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Research article

PM_{10}, $PM_{2.5}$, PM_1, number and surface of particles at the child's seat when smoking a cigarette in a car

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Abstract: The exposure to particles was measured by a diffusion size classifier (10–300 nm) and an optical particle counter (300 nm–10 µm) at the child's seat of a car during repeated drives on a fixed route from a suburban domestic area to a school and back. One single cigarette smoked in a car at the front seat during a 10 minute trip, lead to an increase of PM_{10} on the back seat by a factor of 10.5, for $PM_{2.5}$ by a factor of 21.3 and for PM_1 by a factor of 23.9. Concentrations dropped after opening the back door, but stayed elevated on the way back, compared to outdoor concentrations. Holding the cigarettes to the open window of the front seat did not reduce exposure on the back seat. When a second cigarette was smoked on the way back, PM_{10} concentrations rose again to 300 µg m^{-3}. While background PM_1 made up 19–39% of PM_{10}, PM_1 during smoking amounted to 78–89% of PM_{10}. PM_1 was highly correlated to particle number (mean 97,701 pt cm^{-3}, SD 82,537) and lung deposited surface area (LDSA, mean 270 cm^2 cm^{-3}, SD 229). Positioning of the cigarette at the open window did not decrease the exposure to LDSA at the child's seat. In conclusion, particles can reach exorbitant high levels at the back seat, when cigarettes are smoked in a small place like a car, even with a 2 inches open window next to the smoker at the front seat. Through smoking in cars parents can harm their or other's children severely.

Keywords: Car; secondhand smoke; cigarettes; smoking; children; school; ultrafine particles; PM_{10}; $PM_{2.5}$; PM_1

1. Introduction

A high number of Austrian citizens are exposed to second-hand smoke (SHS) compared to other European countries. Non-smokers and minors are exposed to tobacco smoke (in workplaces, public places, home and in motor vehicles) more frequently than the EU average [1,2]. Intake of toxic and carcinogenic volatile organic compounds from SHS in motor vehicles have been previously studied [3]. However, when investigating acute effects of SHS on children, exposures to fine and ultrafine particles are more important. Existing research has shown how vehicle speed, window position and ventilation [4] can lead to large variation of exposure to $PM_{2.5}$ [5]. Much less is known about exposures to PM_1, ultrafine particle number (PN) and lung deposited surface area (LDSA), which we studied simultaneously with $PM_{2.5}$ in standardized conditions designed to simulate a typical journey to school or kindergarten.

Studies show that children exposed to SHS are at higher risk of illnesses such as respiratory infections [6,7], cardiovascular diseases [8,9], food allergies [10], mental illnesses such as depression and sleeping disorders [11], cancer [12] and sudden infant death syndrome [13,14]. Whilst the role of ultrafine particles in these associations is still unknown, previous research in this field has focused on estimating exposure to $PM_{2.5}$ rather than PN [14] and LDSA [15]. To our knowledge no study has measured LDSA on the child's seat in relation to cigarette smoking.

Nine percent of all smokers in Europe consume tobacco products in cars in the attendance of children. In Austria this is higher with 16 percent of the smokers confessing to do so in 2006 [16].

2. Materials and Methods

For each scenario three return journeys on a fixed route from a suburban domestic area to a school were taken in a KIA Cee'd CRDI 1.6 motion SW (2009). This was designed to simulate a typical ten minute school commute.

An adult was smoking in the front passenger seat, while another drove. The smoker lit the cigarette during the first minute of the trip. In scenario 2 and scenario 3 the cigarette was placed near the opened window while smoking, in contrast to scenario 1 where the cigarette was smoked inside the car.

In scenario 0 two journeys without smoking were taken in advance to assess the background pollution inside the car while driving. These data were used for the statistic analysis (Table 1).

Table 1. Summary of the different conditions.

Scenarios	Cigarette close to passenger window	Number of cigarettes smoked	Cigarette was smoked on the
Scenario 0	-	0	-
Scenario 1	No	1	way to school
Scenario 2	Yes	1	way to school
Scenario 3	Yes	2	way to school and back

In all scenarios the front passenger window remained two inches open, with all other windows closed. The climate-control fan inside the car was turned off at all times. After the destination was reached, the back door on the passenger's side was opened for ten seconds, simulating exit or entering of child, before the return journey under the same conditions.

