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Research article

IDENTIFICATION OF HAZARDS FOR HUMAN HEALTH UNDER CHEMICAL POLLUTION IN AIR INSIDE IN-PATIENT HOSPITALS

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Use of various physical and chemical research techniques, including chromato-mass-spectrometry, made it possible to identify and quantify more than 40 organic compounds in air inside healthcare organizations, including saturated, unsaturated, cyclic, and aromatic hydrocarbons; terpenes, alcohols, aldehydes, esters, ketones, halogen-containing compounds, and organic acids. Levels of ethanol, dichloromethane, carbon tetrachloride, ethyl acetate, propyl acetate, acetone, terpene hydrocarbons, and acetic acid made the main contribution to the total content of all identified compounds. Most detected substances were present in concentrations not exceeding hygienic standards, except for chloroform and iodoform, the levels of which were up to 2 times higher than average daily MPL in intensive care wards and a bronchoscopy room. Organic acids and chlorinated organic compounds were found in elevated concentrations compared with insides of non-medical public buildings. Among the wide list of identified substances, hygienic standards have not been established for more than 70 % of compounds and it is not possible to give a hygienic assessment of hazards or safety of their presence in air inside healthcare facilities. Despite that, the information obtained in this study is extremely useful for accomplishing an important stage in health risk analysis, which is identification of hazards for health of patients and healthcare workers posed by chemical air pollution inside healthcare organizations when using the risk analysis methodology.

In this study, we assessed effects produced by operations of UV recirculator irradiators for air disinfection on its chemical composition inside healthcare institutions. The assessment showed that when such devices worked in the presence of patients and staff, there was an increase in the amount of pollutants in air and their total concentration grew from two to more than four times.

When analyzing risks for health of staff and patients, hazard identification within risk-based control of chemical air pollution in the hospital environment should include monitoring of formaldehyde, styrene, ammonia, ethanol, isopropanol, chloroform, dichloroethane, acetic acid along with identification of a wide range of volatile organic compounds; it should also cover ammonia as one of the priority pollutants occurring in the environment from human excretory products.

Keywords: *chemical pollution, air, in-patient hospitals, internal sources of chemical pollution, physical and chemical research, chromato-mass spectrometric identification, hazard identification, priority chemicals for monitoring, closed-type UV irradiators, risk analysis.*

Air pollution is a major ecological threat for human health. The RF President Order dated March 11, 2019 No. 97 On the Basics of the RF State Policy in the Sphere of Providing Chemical and Biological Safety for the Period up to 2025 and beyond[1] stipulates several priority trends of the state policy in the sphere of providing chemical and biological safety. They include monitoring of chemical risks, development of legal regulations, implementation of activities aimed to prevent and minimize chemical risks, stronger protection of the country population and environment from adverse effects produced by hazardous chemical factors, as well as assessment of effectiveness and chemical safety of 'air cleaning and disin-

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[1] Ob osnovakh gosudarstvennoi politiki Rossiiskoi Federatsii v oblasti obespecheniya khimicheskoi i biologicheskoi bezopasnosti na period do 2025 goda i dal'neishuyu perspektivu: Ukaz Prezidenta RF ot 11 marta 2019 g. № 97 [On the basics of the RF state policy in the sphere of providing chemical and biological safety for the period up to 2025 and beyond: the RF President Order dated March 11, 2019 No. 977]. *GARANT.RU: information and legal portal*. Available at: https://www.garant.ru/products/ipo/prime/doc/72092478/ (December 17, 2023) (in Russian).

fecting' components of implemented environment protection activities.

Complex analysis of chemical pollution in the environment, identification of new chemical hazards and prediction of their possible outcomes are among priority tasks of the state policy in the sphere of chemical safety concerning monitoring of chemical pollution in the environment. Another important task is to assess effectiveness and chemical safety of technologies applied in air conditioning, disinfection and cleaning of the environment.

Chemical cleanness of air inside in-patient hospitals is an important factor in providing the best conditions for patients' fastest recovery and recreation as well as protecting health of medical personnel [1, 2].

It is a well-known fact that patients and healthcare workers are exposed to a whole set of physical and chemical factors inside modern in-patient hospitals. Such factors include radiation, electromagnetic radiation of various frequencies, noise, ion and ozone exposures, UV-radiation, and chemical pollution of indoor air.

