

DOI: 10.15825/1995-1191-2025-3-173-203

STATUS AND TRENDS IN CHRONIC KIDNEY DISEASE AND RENAL REPLACEMENT THERAPY IN THE RUSSIAN FEDERATION: 2024 REPORT

Annual monitoring by the Center for Excellence in Medical Care in Nephrology at Shumakov National Medical Research Center of Transplantology and Artificial Organs, Moscow, Russian Federation

S.V. Gautier^{1, 2}, S.M. Khomyakov^{1, 2}, O.M. Tsirulnikova^{1, 2}, N.V. Chebotareva^{1, 2}, D.N. Kruglov^{1, 2}

¹ Shumakov National Medical Research Center of Transplantology and Artificial Organs, Moscow, Russian Federation

² Sechenov University, Moscow, Russian Federation

Objective: to establish and conduct annual monitoring of the status and development trends in nephrology care across the federal subjects of the Russian Federation for the year 2024. **Materials and methods.** A comprehensive set of indicators was developed, and a structured survey was administered among leading freelance nephrology specialists across the regions. The collected data were systematically analyzed. **Results.** In 2024, the Russian Federation operated 706 hemodialysis (HD) centers and 49 kidney transplant (KT) centers. A total of 73,483 patients were receiving renal replacement therapy (RRT), of whom 76.6% were on HD, 2.7% on peritoneal dialysis (PD), and 20.6% were being monitored with a functioning kidney transplant. During the year, 1,943 KT were performed across 49 centers in 38 regions. The overall RRT availability in the Russian Federation was 503.2 patients per million population (pmp), with HD at 385.7 pmp, PD at 13.7 pmp, and KT at 103.8 pmp. Among patients receiving HD in 2024, 81.9% were treated via arteriovenous fistula, 12.1% through permanent central venous catheter, 3.6% via temporary catheter, and 2.4% using vascular prostheses. In 2024, the Russian Federation had 537 nephrology outpatient offices, staffed by 690 physicians providing specialized care. The ratio of outpatient nephrologists to the population was 0.24 per 50,000, significantly below the recommended standard for medical personnel. Inpatient care for patients with pre-dialysis stages of chronic kidney disease (CKD) was delivered through 263 departments, comprising a total of 5,039 beds (equivalent to 0.35 beds per 10,000 population). Morphological evaluation of kidney biopsies – an important indicator of inpatient nephrological care – was independently conducted in 38 regions. Kidney biopsies were performed in 2.5% of patients hospitalized in inpatient facilities, translating to an average of 32.8 biopsies per million population. **Conclusion.** An annual monitoring framework has been successfully developed, with active collaboration established across regional centers, enabling the collection of up-to-date data on nephrological care in the Russian Federation for 2024. There is no current shortage of dialysis facilities, and a significant proportion of patients receive RRT via HD, an approach that places considerable financial burden on the national healthcare system. The high proportion of working-age individuals (62.4%) among HD patients underscores the substantial socio-economic impact of CKD and its treatment on both the state and society. Although the number of KT continues to rise annually, current transplant volumes remain insufficient to fully meet demand and only partially offset the growing costs associated with RRT. Expanding the use of PD, particularly in sparsely populated regions, may offer advantages over HD. Nonetheless, KT remains the optimal treatment modality for patients with end-stage CKD, supporting the need to further expand transplant infrastructure and increase access to this intervention. The continuation of annual monitoring across all stages of CKD will allow for data-driven improvements in care delivery, incorporating emerging recommendations and regional insights.

Keywords: nephrological care, chronic kidney disease, CKD patient monitoring, vascular access for dialysis, renal replacement therapy, hemodialysis, peritoneal dialysis, kidney transplantation, Shumakov National Medical Research Center of Transplantology and Artificial Organs.

INTRODUCTION

The presented overview of nephrological care in Russia, conducted in the form of monitoring, was carried out within the authority of the Center for the Improvement of Medical Care in the Field of Nephrology at Shumakov National Medical Research Center of Transplantology and Artificial Organs (Order of the Russian Ministry of Health, No. 73, February 28, 2023).

For monitoring purposes, a system of indicators characterizing nephrological care and renal replacement therapy (RRT) in the regions was developed, along with 45 standardized tables for data collection. The resulting monitoring reports include not only statistical data for the reporting period but also a systematic analysis assessing the current state of RRT in Russia, identifying trends, and outlining prospects for further development of this healthcare sector.

The monitoring data is used by the Center for the Improvement of Medical Care in the Field of Nephrology at Shumakov National Medical Research Center of Transplantology and Artificial Organs, to address organizational and methodological tasks assigned by the Russian Ministry of Health. This includes preparation of proposals for improving nephrological care and RRT in Russia.

In addition, the monitoring data is provided to the Russian Ministry of Health, the executive authorities of the federal subjects of the Russian Federation in the field of healthcare, and the chief freelance specialists of the Russian Ministry of Health in the federal districts for use in their activities.

Data for monitoring is collected through questionnaires completed by those in charge – chief freelance specialists in nephrology, dialysis, and transplantation in the federal subjects of the Russian Federation. A comparative dynamic analysis of the obtained data will be presented in the next report to ensure consistency and avoid distortions that may arise when comparing with data from other registries that use different methodological approaches.

The working group expresses its gratitude to the chief freelance specialists in nephrology, dialysis, as well as the chief freelance specialists in transplantation from the federal subjects of the Russian Federation, the heads of nephrology departments and dialysis centers, as well as regional health authorities for their contribution in providing data and supporting the organization and improvement of this monitoring protocol.

It should be noted that the monitoring data may differ from the results of similar studies due to the specific methodology applied in the collection, processing, and analysis of information.

MEDICAL ORGANIZATIONS PROVIDING NEPHROLOGY CARE AND STAFFING

Outpatient nephrology care

According to monitoring data for 2024, 537 nephrology offices were operating in the Russian Federation, staffed by 690 physicians providing outpatient care. This corresponds to a ratio of 0.24 outpatient nephrologists per 50,000 population, which is significantly lower than the established standard of 1 medical personnel per 50,000 registered population, as defined by the Procedure for the Provision of Medical Care to the Adult Population in the Field of Nephrology (Order of the Russian Ministry of Health and Social Development No. 17n of January 18, 2012, as amended on February 21, 2020).

There is a shortage of nephrologists across all regions of the Russian Federation, especially in the Komi Republic, the Republic of Dagestan, Udmurt Republic, Republic of Mordovia, Altai Krai, Tuva Republic, and Tomsk Oblast (Table 1).

In some medical organizations, outpatient consultations and follow-up of patients with CKD are performed by physicians from hospital-based nephrology units and hemodialysis departments. However, this practice does not substantially reduce the need for dedicated outpatient nephrologists at the regional level and results in insufficiently effective monitoring and treatment of CKD patients, particularly those at advanced stages (stages 3–5), who require continuous dispensary follow-up.

In 2024, patient registration at pre-dialysis stages of CKD (primarily stages 3–4) was carried out in 53 regions of the Russian Federation. The number of patients with CKD stages 3–5D under nephrologist supervision, excluding those on dialysis, totaled 167,389. The number of patients receiving dialysis therapy (CKD 5D) in these regions was 41,704, bringing the overall number of patients with CKD stages 3–5D to 208,623.

This figure is markedly lower than the expected prevalence of CKD in the Russian Federation, which is estimated at approximately 13.6 million patients across all stages, based on international registry data and large-scale epidemiological studies [1–3].

The shortage of personnel highlights the urgent need for more targeted training and retraining of physicians in the field of nephrology. At present, specialized nephrology training programs are available in only 25 regions of the Russian Federation. Among the 690 outpatient nephrologists currently practicing, only 89 specialists (12.9%) have received additional training in the management of patients with kidney transplants. Given that 15,162 patients with functioning kidney transplants require continuous monitoring, there is a significant shortage of qualified physicians. This shortage affects not only the quality of dynamic control over immunosuppressive therapy and graft function but also the management of patients on the kidney transplant waiting list.

Table 1

Availability of nephrology medical institutions and nephrologists across regions in the Russian Federation

	Population (thousand)	Outpatient care (nephrologist's office)			Inpatient care (nephrology departments)				Dialysis (dialysis department)			
		Number of offices	Number of nephrologists	Availability of nephrologists per 50,000 population	Number of departments	Number of nephrology beds	Number of nephrologists	Availability of nephrology beds per 10,000 population	Number of centers (departments)	Number of dialysis stations	Number of doctors	Availability of dialysis stations per million population
1	2	3	4	5	6	7	8	9	10	11	12	13
Russian Federation	146028.3	537	690	0.236	263	5039	783	0.345	706	21 828	2774	149.48
Central Federal District	40263.7	149	180	0.224	57	1022	165	0.254	175	4894	724	121.55
Belgorod Oblast	1481.1	3	3	0.101	2	37	6	0.250	7	149	24	100.60
Bryansk Oblast	1132.5	3	3	0.132	1	40	2	0.353	5	141	18	124.50
Vladimir Oblast	1295.9	7	10	0.386	4	36	5	0.278	10	592	19	456.83
Voronezh Oblast	2259.6	10	10	0.221	3	71	10	0.314	9	171	33	75.68
Ivanovo Oblast	897.9	3	3	0.167	1	21	3	0.234	4	88	13	98.01
Kaluga Oblast	1064.7	3	3	0.141	1	18	3	0.169	3	52	6	48.84
Kostroma Oblast	560.8	4	3	0.267	2	30	6	0.535	5	390	13	695.44
Kursk Oblast	1050.1	6	7	0.333	2	52	6	0.495	5	101	21	96.18
Lipetsk Oblast	1107.8	4	4	0.181	3	62	11	0.560	9	142	24	128.18
Moscow Oblast	8766.6	54	49	0.279	15	67	30	0.076	22	1069	165	121.94
Oryol Oblast	685.7	3	3	0.219	2	50	7	0.729	5	69	15	100.63
Ryazan Oblast	1074.0	2	2	0.093	2	43	7	0.400	9	93	26	86.59
Smolensk Oblast	857.8	2	2	0.117	2	35	7	0.408	7	97	17	113.08
Tambov Oblast	946.0	7	10	0.529	2	47	4	0.497	8	102	20	107.82
Tver Oblast	1189.7	7	10	0.420	3	73	6	0.614	5	93	20	78.17
Tula Oblast	1455.9	5	7	0.240	2	60	7	0.412	8	288	23	197.82
Yaroslavl Oblast	1179.3	2	2	0.085	1	30	3	0.254	4	73	21	61.90
Moscow	13258.3	24	49	0.185	9	250	42	0.189	50	1184	246	89.30
Northwestern Federal District	13863.9	41	70	0.252	24	427	50	0.308	82	1552	356	111.95
Republic of Karelia	518.6	1	1	0.096	1	43	5	0.829	4	49	18	94.49
Komi Republic	714.4	1	1	0.070	2	40	6	0.560	9	111	13	155.38
Nenets Autonomous Okrug	41.8	1	1	1.196	0	0	0	0.000	1	3	1	71.77
Arkhangelsk Oblast without autonomy	946.0	11	14	0.740	3	27	4	0.285	9	126	28	133.19
Vologda Oblast	1114.6	4	7	0.314	1	12	1	0.108	5	104	17	93.31
Kaliningrad Oblast	1033.1	1	2	0.097	1	35	3	0.339	4	89	23	86.15
Leningrad Oblast	2057.7	7	5	0.121	2	26	5	0.126	15	222	62	107.89
Murmansk Oblast	650.9	1	3	0.230	1	26	3	0.399	2	281	11	431.71
Novgorod Oblast	566.7	1	2	0.176	1	15	2	0.265	6	61	9	107.64
Pskov Oblast	574.2	1	2	0.174	1	20	3	0.348	3	48	9	83.59
St. Petersburg	5645.9	12	32	0.283	11	183	18	0.324	24	458	165	81.12
Southern Federal District	16585.9	60	70	0.211	30	612	88	0.369	39	2123	169	128.00
Republic of Adygea	501.0	2	2	0.200	2	27	3	0.539	4	67	9	133.73
Republic of Kalmykia	267.4	1	2	0.374	1	10	1	0.374	4	67	7	250.56
Republic of Crimea	1901.1	7	9	0.237	3	82	7	0.431	7	765	31	402.40
Krasnodar Krai	5841.8	10	14	0.120	5	138	20	0.236	5	385	17	65.90
Astrakhan Oblast	946.0	8	9	0.476	3	45	6	0.476	4	77	14	81.40
Volgograd Oblast	2435.4	22	22	0.452	7	135	18	0.554	5	92	26	37.78
Rostov Oblast	4135.0	9	11	0.133	7	144	30	0.348	7	606	53	146.55
Sevastopol	558.2	1	1	0.090	2	31	3	0.555	3	64	12	114.65