The air quality was monitored by two devices: A miniature diffusion size classifier "minidisc" (Matter Aerosol), model G3_016 and by a laser-spectrometer and optical particle counter, model 1.108 (Grimm), which were fixed using a child's car safety seat at approximately the height of a child's nose (Figure 1). With these two devices the concentrations of the following parameters were recorded: PM_1, $PM_{2.5}$ and PM_{10} of particles larger than 300 nm, and number and LDSA of ultrafine particles (10–300 nm).

Figure 1. Photo of equipment setup inside the car at the backseat on the passenger's side.

Nineteen public monitoring stations quantify ambient fine particulates on a daily data basis in Vienna. These facilities collect data on PM_{10} and $PM_{2.5}$ every half an hour and were used to get an idea of the outdoor concentrations during the scenarios. Because higher background concentrations of PM_{10} and $PM_{2.5}$ were observed on the day of scenario 1, the indoor exposures were also compared to the indoor baseline before lighting a cigarette.

3. Results and Discussion

Concentrations of PM_{10}, $PM_{2.5}$ and PM_1 for each scenario are shown in Figures 2–5. For statistical analysis the following exposure times were distinguished: baseline (first minute of trip, before cigarette lit), smoking of first cigarette, after smoking, opening of backdoor (red line) and the return journey partitioned in 2 phases. As scenario 2 and scenario 3 had the same conditions during the way to school, the two scenarios were summarised for the statistical analysis and marked as scenario 2/3.

One single cigarette smoked during a simulated 10 minute journey from home to school, lead to a significant increase of PM_{10} (scenario 0: I: p 0.007; II/III: p 0.004; baseline: I: p 0.032), $PM_{2.5}$ (scenario 0: I: p 0.01; II/III: $p < 0.001$; baseline: I: p 0.023) and PM_1 (scenario 0: I: p 0.008; II/III: $p < 0.001$; baseline: I: p 0.023) in all scenarios during the outward journey in comparison to scenario 0 and the baseline for each journey.

There remained a significant increase of PM_{10} (I: $p < 0.001$; II: p 0.004), $PM_{2.5}$ (I: p 0.003; II: p 0.009) and PM_1 (I: p 0.002; II: p 0.036) in scenario 1 and scenario 2 until minute 8 of the return journey in comparison to scenario 0. Compared to the baseline there was a significant increase of PM_{10} in scenario 1 for the first 2 minutes of the way back home.

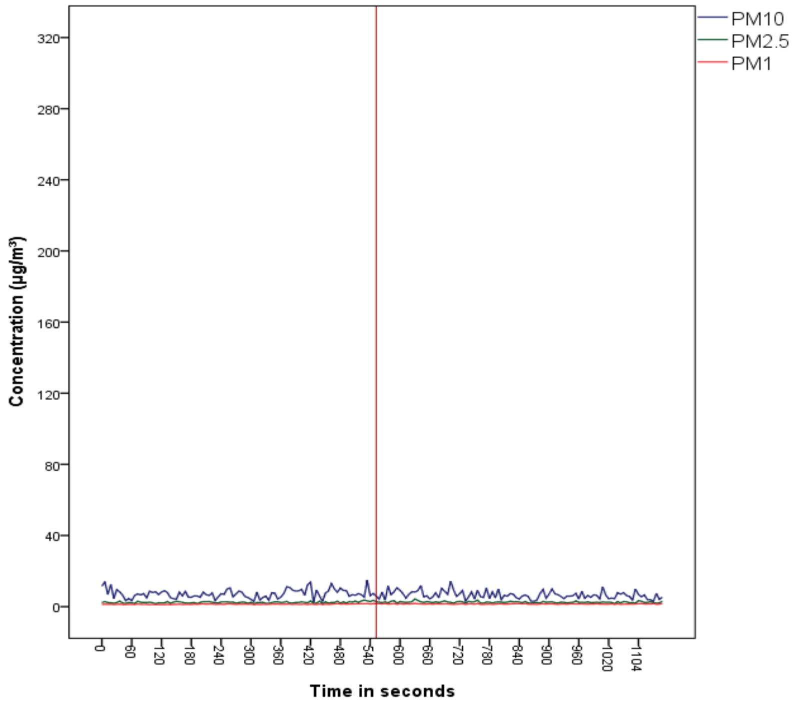

Figure 2. Average levels of PM_{10}, $PM_{2.5}$ and PM_1 measured in scenario 0 (background).