Better provision of healthcare organizations with technical equipment, implementation of up-to-date medical equipment and devices, use of effective disinfectants and disinfecting technologies, new furniture, new medications and new treatment methods are the reason for physical and chemical factors creating a specific indoor environment in in-patient hospitals alongside biological contamination. This specific environment can affect patients' treatment and recovery [3–7]. Our studies have revealed that in-patients hospitals are places with elevated health risks caused by exposure to adverse factors intrinsic for indoor environment in them [8]. This creates higher sanitary-epidemiological and hygienic requirements to indoor air quality, on the one hand, for patients' recovery and, on the other hand, for providing safe workplace settings for healthcare workers.

Given that, further development of methods applied to assess a sanitary-hygienic situation is a most significant guarantee of more qualitative healthcare. This includes chemical and analytical monitoring of chemical pollution in air inside healthcare organizations and chemical safety of technologies applied to clean and disinfect it.

In this study, our aim was to assess chemical pollution of air inside healthcare organizations performing different functions. The assessment involved identifying and quantifying the maximum full range of volatile organic compounds and establishing priority pollutants with the highest hygienic significance. This was necessary for accomplishing the hazard identification stage within risk-based control of the indoor environment inside in-patient hospitals.

Materials and methods. We chose three in-patients hospitals as our research objects. They were a multi-profile municipal clinical hospital, a maternity hospital and an in-patient hospital of a scientific research institute specializing in treating inflammatory bowel disease. We identified and quantified chemical pollution in air inside surgery wards, patient wards, treatment and dressing rooms, laboratory and diagnostic rooms, a physiotherapy department, staff rooms, corridors, buffets, and nutrition units. Overall, we examined 96 premises with various functional purposes. Also, the attention focus was on such research objects as supply-exhaust ventilation systems and split systems installed in the examined premises.

Snap samples were taken in the examined premises in different seasons. Sampling was made in a usual operation environment for these premises considering typical microclimatic parameters and ventilation work modes in accordance with the construction design with closed windows and doors. No further measures were taken to make the examined premises more airtight. Air samples were taken in an average breathing zone at a height between 1 and 1.5 meters from the floor. At least three air samples were taken in each premise.

Some experimental investigations were accomplished in laboratories equipped with three different kinds of closed-type UV recirculator irradiators (different makes). It was done to assess influence exerted by new disinfection technologies on chemical pollution in air inside healthcare organizations. It is allowed to use UV-devices in such premises for a long time even when people are present in them. All three different makes of UV recirculator irradiators were equipped with ozone-free bactericidal lamps.

We identified chemicals that polluted air inside in-patient hospitals by chromatography-mass spectrometry and photocolorimetry. Chromatography-mass spectrometry made it possible to identify and quantify practically the entire range of volatile organic compounds present in indoor air in the examined in-patient hospitals with sensitivity equal to or even below the existing hygiene standards. Chromatographic-mass spectrometric investigations were accomplished on a gas chromatograph mass spectrometer Focus DSQ (USA) in conformity with the relevant methodical documents[2].

Levels of formaldehyde and nitrogen oxides were identified in air by using colorimetric methods. Ozone levels were identified with an ozone gas analyzer 3.02P-R; oxygen, gas analyzer PKG-4; carbon dioxide, gas analyzer Optogaz 500.4S. Levels of mercury vapors were identified in indoor air with a mercury analyzer, model RA-915M.

Levels of identified chemicals were compared with average annual, average daily and single maximum permissible levels (MPL) established for ambient air in residential areas; in case such MPLs were absent, the established levels were compared with tentative safe exposure levels (TSEL)[3].

Results and discussion. Indoor air quality is known to depend, to a great extent, on ambient air quality as regards its chemical structure. All buildings, including those used by healthcare organizations, have constant air exchange with the external environment and therefore are unable to protect people from ambient air pollution even in premises with installed air conditioning [9]. Chemical pollution tends to be even higher inside premises than in ambient air, as regards quantity of identified chemicals and their identified levels as well.

Chromatography-mass spectrometry made it possible to obtain the most comprehensive picture of chemical pollution in air inside in-patient hospitals with volatile organic compounds (VOCs). In particular, we managed to identify their total concentration, which, in case no hygiene standards are provided for a particular chemical, can be an eligible indicator describing chemical pollution in air inside premises.

Table 1 provides VOC levels in air inside some work and staff rooms with different functional purposes in the examined in-patients hospitals. Table 2 provides data on VOC levels in patient wards with different numbers of beds in them.