Continuation of Table 1

1	2	3	4	5	6	7	8	9	10	11	12	13
North Caucasian Federal District	10307.6	31	40	0.194	23	407	69	0.395	60	1257	213	121.95
Republic of Dagestan	3259.0	1	1	0.015	1	10	0	0.031	16	272	51	83.46
Republic of Ingushetia	534.2	1	2	0.187	1	15	2	0.281	3	25	8	46.80
Kabardino-Balkarian Republic	908.1	6	7	0.385	5	117	11	1.288	7	116	20	127.74
Karachay-Cherkess Republic	468.5	3	4	0.427	5	50	10	1.067	2	80	6	170.76
Republic of North Ossetia – Alania	678.5	4	3	0.221	3	59	31	0.870	5	121	31	178.33
Chechen Republic	1575.8	5	5	0.159	2	50	3	0.317	10	154	34	97.73
Stavropol Krai	2883.5	11	18	0.312	6	106	12	0.368	17	489	63	169.59
Volga Federal District	28397.8	107	153	0.269	50	1168	166	0.411	126	4542	554	159.94
Republic of Bashkortostan	4046.1	7	7	0.087	4	125	11	0.309	4	1622	89	400.88
Mari El Republic	666.0	2	4	0.300	2	65	6	0.976	5	72	14	108.11
Republic of Mordovia	758.4	1	1	0.066	1	30	3	0.396	5	98	12	129.22
Republic of Tatarstan	4016.6	8	14	0.174	4	69	10	0.172	23	329	58	81.91
Udmurt Republic	1427.0	2	2	0.070	3	70	8	0.491	15	178	31	124.74
Chuvash Republic	1159.8	2	4	0.172	2	43	6	0.371	2	98	13	84.50
Perm Krai	2482.1	26	28	0.564	6	136	21	0.548	11	646	48	260.26
Kirov Oblast	1120.2	8	7	0.312	2	54	1	0.482	5	131	29	116.94
Nizhny Novgorod Oblast	3037.8	9	9	0.148	6	95	27	0.313	16	361	87	118.84
Orenburg Oblast	1815.7	7	8	0.220	4	83	20	0.457	11	183	37	100.79
Penza Oblast	1226.0	7	7	0.285	2	60	5	0.489	4	122	20	99.51
Samara Oblast	3108.9	4	10	0.161	4	107	13	0.344	10	309	47	99.39
Saratov Oblast	2368.4	20	41	0.866	10	231	35	0.975	8	232	52	97.96
Ulyanovsk Oblast	1164.8	4	11	0.472	0	0	0	0.000	7	161	17	138.22
Ural Federal District	11914.3	47	57	0.239	21	396	57	0.332	69	2712	228	227.63
Kurgan Oblast	744.2	2	2	0.134	1	13	4	0.175	4	63	16	84.65
Sverdlovsk Oblast	4218.2	12	16	0.190	8	110	21	0.261	17	585	90	138.68
Khanty-Mansi Autonomous Okrug – Yugra	1779.5	12	12	0.337	6	101	14	0.568	17	194	51	109.02
Yamalo-Nenets Autonomous Okrug	521.7	4	5	0.479	0	0	0	0.000	6	43	14	82.42
Tyumen Oblast without autonomies	1267.5	4	6	0.237	2	70	4	0.552	6	61	16	48.13
Chelyabinsk Oblast	3383.2	13	16	0.236	4	102	14	0.301	19	1766	41	521.99
Siberian Federal District	16482.8	62	73	0.221	32	465	101	0.282	88	3015	284	182.92
Altai Republic	210.1	1	3	0.714	0	0	0	0.000	1	32	3	152.31
Tuva Republic	338.3	0	0	0.000	0	0	0	0.000	1	20	2	59.12
Republic of Khakassia	525.5	1	1	0.095	2	11	8	0.209	4	41	11	78.02
Altai Krai	2099.0	3	2	0.048	2	55	7	0.262	11	1156	42	550.74
Krasnoyarsk Krai	2837.4	7	7	0.123	3	83	9	0.293	20	254	58	89.52
Irkutsk Oblast	2316.6	10	10	0.216	11	60	32	0.259	13	79	26	34.10
Kemerovo (Kuzbass) Oblast	2526.4	18	30	0.594	7	98	19	0.388	17	323	53	127.85
Novosibirsk Oblast	2784.6	13	11	0.198	4	71	16	0.255	7	841	44	302.02
Omsk Oblast	1805.4	8	8	0.222	2	39	3	0.216	8	201	25	111.33
Tomsk Oblast	1039.5	1	1	0.048	1	48	7	0.462	6	68	20	65.42
Far Eastern Federal District	7853.5	31	39	0.248	19	392	64	0.499	58	1571	218	200.04
Republic of Buryatia	970.7	5	7	0.361	3	44	3	0.453	7	130	34	133.92
Sakha (Yakutia) Republic	1007.1	4	4	0.199	2	50	13	0.496	9	849	54	843.01
Zabaykalsky Krai	982.5	5	8	0.407	4	75	7	0.763	10	89	26	90.59
Kamchatka Krai	287.9	2	2	0.347	1	5	0	0.174	2	19	5	66.00
Primorsky Krai	1798.0	3	6	0.167	2	85	17	0.473	14	213	49	118.46
Khabarovsk Krai	1273.1	4	4	0.157	3	55	13	0.432	8	103	25	80.90
Amur Oblast	750.9	3	3	0.200	1	35	6	0.466	3	57	9	75.91
Magadan Oblast	134.2	1	1	0.373	1	22	3	1.639	1	60	3	447.09

End of Table 1

1	2	3	4	5	6	7	8	9	10	11	12	13
Sakhalin Oblast	456.8	3	3	0.328	1	15	1	0.328	2	27	6	59.11
Jewish Autonomous Oblast	144.4	1	1	0.346	1	6	1	0.416	2	24	7	166.20
Chukotka Autonomous Okrug	47.9	0	0	0.000	0	0	0	0.000	0	0	0	0.00
New territories		9	8		7	150	23		9	162	28	
Donetsk People's Republic		6	6		5	120	13		5	108	19	
Luhansk People's Republic		3	2		1	20	9		1	25	7	
Zaporizhzhya Oblast		0	0		1	10	1		3	29	2	
Kherson Oblast		0	0		0	0	0		1	10	0	

Note. Population figures, as well as the availability of specialists and hospital beds in the Russian Federation, were calculated excluding the newly incorporated territories, due to the inability to accurately estimate the permanent population in those regions.

Patient education plays a crucial role in improving adherence to therapy, prognosis, and awareness of kidney disease. To this end, schools for patients with kidney disease are functioning in 29 regions of the Russian Federation. Of these, 20 regions offer in-person classes for patients with CKD, 24 regions for patients on hemodialysis, and 14 regions for patients with kidney transplants. Nevertheless, the need to expand these educational programs nationwide underscores the importance of strengthening outpatient nephrology services through an increase in the number of trained specialists.

Inpatient care in nephrology

In 2024, inpatient treatment for patients with chronic kidney disease (CKD) in pre-dialysis stages was provided in 263 hospital departments with a total capacity of 5,039 beds, corresponding to 0.35 nephrology beds per 10,000 population across the Russian Federation. However, several regions – Nenets Autonomous Okrug, Chukotka Autonomous Okrug, Altai Republic, and Tuva Republic – still lack inpatient nephrology services for pre-dialysis patients (Table 1). Nationwide, 783 nephrologists work in nephrology hospital settings, of whom only 187 have specialized training in managing kidney transplant patients. This remains insufficient to adequately monitor this growing patient category.

One important quality indicator of inpatient nephrology care is the number of kidney biopsies performed per million population per year. In 2024, kidney biopsies were conducted in 3,734 patients (2.5%) out of 147,681 hospitalizations, which corresponds to an average of 32.8 biopsies per million population.

Morphological studies are independently performed in 38 regions, while biopsy material from 26 regions is sent to larger nephrology centers for expert evaluation. Biopsy activity in some regions approaches or exceeds the European average of 76 biopsies per million population [4–8]. Notable examples include Kemerovo Oblast – 209 biopsies (100 per million); Chelyabinsk Oblast – 268 (97.9 per million); Krasnoyarsk Krai – 167 (73.1 per million); Moscow – 705 (63.7 per million);

Republic of Tatarstan – 190 (58.8 per million); Samara Oblast – 146 (56.4 per million); Irkutsk Oblast – 100 (54.8 per million); Novosibirsk Oblast – 121 (53.7 per million); St. Petersburg – 202 (42.5 per million).

To improve diagnosis, optimize treatment strategies, and reduce progression to end-stage CKD, it is necessary to expand nephrobiopsy coverage to all regions, aiming for an average national rate of at least 70 biopsies per million population. This requires not only ensuring the technical capacity to perform kidney biopsies (in urology and surgical departments) but also establishing pathways for sending biopsy material to larger centers where qualified morphological examination can be performed.

CHARACTERISTICS OF THE POPULATION OF CKD PATIENTS ON RRT IN THE RUSSIAN FEDERATION

Data on RRT in 2024 were obtained from 89 regions of the Russian Federation. In total, 73,483 patients with stage 5 CKD were receiving RRT: 56,324 (76.7%) on HD, 1,997 (2.7%) on PD, 15,162 (20.6%) living with a functioning kidney transplant (Fig. 2).

The age distribution of patients by treatment modality is shown in Fig. 3. Kidney transplantation (KT) is the predominant method of RRT among children (0–18 years), accounting for 70% of patients in this age group. In contrast, HD dominates among adults: more than 60% of patients under 50 years and over 80% of those older than 50 years receive this therapy.

The high proportion of working-age patients maintained on HD, the most expensive RRT modality, highlights the urgent need to further expand KT programs across Russian regions.

No significant gender differences were observed in the distribution of patients across RRT modalities (Fig. 4).

The structure of underlying diseases among patients receiving dialysis (HD and PD) is dominated by glomerulonephritis (25.2%), kidney damage in type 2 diabetes mellitus (13.9%), and arterial hypertension (13.4%), followed by polycystic kidney disease (10%), chronic

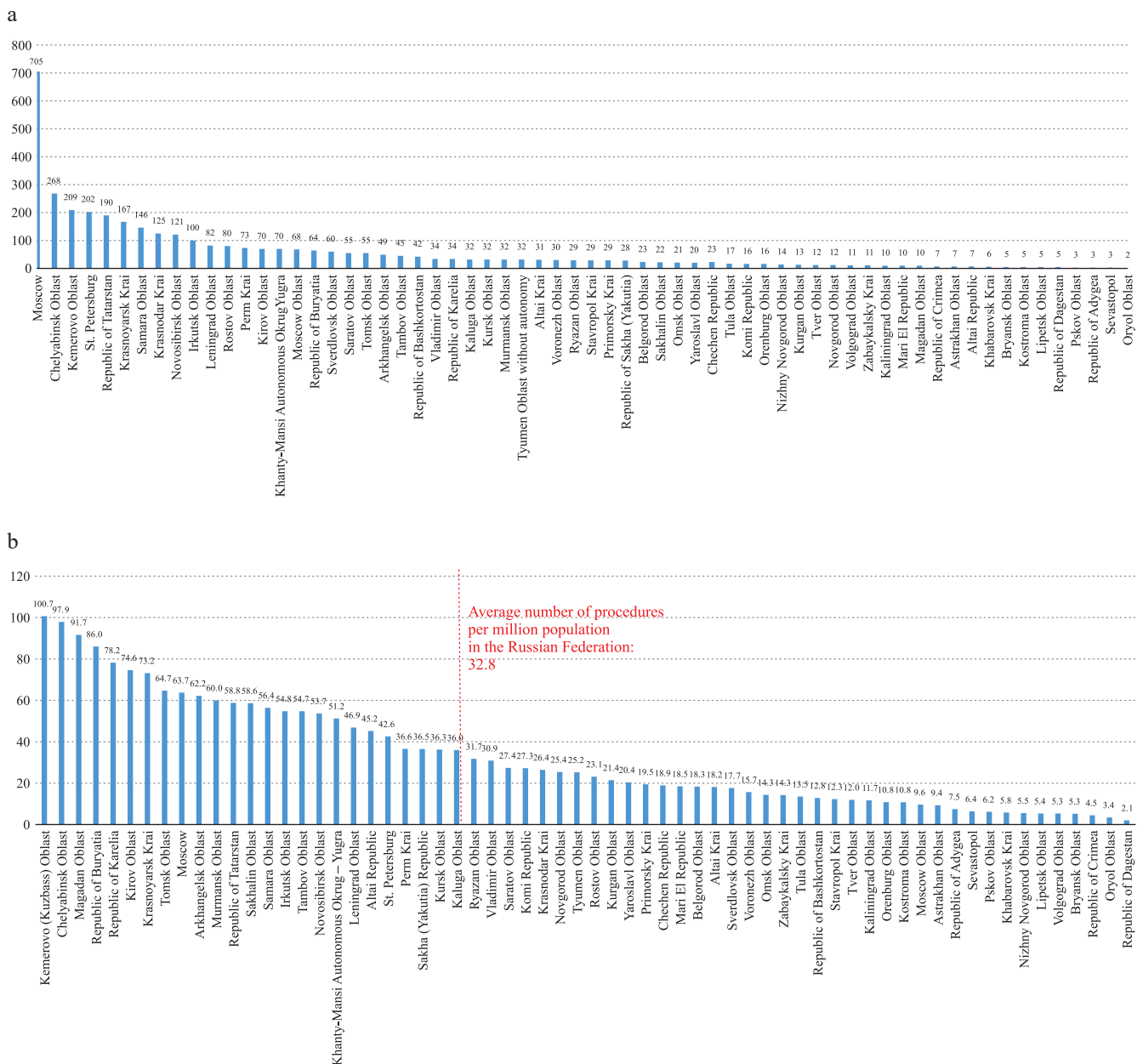


Fig. 1. Number of kidney biopsies performed across regions of the Russian Federation in 2024: a, total number of kidney biopsies; b, regional distribution of kidney biopsies per million population

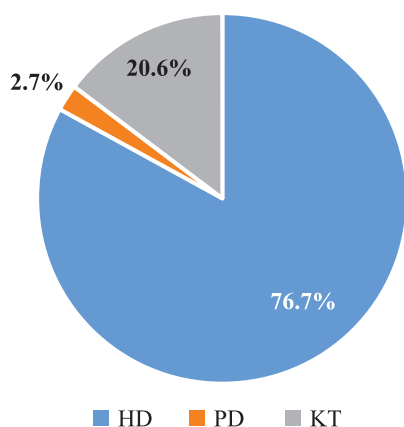


Fig. 2. Distribution of renal replacement therapy (RRT) modalities in the Russian Federation in 2024

pyelonephritis (8.8%), and tubulointerstitial kidney disease (6.8%) (Fig. 5).

The high prevalence of glomerulonephritis as a cause of end-stage CKD (esCKD) underscores the importance of timely kidney biopsy and accurate diagnosis of the underlying nosological form at earlier stages. This approach would facilitate the use of pathogenetic therapy, potentially slowing disease progression and reducing the burden of renal failure.

It should be noted that polycystic kidney disease (10%) and chronic pyelonephritis (8.8%) make a substantial contribution to the etiology of esCKD. Effective management of these conditions requires close collaboration between nephrologists and urologists.

The distribution of glomerulonephritis, diabetes mellitus, and polycystic kidney disease as causes of esCKD in Russia is broadly consistent with data from the international ERA Registry of dialysis patients. However, the relatively high frequency of arterial hypertension and chronic pyelonephritis as primary causes of esCKD in the Russian Federation is noteworthy [9]. Expanding the

use of nephrobiopsy in patients with clinical indications will improve diagnostic accuracy.