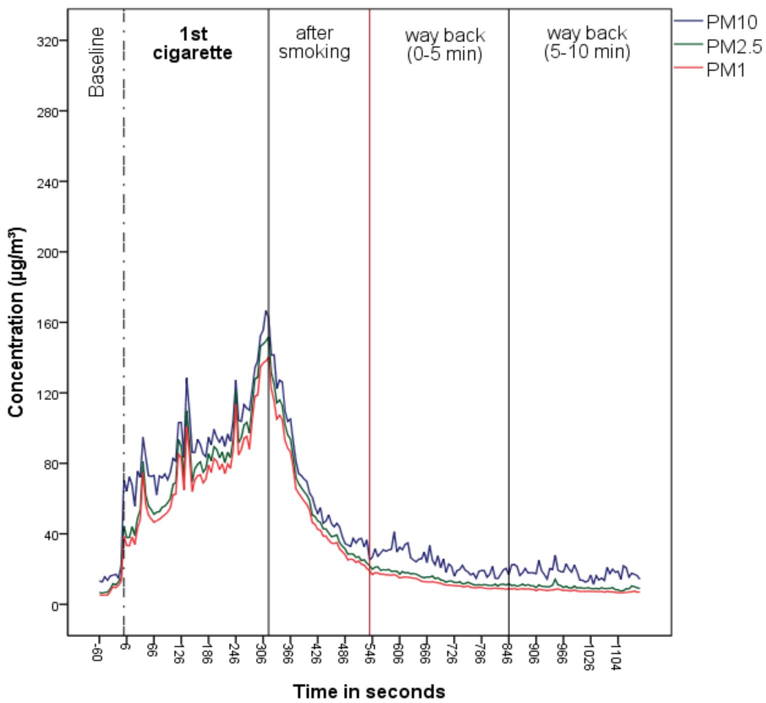

Figure 3. Average levels of PM_{10}, $PM_{2.5}$ & PM_1 measured in scenario 1 where single cigarette was smoked during outward journey. There was a significant increase of PM_{10}, $PM_{2.5}$ and PM_1 until the 8th minute of return journey compared to scenario 0.

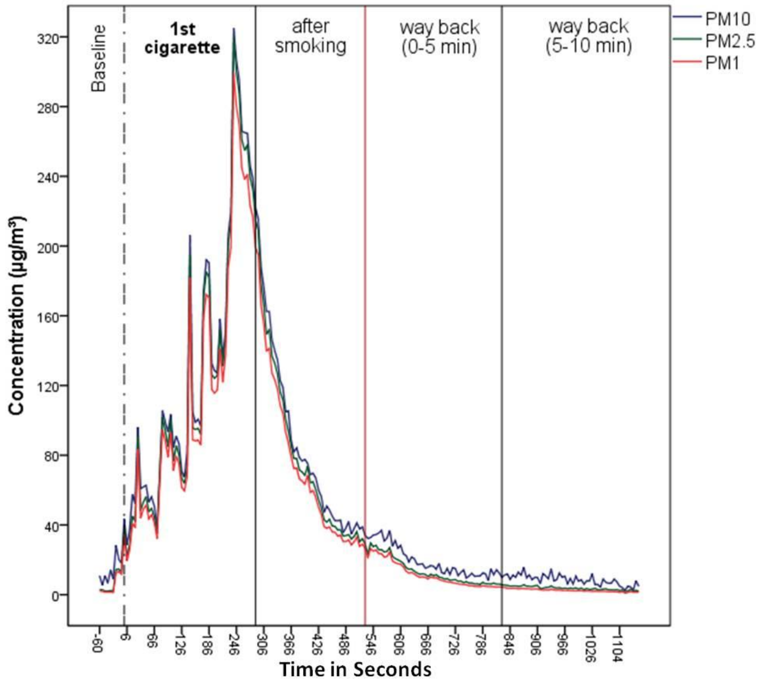

Figure 4. Average levels of PM_{10}, $PM_{2.5}$ & PM_1 measured in scenario 2 where single cigarette was smoked on outward journey and held near the window. There was a significant increase of PM_{10}, $PM_{2.5}$ and PM_1 until the 8th minute of return journey.

