

# The effect of smoking on exhaled carbon monoxide and arterial elasticity during prolonged surgical mask use in the COVID-19 era

Ignatios Ikonomidis <sup>1\*</sup>, Konstantinos Katogiannis <sup>1</sup>, Kallirhoe Kourea<sup>1</sup>, Kostelli Gavriella<sup>1</sup>, Damianos Tsilivarakis<sup>1</sup>, Vaia Lambadiari <sup>2</sup>, Dimitrios Kouretas<sup>3</sup>, and Giuseppe Biondi-Zoccai <sup>4,5</sup>

<sup>1</sup>2nd Cardiology Department, 'Attikon University Hospital', Medical School, National and Kapodistrian University of Athens, Athens, Greece; <sup>2</sup>2nd Department of Internal Medicine, Research Unit and Diabetes Centre, Attikon Hospital, National and Kapodistrian University of Athens, Medical School, Athens, Greece; <sup>3</sup>Department of Biochemistry and Biotechnology, University of Thessaly, Larissa, Greece; <sup>4</sup>Department of Medico-Surgical Sciences and Biotechnologies, Sapienza University of Rome, Latina, Italy; and <sup>5</sup>Mediterranea Cardiocentro, Napoli, Italy

Received 5 January 2022; revised 4 May 2022; editorial decision 11 May 2022; accepted 12 May 2022

In smokers, exposure to carbon monoxide (CO) is associated with health deterioration.<sup>1</sup> During the COVID-19 era, the use of surgical face mask hampers the spread of COVID infection. The impact of smoking while wearing a surgical face mask on exhaled CO and vascular function in smokers has not been investigated. We hypothesized that re-inhalation of CO during wearing a mask in smokers results in vascular dysfunction.

We studied 40 smokers of conventional cigarettes (ConCig), 40 exclusive heat-no-burn cigarettes (HNBC) users and 40 non-smokers with similar age and sex ( $P > 0.05$ ), who were medical personnel in a tertiary care university hospital [ $45.1 \pm 10.8$  years, 34 (28.3%) male]. The participants among the three study groups had similar clinical characteristics (Table 1). The study was conducted for 1 month. Subjects with known cardiovascular disease, hypertension, diabetes, dyslipidemia, chronic kidney disease, or atrial fibrillation were excluded from the study, as these entities may affect vascular function and to exclude patients with overt or subclinical cardiovascular disease.

We measured exhaled CO [parts per million (ppm)] with a validated device (Bedfont Scientific, Maidstone, Kent, UK) and pulse wave velocity (PWV), augmentation index adjusted for heart rate (Aix75), and central systolic blood pressure (cSBP) by a validated pulse wave analysis device (Mobil-O-Graph, IEM GmbH, Aachen, Germany). Central BP and Aix75 were calculated using a transfer function and PWV by utilizing the time difference between the derived forward and reflected waves.

During systole, the blood volume ejected into the aorta generates a pulse wave (systolic peak, P1). The stiffer the aorta the greater the

PWV. This pulse wave runs down and reflects from the bifurcation of aorta and peripheral arteries backwards to the aorta (P2). Aix75 is a marker of the effect of wave reflections on the aortic pulse wave and is defined as  $(P2-P1/\text{pulse pressure [PP]}) \times 100$ . In a stiff aorta, because of increased PWV, the wave reflections return early in systole and augment central SBP while in a compliant aorta they arrive in diastole and augment central DBP. Thus, in a stiff aorta, the early return of wave reflections increases the cardiac afterload and consequently myocardial oxygen demand while reduces the diastolic pressure and consequently the coronary perfusion resulting in reduced myocardial oxygen delivery. Therefore, increased arterial stiffness, as assessed by PWV and Aix, results in impaired cardiac function.

Baseline measurements were performed early in the morning after a night sleep without the use of any mask. After baseline measurements, subjects were randomized to a second assessment at the end of an 8 h morning shift wearing a mask at hospital or to assessment at the end of an 8 h morning period without wearing a mask during out of hospital activities. Then the subjects were crossed-over to a third assessment either at end of an 8 h period without mask out of the hospital after their morning shift or to an 8 h afternoon period wearing a mask during an afternoon hospital shift respectively. Subjects were instructed not to smoke at least 1 h before measurements to avoid any acute effect of smoking. Masks were consistently worn throughout the 8 h shift, and subjects did not use any other face shield.

