Supplementary Information

Understanding the intricate evaluation of fentanyl and carfentanil decontamination: field and laboratory perspectives

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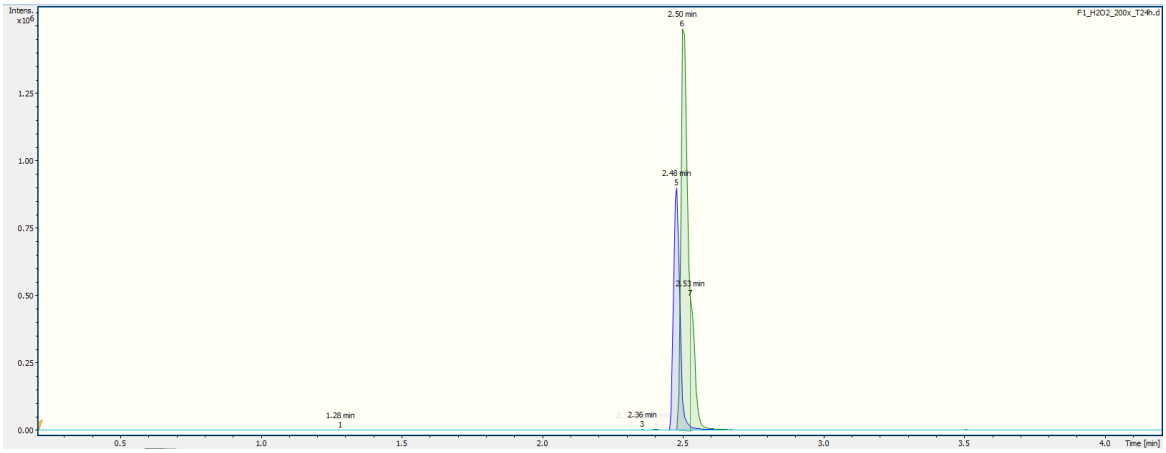
LC/HRMS data for detected degradation products

Supplementary table S1. Degradation products of fentanyl in 10 % H_2O_2 detected by UHPLC-HRMS after 24 h.

#	RT (min)	% signal of fentanyl reference	EIC (*m/z*)	Ion formula (incl. H^+)	Comment
1	1.28	<1	233.165	$C_{14}H_{21}N_2O$	$-C_8H_8$ (norfentanyl)
2	2.32	<1	353.222	$C_{22}H_{29}N_2O_2$	+ O
3	2.36	<1	353.222	$C_{22}H_{29}N_2O_2$	+ O
4	2.40	<1	353.222	$C_{22}H_{29}N_2O_2$	+ O
Fentanyl	2.48	34	337.227	$C_{22}H_{29}N_2O$	
6	2.50	59	353.222	$C_{22}H_{29}N_2O_2$	+ O (N-oxide)
7	2.53	14	353.222	$C_{22}H_{29}N_2O_2$	+ O (N-oxide)

Extracted ion chromatogram = EIC, retention time = RT.

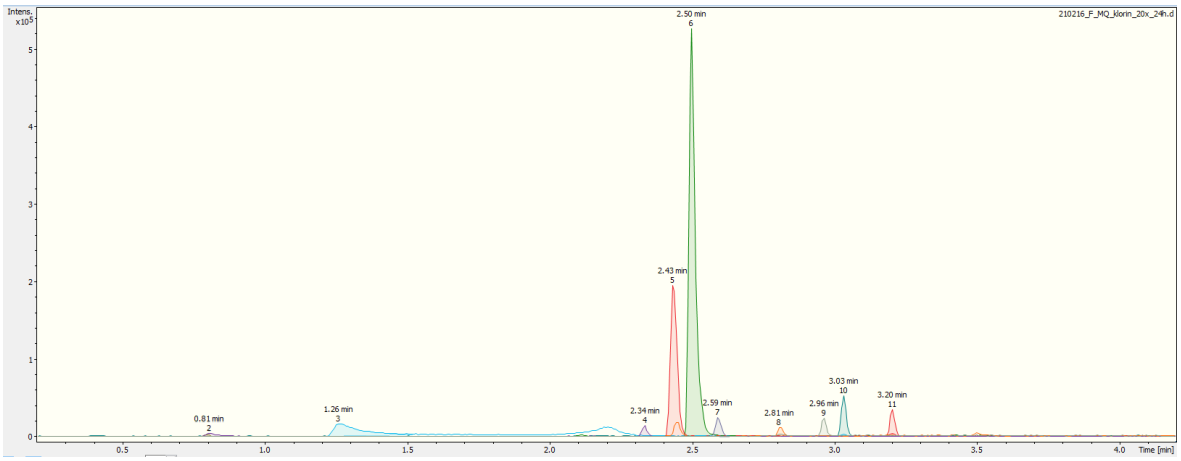


Supplementary figure S1. Chromatogram of degradation products of fentanyl in 10 % H_2O_2 detected by UHPLC-HRMS after 24 h.

Supplementary table S2. Degradation products of fentanyl in bleach detected by UHPLC-HRMS after 24 h.

#	RT (min)	% signal of fentanyl reference	EIC (*m/z*)	Ion formula (incl. H^+)	Comment
2	0.81	<1	192.100	$C_{11}H_{14}NO_2$	
3	1.26	2.7	233.165	$C_{14}H_{21}N_2O$	$-C_8H_8$ (norfentanyl)
4	2.34	<1	266.100	$C_{13}H_{16}NO_5$	$-C_9H_{13}N + O_4$
5	2.43	7.6	355.202	$C_{21}H_{27}N_2O_3$	$-CH_2+O_2$
Fentanyl	2.48	<0.3	337.227	$C_{22}H_{29}N_2O$	
6	2.50	20	353.220	$C_{22}H_{29}N_2O_2$	+O (N-oxide)
7	2.59	<1	437.222	$C_{22}H_{27}N_2O_3Cl_2$	
8	2.81	<1	369.217	$C_{22}H_{27}N_2O_3$	$-H_2+O_2$
9	2.96	<1	351.207	$C_{22}H_{27}N_2O_2$	$-H_2$ + O
10	3.03	1.4	267.126	$C_{14}H_{20}N_2OCl$	$-C_8H_9$ + Cl (norfentanyl+Cl?)
11	3.20	1	389.163	$C_{21}H_{26}N_2O_3Cl$	$-CH_3 + ClO_2$

Extracted ion chromatogram = EIC, retention time = RT.