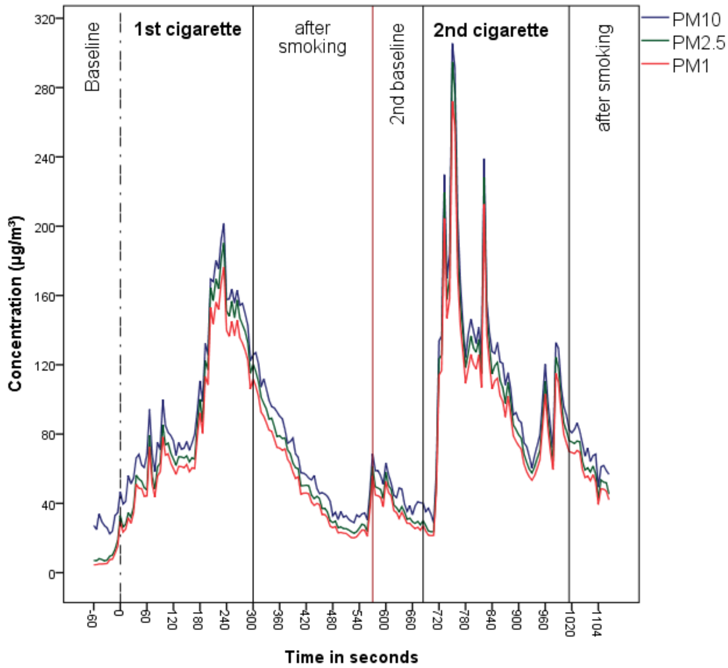

Figure 5. Average levels of PM_{10}, $PM_{2.5}$ & PM_1 measured in scenario 3 where a cigarette was smoked both during outward and return journeys and held near window. There was a significant increase of PM_{10}, $PM_{2.5}$ and PM_1 on both outward and return journeys.

Concentrations of PM_{10}, $PM_{2.5}$ and PM_1 dropped after opening the back door, but remained elevated on the return journey in comparison to low outdoor concentrations. Holding the cigarette near the open window of the front passenger seat, did not reduce exposure on the back seat. A mean increase of PM_{10} by a factor of 10.5, for $PM_{2.5}$ by a factor of 21.3 and for PM_1 by a factor of 23.9 was detected, while smoking a cigarette in the front seat (Table 2). When a second cigarette was smoked on the return journey, concentrations rose again to comparable levels as before.

Table 2. Average concentration of PM_{10}, $PM_{2.5}$ and PM_1.

	Average (µg m^{-3})	scenario 0	scenario 1	scenario 2	scenario 3
baseline	PM_{10}	7.4	15.4	12.3	28.2
	$PM_{2.5}$	2.4	9.2	5.8	9.9
	PM_1	1.4	7.6	4.8	7.5
1st cigarette	PM_{10}	-	94	129.6	104.1
	$PM_{2.5}$	-	80.4	123.3	93.9
	PM_1	-	73.7	114.8	86.2
after smoking	PM_{10}	-	68.9	85.6	54
	$PM_{2.5}$	-	61.2	79.3	46.9
	PM_1	-	55.9	73.3	42.5
2nd baseline	PM_{10}	-	-	-	28.1
	$PM_{2.5}$	-	-	-	16.6
	PM_1	-	-	-	14.4
2nd cigarette	PM_{10}	-	-	-	129.3
	$PM_{2.5}$	-	-	-	120.2
	PM_1	-	-	-	111.2
way back (0–5 min)	PM_{10}	-	24.7	18.7	-
	$PM_{2.5}$	-	15.3	12.8	-
	PM_1	-	12.9	11	-
way back (5–10 min)	PM_{10}	6.3	18.1	8.9	51.1
	$PM_{2.5}$	2.5	9.9	3.8	43.1
	PM_1	1.5	7.8	2.5	39.2

The highest concentration of Ultrafine Particles, at almost 10 times higher than scenario 0, was found in scenario 3 (153,498 pt cm^{-3}), where two cigarettes were smoked. But even one single cigarette smoked (Scenario 1: 97,701 pt cm^{-3} and scenario 2: 90,796 pt cm^{-3}) contaminated the air in the car significantly compared to scenario 0 (Table 3). Similar to the PM analysis the high ultrafine particle numbers decayed continuously after the cigarettes were burnt down. In the scenarios with one cigarette smoked, particle number concentrations reached background concentrations at the end of the return journey. The time course of LDSA was similar (Figure 6).

