OR pb OR 'tin'/exp OR tin OR 'zinc'/exp OR zinc)

Search Strategy B (developed by AA1, AA2, AR)

Embase (n=171):

('electronic cigarettes':ti,ab,kw OR 'electronic cigarette':ti,ab,kw OR 'e cig':ti,ab,kw OR 'ecigs':ti,ab,kw OR 'vaping':ti,ab,kw OR 'e-cigarette':ti,ab,kw OR 'e-cigarettes':ti,ab,kw OR 'nicotine delivery system':ti,ab,kw OR 'nicotine delivery systems':ti,ab,kw OR 'nicotine inhaler':ti,ab,kw OR 'nicotine inhalers':ti,ab,kw OR 'nicotrol':ti,ab,kw OR 'smokeless cigarette':ti,ab,kw OR 'smokeless cigarettes':ti,ab,kw OR 'electronic nicotine':ti,ab,kw OR 'nicotine inhalator':ti,ab,kw OR 'vapor device':ti,ab,kw OR 'vapor devices':ti,ab,kw OR 'vapour device':ti,ab,kw OR 'vapour devices':ti,ab,kw OR 'alternative cigarette':ti,ab,kw OR 'alternative cigarettes':ti,ab,kw OR 'digital cigarette':ti,ab,kw OR 'digital cigarettes':ti,ab,kw OR 'vapor smoking':ti,ab,kw) AND ('metal':ti,ab,kw OR 'metals':ti,ab,kw OR 'nickel':ti,ab,kw OR 'raney alloy':ti,ab,kw OR 'np 2':ti,ab,kw OR 'nichel italian':ti,ab,kw OR 'ni 4303t':ti,ab,kw OR 'ni 270':ti,ab,kw OR 'ni 0901 s':ti,ab,kw OR '58ni':ti,ab,kw OR '7440-02-0':ti,ab,kw OR 'chromium':ti,ab,kw OR 'chrome':ti,ab,kw OR '7440-47-3':ti,ab,kw OR '52cr':ti,ab,kw OR '14092-98-9':ti,ab,kw OR '16065-83-1':ti,ab,kw OR 'cadmium':ti,ab,kw OR 'kadmium':ti,ab,kw OR 'cd 109':ti,ab,kw OR '7440-43-9':ti,ab,kw OR 'lead':ti,ab,kw OR 'olow':ti,ab,kw OR 'lead s2':ti,ab,kw OR 'lead flake':ti,ab,kw OR 'ks 4':ti,ab,kw OR '7439-92-1':ti,ab,kw OR '208pb':ti,ab,kw OR 'plumbum':ti,ab,kw OR '13966-28-4':ti,ab,kw OR 'aluminum':ti,ab,kw OR 'ao a1':ti,ab,kw OR 'alumina fibre':ti,ab,kw OR 'alaun german':ti,ab,kw OR 'ad1m':ti,ab,kw OR 'ad 1':ti,ab,kw OR 'al derivative':ti,ab,kw OR 'ci 77000':ti,ab,kw OR 'pap 1':ti,ab,kw OR 'metana':ti,ab,kw OR 'jisc 3110':ti,ab,kw OR 'jisc 3108':ti,ab,kw OR 'av00':ti,ab,kw OR 'av000':ti,ab,kw OR 'al 26':ti,ab,kw OR 'al 27':ti,ab,kw OR 'aa1199':ti,ab,kw OR '7429-90-5':ti,ab,kw OR 'zinc':ti,ab,kw OR 'zinc dust':ti,ab,kw OR 'zinc powder':ti,ab,kw OR 'merrillite':ti,ab,kw OR 'granular zinc':ti,ab,kw OR 'blue powder':ti,ab,kw OR '7440-66-6':ti,ab,kw OR '64zn':ti,ab,kw OR 'zincum':ti,ab,kw OR 'zn 64':ti,ab,kw OR '14378-32-6':ti,ab,kw OR 'manganese':ti,ab,kw OR '19768-33-3':ti,ab,kw OR 'mangan':ti,ab,kw OR 'colloidal manganese':ti,ab,kw OR '7439-96-5':ti,ab,kw OR 'mn 54':ti,ab,kw OR 'mn 55':ti,ab,kw

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Pubmed and TOXLINE (149):