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[2] MUK 4.1.618-96. Metodicheskie ukazaniya po khromato-mass-spektrometricheskomu opredeleniyu letuchikh organicheskikh veshchestv v atmosfernom vozdukhe [Methodical guidelines on using chromatography-mass spectrometry methods to identify volatile organic compounds in ambient air]. *Opredelenie kontsentratsii zagryaznyayushchikh veshchestv v atmosfernom vozdukhe*: *Sbornik metodicheskikh ukazanii MUK 4.1.591-96–4.1.645-96, 4.1.662-97, 4.1.666-97 [Collection of methodical guidelines MUK 4.1.591-96–4.1.645-96, 4.1.662-97, 4.1.666-97]*. Moscow, Information and Publishing Center of the RF Ministry of Health, 1997, pp. 217–228 (in Russian); MUK 4.1.2594-10. Opredelenie stirola, fenola i naftalina v vozdukhe metodom khromato-mass-spektroskopii, utv. Rukovoditelem Federal'noi sluzhby po nadzoru v sfere zashchity prav potrebitelei i blagopoluchiya cheloveka, Glavnym gosudarstvennym sanitarnym vrachom Rossiiskoi Federatsii G.G. Onishchenko 26 marta 2010 g. [Identification of styrene, phenol and naphthalene in air by using chromatography-mass spectrometry, approved by G.G. Onishchenko, head of the Federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing, the RF Chief Sanitary Inspector on March 26, 2010]. Moscow, Rospotrebnadzor’s Federal Center for Hygiene and Epidemiology, 2010, pp. 1–15 (in Russian).

[3] SanPiN 1.2.3685-21 Gigienicheskie normativy i trebovaniya k obespecheniyu bezopasnosti i (ili) bezvrednosti dlya cheloveka faktorov sredy obitaniya, utv. postanovleniem Glavnogo gosudarstvennogo sanitarnogo vracha Rossiiskoi Federatsii ot 28 yanvarya 2021 goda № 2 [Hygienic standards and requirements to providing safety and (or) harmlessness of environmental factors for people, approved by the Order of the RF Chief Sanitary Inspector on January 28, 2021 No. 2]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/573500115 (December 11, 2023) (in Russian).

Table 1

Volatile organic compounds identified in air inside premises of in-patient hospitals with different functional purposes

No.	Chemical	Concentration, mg/m^3				
		Intensive care ward	Bronchoscopy ward	Gastroscopy ward	Doctor's office	Treatment room
Saturated hydrocarbons						
1	Pentane	< 0.001	< 0.001	< 0.001	0.004	0.007
2	Hexane	0.190	0.080	0.030	0.050	0.060
3	Isooctane	0.006	0.230	< 0.001	0.004	0.001
4	Heptacosane	< 0.001	< 0.001	0.020	< 0.001	< 0.001
Cyclic hydrocarbons						
5	Cyclohexane	0.009	0.003	0.002	0.005	0.001
Unsaturated hydrocarbons						
6	Acetylene	0.060	0.040	0.010	0.010	0.020
7	Isoprene	0.003	0.002	< 0.001	0.005	0.004
Aromatic hydrocarbons						
8	Benzene	0.004	0.001	< 0.001	0.002	0.002
9	Toluene	0.170	0.140	0.050	0.070	0.060
10	Styrene	0.001	0.001	< 0.001	< 0.001	0.002
Terpenes						
11	α-Pinene	0.004	0.003	0.001	0.003	0.002
12	Limonene	0.002	0.001	0.003	0.004	0.001
Oxygen-containing compounds, including						
alcohols						
13	Methanol	0.007	0.003	0.006	0.002	0.001
14	Ethanol	0.110	0.120	0.010	0.010	0.060
15	Isooctadecanol	< 0.001	< 0.001	0.005	< 0.001	< 0.001
organic acids						
16	Acetic	0.002	0.004	< 0.001	0.001	0.001
17	Dodecanoic	0.050	0.070	0.030	0.004	0.002
18	Tetradecanoic	0.040	0.050	0.020	0.001	0.002
19	Pentadecanoic	0.040	0.040	0.010	0.003	0.004
20	Palmitic	0.050	0.070	0.010	0.006	0.005
21	Hexadecenoic	0.020	0.030	0.010	0.001	0.001
22	Oleic	0.030	0.050	0.009	0.002	0.002
mixed and simple ethers						
23	Ethyl acetate	0.020	0.010	0.030	0.010	0.010
24	Dibutyl phthalate	0.090	0.040	0.06	0.005	0.008
25	Dihexyl phthalate	0.004	0.050	0.008	0.001	0.003
26	Monooctyl phthalate	0.009	0.010	0.007	< 0.001	0.030
27	Dioctyl phthalate	0.002	0.003	0.001	0.001	0.004
28	Docotyl adipate	0.040	0.030	0.05	0.008	0.030
29	Diethyl ether	0.060	0.050	0.030	0.010	0.010
aldehydes and ketones						
30	Acetone	0.007	< 0.001	0.003	< 0.001	< 0.001
31	Benzaldehyde	0.010	0.003	0.002	0.006	0.008
32	Formaldehyde	0.001	0.008	0.006	0.010	0.003
33	2 6-butylhydroquinone	0.010	0.005	0.060	0.005	0.004
34	Divinylbenzophenon	0.001	0.001	< 0.001	< 0.001	0.003
terpene ketones						
35	Camphor	0.050	0.030	0.040	0.020	0.020
Sulfur-containing organic compounds						
36	Ethyl mercaptan	0.001	< 0.001	< 0.001	0.001	0.001
37	Dibutyl sulfide	0.001	< 0.001	0.002	< 0.001	0.001