Inferential analysis was based on analysis of variance (ANOVA), reporting two-tailed  $P$  values. Analysis was adjusted for age, sex, baseline values of measured markers, heart rate and blood pressure changes.

\* Corresponding author. Tel: +30 6944805732, Fax: +30 210-5832192. Email: [ignoi@gmail.com](mailto:ignoi@gmail.com)

© The Author(s) 2022. Published by Oxford University Press on behalf of the European Society of Cardiology. All rights reserved. For permissions, please email: [journals.permissions@oup.com](mailto:journals.permissions@oup.com).

**Table 1** Clinical characteristics and vascular markers of the three study groups at baseline, with and without use of surgical mask

|  | Total (n = 120)               | Conventional cig (n = 40)       | HNBC (n = 40)                  | Non-smokers (n = 40) | P      |
|--|-------------------------------|---------------------------------|--------------------------------|----------------------|--------|
| Age (years)                              | 45.1 ± 10.8                   | 44.2 ± 12.2                     | 45.2 ± 10.3                    | 46.5 ± 8.8           | 0.593  |
| Sex (male)                               | 34 (28.3%)                    | 12 (30%)                        | 9 (22.5%)                      | 13 (32.5%)           | 0.961  |
| Heart rate                               |                               |                                 |                                |                      |        |
| baseline                                 | 77.1 ± 11.5                   | 79.3 ± 7.1                      | 79.1 ± 10.2                    | 78.2 ± 7.4           | 0.273  |
| 8 h without mask                         | 75.4 ± 11                     | 77.6 ± 11.8                     | 76.9 ± 10.3                    | 76.8 ± 9.2           | 0.508  |
| 8 h with mask                            | 73.6 ± 10.3                   | 77.8 ± 11.6                     | 74.9 ± 9.8                     | 77.2 ± 9.4           | 0.289  |
| Systolic BP                              |                               |                                 |                                |                      |        |
| baseline                                 | 113.6 ± 8.3                   | 112.60 ± 9                      | 114.5 ± 8.8                    | 114.3 ± 7.3          | 0.831  |
| 8 h without mask                         | 117.5 ± 9.3 <sup>a</sup>      | 119.27 ± 11 <sup>a</sup>        | 117.9 ± 9.4 <sup>a</sup>       | 115.1 ± 7.1          | 0.501  |
| 8 h with mask                            | 124.7 ± 15.3 <sup>b,c</sup>   | 129.60 ± 17.2 <sup>b,c,f</sup>  | 128.83 ± 14.8 <sup>b,c,e</sup> | 115.4 ± 8.6          | 0.023  |
| Diastolic BP                             |                               |                                 |                                |                      |        |
| baseline                                 | 77.9 ± 7.9                    | 78.1 ± 10.4                     | 77.3 ± 10.3                    | 80.8 ± 9.2           | 0.883  |
| 8 h without mask                         | 75.3 ± 7.6                    | 77.2 ± 7.7                      | 73.1 ± 7.1                     | 79.2 ± 7.6           | 0.167  |
| 8 h with mask                            | 75.8 ± 7.2                    | 75.8 ± 8.9                      | 75.6 ± 4.9                     | 77.3 ± 8.5           | 0.968  |