Table 3. Number of Ultrafine Particles and LDSA.

		LDSA (μm² cm⁻³)	Ultrafine Particles (pt cm⁻³)
scenario 0	Mean	38.4	15,545
	Maximum	10	3690
	Minimum	81	31,362
scenario 1	Mean	270	97,701
	Maximum	27	11,205
	Minimum	937	401,026
scenario 2	Mean	231.9	90,796
	Maximum	15	6446
	Minimum	998	411,197
scenario 3	Mean	383.9	153,498
	Maximum	15	6830
	Minimum	862	418,616

Figures 6 and 7 show that in scenario 1 there was a longer duration of high particle number concentration and LDSA in comparison to scenario 2 and 3, although the maxima were similar. An explanation could be that the faster airstream caused by smoking closer to the open window led to a faster burning of the cigarettes in scenario 2 and 3. In scenario 1 the mean smoking duration was 5.3 minutes and in the other scenarios 4.7 minutes, however, due to the small number of measurements taken this difference was not statistically significant.

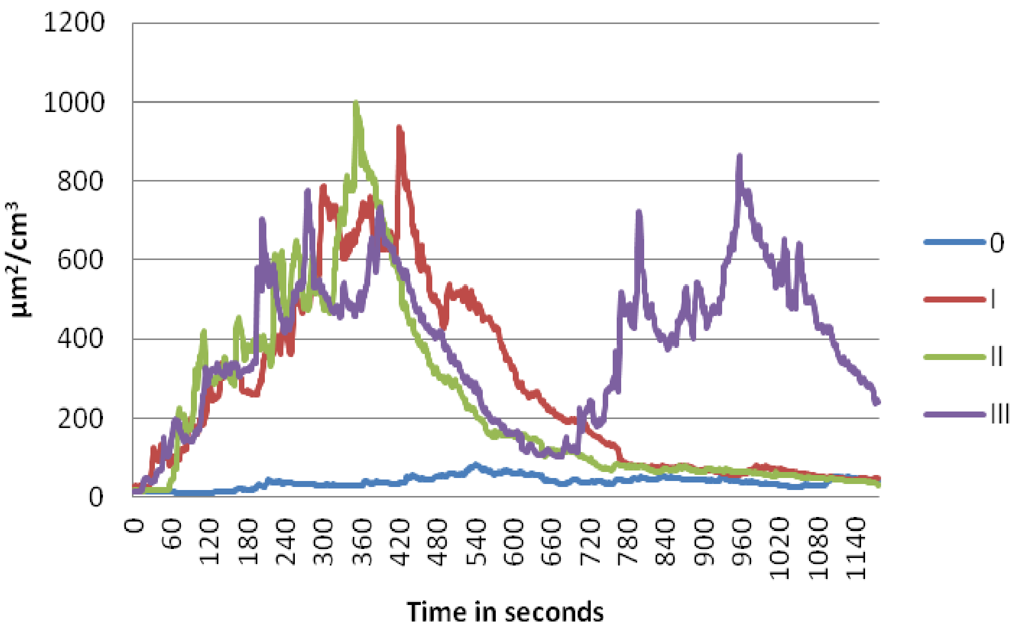

Figure 6. Lung deposited surface area (LDSA) concentrations of all scenarios.