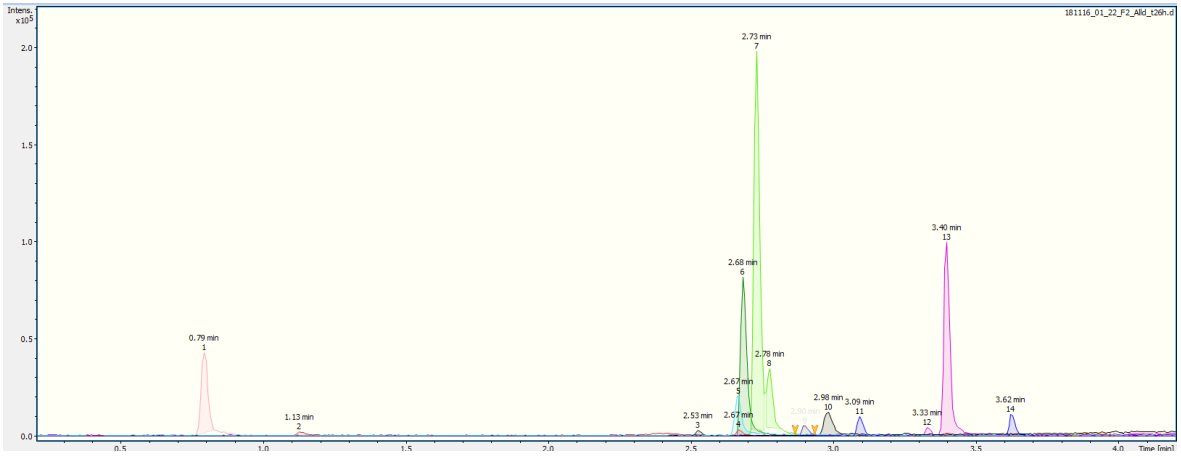


Supplementary figure S2. Chromatogram of degradation products of fentanyl in bleach detected by UHPLC-HRMS after 24 h.

Supplementary table S3. Degradation products of fentanyl in alldecont MED, detected by UHPLC-HRMS after 26 h.

#	RT (min)	% signal of fentanyl reference	EIC (*m/z*)	Ion Formula (incl. H^+)	Comment
1	0.79	3.5	192.102	$C_{11}H_{14}NO_2$	$-C_{11}H_{15}N + O$
2	1.13	<1	233.165	$C_{14}H_{21}N_2O$	$-C_8H_8$ (norfentanyl)
3	2.53	<1	266.103	$C_{13}H_{16}NO_5$	
4	2.67	<1	255.202	$C_{21}H_{27}N_2O_3$	
5	2.67	1.7	150.091	$C_9H_{12}NO$	$-C_{13}H_{17}N$
Fentanyl	2.68	6.7	337.227	$C_{22}H_{29}N_2O$	
7	2.73	14.4	353.222	$C_{22}H_{29}N_2O_2$	+ O, N-oxide
8	2.78	2.3	353.222	$C_{22}H_{29}N_2O_2$	+ O, N-oxide
9	2.90	<1	437.139	$C_{22}H_{27}N_2O_3Cl_2$	$-H_2 + Cl_2O_2$
10	2.98	1.3	244.191	$C_{13}H_{26}NO_3$	
11	3.09	<1	258.089	$C_{12}H_{17}NO_3Cl$	$-C_{10}H_{12}N + ClO_2$
12	3.33	<1	351.207	$C_{22}H_{27}N_2O_2$	$-H_2 + O$
13	3.40	7.5	267.126	$C_{14}H_{20}N_2OCl$	$-C_8H_9 + Cl$ (norfentanyl+Cl?)
14	3.62	<1	389.163	$C_{21}H_{26}N_2O_3Cl$	$-CH_3 + ClO_2$

Extracted ion chromatogram = EIC, retention time = RT.

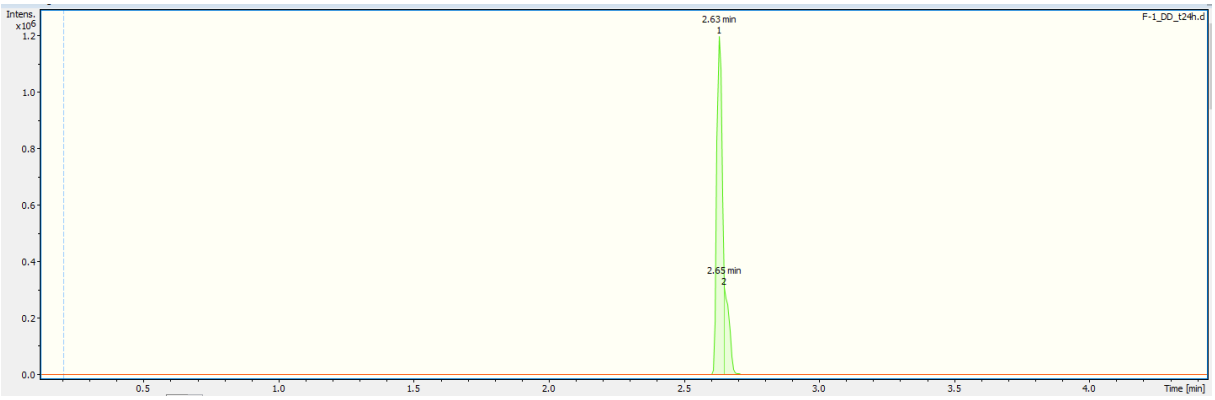


Supplementary figure S3. Chromatogram of degradation products of fentanyl in alldecont MED detected by UHPLC-HRMS after 26 h.

Supplementary table S4. Degradation products of fentanyl in DahlgrenDecon detected by UHPLC-HRMS after 24 h.