End of the Table 1

No.	Chemical	Concentration, mg/m^3				
		Intensive care ward	Bronchoscopy ward	Gastroscopy ward	Doctor's office	Treatment room
Halogenated organic compounds						
38	Chloroform	0.060	0.050	0.060	0.010	0.020
39	Tetrachloromethane	0.140	0.150	0.090	0.030	0.040
40	Dichloroethane	0.001	0.002	< 0.001	0.005	0.003
41	Hexachloroethane	0.008	0.006	0.005	0.001	0.002
42	Bromomethane	0.001	0.002	0.001	< 0.001	< 0.001
43	Iodoform	0.050	0.030	0.040	0.020	0.020
Total organic compound concentration		1.364	1.418	0.721	0.330	0.458

Table 2

Volatile organic compounds identified in air inside patient wards of in-patient hospitals

No.	Chemical	Concentration, mg/m^3			
		5-bed ward	4-bed ward	2-bed ward	1-bed ward
Saturated hydrocarbons					
1	Hexane and its isomers	0.070	0.050	0.080	0.040
2	Isooctane	0.020	0.010	0.020	0.010
3	Decane	0.003	0.005	0.006	0.010
4	Tetradecane	0.005	0.003	0.008	0.002
5	Hexadecane	0.002	0.001	0.002	0.001
Cyclic hydrocarbons					
6	Cyclohexane	0.007	0.004	0.005	0.006
7	Methyl cyclohexane	< 0.001	0.001	0.002	0.001
Unsaturated hydrocarbons					
8	Isoprene	0.002	0.001	0.001	0.003
Aromatic hydrocarbons					
9	Toluene	0.030	0.020	0.010	0.040
10	o-Xylene	0.002	0.003	0.001	0.001
11	p-Xylene	0.003	0.004	0.006	0.005
Terpenes					
12	α-Pinene	0.040	0.010	0.030	0.020
13	β-Pinene	0.050	0.060	0.090	0.040
14	Limonene	0.010	0.020	0.050	0.060
15	Carene	0.030	0.060	0.030	0.070
Alcohols					
16	Methanol	0.001	< 0.001	0.001	0.002
17	Ethanol	0.060	0.040	0.050	0.080
18	Isopropanol	0.009	0.004	0.003	0.010
19	Isopentanol	0.001	0.001	< 0.001	0.002
Organic acids					
20	Acetic	0.030	0.050	0.070	0.020
21	Propionic	0.008	0.003	0.002	0.006
22	Pentanoic	0.001	0.001	< 0.001	< 0.001
23	Hexanoic	0.001	< 0.001	< 0.001	0.002
Simple and mixed ethers					
24	Methyl acetate	< 0.001	0.004	0.002	< 0.001
25	Ethyl acetate	0.090	0.050	0.030	0.060
26	Propyl acetate	0.001	0.001	0.002	0.002
27	Ethyl propionate	< 0.001	0.001	< 0.001	< 0.001
28	Dibutyl phthalate	0.003	0.002	0.001	0.001