| Pack years                               | 21.9 ± 10.8                   | 22.9 ± 12.4                     | 19.8 ± 6.8                     | –                    | 0.631  |
| Fagestrom score                          | 4.58 ± 2.20                   | 5.34 ± 2.12                     | 3.95 ± 1.31                    | –                    | 0.004  |
| CO (ppm)                                 |                               |                                 |                                |                      |        |
| baseline                                 | 3.48 ± 3.98                   | 8.00 ± 3.86 <sup>d,f</sup>      | 1.15 ± 0.37                    | 1.11 ± 0.56          | <0.001 |
| 8 h without mask                         | 5.09 ± 6.19 <sup>a</sup>      | 12.15 ± 6.01 <sup>a,d,f</sup>   | 1.43 ± 0.50 <sup>a</sup>       | 1.26 ± 0.652         | <0.001 |
| 8 h with mask                            | 7.26 ± 8.47 <sup>b,c</sup>    | 17.45 ± 7.10 <sup>b,c,d,f</sup> | 2.20 ± 1.03 <sup>b,c</sup>     | 1.36 ± 0.852         | <0.001 |
| PWV (m/sec)                              |                               |                                 |                                |                      |        |
| baseline                                 | 6.11 ± 0.81                   | 6.28 ± 1.04                     | 6.08 ± 0.68                    | 5.87 ± 0.48          | 0.390  |
| 8 h without mask                         | 6.29 ± 0.84 <sup>a</sup>      | 6.54 ± 1.09 <sup>a</sup>        | 6.23 ± 0.61 <sup>a</sup>       | 5.94 ± 1.56          | 0.120  |
| 8 h with mask                            | 6.74 ± 1.13 <sup>b,c</sup>    | 7.26 ± 1.32 <sup>b,c,d,f</sup>  | 6.67 ± 0.93 <sup>b,c</sup>     | 6.06 ± 1.44          | 0.003  |
| Augmentation index (%)                   |                               |                                 |                                |                      |        |
| baseline                                 | 21.67 ± 5.19                  | 24.80 ± 5.95 <sup>f</sup>       | 22.16 ± 2.82 <sup>e</sup>      | 18.46 ± 7.02         | <0.001 |
| 8 h without mask                         | 25.10 ± 6.55 <sup>a</sup>     | 30.53 ± 6.03 <sup>a,d,f</sup>   | 24.75 ± 3.95 <sup>a,e</sup>    | 18.86 ± 6.84         | <0.001 |
| 8 h with mask                            | 29.42 ± 8.94 <sup>b,c</sup>   | 34.60 ± 7.64 <sup>b,c,f</sup>   | 33.16 ± 6.61 <sup>b,c,e</sup>  | 19.46 ± 7.23         | <0.001 |
| Central systolic blood pressure (mmHg)   |                               |                                 |                                |                      |        |
| baseline                                 | 111.15 ± 10.07                | 113.01 ± 9.42                   | 110.01 ± 10.11                 | 107.70 ± 8.92        | 0.679  |
| 8 h without mask                         | 114.10 ± 10.29 <sup>a</sup>   | 117.20 ± 9.68 <sup>a</sup>      | 113.92 ± 10.04 <sup>a</sup>    | 106.80 ± 8.64        | 0.253  |
| 8 h with mask                            | 117.85 ± 10.64 <sup>b,c</sup> | 121.33 ± 9.52 <sup>b,c,f</sup>  | 119.08 ± 11.67 <sup>b,c</sup>  | 108.20 ± 8.88        | 0.087  |
| Cigarettes/heets during 8 h without mask |                               | 3.8 ± 2.4 (3)                   | 3.7 ± 2.1 (3)                  |                      | 0.8    |
| Cigarettes/heets during 8 h with mask    |                               | 3.9 ± 1.8 (4)                   | 3.8 ± 1.9 (4)                  |                      | 0.9    |