#	RT (min)	% signal of fentanyl reference	EIC (*m/z*)	Ion formula (incl. H^+)	Comment
Fentanyl	2.59	<0.3	337.227	$C_{22}H_{29}N_2O$	
1	2.63	107	353.222	$C_{22}H_{29}N_2O_2$	+ O (N-oxide)
2	2.65	27	353.222	$C_{22}H_{29}N_2O_2$	+ O (N-oxide)

Extracted ion chromatogram = EIC, retention time = RT.

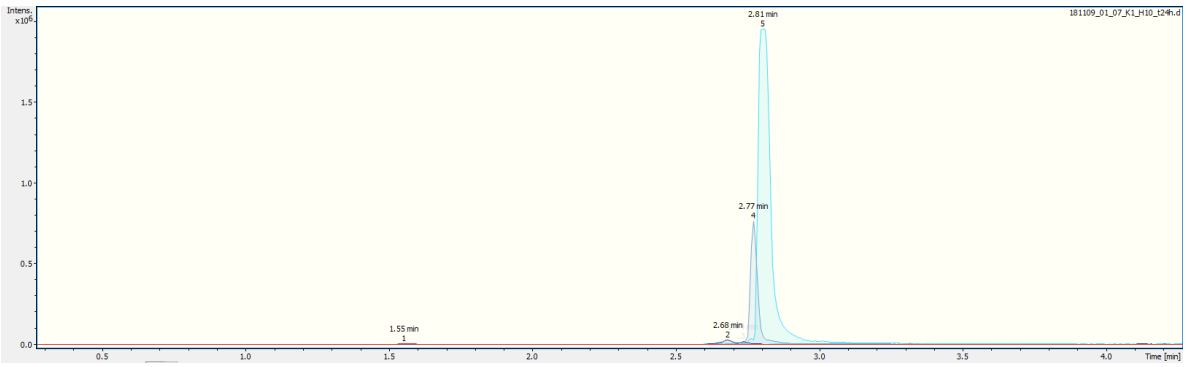


Supplementary figure S4. Chromatogram of degradation products of fentanyl in DahlgrenDecon detected by UHPLC-HRMS after 24h

Supplementary table S5. Degradation products of carfentanil in 10 % H_2O_2 detected by UHPLC-HRMS after 24 h.

#	RT (min)	% signal of carfentanil reference	EIC (*m/z*)	Ion formula (incl. H^+)	Comment
1	1.55	<1	291.170	$C_{16}H_{23}N_2O_3$	Norcarfentanil
2	2.68	<1	427.2227	$C_{24}H_{31}N_2O_5$	$+O_2$
3	2.74	<1	427.2227	$C_{24}H_{31}N_2O_5$	$+O_2$
4 Carfentanil	2.77	13	395.233	$C_{24}H_{31}N_2O_3$	
5	2.81	84	411.228	$C_{24}H_{31}N_2O_4$	+ O (N-oxide)

Extracted ion chromatogram = EIC, retention time = RT.

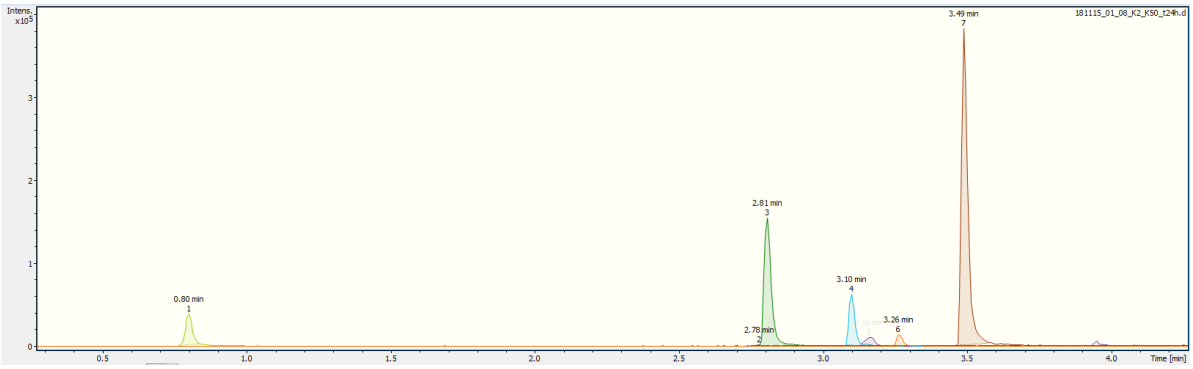


Supplementary figure S5. Chromatogram of degradation products of carfentanil in 10 % H_2O_2 detected by UHPLC-HRMS after 24 h.

Supplementary table S6. Degradation products of carfentanil in bleach detected by UHPLC-HRMS after 24 h.

#	RT (min)	% signal of carfentanil reference	EIC (*m/z*)	Ion formula (incl. H^+)	Comment
1	0.80	2.5	192.102	$C_{11}H_{14}NO_2$	$-C_{13}H_{17}NO$
Carfentanil	2.78	<1	395.233	$C_{24}H_{31}N_2O_3$	
3	2.81	10.6	411.227	$C_{24}H_{31}N_2O_4$	+ O (N-oxide)
4	3.10	3.4	258.089	$C_{12}H_{17}NO_3Cl$	$-C_{12}H_{14}NO + Cl$
5	3.16	<1	383.195	$C_{22}H_{27}N_2O_4$	$-C_2H_4 + O$
6	3.26	<1	228.078	$C_{11}H_{15}NO_2Cl$	$-C_{13}H_{16}NO + Cl$
7	3.49	24	325.14	$C_{16}H_{22}N_2O_3Cl$	$-C_8H_9 + Cl$ (Norcarfentanyl+Cl?)

Extracted ion chromatogram = EIC, retention time = RT.