End of the Table 2

No.	Chemical	Concentration, mg/m^3			
		5-bed ward	4-bed ward	2-bed ward	1-bed ward
29	Dioctyl phthalate	0.001	< 0.001	< 0.001	0.001
30	Dioxane	0.003	0.002	0.001	0.002
31	Methyl methacrylate	0.001	0.001	< 0.001	0.001
Aldehydes and ketones					
32	Acetone	0.020	0.030	0.030	0.010
33	Methyl isobutyl ketone	0.001	0.002	0.001	0.003
34	Nonanal	0.001	< 0.001	0.002	< 0.001
35	Formaldehyde	0.004	0.006	0.008	0.003
36	Acetyl acetone	< 0.001	< 0.001	< 0.001	0.001
Terpene ketones					
37	Camphor	0.040	0.020	0.030	0.020
Halogenated organic compounds					
38	Dichloromethane	0.002	0.003	0.002	0.001
39	Chloroform	0.010	0.020	0.010	0.030
40	Tetrachloromethane	0.001	0.008	0.009	0.010
41	Dichloroethane	0.001	0.001	0.001	0.001
42	Tetrachloroethylene	0.003	0.002	0.004	0.003
43	Chlorobenzene	< 0.001	< 0.001	0.002	< 0.001
Total organic compound concentration		0.587	0.434	0.602	0.580

Obviously, the chromatographic-mass spectrometric investigations, which aimed to identify and quantify a wide range of chemical in environmental objects, established more than 40 volatile organic compounds in air inside in-patient hospitals with different functional purposes. These chemicals belonged to different groups including saturated, unsaturated, cyclic, and aromatic hydrocarbons; terpenes; alcohols; aldehydes; ethers; ketones; halogenated organic compounds; organic acids. Chemical air pollution inside premises with different functional purposes has different quantitative and qualitative structure and depends on presence or absence of internal pollution sources, in particular, use of technical or chemical cleaners, disinfectants or air conditioning as well as use of different technical devices for diagnostics or maintaining patients' vital activities.

Levels of ethanol, dichloromethane, tetrachloromethane, ethyl acetate, propyl acetate, acetone, terpene hydrocarbons, and acetic acids were shown to make the major contribution to the total concentrations of all identified organic compounds.

It is noteworthy that most identified chemicals were detected in concentrations not exceeding the existing hygiene standards. Chloroform and iodoform were the only exceptions with their levels being almost 2 times higher than the existing standards in the intensive care ward and the bronchoscopy ward.

At the same time, our attention was drawn to chemicals occurring in air in concentrations higher than their usual levels inside non-medical public buildings. Such chemicals include organic acids and chlorinated organic compounds. The highest chemical levels were established in air inside the intensive care ward and the bronchoscopy ward.

In addition to that, higher levels of ethanol, acetone, acetic acid and terpenes (α-pinene, β-pinene, limonene, and carene) were established in air inside patient wards. It is worth noting that we did not identify any significant differences in levels of chemical pollution in air between wards with different number of beds since their square and volume per one patient conformed to the existing regulations.

It is rather alerting that among the wide list of identified substances, hygienic standards have not been established for more than 70 % of compounds and therefore it is not possible to give a hygienic assessment of hazards or safety of their presence in air inside healthcare facilities. In an effort to achieve that, as well as to perform comparative monitoring of chemical pollution in air inside wards with different functional purposes, we calculated the total volatile organic compound concentration covering all chemicals identified in air inside the examined premises.

Despite the fact that a total volatile organic compound concentration in air cannot fully describe health hazards posed by chemical contamination, it is still used quite often in present studies by many researchers both for comparative assessment and for assessment of total chemical pollution in indoor air [10–13]. It should also be noted that any information about identification of a wide range of organic compounds in air inside in-patient hospitals can be extremely useful at the hazard identification stage within analysis of health risks for healthcare workers and patients caused by chemical pollution in air inside in-patient hospitals.

In some countries, suggestions have been made to develop some regulations as regards a total volatile organic compound concentration in air inside premises not used for any production [14–17]. Thus, in Germany and Great Britain, a total volatile organic compound concentration in indoor air below 0.3 mg/m³ is considered safe in case hygiene standards are not violated for any of identified chemicals. This value is 0.5 mg/m³ in China; 0.4 mg/m³ in Japan; between 0.2 and 0.6 mg/m³ in Finland [18].

The total volatile organic compound concentrations established in air inside premises in in-patient hospitals with different functional purposes and patient wards (Tables 1 and 2) clearly show it is rather inadvisable to use this indicator to assess either health hazards or safety. At the same time, the said indicator can be effectively used to make comparative assessments of chemical pollution in air when it comes down to premises with the same functional purpose or to assess effectiveness and safety of cleaning, disinfecting or air- conditioning technologies applied inside a given premise.