RENAL REPLACEMENT THERAPY IN THE RUSSIAN FEDERATION IN 2024

In 2024, the overall RRT coverage rate in the Russian Federation was 503.2 patients per million population,

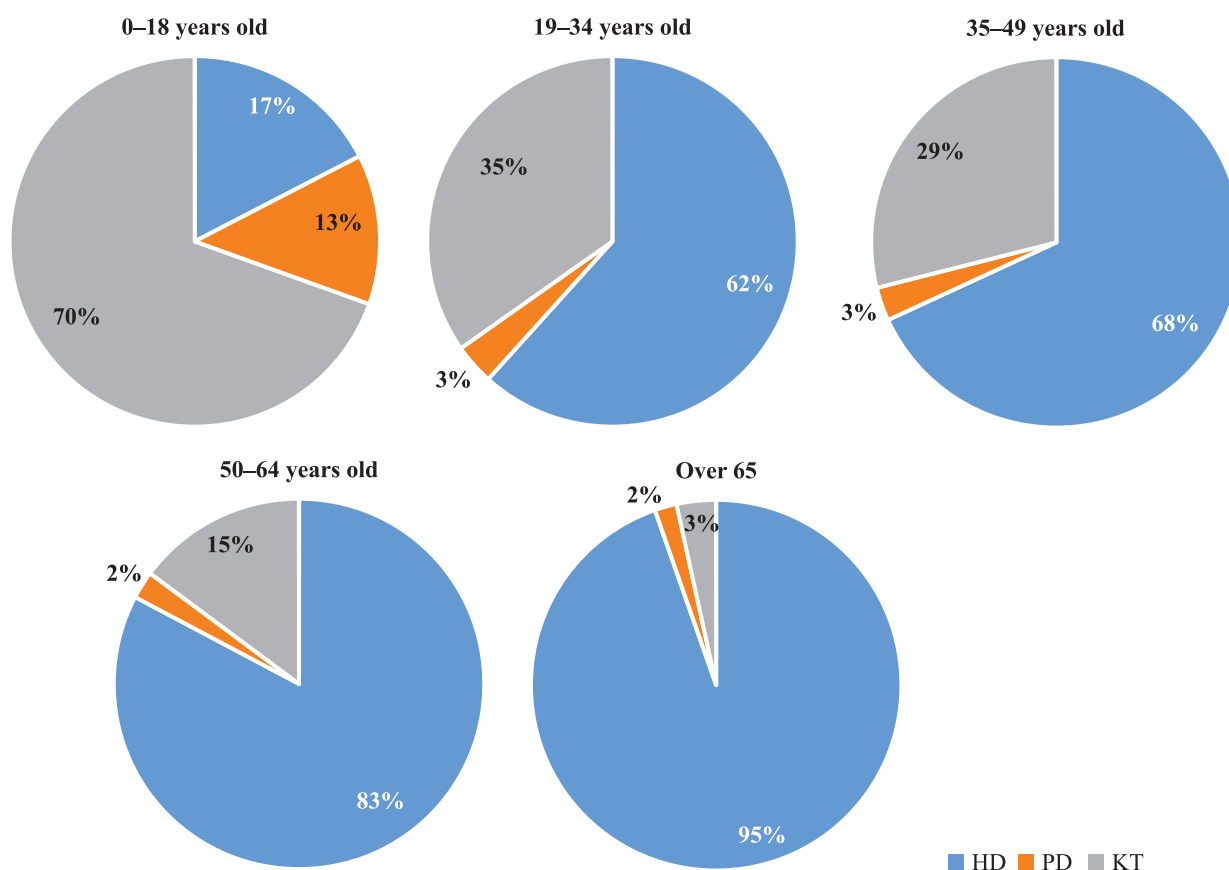


Fig. 3. Age distribution of patients with stage 5 chronic kidney disease receiving renal replacement therapy in the Russian Federation in 2024

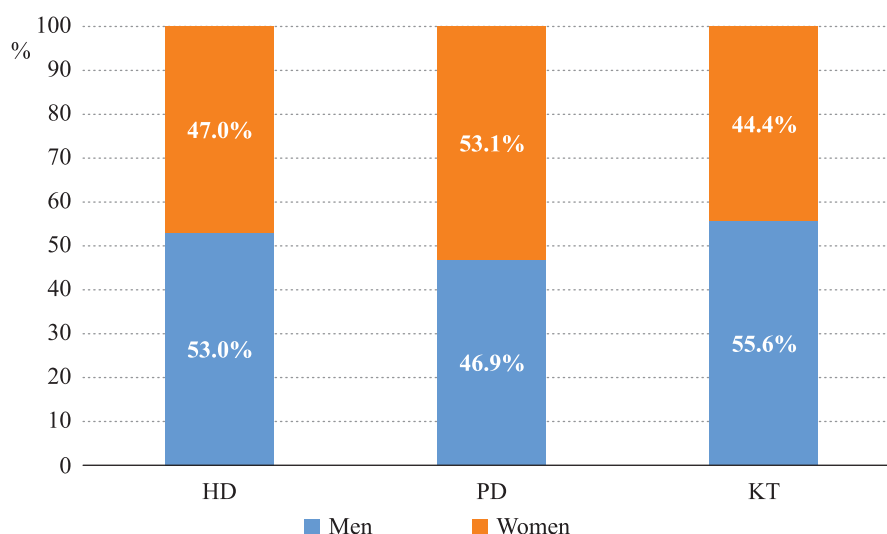


Fig. 4. Gender distribution of patients with stage 5 chronic kidney disease undergoing renal replacement therapy in the Russian Federation in 2024

including 385.7 per million on HD, 13.7 per million on PD, and 103.8 per million living with a functioning kidney transplant. Data on the availability of RRT in the newly incorporated regions are reported separately, taking into account changes in population size.

The number of dialysis patients, and consequently the financial burden on the national healthcare system, continues to rise in the Russian Federation [10]. In 2024, 14,426 patients initiated HD, 685 patients began PD, and 1,943 patients underwent KT. The indicators of RRT provision in the Russian Federation are presented in Table 2. In 2024, 6,995 patients on HD (9.8%) and 200 KT recipients (0.3%) died (Table 2). Mortality rates for HD varied slightly across regions but remained generally consistent with global data [11].

In 2024, a total of 706 dialysis centers were operating in the Russian Federation, of which 400 (56.7%) were privately or publicly owned. The total number of dialysis beds reached 21,828, corresponding to 149.5 per million population. Over the past five years, the number of centers increased by 18%, while the number of dialysis beds grew 2.4 times [12].

The staffing of dialysis units included 2,774 physicians and 5,966 nurses, resulting in an average of one nephrologist per 7.9 dialysis stations and one nurse per 3.7 stations per shift. These ratios meet the requirements established by the Procedure for the Provision of Medical Care to the Adult Population in the Field of Nephrology (Order of the Russian Ministry of Health and Social Development, January 18, 2012, No. 17n; as amended on February 21, 2020).

Across most regions of the Russian Federation, provision of HD per million population was comparable to the national average. However, some territories reported notable deviations: Krasnodar Krai, Republic of Bury-

atia, Republic of Kalmykia, Republic of North Ossetia, and Kabardino-Balkarian Republic had 1.5 times more patients on HD than the national mean. By contrast, Voronezh, Tomsk, Amur, and Volgograd regions, as well as the Altai Republic and Kaluga Oblast, reported lower-than-average HD prevalence. In several of these regions, reduced HD utilization was offset by higher rates of PD and KT (Figs. 6–8).

In Russia in 2024, vascular access for HD was distributed as follows: 81.9% of patients were treated via an arteriovenous fistula (AVF), 3.6% via a temporary central venous catheter, 12.1% via a permanent catheter, and 2.4% with a vascular prosthesis. AVF is the preferred vascular access method, as it provides the best outcomes. Overall, the proportion of patients receiving HD through AVF in the Russian Federation is sufficiently high, exceeding 80% in most regions, which is in line with international standards. In several regions, more than 90% of patients use AVF: Bryansk, Ryazan, the Republic of Karelia, the Republic of Mordovia, Chuvashia, Crimea, Republic of Dagestan, Zabaykalsky Krai, and Omsk Oblast.

However, in 10 regions, the proportion of patients undergoing HD via temporary catheters exceeds the national average. Reliance on temporary vascular access is associated with a significantly increased risk of infectious complications and mortality in HD patients.

In 2024, the Russian Federation reported a total of 15,030 HD machines, of which 14,188 (94.4%) were operational. In most regions, high-flux dialyzers – associated with greater efficiency compared to low-flux membranes – were predominantly used, accounting for 4,973,578 sessions (69%) out of the total 7,236,018 HD sessions performed.

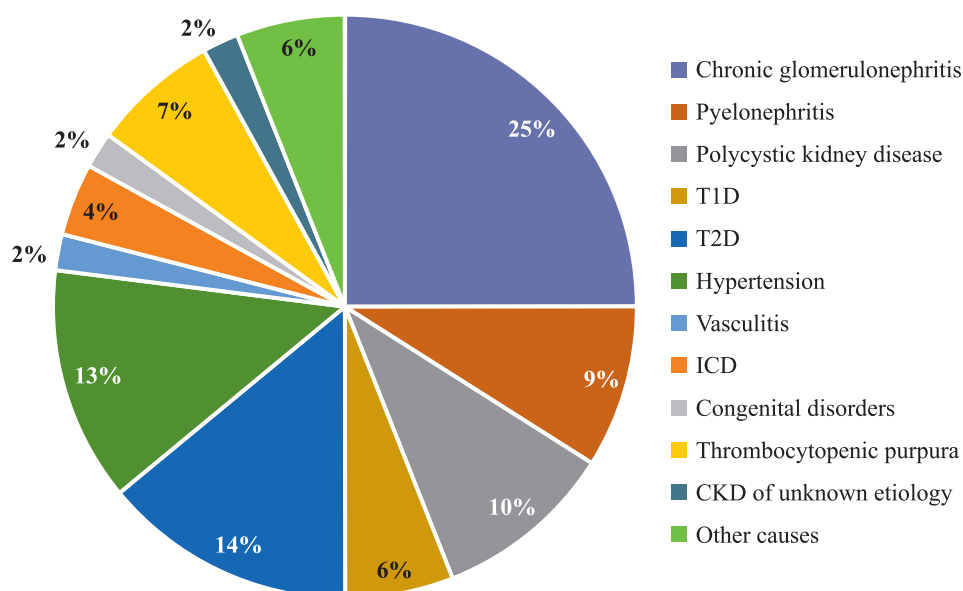


Fig. 5. Nosological structure of kidney disease in patients receiving renal replacement therapy in the Russian Federation

Table 2

Availability of renal replacement therapy for stage 5 CKD across regions of the Russian Federation. 2024

Federal Subjects of the Russian Federation	Population (thousand)	Number of HD patients (abs.)	Number of PD patients (abs.)	Number of KT recipients with functioning grafts (abs.)	Number of patients on the KT waitlist (abs.)	Total number of patients receiving RRT (abs.)	Availability of HD (patients per million population)	Availability of PD per million population	Availability of KT per million population	Availability of RRT per million population	Number of new HD patients (abs.)	Number of new PD patients (abs.)	Number of new KT recipients (abs.)	Number of new HD patients per million population	Number of new PD patients per million population	Number of new KT recipients per million population	Number of deaths among HD patients (abs.)	Number of deaths among PD patients (abs.)	Number of deaths among KT recipients (abs.)	Proportion of deaths on dialysis as a percentage of total RRT patients (%)	Proportion of among KT recipients as a percentage of total RRT patients (%)	Ratio of patients on HD/PD/KT		
																						HD	PD	KT
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Russian Federation	146028.3	56 324	1997	15 162	7331	73 483	385.7	13.7	103.8	503.2	14 426	685	1943	98.8	4.7	13.3	6995	215	200	9.8	0.3	76.6	2.7	20.6
Central Federal District	40263.7	14743	658	6032	2566	21433	366.2	16.3	149.8	532.3	4861	265	752	120.7	6.6	18.7	1816	50	73	8.7	0.3	68.8	3.1	28.1
Belgorod Oblast	1481.1	689	0	113	81	802	465.2	0.0	76.3	541.5	151	0	8	102.0	0.0	5.4	121	0	2	15.1	0.2	85.9	0.0	14.1
Bryansk Oblast	1132.5	425	0	64	16	489	375.3	0.0	56.5	431.8	81	0	6	71.5	0.0	5.3	34	0	0	7.0	0.0	86.9	0.0	13.1
Vladimir Oblast	1295.9	468	5	131	78	604	361.1	3.9	101.1	466.1	121	2	12	93.4	1.5	9.3	60	0	0	9.9	0.0	77.5	0.8	21.7
Voronezh Oblast	2259.6	573	8	118	61	699	253.6	3.5	52.2	309.3	159	6	13	70.4	2.7	5.8	65	2	4	9.6	0.6	82.0	1.1	16.9
Ivanovo Oblast	897.9	313	0	53	14	366	348.6	0.0	59.0	407.6	68	0	10	75.7	0.0	11.1	27	0	0	7.4	0.0	85.5	0.0	14.5
Kaluga Oblast	1064.7	149	11	98	61	258	139.9	10.3	92.0	242.3	36	7	10	33.8	6.6	9.4	9	1	0	3.9	0.0	57.8	4.3	38.0
Kostroma Oblast	560.8	273	5	41	36	319	486.8	8.9	73.1	568.8	77	0	4	137.3	0.0	7.1	60	0	1	18.8	0.3	85.6	1.6	12.9
Kursk Oblast	1050.1	309	4	49	10	362	294.3	3.8	46.7	344.7	41	0	3	39.0	0.0	2.9	37	0	0	10.2	0.0	85.4	1.1	13.5
Lipetsk Oblast	1107.8	550	30	78	56	658	496.5	27.1	70.4	594.0	153	9	9	138.1	8.1	8.1	76	3	1	12.0	0.2	83.6	4.6	11.9
Moscow Oblast	8766.6	3352	96	958	765	4406	382.4	11.0	109.3	502.6	655	28	125	74.7	3.2	14.3	357	12	1	8.4	0.0	76.1	2.2	21.7
Oryol Oblast	685.7	292	0	49	23	341	425.8	0.0	71.5	497.3	74	0	7	107.9	0.0	10.2	37	0	0	10.9	0.0	85.6	0.0	14.4
Ryazan Oblast	1074.0	401	20	106	40	527	373.4	18.6	98.7	490.7	116	6	21	108.0	5.6	19.6	63	3	2	12.5	0.4	76.1	3.8	20.1
Smolensk Oblast	857.8	279	5	45	17	329	325.3	5.8	52.5	383.5	64	0	9	74.6	0.0	10.5	40	0	1	12.2	0.3	84.8	1.5	13.7
Tambov Oblast	946.0	392	5	44	14	441	414.4	5.3	46.5	466.2	111	3	2	117.3	3.2	2.1	51	1	3	11.8	0.7	88.9	1.1	10.0
Tver Oblast	1189.7	416	20	106	45	542	349.7	16.8	89.1	455.6	216	9	7	181.6	7.6	5.9	70	9	1	14.6	0.2	76.8	3.7	19.6
Tula Oblast	1455.9	436	18	136	44	590	299.5	12.4	93.4	405.2	88	6	10	60.4	4.1	6.9	54	4	5	9.8	0.8	73.9	3.1	23.1
Yaroslavl Oblast	1179.3	411	19	116	63	546	348.5	16.1	98.4	463.0	113	15	14	95.8	12.7	11.9	39	1	1	7.3	0.2	75.3	3.5	21.2
Moscow	13258.3	5015	412	3727	1142	9154	378.3	31.1	281.1	690.4	2537	174	482	191.4	13.1	36.4	616	14	51	6.9	0.6	54.8	4.5	40.7