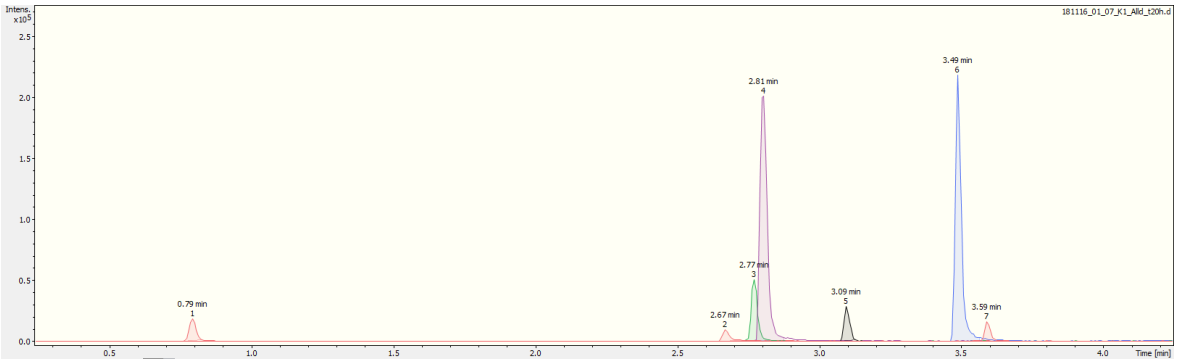


Supplemetary figure S6. Chromatogram of degradation products of carfentanil in bleach detected by UHPLC-HRMS after 24 h.

Supplementary table S7. Degradation products of carfentanil in alldecont MED, detected by UHPLC-HRMS after 20 h.

#	RT (min)	% signal of carfentanil reference	EIC (*m/z*)	Ion formula (incl. H^+)	Comment
1	0.79	<1	192.102	$C_{11}H_{14}NO_2$	$-C_{13}H_{17}NO$
2	2.67	<1	150.091	$C_9H_{12}NO$	$-C_{15}H_{19}NO_2$
Carfentanil	2.77	1.6	395.233	$C_{24}H_{31}N_2O_3$	
4	2.81	7.5	411.228	$C_{24}H_{31}N_2O_4$	+ O (N-oxide)
5	3.09	<1	258.089	$C_{12}H_{17}NO_3Cl$	$-C_{12}H_{14}N + Cl$
6	3.49	6.6	325.14	$C_{16}H_{22}N_2O_3Cl$	$-C_8H_9 + Cl$ (norcarfentanil+Cl?)
7	3.59	<1	361.071	$C_{15}H_{19}N_2O_4Cl_2$	$-C_9H_{12} + Cl_2O$

Extracted ion chromatogram = EIC, retention time = RT.

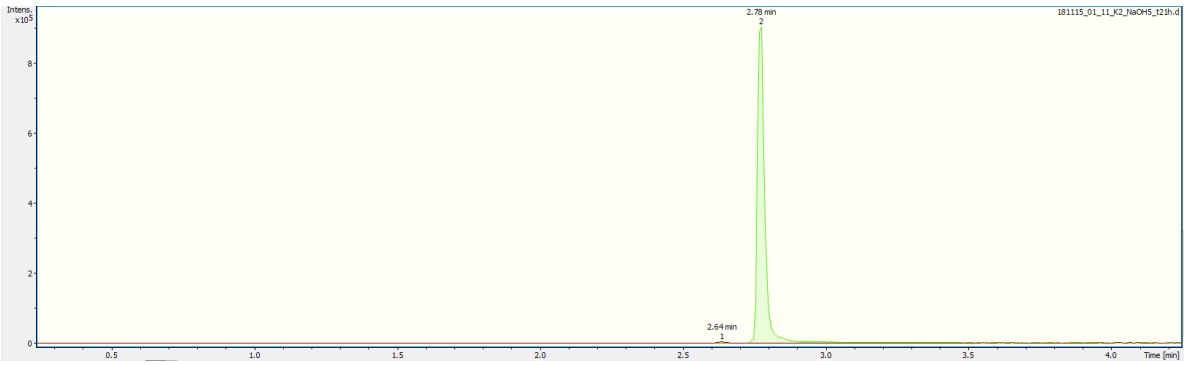


Supplementary figure S7. Chromatogram of degradation products of carfentanil in alldecont MED detected by UHPLC-HRMS after 20 h.

Supplementary table S8. Degradation product of carfentanil in NaOH detected by UHPLC-HRMS after 21 h.

#	RT (min)	% signal of carfentanil reference	EIC (*m/z*)	Ion formula (incl. H^+)	Comment
1	2.64	<1	281.2173	$C_{23}H_{29}N_2O_3$	$-CH_2$
Carfentanil	2.77	21	395.233	$C_{24}H_{31}N_2O_3$	

Extracted ion chromatogram = EIC, retention time = RT.

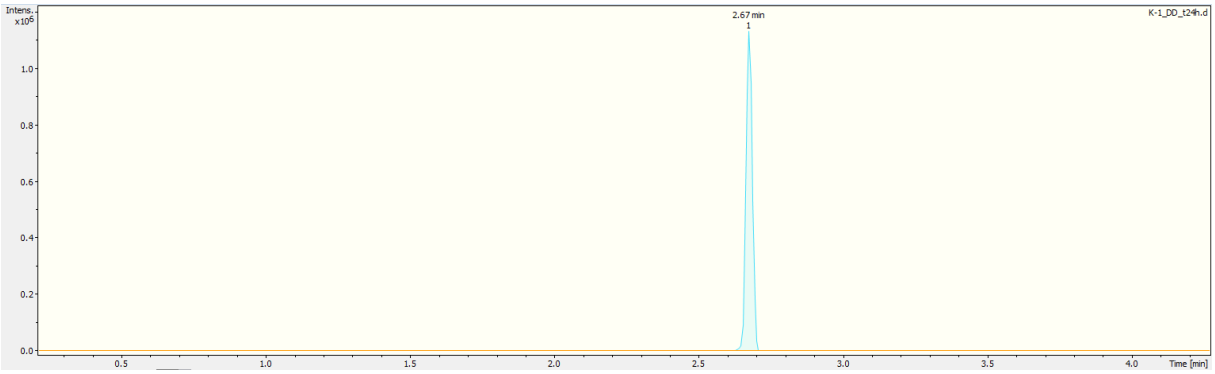


Supplementary figure S8. Chromatogram of degradation products of carfentanil in NaOH detected by UHPLC-HRMS after 21 h.