Table 3 provides ranges of total volatile organic compound concentrations and levels of pother chemicals in air inside all examined premises in in-patient hospitals.

Obviously, the highest total volatile organic compound concentrations were established in air inside patient wards; the lowest ones, in surgery wards, treatment and dressing rooms.

Levels of mercury vapors were below the established safety standards in all examined premises and the chemical was identified only in trace quantities.

Levels of carbon dioxide and oxygen directly depended on a number of people in a room and time they spent inside it as well as on ventilation system functioning.

Monitoring of ozone levels in air inside in-patient hospitals revealed its levels to be 0.005–0.03 mg/m³ in summer, which is either equal or below its average daily maximum

Table 3

Ranges of identified chemical concentrations in indoor air inside in-patient hospitals

Indicator, concentration		Research objects				
		Patient wards	Surgery wards, treatment and dressing rooms	Diagnostic rooms and laboratories	Physiotherapeutic wards	Auxiliary rooms (nutrition units and corridors)
Total volatile organic compound concentration, mg/m³		0.43–1.67	0.27–0.46	0.36–1.42	0.35 – 0.88	0.38–1.45
Mercury vapors, mg/m³		< 0.00005	< 0.00003	< 0.00003	< 0.00004	< 0.00005
Ozone, mg/m³	summer	0.0–0.03	0.001–0.01	0.0–0.005	0.01–0.03	0.0–0.03
	winter	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Carbon dioxide, pmm		400–1600	400–610	600–1200	500–800	450–710
Oxygen, %		20.6–20.8	20.8–21.4	19.0–20.1	20.0–20.9	20.8–21.0

permissible level in ambient air in residential areas (0.03 mg/m^3). In autumn and winter, when windows are usually closed, ozone was not identified in indoor air in in-patient hospitals.

Therefore, we established that air inside modern healthcare facilities tends to have a multi-component chemical structure, which is formed mostly depending on presence of internal pollution sources and their capacity. It is noteworthy that not only construction and finishing materials or human excretory products create chemical pollution in indoor air in healthcare organizations. A considerable contribution to it is also made by disinfectants, medications, and medical devices applied both to treat patients and to maintain proper quality of indoor air.

Thus, at present UV recirculator irradiators are widely used to disinfect air in healthcare facilities. However, when they work for a long time in premises where people are present, complaints are often made as regards some alien unpleasant smells [19–21].

Effects produced by UV recirculator irradiators manufactured by different companies and applied to disinfect air inside healthcare organizations were examined in an experiment with a chamber. Table 4 provides the results of these investigations including a wide range of identified chemicals and their levels in air inside the experimental chamber prior to and after treatment with UV irradiators.

Table 4

Chemical structure of air inside the chamber prior to after 3-hour treatment with different UV recirculator irradiators

No.	Chemical	RfC, mg/m^3	MPL*, mg/m^3	Concentration, mg/m^3			
				Background	No. 1	No. 2	No. 3
1	Ethanol	n/id	5.0	0.15	0.22	0.25	0.12
2	Acetone	31.0	0.35**	0.10	0.13	0.16	0.14
3	Isopropanol	0.2	0.6**	0.015	0.015	0.016	0.015
4	Pentane	1.0	25.0	0.01	0.01	0.01	0.011
5	Ethyl acetate	0.07	0.1	0.04	0.05	0.04	0.06
6	Benzene	0.005	0.1	0.010	0.020	0.015	0.010
7	Toluene	0.4	0.6	0.03	0.04	0.07	0.13
8	Hexanal	n/id	0.02**	0.015	0.020	0.020	0.060
9	Butyl acetate	n/id	0.1	0.012	0.012	0.012	0.010
10	Ethylbenzene	1.0	0.02	0.013	0.013	0.015	0.020
11	m,p-Xylenes	0.1	0.2	0.035	0.040	0.090	0.170
12	o-Xylene	0.1	0.2	0.032	0.045	0.060	0.120
13	Nonane	0.02	n/id	0.02	0.04	0.90	0.18
14	a-Pinene	n/id	0.3**	0.06	0.10	0.10	0.11
15	Methylpropyl cyclohexane	n/id	n/id	< 0.001	0.07	0.09	0.15
16	Decane	n/id	n/id	0.06	0.25	0.40	0.60
17	Undecane isomers	n/id	n/id	0.02	0.12	0.16	0.20
18	Methylbutyl cyclohexane	n/id	n/id	< 0.001	0.120	0.140	0.160
19	Undecane	n/id	n/id	0.07	0.40	0.30	0.65
20	Dodecane isomers	n/id	n/id	0.012	0.060	0.040	0.040
21	Pentyl cyclohexane	n/id	n/id	< 0.001	0.05	0.03	0.03
22	Dodecane	n/id	n/id	0.08	0.01	0.09	0.12
23	Styrene	1.0	0.002	< 0.001	< 0.001	0.002	< 0.001
24	Nitrogen oxide	0.06	0.06	0.015	0.017	0.020	0.015
25	Nitrogen dioxide	0.04	0.04	0.020	0.025	0.029	0.020
26	Carbon oxide	3.0	3.0	1.0	1.0	1.0	1.0
Total organic compound concentration				0.784	1.835	3.010	3.206

