Higher toxic potential of 2-stroke scooter exhaust emissions compared to 4-stroke scooter and diesel car emissions

L.L. Müller, PhD student[1], P. Comte, engineer[2], J. Czerwinski, Dr. Eng.[2], P. Gehr, PhD[1], M. Kasper, Dr. Sc. nat.[3], A.C.R. Mayer, engineer[4], B.M. Rothen-Rutishauser, PhD[1]
[1]University of Bern - Bern/CH, [2]Bern University of Applied Sciences - Nidau/CH, [3]Matter Engineering AG, Nanoparticle Measurement - Wohlen/CH, [4]Technik Thermische Maschinen (TTM) - Niederrohrdorf/CH

Rationale: A growing number of scooters (small two-wheeled vehicles, maximum speed of 45 km/h, engine capacity of 50 cm^3) produce an increasing amount of potentially harmful emissions. Comparisons between cars (Euro 3 standard) and various scooters show that two-stroke scooters can emit 10-23 times more carbon monoxide (CO), 10-171 times more total hydrocarbons (HC) and 3-8 times more nitrogen oxides (NO_x), depending on scooter type. Further high emissions of polycyclic aromatic HCs and very high amounts of particulate matter in the nanoscale range are typical for scooter exhaust emissions. Therefore, scooters are significant contributors to air pollution and may play a role in the development of pulmonary and cardiovascular diseases. For that reason, the toxicity of exhaust emissions was tested, by exposing cell cultures to it.

Methods: The toxicity of exhaust emissions was evaluated using a newly developed exposure system: Triple cell co-cultures, simulating the human epithelial airway barrier, were directly exposed at the air-liquid interface to exhaust emissions (2h exposure, dilution of 1:100, constant conditions of 5% CO_2, 37°C and 80% relative humidity). Parallel to the exposure chamber, a reference chamber was also treated equally, however with ultra clean air only. Particle number, total particle surface area, mean particle diameter, CO, HC and NO_x concentrations were measured (Table 1). Cellular responses were assessed by measuring the cytotoxicity (lactate dehydrogenase assay) and (pro-) inflammatory responses (Tumor necrosis factor α, Interleukin 8) after 8 and 24h post-exposure time. For comparison, the cellular responses were summarized assessing each significant difference between control and exposure as ++ and each tendency as + (Table 1).

Results: After comparison of the overall toxic potential (Table 1), it was found that carburetor worst case (dummy muffler, Army oil, unleaded fuel) provokes the strongest cellular reactions (13+), followed by two-stroke direct injection (TSDI) worst case (8+) and four-stroke scooter (7+). TSDI absolute best case (prototype of particle filter, oxi catalyst, aspen fuel, 50% of oil ratio), diesel car without particle filter (both 5+), carburetor absolute best case and the diesel car with particle filter (both 3+) showed weaker reactions. For indentifying the relevant exhaust components, further analysis of more vehicle types and conditions are necessary.

Conclusions: Two-stroke scooter exhaust emissions have stronger adverse impacts on lung cell cultures than exhaust emissions of 4-stroke scooters or diesel cars. Technical implementations, such as particle filters, catalysts, and better fuel and oil, can reduce this impact and should be introduced.

Table 1. Physical characterization of the exhaust emissions and biological reactions.

	two-stroke direct injection		carburetor		four-stroke direct injection	diesel car	
	worst case	absolute best case	worst case	absolute best case		with particle filter	without particle filter
particle # (10-400nm) [counts/cm^3]	$6.23 \cdot 10^6 \pm 2.02 \cdot 10^4$	$2.32 \cdot 10^5 \pm 1.10 \cdot 10^5$	$5.51 \cdot 10^6 \pm 1.17 \cdot 10^6$	$9.21 \cdot 10^4 \pm 1.72 \cdot 10^4$	$1.33 \cdot 10^3 \pm 1.96 \cdot 10^3$	13.3 ± 16.6	$4.08 \cdot 10^5 \pm 4.89 \cdot 10^4$
total active surface area [μm^2/cm^3]	$6.73 \cdot 10^4 \pm 6.05 \cdot 10^3$	$2.36 \cdot 10^2 \pm 41.7$	$5.79 \cdot 10^4 \pm 1.38 \cdot 10^4$	not available	2.69 ± 1.86	0.783 ± 0.0787	$2.65 \cdot 10^3 \pm 3.81 \cdot 10^2$
carbon monoxide [ppm]	16.72 ± 1.95	0.64 ± 0.01	77.05 ± 44.99	1.19 ± 0.26	204.96 ± 35.91	0.66 ± 0.00	3.55 ± 4.97
hydrocarbons [ppm]	235 ± 12.5	8.32 ± 1.22	922 ± 7.43	29.7 ± 3.79	111 ± 12.9	2.05 ± 0.212	8.83 ± 0.382
nitrogen oxide [ppm]	30.9 ± 2.34	13.6 ± 1.79	5.47 ± 0.167	3.08 ± 0.0234	7.21 ± 0.311	11.3 ± 0.103	12.5 ± 0.249
ldh	+	0	++++	0	+++	++	0
tnfa	++++	+	++++++	+	++	+	+
il8	+++	++++	+++	++	++	0	++++
total biological reaction	**8+**	**5+**	**13+**	**3+**	**7+**	**3+**	**5+**