Supplementary table S9. Degradation products of carfentanil in DahlgrenDecon detected by UHPLC-HRMS after 24 h.

#	RT (min)	% signal of carfentanil reference	EIC (*m/z*)	Ion formula (incl. H^+)	Comment
Carfentanil	2.65	<0.3	395.233	$C_{24}H_{31}N_2O_3$	
1	2.67	99	411.228	$C_{24}H_{31}N_2O_4$	+ O (N-oxide)

Extracted ion chromatogram = EIC, retention time = RT.



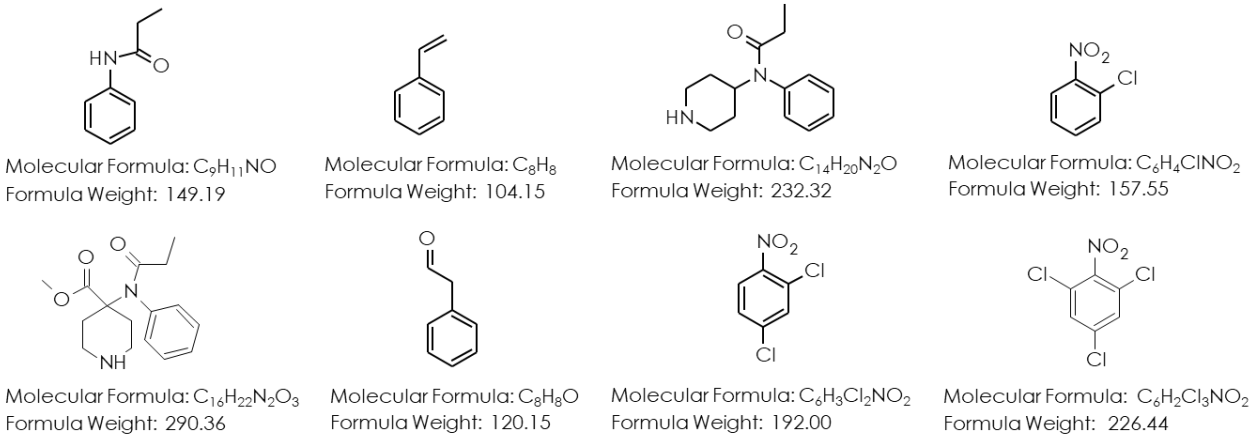
Supplementary figure S9. Chromatogram of degradation products of carfentanil in DahlgrenDecon detected by UHPLC-HRMS after 24 h.

GC/HRMS data for detected degradation products

Aliquots (100 µL) of degradation solutions were extracted using 2 × 500 µL of dichloromethane. The percentage signal of the fentanyl reference was determined. The extracts were analyzed by GC-HRMS using a Thermo Scientific Exactive GC Orbitrap GC/MS system. The experimental GC conditions were as follows: initial temperature of 40 °C for 1 minute, followed by ramping the temperature at 10 °C per minute until 300 °C, then maintaining the temperature at 300 °C for 5 minutes. A DB-5MS column (30 m length, 0.25 mm inner diameter, 0.25 µm film thickness), injection volume of 1 µL and injection temperature of 280 °C were used. Mass spectrometry parameters were as follows: scan range 30-750 *m/z*, scan rate 12 Hz, resolution 30k, ion source temperature 230 °C, transfer line temperature 250 °C. Data analysis was performed using Thermo Xcalibur software in combination with NIST17.

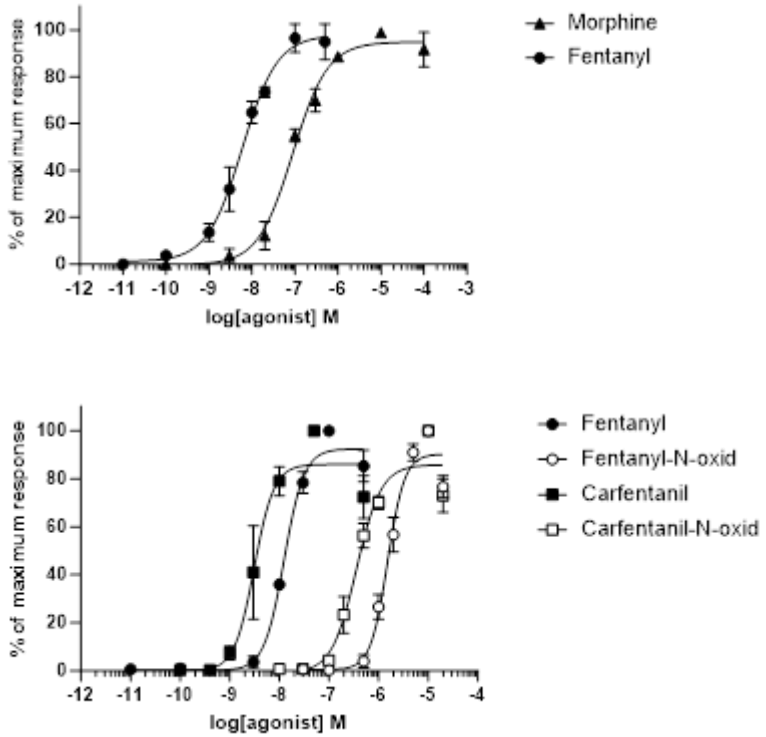
Supplementary table S10. Degradation products of fentanyl and carfentanil detected by GC-HRMS in different decontamination solutions presented as % signal of the fentanyl/carfentanil reference.