Note: RfC is maximum acceptable concentration below which no adverse health effects should result from long (chronic) exposure in most sensitive individuals; * means average daily maximum permissible level ($MPL_{av.d.}$) of pollutants in ambient air in residential areas (Sanitary Rules and Norms SanPiN 1.2.3685-21); ** means single maximum permissible level MPL_s of pollutants in ambient air in residential areas (Sanitary Rules and Norms SanPiN 1.2.3685-21).

Obviously, work of each examined device resulted in occurrence of methylpropyl-, methylbutyl- and pentyl cyclohexanes, saturated acyclic hydrocarbons, in air in the examined premises. All these chemicals have not been identified in background air. By now, safety standards have been established only for one chemical in this group, namely cyclohexane. Its single maximum permissible level ($MPL_{s.}$) is 1.4 mg/m³ in air in residential areas. The chemical is of hazard class IV. It is noteworthy that saturated acyclic hydrocarbons can be found in oil and gases and are widely used as solvents in fuels.

In addition to that, work of UV irradiators creates higher levels of nonane (between 2 and 45 times), decane (up to 10 times), undecane (up to 10 times, xylenes (up to 4 times), toluene (more than 4 times), benzene (up to 2 times), hexanal (up to 4 times) and some other hydrocarbons in indoor air. We established that work of the device No. 2 created elevated styrene levels and the working irradiator No. 3 emitted toluene, xylenes and hexanal into indoor air. Work of UV irradiators was established to lead to a greater quantity of pollutants in indoor air as well as a growth in their total concentrations, which went up by between 2 and 4 and even more times. In particular, they grew by 2.3 times due to work of the device No 1; device No. 2, by 3.8 times; and device No. 3, by 4.1 times.

At the same time, tests aiming to identify levels of nitrogen oxides and ozone did not establish their emissions in indoor air due to work of all analyzed devices. After 3-hour use of the analyzed devices, levels of nitrogen oxides and ozone in indoor air were not higher than average daily MPL and did not differ from background concentrations.

Therefore, our study revealed higher levels of saturated and acyclic hydrocarbons (nonane, decane, undecame, and cyclohexanes) in indoor air due to work of UV recirculator irradiators of all three examined makes. Analysis of the study results makes it possible to assume that these identified chemicals occur in indoor air due to emission from materials, which device cases and some spare parts are made of; or, they occur in indoor air due to transformation of some pollutants under effects of UV radiation [22]. However, further chemical and analytical investigations are required to prove these assumptions.

Air inside healthcare facilities contains multiple chemicals and some of them are likely to transform under influence of working devices and technologies applied in healthcare organizations. Given that, we can make a statement that assessment of health risks posed by effects of chemical pollution on patients' health should involve monitoring that covers the entire range of chemicals coming from various pollution sources.

However, in contrast to microbiological monitoring, control of physical and chemical factors that affect patients and healthcare workers in in-patients hospitals is often accomplished with insufficient methodical support. This is due to absence of relevant regulatory and methodical documents aimed to provide methodical support for complex hygienic assessment of the indoor environment inside healthcare facilities considering the entire range of affecting factors.

In addition to that, another significant issue has not been resolved yet. It concerns absence of adequate hygienic assessments of hazards posed by multi-component chemical pollution in indoor air since there are no established hygiene / safety standards for more than a half of identified chemicals. Use of a total volatile organic compound concentration is eligible only for comparative assessments of chemical levels in premises with the same functional purposes. The ultimate goal is to perform adequate assessment of hazards or safety of air inside in-patient hospitals considering possible pollution created by internal sources (human excretory products, use of various technical means for air cleaning and disinfection, etc.). To achieve it, it is advisable to use the following algorithm of a chemical and analytical investigation: identification of a most comprehensive range of pollutants; selection of priority pollutants for monitoring; use of the risk analysis methodology[4] [23–25]. The latter is especially important since health risk analysis is known to allow predicting and minimizing a growth in incidence among healthcare workers under occupational long-term exposure to chemicals in low doses, which can often be below MPLs[4] [24, 25].