Continuation of Table 2

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Northwestern Federal District	13863.9	5400	146	1449	507	6995	389.5	10.5	104.5	504.5	1112	64	234	80.2	4.6	16.9	573	5	18	8.3	0.3	77.2	2.1	20.7
Republic of Karelia	518.6	214	7	31	21	252	412.6	13.5	59.8	485.9	57	1	2	109.9	1.9	3.9	27	2	0	11.5	0.0	84.9	2.8	12.3
Komi Republic	714.4	329	15	27	0	371	460.5	21.0	37.8	519.3	36	4	0	50.4	5.6	0.0	17	0	0	4.6	0.0	88.7	4.0	7.3
Nenets Autonomous Okrug	41.8	11	0	0	0	11	263.2	0.0	0.0	263.2	5	0	0	119.6	0.0	0.0	2	0	0	18.2	0.0	100.0	0.0	0.0
Arkhangelsk Oblast without autonomy	946.0	529	17	53	41	599	559.2	18.0	56.0	633.2	103	5	10	108.9	5.3	10.6	46	0	1	7.7	0.2	88.3	2.8	8.8
Vologda Oblast	1114.6	371	0	107	12	478	332.9	0.0	96.0	428.9	88	0	18	79.0	0.0	16.1	56	0	2	11.7	0.4	77.6	0.0	22.4
Kaliningrad Oblast	1033.1	366	4	49	0	419	354.3	3.9	47.4	405.6	58	0	3	56.1	0.0	2.9	32	0	2	7.6	0.5	87.4	1.0	11.7
Leningrad Oblast	2057.7	578	1	267	79	846	280.9	0.5	129.8	411.1	113	0	36	54.9	0.0	17.5	70	0	1	8.3	0.1	68.3	0.1	31.6
Murmansk Oblast	650.9	259	15	11	1	285	397.9	23.0	16.9	437.9	33	2	3	50.7	3.1	4.6	17	1	1	6.3	0.4	90.9	5.3	3.9
Novgorod Oblast	566.7	259	0	30	0	289	457.0	0.0	52.9	510.0	73	0	2	128.8	0.0	3.5	15	0	0	5.2	0.0	89.6	0.0	10.4
Pskov Oblast	574.2	209	0	23	7	232	364.0	0.0	40.1	404.0	34	0	7	59.2	0.0	12.2	26	0	0	11.2	0.0	90.1	0.0	9.9
St. Petersburg	5645.9	2275	87	851	346	3213	402.9	15.4	150.7	569.1	512	52	153	90.7	9.2	27.1	265	2	11	8.3	0.3	70.8	2.7	26.5
Southern Federal District	16585.9	6545	217	1350	528	8112	394.6	13.1	81.4	489.1	1064	51	138	64.2	3.1	8.3	743	55	24	9.8	0.3	80.7	2.7	16.6
Republic of Adygea	501.0	205	2	13	8	220	409.2	4.0	25.9	439.1	63	1	1	125.7	2.0	2.0	39	0	0	17.7	0.0	93.2	0.9	5.9
Republic of Kalmykia	267.4	179	1	36	0	216	669.4	3.7	134.6	807.8	28	0	4	104.7	0.0	15.0	25	0	0	11.6	0.0	82.9	0.5	16.7
Republic of Crimea	1901.1	692	15	110	41	817	364.0	7.9	57.9	429.8	213	8	12	112.0	4.2	6.3	78	1	4	9.7	0.5	84.7	1.8	13.5
Krasnodar Krai	5841.8	3253	97	550	35	3900	556.8	16.6	94.1	667.6	98	10	25	16.8	1.7	4.3	311	24	7	8.6	0.2	83.4	2.5	14.1
Astrakhan Oblast	946.0	371	2	78	31	451	392.2	2.1	82.5	476.7	101	0	21	106.8	0.0	22.2	65	1	1	14.6	0.2	82.3	0.4	17.3
Volgograd Oblast	2435.4	394	79	249	300	722	161.8	32.4	102.2	296.5	241	31	26	99.0	12.7	10.7	52	25	8	10.7	1.1	54.6	10.9	34.5
Rostov Oblast	4135.0	1233	20	301	108	1554	298.2	4.8	72.8	375.8	270	1	48	65.3	0.2	11.6	141	4	4	9.3	0.3	79.3	1.3	19.4
Sevastopol	558.2	218	1	13	5	232	390.5	1.8	23.3	415.6	50	0	1	89.6	0.0	1.8	32	0	0	13.8	0.0	94.0	0.4	5.6
North Caucasian Federal District	10307.6	3960	36	457	133	4453	384.2	3.5	44.3	432.0	901	4	56	87.4	0.4	5.4	551	1	5	12.4	0.1	88.9	0.8	10.3
Republic of Dagestan	3259.0	951	3	134	22	1088	291.8	0.9	41.1	333.8	226	2	17	69.3	0.6	5.2	133	0	2	12.2	0.2	87.4	0.3	12.3
Republic of Ingushetia	534.2	140	28	27	30	195	262.1	52.4	50.5	365.0	37	0	1	69.3	0.0	1.9	15	0	0	7.7	0.0	71.8	14.4	13.8
Kabardino-Balkarian Republic	908.1	496	3	17	3	516	546.2	3.3	18.7	568.2	110	2	2	121.1	2.2	2.2	59	0	0	11.4	0.0	96.1	0.6	3.3
Karachay-Cherkess Republic	468.5	203	0	22	3	225	433.3	0.0	47.0	480.3	21	0	1	44.8	0.0	2.1	27	0	0	12.0	0.0	90.2	0.0	9.8

Continuation of Table 2

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Republic of North Ossetia – Alania	678.5	391	1	20	8	412	576.3	1.5	29.5	607.2	87	0	5	128.2	0.0	7.4	45	0	0	10.9	0.0	94.9	0.2	4.9
Chechen Republic	1575.8	629	0	123	7	752	399.2	0.0	78.1	477.2	164	0	13	104.1	0.0	8.2	99	0	0	13.2	0.0	83.6	0.0	16.4
Stavropol Krai	2883.5	1150	1	114	60	1265	398.8	0.3	39.5	438.7	256	0	17	88.8	0.0	5.9	173	1	3	13.8	0.2	90.9	0.1	9.0
Volga Federal District	28397.8	10771	620	2530	1991	13921	379.3	21.8	89.1	490.2	2785	210	315	98.1	7.4	11.1	1616	69	30	12.1	0.2	77.4	4.5	18.2
Republic of Bashkortostan	4046.1	1074	23	410	128	1507	265.4	5.7	101.3	372.5	375	16	40	92.7	4.0	9.9	236	2	0	15.8	0.0	71.3	1.5	27.2
Mari El Republic	666.0	245	4	42	40	291	367.9	6.0	63.1	436.9	57	2	5	85.6	3.0	7.5	26	0	1	8.9	0.3	84.2	1.4	14.4
Republic of Mordovia	758.4	308	17	46	109	371	406.1	22.4	60.7	489.2	43	1	4	56.7	1.3	5.3	37	0	0	10.0	0.0	83.0	4.6	12.4
Republic of Tatarstan	4016.6	1616	16	548	509	2180	402.3	4.0	136.4	542.7	469	4	101	116.8	1.0	25.1	234	2	8	10.8	0.4	74.1	0.7	25.1
Udmurt Republic	1427.0	720	38	94	79	852	504.6	26.6	65.9	597.1	173	6	9	121.2	4.2	6.3	87	5	2	10.8	0.2	84.5	4.5	11.0
Chuvash Republic	1159.8	370	0	72	47	442	319.0	0.0	62.1	381.1	92	0	5	79.3	0.0	4.3	64	0	0	14.5	0.0	83.7	0.0	16.3
Perm Krai	2482.1	1034	50	143	102	1227	416.6	20.1	57.6	494.3	178	19	11	71.7	7.7	4.4	139	1	1	11.4	0.1	84.3	4.1	11.7
Kirov Oblast	1120.2	494	14	50	22	558	441.0	12.5	44.6	498.1	86	2	3	76.8	1.8	2.7	45	1	1	8.2	0.2	88.5	2.5	9.0
Nizhny Novgorod Oblast	3037.8	1301	52	374	211	1727	428.3	17.1	123.1	568.5	319	14	26	105.0	4.6	8.6	188	7	0	11.3	0.0	75.3	3.0	21.7
Orenburg Oblast	1815.7	724	94	171	39	989	398.7	51.8	94.2	544.7	220	42	39	121.2	23.1	21.5	131	26	4	15.9	0.4	73.2	9.5	17.3
Penza Oblast	1226.0	475	63	47	241	585	387.4	51.4	38.3	477.2	86	12	6	70.1	9.8	4.9	69	5	0	12.6	0.0	81.2	10.8	8.0
Samara Oblast	3108.9	1197	144	265	109	1606	385.0	46.3	85.2	516.6	376	58	33	120.9	18.7	10.6	185	9	4	12.1	0.2	74.5	9.0	16.5
Saratov Oblast	2368.4	799	51	177	69	1027	337.4	21.5	74.7	433.6	183	21	24	77.3	8.9	10.1	116	7	6	12.0	0.6	77.8	5.0	17.2
Ulyanovsk Oblast	1164.8	414	54	91	286	559	355.4	46.4	78.1	479.9	128	13	9	109.9	11.2	7.7	59	4	3	11.3	0.5	74.1	9.7	16.3
Ural Federal District	11914.3	5145	36	992	611	6173	431.8	3.0	83.3	518.1	1334	8	121	112.0	3.0	10.2	592	3	17	9.6	0.3	83.3	0.6	16.1
Kurgan Oblast	744.2	334	0	27	8	361	448.8	0.0	36.3	485.1	177	0	3	237.8	0.0	4.0	65	0	0	18.0	0.0	92.5	0.0	7.5
Sverdlovsk Oblast	4218.2	2061	26	388	190	2475	488.6	6.2	92.0	586.7	587	2	38	139.2	0.5	9.0	296	2	6	12.0	0.2	83.3	1.1	15.7
Khanty-Mansi Autonomous Okrug – Yugra	1779.5	698	0	132	145	830	392.2	0.0	74.2	466.4	179	0	18	100.6	0.0	10.1	79	0	5	9.5	0.6	84.1	0.0	15.9
Yamalo-Nenets Autonomous Okrug	521.7	129	0	23	30	152	247.3	0.0	44.1	291.4	36	0	1	69.0	0.0	1.9	16	0	1	10.5	0.7	84.9	0.0	15.1
Tyumen Oblast without autonomies	1267.5	585	1	136	40	722	461.5	0.8	107.3	569.6	139	1	31	109.7	0.8	24.5	42	0	4	5.8	0.6	81.0	0.1	18.8
Chelyabinsk Oblast	3383.2	1338	9	286	198	1633	395.5	2.7	84.5	482.7	216	5	30	63.8	1.5	8.9	94	1	1	5.8	0.1	81.9	0.6	17.5
Siberian Federal District	16482.8	6162	122	1636	685	7920	373.8	7.4	99.3	480.5	1478	32	230	89.7	1.9	14.0	736	18	28	9.5	0.4	77.8	1.5	20.7
Altai Republic	210.1	11	0	8	11	19	52.4	0.0	38.1	90.4	4	0	3	19.0	0.0	14.3	4	0	0	21.1	0.0	57.9	0.0	42.1