	Decontamination solution	$C_9H_{11}NO$ Mw 149.19	C_8H_8 Mw 104.15	Norfentanyl $C_{14}H_{20}N_2O$ Mw 232.32	$C_6H_4ClNO_2$ Mw 157.55	$C_{16}H_{22}N_2O_3$ Mw 290.36	C_8H_8O Mw 120.15	$C_6H_3Cl_2NO_2$ Mw 192.00	$C_6H_2Cl_3NO_2$ Mw 226.44
Fentanyl	H_2O_2 (10 %)	8 %	11 %	5 %					
	alldecont MED	2 %	< 1 %						
	bleach	< 1 %			< 1 %			<1%	< 1%
Carfentanil	H_2O_2 (10 %)	12 %	16 %			4 %	< 1 %		
	alldecont MED	2 %	< 1 %			< 1%			
	bleach	2 %	< 1 %			< 1 %			



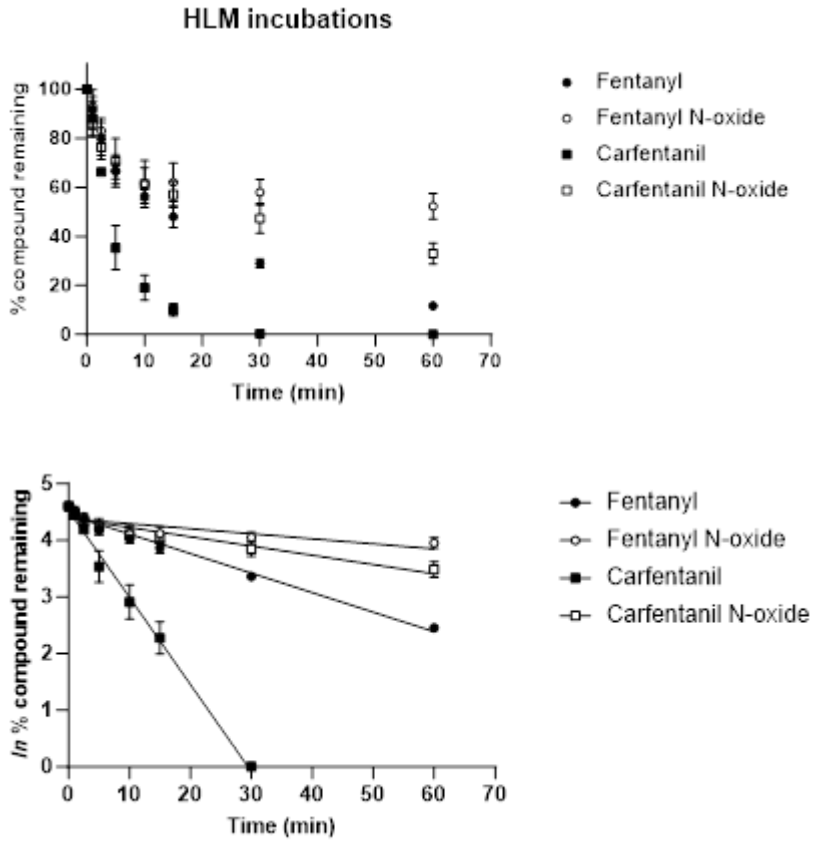
Supplementary figure S10. Degradation products of fentanyl and carfentanil detected by GC-HRMS in different decontamination solutions.

Dose-response curves for N-oxide activation of the human μ-opioid receptor



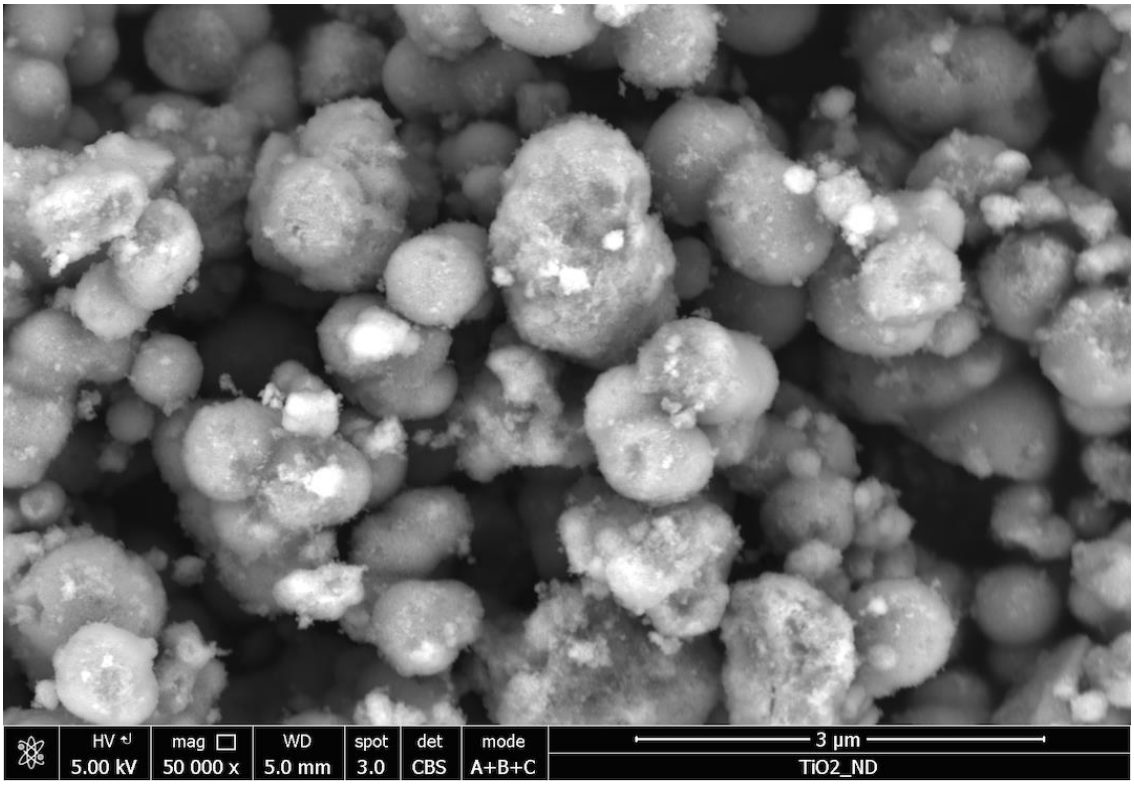
Supplementary figure S11. Dose-response curves measured in the human μ-opioid receptor activation assay.