We created a list of the chemicals with the greatest hygienic significance relying on our study results and considering the following criteria: a) frequency of occurrence in air inside in-patient hospitals; b) identified levels; c) likelihood of a chemical simultaneously coming from several sources. This list is relevant for analyzing health risks for healthcare workers and patients as well as for conducting chemical and analytical control of quality and safety of air inside healthcare facilities. It includes the following chemicals: formaldehyde, styrene, ethanol, isopropanol, chloroform, dichloroethane, acetic acid, as well as ammonia as one of the priority pollutants occurring in air from human excretory products [8, 9, 22]. The list covers chemicals from different chemical groups typical for major sources of chemical pollution in air inside healthcare facilities. Table 5 provides chemical groups, hazard classes and major pollution sources for each chemical selected for monitoring.

Air inside healthcare facilities contains multiple chemicals and some of them are likely to transform under influence of physical and chemical factors used in air cleaning, disinfection or air conditioning. Given that, assessment of health risks posed by effects of chemical pollution on patients' health should involve monitoring of possible changes in quality of the indoor environment under impacts of applied technologies and use of the risk analysis methodology.

Conclusions. We identified and quantified between 25 and 43 chemicals in air inside in-patient hospitals. They belonged to different chemical groups including saturated, unsaturated, cyclic, and aromatic hydrocarbons; terpenes, alcohols, aldehydes, esters, ketones, halogen-containing compounds, and organic acids. Quantitative and qualitative structures of air inside premises with different fictional purposes are different and depend on presence or absence of internal pollution sources, in particular, technical devices for air cleaning, disinfection or conditioning as well as use of various technical diagnostic devices.

Major contributions to the total chemical concentrations in air inside in-patient hospitals were made by ethanol, dichloromethane, tetrachloromethane, ethyl acetate, propyl acetate, acetone, terpenes, acetic acid, and dichloroethane.

Table 5

The list of priority chemical for monitoring and analysis of health risks for healthcare workers and patients in air inside in-patient hospitals

Chemical	Group	Hazard class	Major pollution sources
Formaldehyde	Aldehydes	2	Furniture, construction and finishing materials, disinfectants
Styrene	Aromatic hydrocarbons	2	Construction and finishing materials, cases of household appliances and medical devices
Ethanol	Alcohols	4	Treatment, disinfection including that off medical devices
Isopropanol	Alcohols	3	Household chemicals, room cleaning and disinfection, lacquers, paints
Chloroform	Chlorinated organic compounds	2	Disinfectants
Dichloroethane	Chlorinated organic compounds	2	Disinfectants
Acetic acid	Organic acids	3	Excretory products
Ammonia	Nitrogen-containing compounds	4	Excretory products, construction materials

[4] Dubel E.V. Gigienicheskaya otsenka faktorov riska zdorov'yu meditsinskikh rabotnikov krupnogo mnogoprofil'nogo statsionara [Hygienic assessment of risk factors for healthcare workers employed at a large multi-profile in-patient hospital]: Abstract of the thesis … for Candidate of Medical Sciences. Arkhangelsk, 2016, 25 p. (in Russian).

Organic acids and chlorinated organic compounds were found in elevated concentrations compared with insides of non-medical public buildings. The highest chemical levels in air inside in-patient hospitals were identified in patient wards and diagnostic rooms.

We have established in this study that chemical pollution in air inside healthcare facilities is multicomponent and hygiene or safety standards are not fixed for more than a half of the identified chemicals. Given that, we can conclude that hygienic assessment of hazards posed by chemical pollution in air inside healthcare facilities should rely on using the health risk assessment methodology, which makes it possible to assess hazards of exposure to chemicals both for healthcare workers and for oversensitive patients.

When accomplishing the first stage in assessing health risks for staff and patients as well as within risk-based control of chemical pollution in air inside in-patient hospitals, it is advisable to conduct monitoring of the established priority chemicals, in particular, formaldehyde, styrene, ethanol, isopropanol, chloroform, dichloroethane, and acetic acid as well as ammonia as one of the priority pollutants occurring in the environment from human excretory products.

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