(((((("Electronic Cigarettes"[Mesh] OR "Vaping"[Mesh] OR electronic cigarette*[tw] OR e cig*[tw] OR ecig*[tw] OR vaping[tw] OR "nicotine delivery system"[tw] OR "nicotine delivery systems"[tw] OR "nicotine inhaler"[tw] OR "nicotine inhalers"[tw] OR nicotrol[tw] OR "smokeless cigarette"[tw] OR "smokeless cigarettes"[tw] OR "electronic nicotine"[tw] OR "nicotine inhalator"[tw] OR "vapor device"[tw] OR "vapor devices"[tw] OR "vapour device"[tw] OR "vapour devices"[tw] OR "alternative cigarettes"[tw] OR "digital cigarettes"[tw] OR "vapor smoking"[tw]))) AND (((("Metals"[Mesh] OR metal[tw] OR metals[tw]))) OR (((((((((((tin[tw] OR Stannum[tw] OR stannium[tw] OR "14314-35-3"[tw] OR "14314-35-3"[rn] OR "7440-31-5"[tw] OR "7440-31-5"[rn]))) OR ((antimony[tw] OR stibium OR "antymon polish " OR "antimony black" OR "7440-36-0"[rn] OR antimonic OR antimonium OR "Sb 122" OR "14374-79-9"[rn]))) OR ((Copper [tw] OR cda 122 [tw] OR cda 110 [tw] OR cda 102 [tw] OR cda 101 [tw] OR Cu62 [tw] OR Cu 63 [tw] OR Cu 64 [tw] OR Cu 67 [tw] OR arwood copper [tw] OR anac 110 [tw] OR 1721 gold [tw] OR bronze powder [tw] OR ci 77400 [tw] OR raney copper [tw] OR ofhc cu [tw] OR kafar copper [tw] OR gold bronze [tw] OR 7440-50-8 [rn]))) OR ((iron[tw] OR 56Fe OR Fe OR ferro OR ferrum OR "iron polymaltose" OR "suy b 2" OR pzh2m OR loha OR "ferrovac e" OR "eo 5a" OR "armco iron" OR "53858-86-9"[rn] OR "7439-89-6"[rn] OR "14093-02-8"[rn]))) OR ((Manganese [tw] OR 19768-33-3 [tw] OR mangan polish [tw] OR colloidal manganese [tw] OR 7439-96-5 [tw] OR 7439-96-5 [rn] OR Mn 54 [tw] OR Mn 55 [tw]))) OR ((zinc[tw] OR "zinc dust" OR "zinc powder" OR merrillite OR "granular zinc" OR "blue powder" OR "7440-66-6"[rn] OR 64Zn OR zincum OR "Zn 64" OR "14378-32-6"[rn]))) OR ((Aluminum [tw] OR ci 77000 [tw] OR "pap 1" [tw] OR metana [tw] OR "jisc 3110" [tw] OR "jisc 3108" [tw] OR "ao a1" [tw] OR alumina fibre [tw] OR alumina fibre [tw] OR alaun german [tw] OR ad1m [tw] OR ad 1 [tw] OR Al derivative [tw] OR ci 77000 [tw] OR pap 1 [tw] OR jisc 3110 [tw] OR jisc 3108 [tw] OR Al 26 [tw] OR Al 27 [tw] OR 7429-90-5 [RN] OR 7429-90-5 [tw]))) OR ((lead[tw] OR "olow polish " OR "lead s2" OR "lead flake" OR "ks 4" OR "7439-92-1"[rn] OR 208Pb OR plumbum OR "13966-28-4"[rn]))) OR ((cadmium[tw] OR cadmium OR Cd 109[tw] OR 7440-43-9[rn] OR 7440-43-9[tw]))) OR ((chromium[tw] OR chrome OR "7440-47-3"[rn] OR 52Cr OR "14092-98-9"[rn] OR "16065-83-1"[rn]))) OR ((Nickel[tw] OR "raney alloy" OR "np 2" OR "nichel Italian" OR "ni 270" OR "ni 0901 s" OR "58Ni" OR "7440-02-0"[tw] OR "7440-02-0"[rn]))))

Table S1. Metals/metalloids measured in e-liquid by each study (n=12).