Metabolism data of fentanyl- and carfentanil N-oxides in human liver microsomes

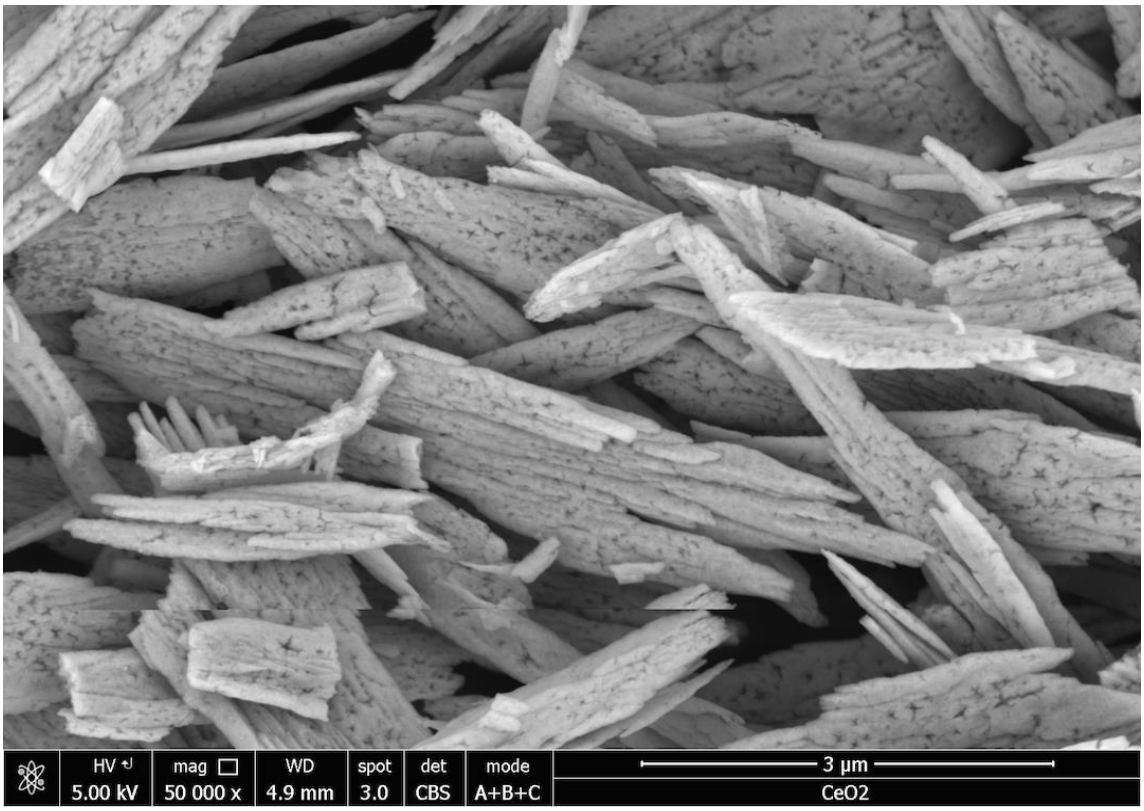


Supplementary figure S12. Human liver microsome (HLM) incubations. Compound depletion over 60 minutes, and log linear regression of percentage of compound remaining against time for calculation of compound half-life in HLM.

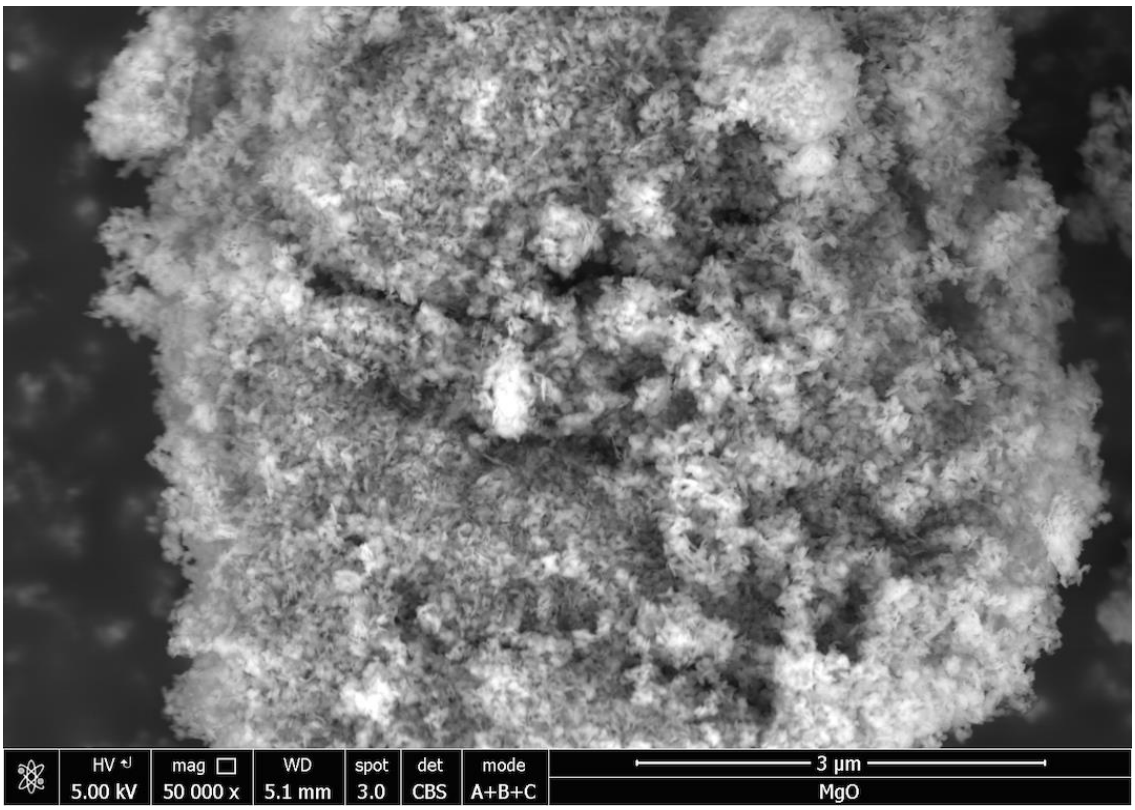
Representative SEM images



Supplementary figure S13. Representative SEM image of the TiO_2-ND sample. The crystallite size was about 10 nm, the BET surface area 232 m^2/g and total pore volume 0.28 cm^3/g.