End of Table 2

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Tuva Republic	338.3	103	2	47	0	152	304.5	5.9	138.9	449.3	24	0	9	70.9	0.0	26.6	5	0	0	3.3	0.0	67.8	1.3	30.9
Republic of Khakassia	525.5	250	6	52	33	308	475.7	11.4	99.0	586.1	0	0	3	71.0	0.0	5.7	39	0	0	12.7	0.0	81.2	1.9	16.9
Altai Krai	2099.0	954	2	165	136	1121	454.5	1.0	78.6	534.1	322	0	16	153.4	0.0	7.6	169	0	1	15.1	0.1	85.1	0.2	14.7
Krasnoyarsk Krai	2837.4	1063	13	223	53	1299	374.6	4.6	78.6	457.8	294	1	42	103.6	0.4	14.8	96	0	3	7.4	0.2	81.8	1.0	17.2
Irkutsk Oblast	2316.6	1024	10	207	25	1241	442.0	4.3	89.4	535.7	162	2	36	69.9	0.9	15.5	72	0	4	5.8	0.3	82.5	0.8	16.7
Kemerovo (Kuzbass) Oblast	2526.4	908	17	454	135	1379	359.4	6.7	179.7	545.8	234	10	76	92.6	4.0	30.1	136	0	12	9.9	0.9	65.8	1.2	32.9
Novosibirsk Oblast	2784.6	868	48	300	57	1216	311.7	17.2	107.7	436.7	232	14	41	83.3	5.0	14.7	115	9	6	10.2	0.5	71.4	3.9	24.7
Omsk Oblast	1805.4	736	5	124	227	865	407.7	2.8	68.7	479.1	157	0	2	87.0	0.0	1.1	83	0	1	9.6	0.1	85.1	0.6	14.3
Tomsk Oblast	1039.5	245	19	56	8	320	235.7	18.3	53.9	307.8	49	5	2	47.1	4.8	1.9	17	9	1	8.1	0.3	76.6	5.9	17.5
Far Eastern Federal District	7853.5	2975	151	583	254	3709	378.8	19.2	74.2	472.3	658	49	83	83.8	6.2	10.6	287	12	5	8.1	0.1	80.2	4.1	15.7
Republic of Buryatia	970.7	558	5	116	17	679	574.8	5.2	119.5	699.5	87	5	10	89.6	5.2	10.3	52	2	0	8.0	0.0	82.2	0.7	17.1
Sakha (Yakutia) Republic	1007.1	618	16	194	50	828	613.6	15.9	192.6	822.2	270	3	27	268.1	3.0	26.8	55	0	0	6.6	0.0	74.6	1.9	23.4
Zabaykalsky Krai	982.5	353	16	34	0	403	359.3	16.3	34.6	410.2	10	2	13	10.2	2.0	13.2	18	0	0	4.5	0.0	87.6	4.0	8.4
Kamchatka Krai	287.9	81	0	17	0	98	281.3	0.0	59.0	340.4	25	0	1	86.8	0.0	3.5	9	0	0	9.2	0.0	82.7	0.0	17.3
Primorsky Krai	1798.0	499	64	80	126	643	277.5	35.6	44.5	357.6	146	20	14	81.2	11.1	7.8	62	3	2	10.1	0.3	77.6	10.0	12.4
Khabarovsk Krai	1273.1	422	14	48	46	484	331.5	11.0	37.7	380.2	32	3	11	25.1	2.4	8.6	36	7	1	8.9	0.2	87.2	2.9	9.9
Amur Oblast	750.9	148	30	48	7	226	197.1	40.0	63.9	301.0	51	11	4	67.9	14.6	5.3	23	0	2	10.2	0.9	65.5	13.3	21.2
Magadan Oblast	134.2	37	4	4	3	45	275.7	29.8	29.8	335.3	3	3	0	22.4	22.4	0.0	2	0	0	4.4	0.0	82.2	8.9	8.9
Sakhalin Oblast	456.8	206	1	38	5	245	451.0	2.2	83.2	536.3	26	2	3	56.9	4.4	6.6	18	0	0	7.3	0.0	84.1	0.4	15.5
Jewish Autonomous Oblast	144.4	53	1	3	0	57	367.0	6.9	20.8	394.7	8	0	0	55.4	0	0.0	12.0	0.0	0.0	21.1	0	93.0	1.8	5.3
Chukotka Autonomous Okrug	47.9	0	0	1	0	1	0.0	0.0	20.9	20.9	0	0	0	0.0	0	0.0	0	0	0	0.0	0	0.0	0.0	100.0
New territories	3227.4	623	11	133	56	767	193.0	3.4	41.2	237.7	233	2	14	72.2	0.6	4.3	81	2	0	10.9	0	81.2	1.4	17.3
Donetsk People's Republic		395	8	95	53	498					156	2	2				49	1	0	10.0	0	79.3	1.6	19.1
Luhansk People's Republic		155	3	30	3	188					43	0	5				27	1	0	14.9	0	82.4	1.6	16.0
Zaporizhzhya Oblast		73	0	7	0	80					34	0	6				5	0	0	6.3	0	91.3	0.0	8.8
Kherson Oblast		18	0	1	0	19					12	0	1				6	0	0	31.6	0	94.7	0.0	5.3

Note. Population figures and indicators per million population for the Russian Federation were calculated excluding the newly incorporated territories. due to the inability to accurately determine the permanent population in those regions.

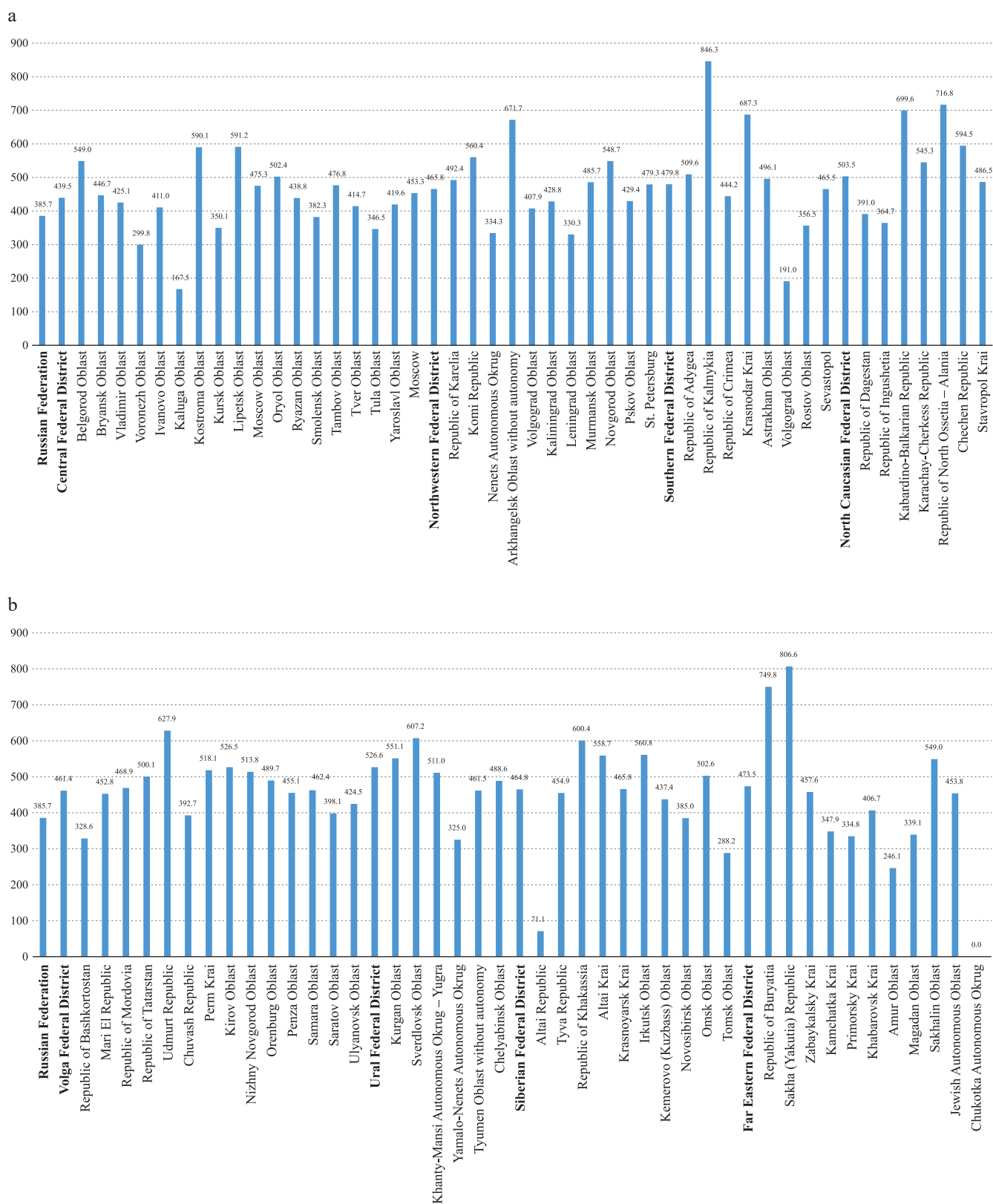


Fig. 6. Availability of hemodialysis per million population in regions of the Russian Federation: a, Central, Northwestern, Southern, and North Caucasian Federal Districts; b, Volga, Ural, Siberian, and Far Eastern Federal Districts

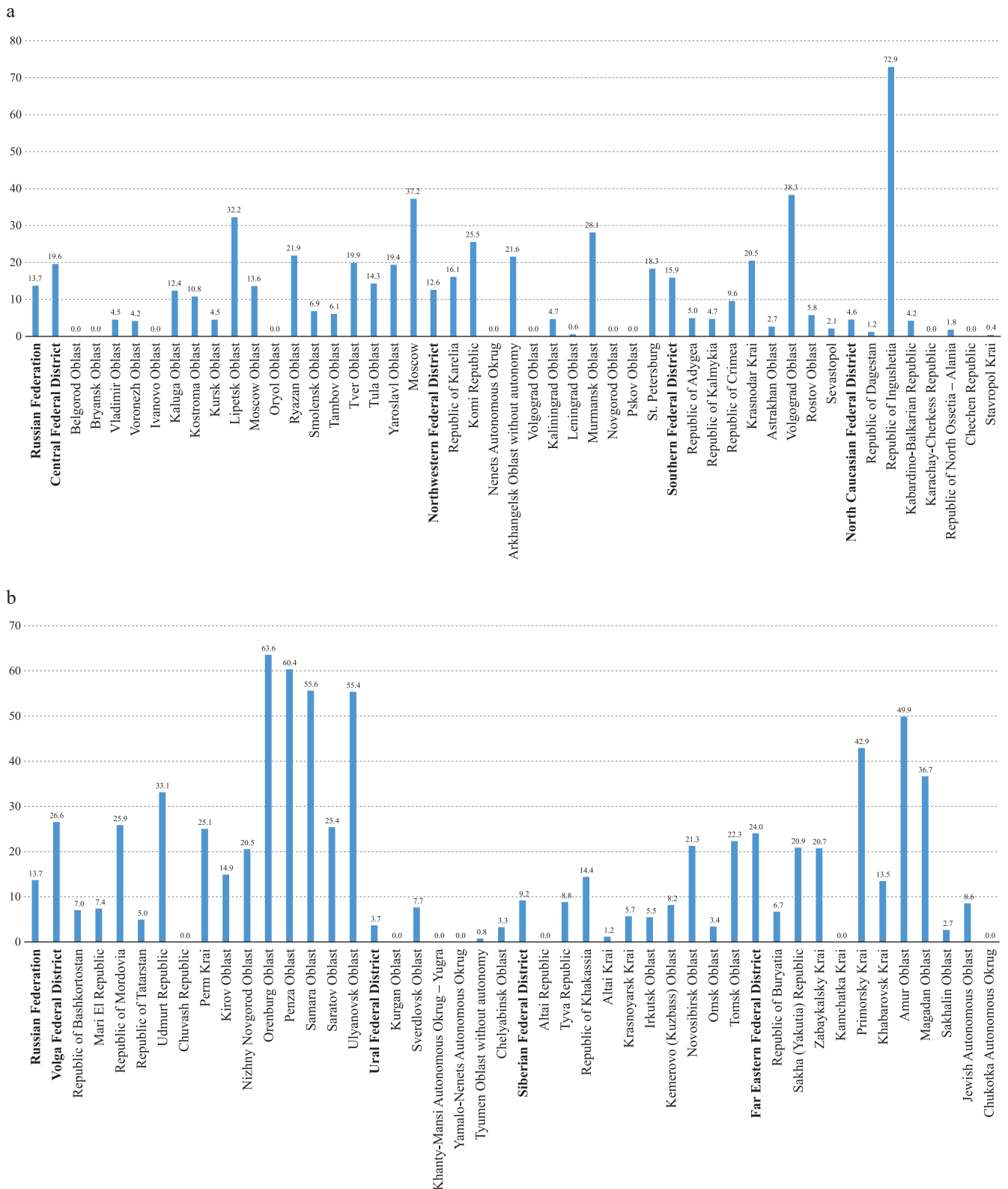


Fig. 7. Availability of peritoneal dialysis per million population in regions of the Russian Federation: a, Central, Northwestern, Southern, and North Caucasian Federal Districts; b, Volga, Ural, Siberian, and Far Eastern Federal Districts

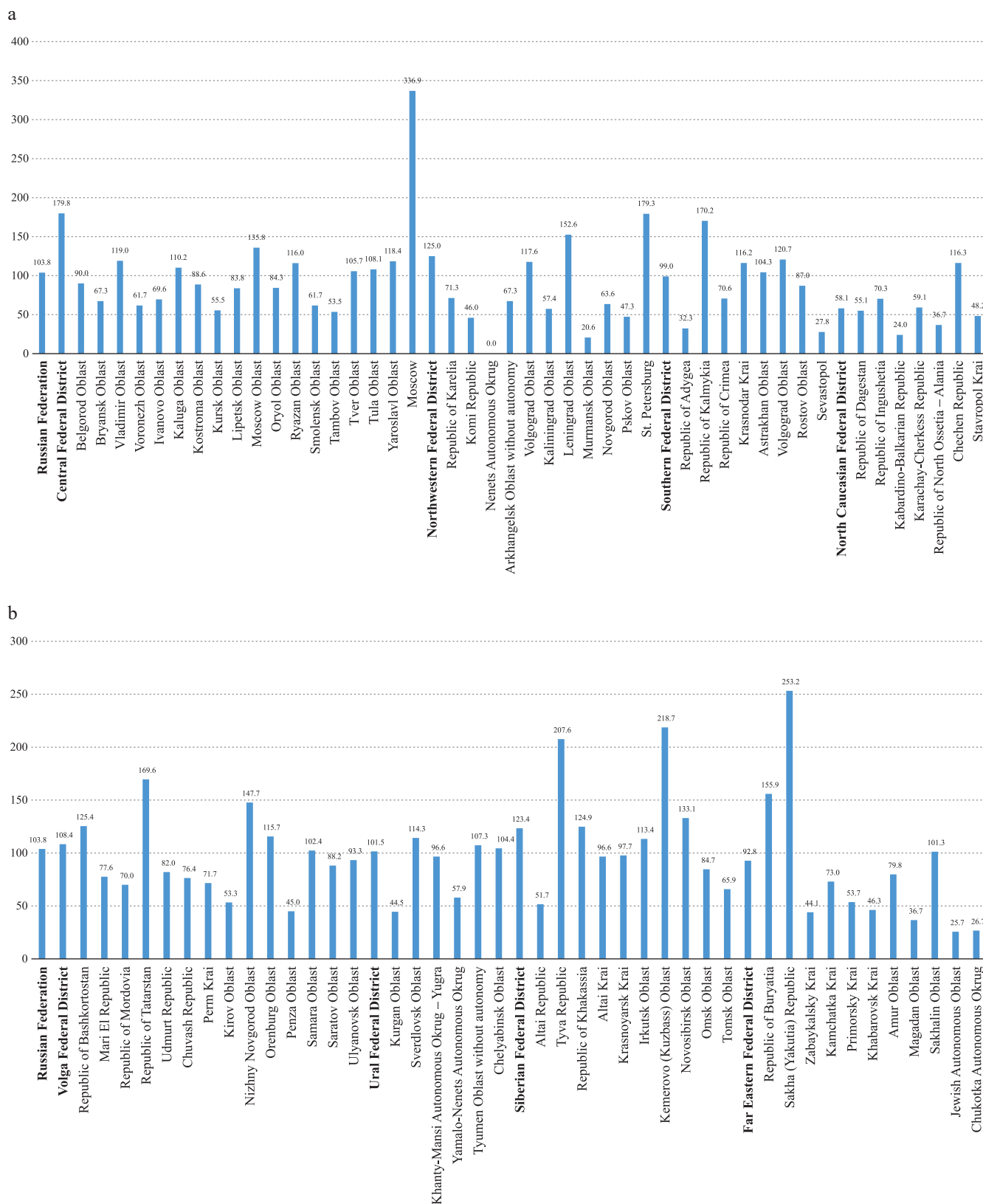


Fig. 8. Availability of kidney transplantation per million population in regions of the Russian Federation: a, Central, North-western, Southern, and North Caucasian Federal Districts; b, Volga, Ural, Siberian, and Far Eastern Federal Districts

The share of sessions conducted with low-flux membranes was 12%, which is consistent with global practice.