Citation	Type of e-liquid	N-metals per study	Al	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sb	Tl	V	Zn
Talio et al. 2015	Bottle	1	N	N	N	N	N	N	N	N	N	N	Y*	N	N	N	N
Beauval et al. 2016	Bottle	14	Y*	Y*	Y	Y*	Y*	Y*	N	Y*	Y*	Y	Y	Y*	Y	Y*	Y*
Beauval et al. 2017	Bottle	14	Y*	Y*	Y	Y*	Y*	Y*	N	Y	Y*	Y	Y	Y*	Y	Y*	Y
Palazzolo et al. 2017	Bottle	9	Y*	Y*	Y	N	N	Y	Y*	N	Y*	Y*	Y	N	N	N	Y*
Talio et al. 2017	Bottle	2	N	N	Y*	N	N	N	N	N	N	Y*	N	N	N	N	N
Dunbar et al. 2018	Bottle	1	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N
Kamilari et al. 2018	Bottle	6	N	Y	Y	N	Y*	Y*	N	N	N	Y*	Y*	N	N	N	N
Olmedo et al. 2018	Bottle	12	Y*	Y*	Y*	Y*	Y*	Y*	Y*	N	Y*	Y*	Y*	Y*	N	N	Y*
Song et al. 2018	Bottle	7	N	Y*	Y*	N	Y	Y	N	N	N	Y*	Y*	N	N	N	Y
Flora et al. 2016	Cartridge	2	N	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N
Hess et al. 2017	Cartridge	5	N	N	Y*	N ,	Y*	N	N	N	Y*	Y*	Y*	N	N	N	N
Dunbar et al. 2018	Cartridge (cig-a-likes)	1	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N
	Cartridge (pod)	1	N	N	N	N	N	N	N	N	N	N	Y	N	N	N	N
	Open wick	1	N	N	N	N	N	N	N	N	N	N	Y*	N	N	N	N
Zhao et al. 2018	Bottle, cartridge	1	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y*
Olmedo et al. 2018	Tank	12	Y*	Y*	Y*	Y*	Y*	Y*	Y*	N	Y*	Y*	Y*	Y*	N	N	Y*
N-Studies per metal			5	8	10	4	7	7	3	2	6	9	13	4	2	2	7

Note: N means the metal was not measured, Y means the metal was measured but below the LOD, Y* means the metal concentration above the LOD.

Table S2. Metals/metalloids measured in aerosol by each study (n=12).

Citation	Device type	N-Metals per study	Al	As	Be	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sb	Se	Si	Sn	Zn
Williams et al. 2013	Cig-a-likes	10	Y*	N	N	N	Y*	Y*	Y*	N	Y*	Y*	Y*	N	N	Y*	Y*	Y*
Goniewicz et al. 2014	Cig-a-likes	9	N	Y	N	Y*	Y	Y	N	N	Y	Y*	Y*	N	Y	N	N	Y
Tayyarahand Long 2014	Cig-a-likes	10	N	Y	Y	Y	Y*	N	N	Y	Y	Y	Y	N	Y	N	Y	N
Lerner et al. 2015	Cig-a-likes	1	N	N	N	N	N	Y*	N	N	N	N	N	N	N	N	N	N
Williams et al. 2015	Cig-a-likes	5	N	N	N	N	Y*	Y*	N	N	N	Y*	N	N	N	N	Y*	Y*
Margham et al. 2016	Cig-a-likes	12	N	Y	Y	Y	Y*	Y*	Y*	Y	N	Y	Y	N	Y	N	Y	Y*
Mikheev et al. 2016	Cig-a-likes	7	N	Y*	N	N	Y*	Y*	N	N	N	Y*	N	Y*	N	N	Y*	Y*
Williams et al. 2017	Cig-a-likes	10	Y*	Y*	N	N	N	Y*	Y*	N	N	Y*	N	Y*	Y*	Y*	Y*	Y*
Beauval et al. 2017	Tank	5	N	Y	N	Y*	Y*	N	N	N	N	N	Y*	Y*	N	N	N	N
Palazzolo et al. 2017	Tank	9	Y*	Y*	N	Y	N	Y	Y*	N	Y	Y*	Y	N	N	N	N	Y*
Olmedo et al. 2018	Tank	12	Y*	Y*	N	Y*	Y*	Y*	Y*	N	Y*	Y*	Y*	Y*	N	N	Y*	Y*
Zhao et al. 2018	Cig-a-likes, tank	7	Y*	N	N	N	N	Y*	Y*	N	Y*	Y*	Y*	N	N	N	N	Y*
N-Studies per metal			5	8	2	6	8	10	6	2	6	10	8	4	4	2	7	9

Note: N means the metal was not measured, Y means the metal was measured but below the LOD, Y* means the metal concentration above the LOD.