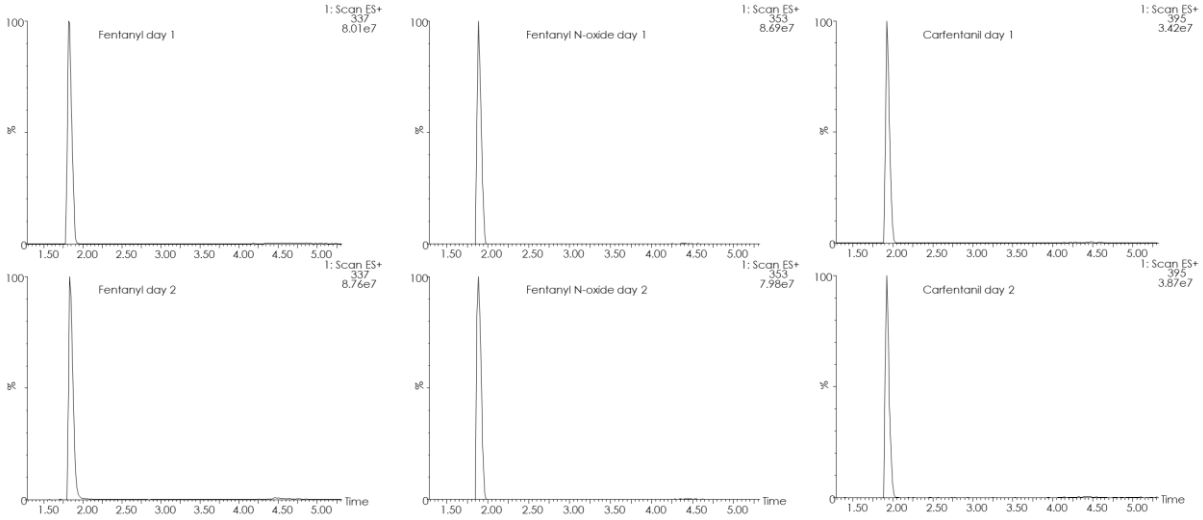
Supplementary figure S14. Representative SEM image of the CeO_2 sample. The crystallite size was about 28 nm, BET surface area 85 m^2/g and total pore volume 0.07 cm^3/g.



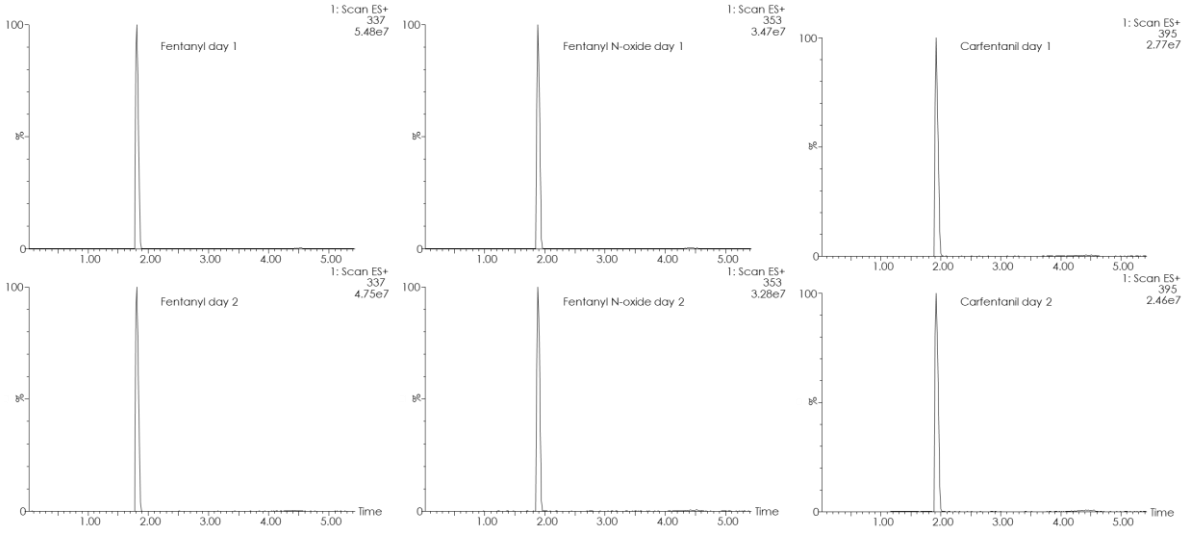
Supplementary figure S15. Representative SEM image of the MgO sample. The BET surface area was about 125 m^2/g.

Stability of fentanyl, fentanyl N-oxide and carfentanil in water and acetonitrile

The compounds were dissolved in both Milli-Q water and acetonitrile to a concentration of 10 µg/ml and 2 µg/ml, respectively. The same sample were then analyzed for two consecutive days, and stored in room temperature in-between analysis. The samples were also analyzed three times in a row to calculate the relative standard deviation (RDS%) between runs. The results showed that the RDS% between runs were between 3-6 % depending on compound. As shown in Figure S16 and S17, fentanyl, fentanyl N-oxide and carfentanil where all stable in both water and acetonitrile when stored in room temperature for two days.



Supplementary figure S16. Mass chromatogram of fentanyl (m/z = 337), fentanyl N-oxide (m/z = 353) and carfentanil (m/z = 395) dissolved in Milli-Q water. The same sample was analysed for two consecutive days. The relative standard deviation was between 0.5 % for N-oxide and 8.0 % for carfentanil.



Supplementary figure S17. Mass chromatogram of fentanyl (m/z = 337), fentanyl N-oxide (m/z = 353) and carfentanil (m/z = 395) dissolved in acetonitrile. The same sample was analysed for two consecutive days. The relative standard deviation was between 2.2 % for fentanyl and 8.3 % for fentanyl N-oxide.