Values are mean ± SD.

<sup>a</sup>P < 0.05, 8 h without mask vs. baseline.

<sup>b</sup>P < 0.05, 8 h with mask vs. without mask.

<sup>c</sup>P < 0.05, 8 h with mask vs. baseline.

<sup>d</sup>P < 0.05, HNBC vs. ConCig.

<sup>e</sup>P < 0.05, HNBC vs. non-smokers.

<sup>f</sup>P < 0.05, ConCig vs. non-smokers.

P corresponds to the differences between the three study groups at each assessment (baseline, 8 h with, and 8 h without mask) by ANOVA.

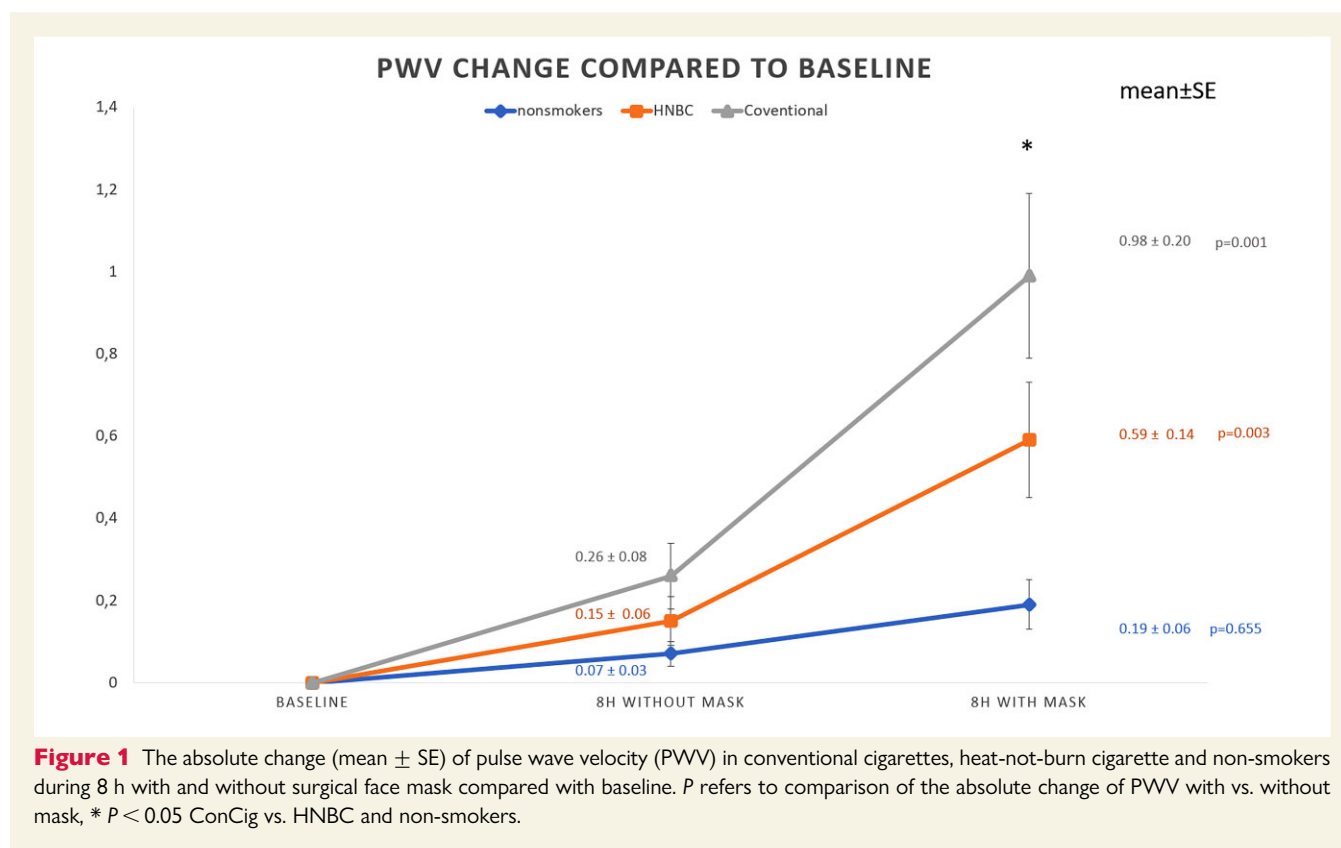
The number of smoked cigarettes/HNBC sticks during 8 h with or without mask was similar ( $P = 0.9$ , Table 1).

In ConCig smokers, the increase of CO was greater while wearing than without wearing a mask for 8 h {absolute difference 9.45 [95% confidence interval (CI): 8.01–10.88] vs. 4.15 [95% CI: 3.15–5.14] ppm,  $P < 0.001$ } compared with baseline. In HNBC users, the increase of CO was greater while wearing than without wearing a mask [1.05 (95% CI: 0.71–1.38) vs. 0.28 (95% CI: 0.11–0.44) ppm,

$P < 0.001$ ] (Table 1). Among non-smokers, the use of mask did not alter exhaled CO ( $P > 0.05$ ).

In both ConCig and HNBC users, all vascular markers were increased after 8 h with or without mask with compared to baseline ( $P < 0.05$ ). In non-smokers, the use of a mask had a neutral effect on vascular markers ( $P > 0.05$ ).

In ConCig smokers, the increase of PWV was greater while wearing than without wearing a mask for 8 h [0.98 (95% CI: 0.55–1.41) vs.



0.26 (95% CI: 0.09–0.42 m/sec, *P* = 0.001] compared with baseline (Figure 1). Similarly, the increase of cSBP, Aix75, and brachial SBP was greater after smoking ConCig while wearing than without wearing a mask [cSBP: 8.32 (95% CI: 5.00–11.66) vs. 4.0 (95% CI: 0.92–7.47) mmHg, *P* < 0.001, Aix75: 9.80 (CI: 5.38–14.21) vs. 5.73 (95% CI: 1.98–9.48)%, *P* = 0.01 and SBP: 7 (95% CI: 8.37–25.62) vs. 6.67 (95% CI: 1.39–11.93 mmHg, *P* = 0.004].