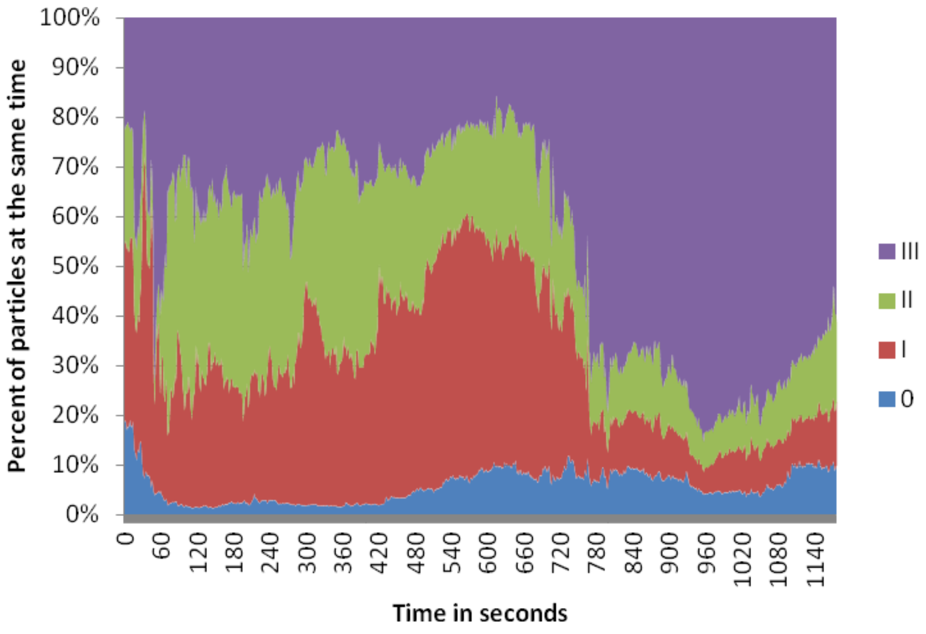

Figure 7. Fractions of particle number concentrations from all scenarios at the progressed time. Prolonged high levels are seen in scenario 1, when the cigarette was smoked inside the car, in comparison to scenario 2 where the cigarette was smoked next to the window.

The correlation between LDSA and particle number was highly significant: Spearman's rank correlation coefficient between 0.95 and 0.996, $p < 0.0001$. The total amount of LDSA accumulated over the return journey, of approximately 20 minutes duration, was in scenario 1 (21.6 mm^2), scenario 2 (18.6 mm^2) and scenario 3 (30.7 mm^2).

This study shows that a single cigarette smoked in a car, even with the window opened, lead to an alarming increase of fine particle mass and ultrafine particle number and surface, which is in agreement with results of former studies [17,18].

There were slightly lower averages of PM_{10}, $PM_{2.5}$ and PM_1 concentrations found in scenario 1, when the cigarette was smoked inside the car, than in scenario 2 and scenario 3 where the cigarette was held near the window (Table 2). This unexpected result confirms earlier observations of higher averages when holding a cigarette outside the car [5,19]. Under similar conditions Edwards et al. [19] have found a mean concentration of $PM_{2.5}$ of 162 µg m^{-3} when the cigarette smoked was held outside compared to 119 µg m^{-3} when the cigarette was held inside the car.

Sohn et al. [20] investigated the effect of the window opening conditions on $PM_{2.5}$ and UFP while smoking in a moved car. $PM_{2.5}$ levels stayed elevated even after a 15 minute ride with the driver's window 4 inches open, while UFP levels reduced to the baseline levels in 10 minutes, independently of the opening of the driver's window (fully, half or 4 inches open) [5,20].

Private family cars are one of the most frequent areas where exposure to SHS happens. A survey of 12,269 adults in England in 2014 revealed that 77 percent of the people, 63 percent of them active smokers, supported legislation that bans smoking under the presence of children in the car [21].

4. Conclusion

One single cigarette smoked in a moving car, with the passenger's window open, exposes other passengers and especially children to elevated particle concentrations in the fine (0.3–2.5 µm) and ultrafine (10–300 nm) size range. This may pose threats to health. On the child's car safety seat there was an increase of $PM_{2.5}$ and PM_1 by the factor of 21.3 and 23.9 compared to background concentrations before the cigarette was lit. Holding the cigarette to the 2 inches open window did not prevent an increase of $PM_{2.5}$/PM_1/PN/LDSA to 123.3 µg m^{-3}/114.8 µg m^{-3}/90,796 pt cm^{-3}/231.9 mm^2 m^{-3} on the outward journey. Some contamination remained on return journey, but when a second cigarette was lit, PN concentration reached 153,498 pt cm^{-3} on the child's car safety seat. This paper also shows that the common belief that, smoking near an open window reduces concentration of toxic fine particles within the vehicle, is incorrect.

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Conflicts of interest

All authors declare no conflicts of interest in this paper.

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