Hemodiafiltration (HDF), a more advanced modality compared to both low-flux and high-flux HD, accounted for 30% of all sessions (2,150,970), a frequency comparable to that observed in Europe [13]. Although the wider adoption of HDF in Russia appears to be constrained by its higher cost relative to high-flux HD, accumulating evidence highlights its long-term benefits, such as reduced mortality, fewer hospitalizations, reduced need for medication, and improved quality of life for patients [14, 15].

In Russia, 65.3% of HD patients have completed full vaccination against viral hepatitis B. The prevalence of infections among this population is as follows: 2.4% are infected with hepatitis B virus (HBV), 6.2% with hepatitis C virus (HCV), and 0.7% with human immunodeficiency virus (HIV). Notably, in several regions, including Kaluga, Kursk, Republic of Crimea, Republic of Dagestan, Kabardino-Balkarian Republic, Chechen Republic, Saratov, Khanty-Mansi Autonomous Okrug, Krasnoyarsk Krai, Kamchatka Krai, and Primorsky Krai, the proportion of HD patients with HCV exceeds 10%, significantly higher than the national average.

Peritoneal dialysis (PD) is available in 70 regions of the Russian Federation. In 2024, 1,997 patients were treated with PD, the majority (1,445; 72.4%) using continuous ambulatory peritoneal dialysis (CAPD). Automated peritoneal dialysis (APD) is also developing, with 552 patients (27.6%) receiving this modality, a distribution consistent with global practice. The availability of PD was more than twice the national average in several regions, including Moscow, Orenburg Oblast, Penza Oblast, Samara Oblast, Ulyanovsk Oblast, Amur Oblast, Primorsky Krai, Volgograd Oblast, Magadan Krai, Lipetsk Oblast, and Murmansk Oblast (Fig. 7).

ASSESSMENT OF THE EFFECTIVENESS AND QUALITY OF HEMODIALYSIS IN 2024

The effectiveness and quality of hemodialysis in the Russian Federation in 2024 were evaluated using the indicators presented in Table 3.

Target values were established in accordance with the 2024 clinical guidelines for CKD, except for hyperphosphatemia. Research evidence [16] shows that fewer than 50% of dialysis patients achieve a stable serum phosphate level below 1.78 mmol/L; therefore, this threshold was applied as the evaluation criterion.

Data were collected from 571 dialysis centers across the country. The target hemoglobin level was achieved in 80% of patients (95% CI: 71–87.5%), a result consistent with published global data [17]. Performance above the national average was reported in several regions of the Central Federal District, the Far Eastern Federal District, and multiple regions of the Ural Federal District (Fig. 9). By contrast, regions reporting results below the national average emphasized the need to improve access to essential medications for patients with CKD.

Target blood albumin levels were achieved in an average of 94% of HD patients in Russia in 2024 (95% CI: 89–98%) (Fig. 10). Serum albumin level is a key indicator of nutritional status in dialysis patients and is strongly associated with survival and hospitalization rates. Evidence from several large cohort studies demonstrates that albumin levels above 35 g/L are linked to reduced mortality, lower hospitalization rates, and improved quality of life in this patient population [18, 19].

Globally, approximately 10.5% of dialysis patients present with reduced serum albumin levels [16]. Clinical studies have shown that infusions of 25% albumin solution prior to HD can reduce the incidence of intradialytic hypotension in patients with hypoalbuminemia [20]. Dialysis centers reporting more than 10% of patients with hypoalbuminemia should therefore consider targeted interventions, including pre-dialysis albumin infusions and the use of specialized therapeutic nutrition, to correct hypoalbuminemia and improve outcomes.

Phosphorus–calcium metabolism indicators reflect the quality of medical care in patients receiving dialysis (Figs. 11–13). According to reports from dialysis centers, an average of 69% [95% CI: 58–79] of patients in Russia achieved target blood phosphate levels, and 71% [95% CI: 57–81] achieved target parathyroid hormone levels, figures that are consistent with global data [16].

Table 3

Indicators of hemodialysis efficiency and quality

S/N	Indicator	Value	Percentage of patients
1	Hemoglobin	$\geq 100 \leq 120$	≥ 75
2	Albumin*	≥ 35	≥ 90
3	Calcium**	$\geq 2.1 \leq 2.5$	≥ 75
4	Phosphorus	≤ 1.78	≥ 70
5	Parathyroid hormone	$\geq 130 \leq 325$	≥ 70
6	Kt/V	≥ 1.4	≥ 90

Note. Hemodialysis efficiency and quality indicators are assessed as of December 31 of the reporting year; * Provided that serum albumin levels are measured using the bromocresol green (BCG) method; ** Calcium levels >2.1 mmol/L, excluding patients receiving calcimimetic therapy.

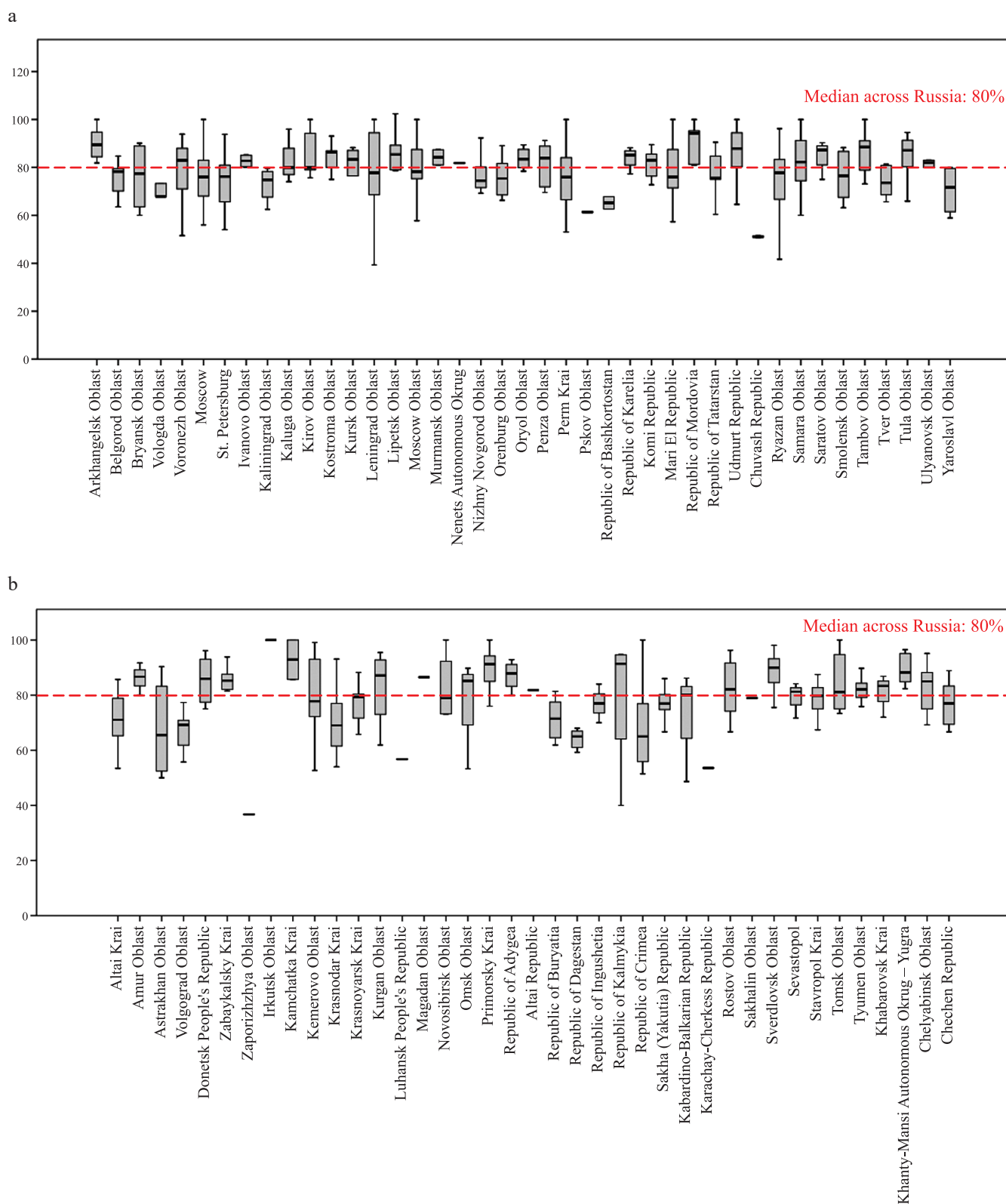


Fig. 9. Percentage of patients with target hemoglobin levels on dialysis in 2024: a, Central, Northwestern, and Volga Federal Districts; b, North Caucasian, Siberian, Far Eastern, Southern, Ural Federal Districts, and new territories. The figure shows medians and interquartile ranges [95% CI, 25–75%]

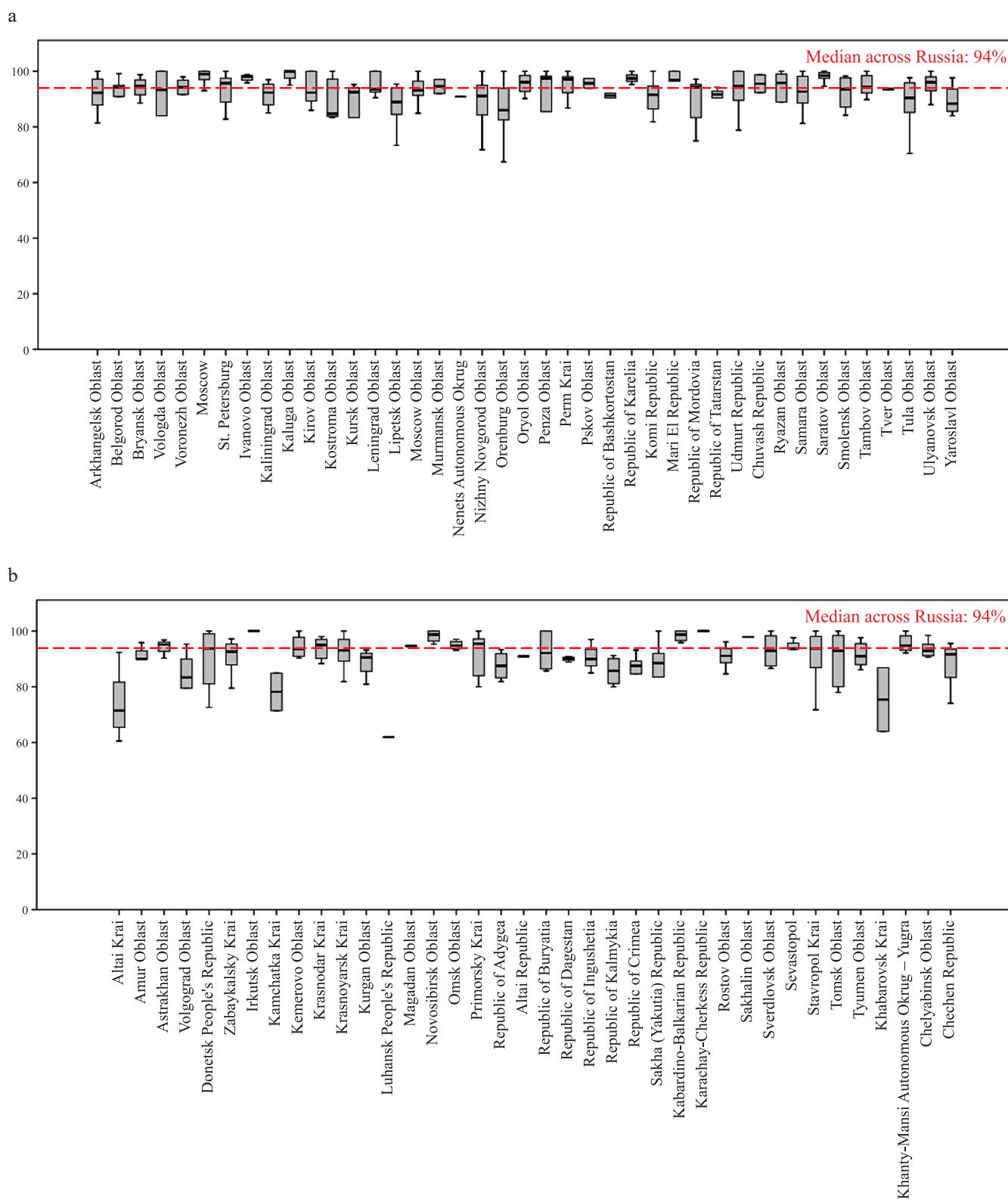


Fig. 10. Percentage of patients with target albumin levels on dialysis in 2024: a, Central, Northwestern, and Volga Federal Districts; b, North Caucasian, Siberian, Far Eastern, Southern, Ural Federal Districts, and new territories. The figure shows medians and interquartile ranges [95% CI, 25–75%]