In HNBC users, the increase of PWV was greater after wearing than without wearing a mask [0.59 (95% CI: 0.27–0.91) vs. 0.15 (95% CI: 0.01–0.29 m/sec), *P* = 0.005] compared with baseline (Figure 1). Similarly, the increase of cSBP, Aix75, and brachial SBP was greater after smoking HNBC while wearing than without wearing a mask [cSBP: 9.07 (95% CI: 3.13–15.03) vs. 3.91 (95% CI: 0.18–7.64 mmHg), *P* = 0.035, Aix75: 11.00 (95% CI: 6.24–15.75) vs. 2.59 (95% CI: 0.06–5.10)%, *P* = 0.001 and SBP: 14.33 (95% CI: 6.53–22.13) vs. 3.4 (95% CI: 0.38–6.45) mmHg, *P* = 0.012]. Exhaled CO remained higher in ConCig smokers compared with HNBC and non-smokers throughout the study (Table 1, *P* < 0.05). ConCig smokers and HNBC users showed no significant differences between the changes of vascular markers during the study (*P* > 0.05) with exception of a borderline greater increase of PWV with mask in ConCig smokers compared the respective PWV change in HNBC users (*P* = 0.047).

Our study showed that smoking while wearing a surgical mask resulted in a two-fold rise of exhaled CO and concomitant impairment of arterial elasticity in ConCig or HNBC smokers, possibly due to re-inhalation of exhaled CO and/or vapour rich in nicotine. Conversely, surgical mask had no effect in non-smokers.

Elevated CO levels after ConCig smoking is associated with platelet activation,<sup>2</sup> whereas chronic nicotine exposure may impair aortic elasticity.<sup>3</sup>

The following limitations should be acknowledged. This is a single-center study including a modest sample size of smokers. A follow-up period is required to detect, whether the increase in the measured markers while wearing a mask is related with a higher incidence of cardiovascular disease. The effects of stress during work, environmental pollution, diet, or sleep on the observed changes the examined markers may not be excluded in our study. The conditions may be not identical between the with and without mask time periods of the study despite its randomized cross-over design.

This study demonstrates that smoking of any tobacco product during a prolonged use of a surgical facemask may further compromise vascular function at least partly because of increased CO re-inhalation and/or vapour rich in nicotine. These detrimental effects are not evident in non-smokers. Thus, smokers should definitely abstain from smoking while wearing a mask and quitting both conventional and HNBC cigarettes is imperative for a better health in the COVID-19 pandemic.

## Clinical trial registration

NCT04966845

## Ethics committee approval identifier

EBA 341/1-7-2021.

## Acknowledgements

The authors thank Professor Gerasimos Filippatos for critically reviewing the manuscript.

## Authors' contributions

I.I. and Ka.K. contributed to the conception and design of the work; Ka.K., K.G., D.T., and V.L. contributed to the acquisition of data for the work; I.I. and Ko.K. contributed to data analysis and interpretation of data for the work; I.I. and Ko.K. drafted the manuscript. D.K. and G.B.-Z. critically revised the manuscript. All gave final approval and agree to be accountable for all aspects of work ensuring integrity and accuracy.

**Conflict of interest:** Giuseppe Biondi-Zoccai has consulted for Cardionovum, Crannmedical, Innovheart, Meditrial, Replycare and Terumo. There are no conflicts to report from all other co-authors.

## References

1. Zevin S, Saunders S, Gourlay SG, Jacob P, Benowitz NL. Cardiovascular effects of carbon monoxide and cigarette smoking. *J Am Coll Cardiol* 2001;**38**: 1633–1638.
2. Ikonomidou I, Katogiannis K, Kostelli G, Kourea K, Kyriakou E, Kypraiou A, Tsoumani M, Andreadou I, Lambadiari V, Plotas P, Thymis I, Tsantes AE. Effects of electronic cigarette on platelet and vascular function after four months of use. *Food Chem Toxicol* 2020;**141**:111389.
3. Vlachopoulos C, Alexopoulos N, Panagiotakos D, O'Rourke MF, Stefanadis C. Cigar smoking has an acute detrimental effect on arterial stiffness. *Am J Hypertens* 2004;**17**: 299–303.