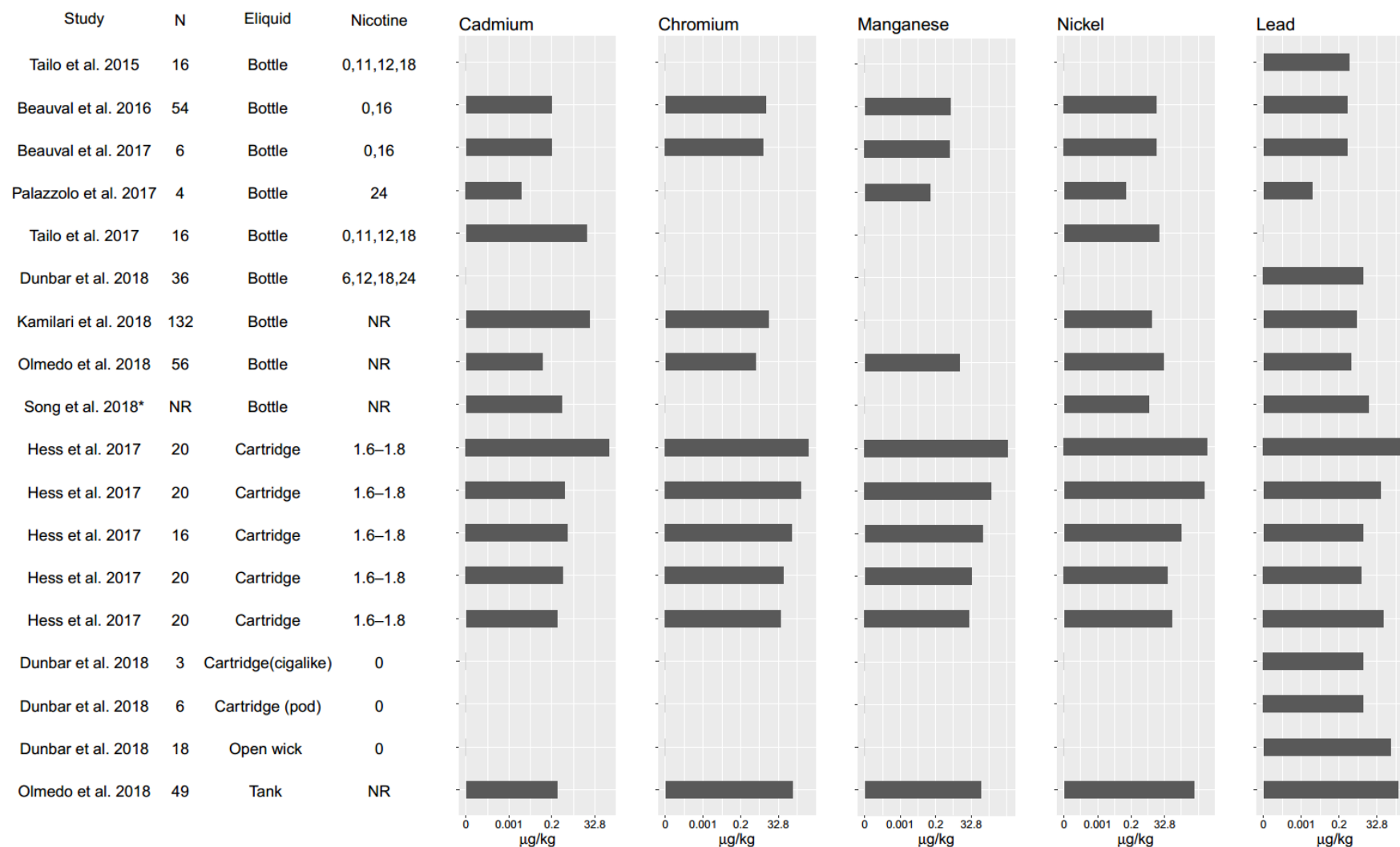


Figure S1. Mean metal/metalloid levels in e-liquid samples ($\mu\text{g/kg}$) used in e-cigarette devices. *The study by Song et al. (2018) measured chromium but did not report the levels. Other missing metal/metalloids in other studies were not measured. The unit of nicotine was mg/ml. Arsenic and cadmium were measured by Flora et al. (2016) but not showed in the Figure due to the high LOQ. NR: not reported.