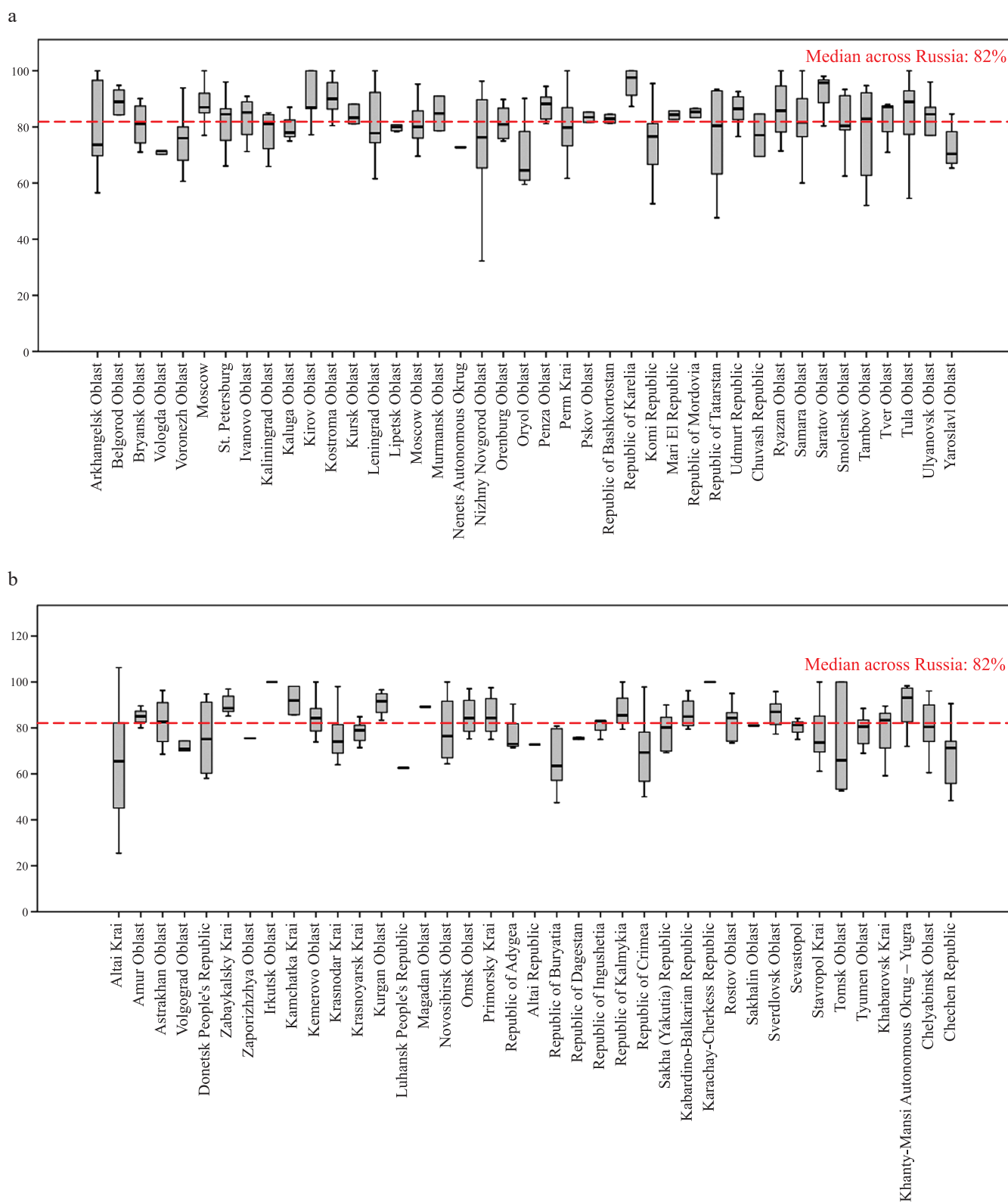


Fig. 11. Percentage of patients with target calcium levels on dialysis in 2024: a, Central, Northwestern, and Volga Federal Districts; b, North Caucasian, Siberian, Far Eastern, Southern, Ural Federal Districts, and new territories. The figure shows medians and interquartile ranges [95% CI, 25–75%]

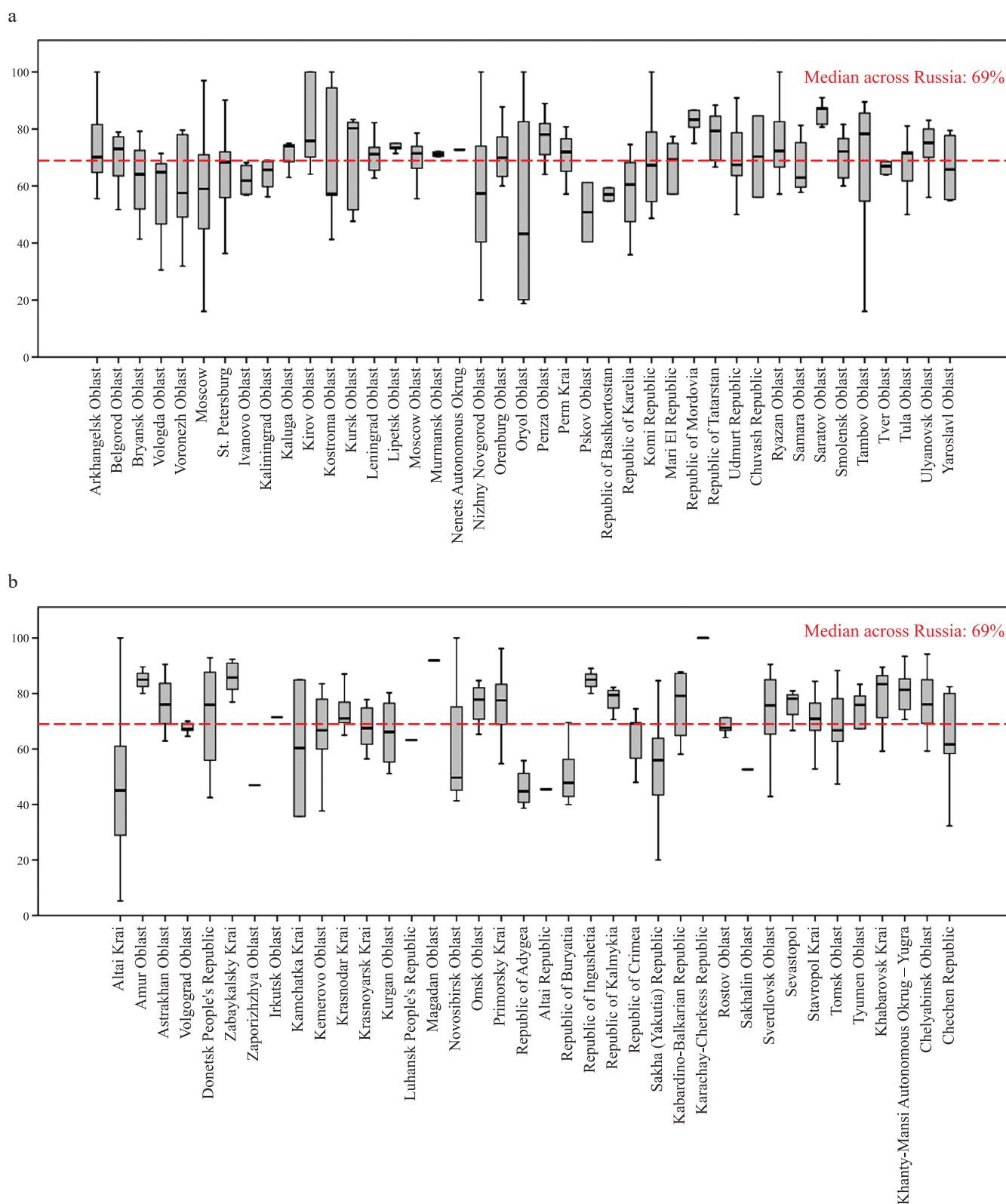


Fig. 12. Percentage of patients with target phosphorus levels on dialysis in 2024: a, Central, Northwestern, and Volga Federal Districts; b, North Caucasian, Siberian, Far Eastern, Southern, Ural Federal Districts, and new territories. The figure shows medians and interquartile ranges [95% CI, 25–75%]

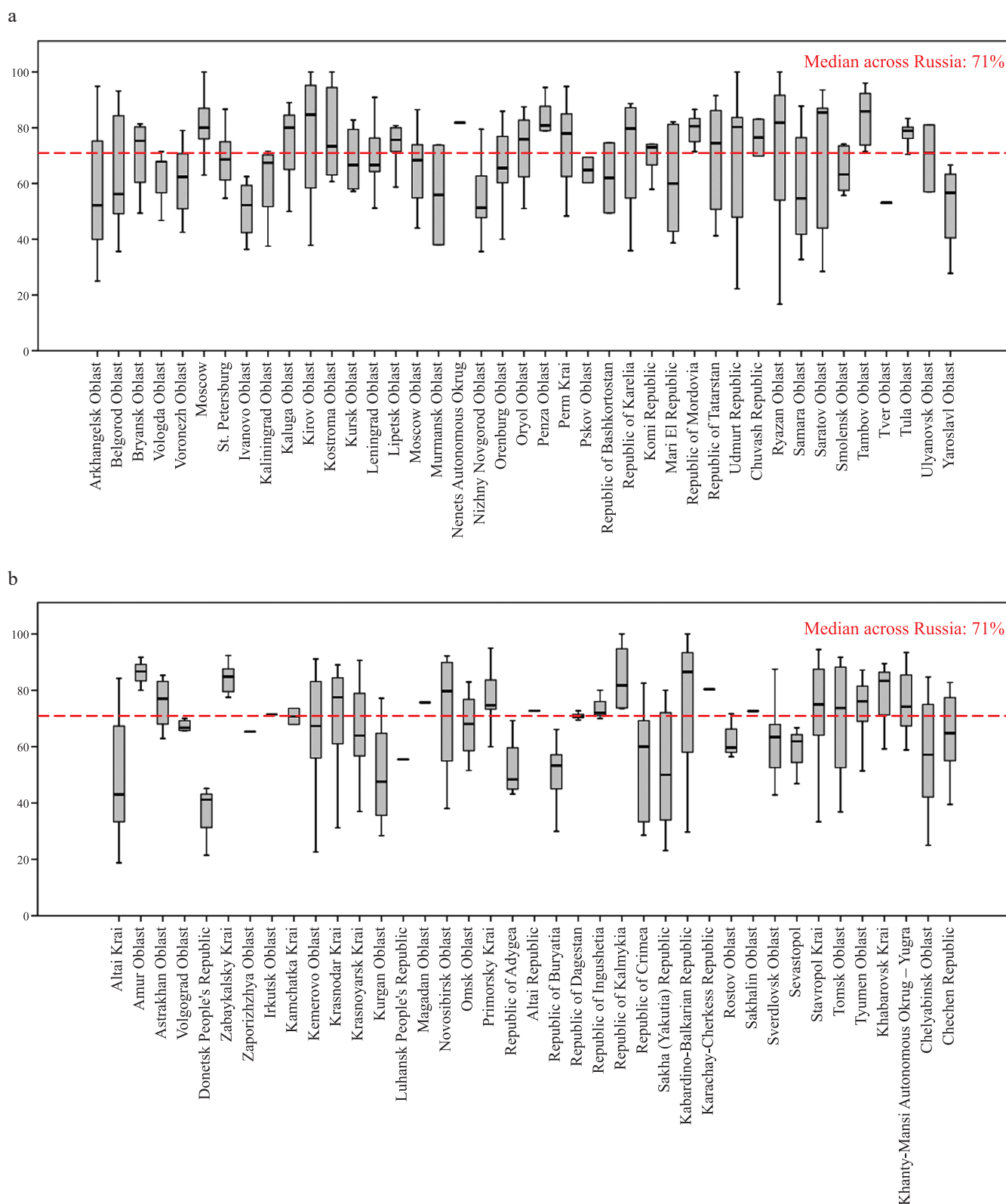


Fig. 13. Percentage of patients with target parathyroid hormone levels on dialysis in 2024: a, Central, Northwestern, and Volga Federal Districts; b, North Caucasian, Siberian, Far Eastern, Southern, Ural Federal Districts, and new territories. The figure shows medians and interquartile ranges [95% CI, 25–75%]

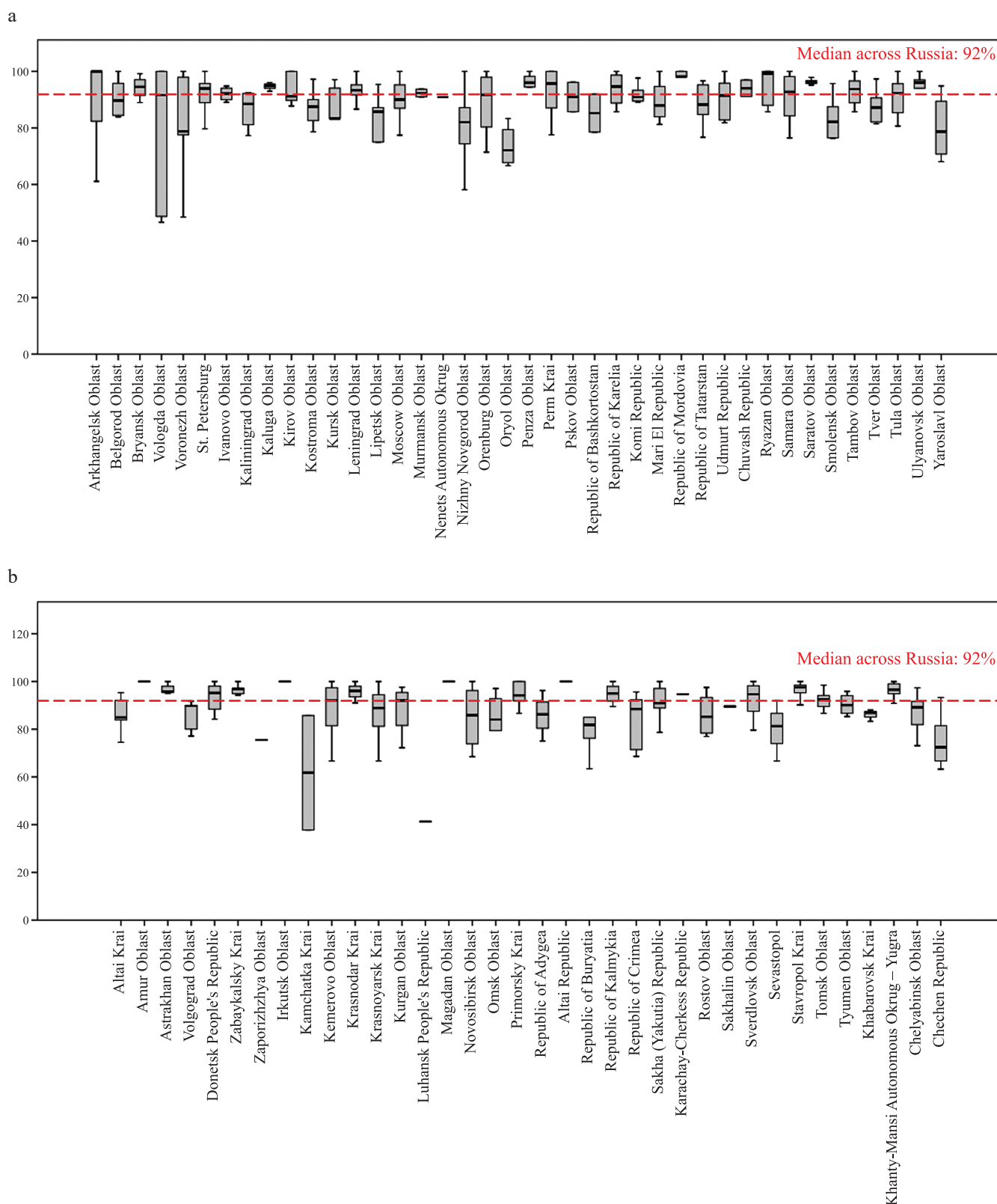


Fig. 14. Percentage of patients with target Kt/V levels on dialysis in 2024: a, Central, Northwestern, and Volga Federal Districts; b, North Caucasian, Siberian, Far Eastern, Southern, Ural Federal Districts, and new territories. The figure shows medians and interquartile ranges [95% CI, 25–75%]

Effectiveness indicators for a single HD session were also high: more than 90% of patients achieved the standard target Kt/V, with an overall average of 92% [95% CI: 84–97] (Fig. 14).