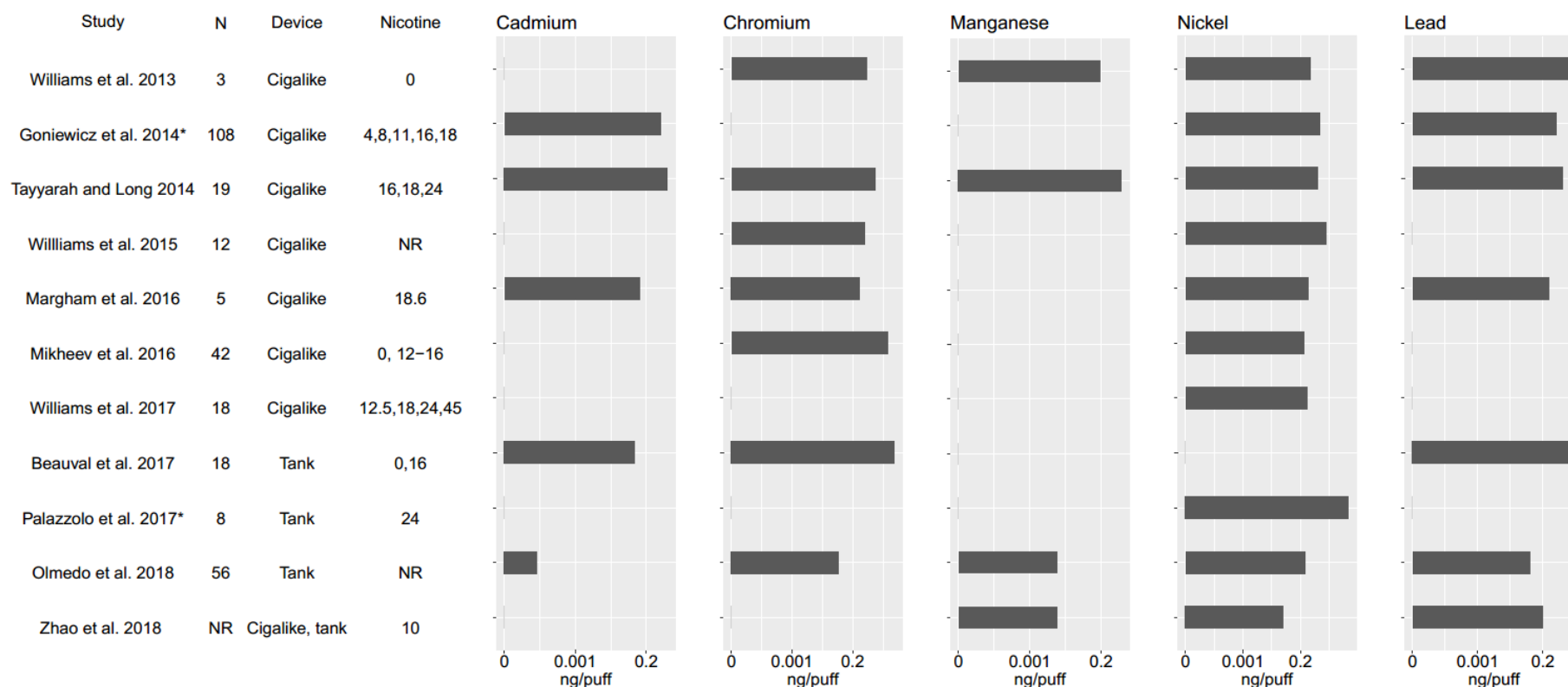


Figure S2. Mean metal/metalloid levels in aerosol samples (ng/puff) collected from e-cigarette devices. *The study by Goniewicz et al. (2014) measured chromium and manganese levels and the study by Palazzolo et al. (2017) measured cadmium, manganese, and lead levels. Other missing metal/metalloids in other studies were not measured. The unit of nicotine was mg/ml. NR: not reported.