RENAL REPLACEMENT THERAPY IN PEDIATRIC PATIENTS

In 2024, 579 children with CKD stage 5 were on renal replacement therapy (RRT). Of these, 101 (17.4%) re-

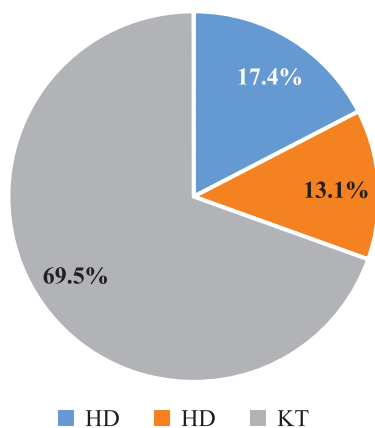


Fig. 15. Distribution of RRT types among children with stage 5 CKD in the Russian Federation in 2024

ceived HD, 76 (13.1%) underwent PD, and 402 (69.5%) had a functioning kidney transplant. Thus, kidney transplantation (KT) remains the predominant RRT modality in children in the Russian Federation, with other RRT modalities accounting for a considerably smaller proportion (Fig. 15).

Across all pediatric patient groups, KT remains the predominant RRT modality, with the proportion of children living with a functioning transplanted kidney ranging from 76% to 81%. In the youngest age group (0–4 years), PD accounts for 44% of cases, whereas among older children (15–18 years), HD represents 19% of RRT, primarily as a preparatory stage before KT (Fig. 16). In 2024, a general trend was observed toward a higher proportion of male patients on RRT overall, particularly among those receiving HD and those with a functioning kidney transplant (Fig. 17).

Congenital malformations of the urinary system account for more than half of the underlying diseases in children undergoing RRT (54.8% of cases), with glomerulonephritis (9.6%) and hemolytic-uremic syndrome (HUS, 10.3%) also contributing significantly. Approximately 5% of pediatric CKD cases are of unknown origin, likely reflecting undiagnosed genetic or other rare causes. This highlights the need to improve diagnostic

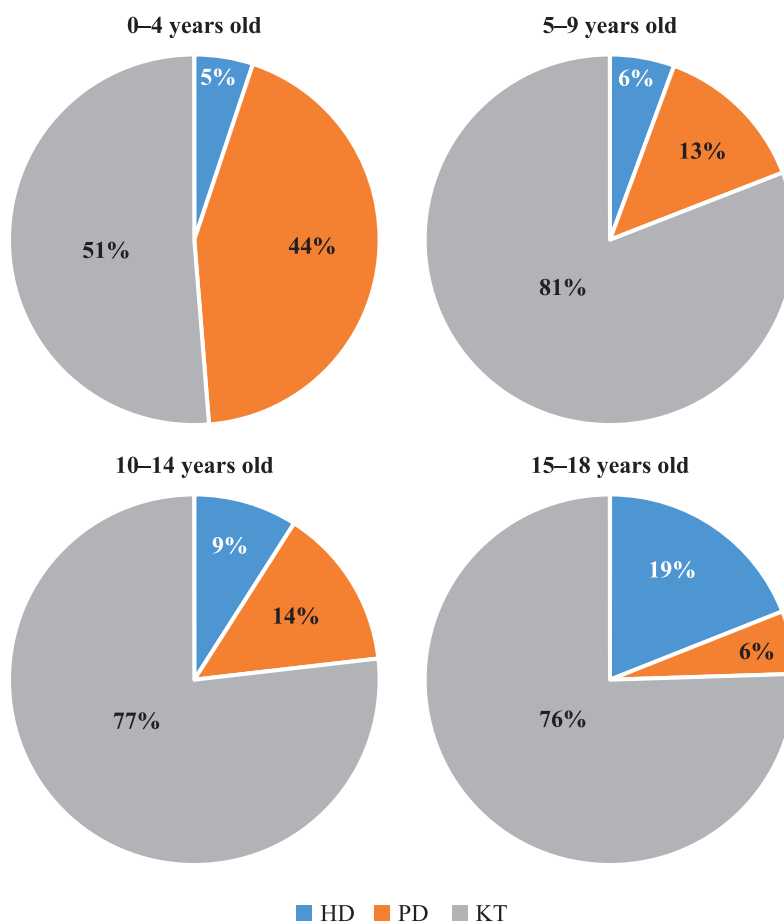


Fig. 16. Age distribution of children with stage 5 CKD receiving RRT in the Russian Federation in 2024

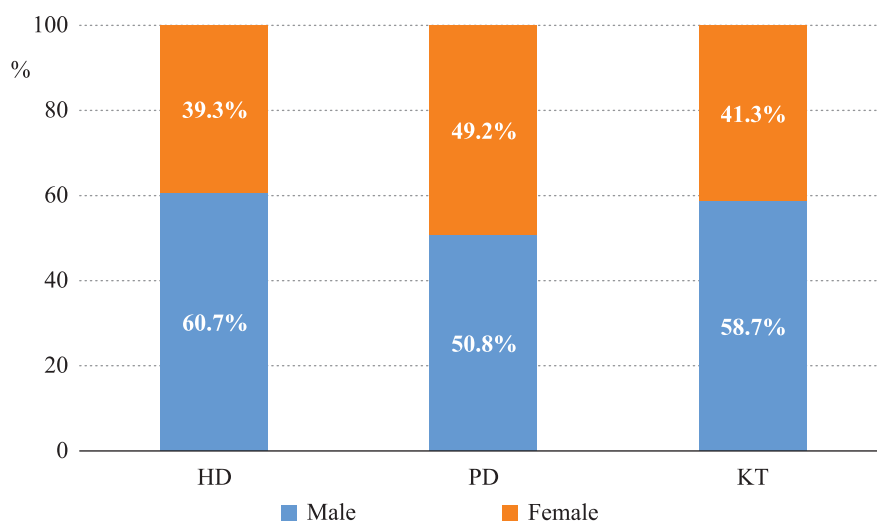


Fig. 17. Gender distribution of children with stage 5 CKD receiving RRT in the Russian Federation in 2024

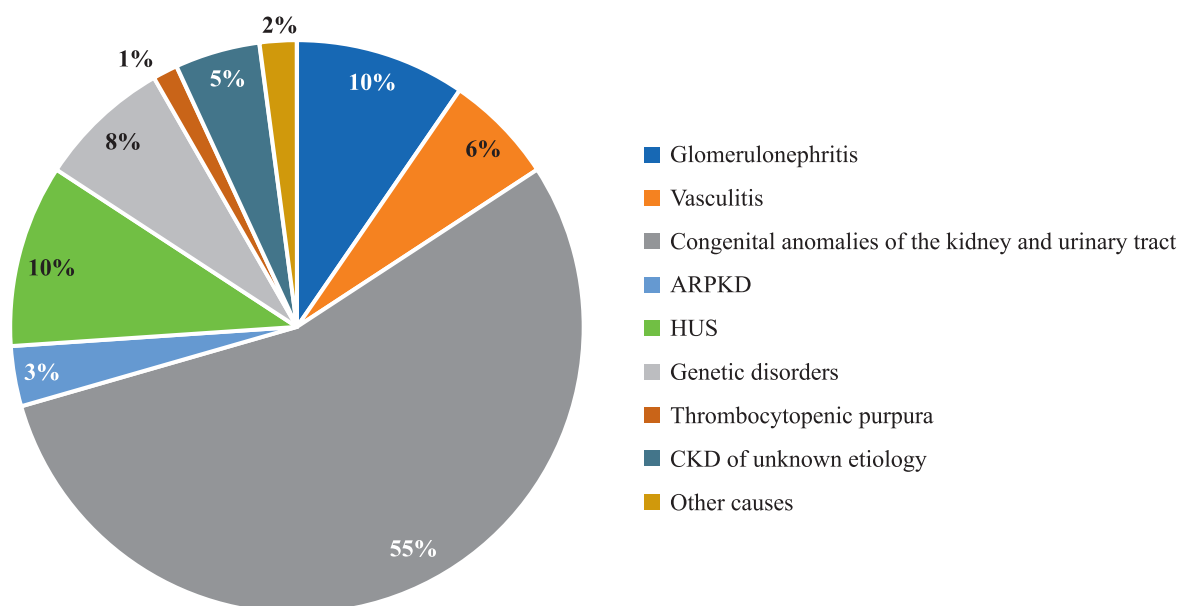


Fig. 18. Nosological structure of kidney disease in children receiving RRT in the Russian Federation

approaches, particularly through wider use of nephrobiopsy and expanded access to genetic testing, including molecular analysis of atypical HUS-associated genes and comprehensive kidney disease gene panels for pediatric patients (Fig. 18).

The availability of RRT for children in the Russian Federation is 24.7 per million of the pediatric population, of which KT accounts for 17.0 per million, PD for 3.2 per million, and HD for 4.3 per million. The highest numbers of children living with transplanted kidneys are observed in Moscow Oblast, Chelyabinsk Oblast, St. Petersburg, Krasnodar Krai, and Kemerovo Oblast.

CONCLUSION

The Center for Excellence in Medical Care in Nephrology at Shumakov National Medical Research Center

of Transplantology and Artificial Organ has developed a framework for annual monitoring and established cooperation with regional health authorities, which has enabled the collection of data on the state of nephrology care and RRT across all regions of the Russian Federation. The set of monitoring indicators has been recommended for use by executive health authorities at federal subjects of the Russian Federation, as well as by regional chief freelance specialists in nephrology, dialysis, and transplantation.

However, it was noted that only 28 (31.5%) of 89 regions maintain records of patients in the pre-dialysis stages of CKD. This lack of systematic registration makes it difficult to accurately assess the prevalence of early CKD and to plan or organize appropriate nephrology care. Establishing comprehensive registries of patients in the pre-dialysis stages of CKD would provide more precise

epidemiological data, enable more effective planning of medical services, and improve the quality of nephrology care across the Russian Federation. This is particularly important given that patients with CKD already have a high or very high risk of cardiovascular mortality already in the pre-dialysis stages, starting from stage 3 of the disease [21].

The need to systematically register nephrology patients, conduct regular medical examinations for individuals with CKD, and establish patient education programs (such as kidney disease schools) underscores the importance of expanding outpatient nephrology services. Addressing the shortage of outpatient nephrologists requires not only intensified training of specialized nephrologists but also retraining and professional development of physicians from related specialties, including general internists, who are actively involved in the management of CKD patients. In many regions, there is also a shortage of nephrologists with expertise in managing kidney transplant recipients – a demand that will continue to grow in light of the steady annual increase in the number of transplant recipients.

One of the tools for tackling this issue is the Procedure for Dispensary Observation of Adults (Order of the Russian Ministry of Health, No. 168n, March 15, 2022), which mandates the dynamic follow-up of all patients with CKD stages 3b–5 as well as kidney transplant recipients. The proposal developed at Shumakov National Medical Research Center of Transplantology and Artificial Organ specifies the structure of follow-up medical care groups, recommended follow-up frequency, and the set of controlled clinical and laboratory indicators (Table 4). This decision will require regions to improve the staffing of outpatient clinics with nephrologists.

In 2024, HD remained the predominant RRT modality, with the distribution of patients across HD, PD, and KT in the Russian Federation being 76.7%, 2.7%, and 20.6%, respectively. Overall, the availability of HD remains consistently high across most regions. However, despite the generally high use of AVF access, some regions still report a substantial proportion of patients receiving HD through temporary central venous catheters. This is largely attributable to delays in the creation of permanent vascular access and highlights the need for enhanced training and continuing education of vascular surgeons, the establishment of specialized vascular access units, and the development of clear patient routing pathways in these regions.

Another important priority is to achieve universal coverage of HD patients with hepatitis B vaccination. One effective approach could be to recommend and implement vaccination already at the pre-dialysis stages of CKD, thereby improving both overall coverage and vaccine response rates, since patients with end-stage

CKD often demonstrate a reduced immunologic response. This recommendation may be integrated into patient education programs such as CKD schools or included as part of structured follow-up medical care.

In regions where HCV prevalence among dialysis patients exceeds 10%, it is advisable to expand access to antiviral therapy. Broader treatment coverage will not only lower mortality but also improve eligibility for inclusion on the kidney transplant waiting list.

It is noteworthy that PD remains underutilized in the Russian Federation. Expanding PD services could be particularly valuable in regions with low population density and vast geographic areas, where access to dialysis centers is limited. Of special interest is the growing role of APD. Although APD is approximately 30% more expensive than CAPD) it offers clear advantages: improved quality of life due to greater daytime physical activity, increased ultrafiltration volume during nighttime exchanges, enhanced social participation, and particular suitability for children in the pre-transplant stage of RRT [22]. Prospects for further development of APD in Russia are favorable, as 60.2% of the total devices available ($n = 917$) are already in use.

In 2024, most indicators of dialysis effectiveness in the Russian Federation were consistent with global benchmarks, though the percentage of patients achieving target phosphorus and parathyroid hormone levels remained comparatively low. Given the importance of diet in maintaining target phosphorus levels, in addition to eliminating this trace element during dialysis or when taking medications, increasing patient adherence to treatment and compliance with dietary recommendations is a priority for education in schools for patients with end-stage CKD on dialysis.

Increasing the proportion of patients with functioning kidney transplants and those on PD, particularly in regions with low population density, remains a priority for the further development of nephrological care in the Russian Federation. Encouragingly, the number of kidney transplants has steadily increased over the past five years, and in several regions, the rise in the total number of patients on RRT has been primarily driven by an increase in transplant recipients. This trend can be regarded as a positive shift toward more effective and cost-efficient long-term treatment of end-stage CKD.

Ongoing monitoring of nephrological care and RRT across the Russian Federation will remain essential with an assessment of key indicators of medical care for patients at all stages of CKD and their dynamics. A summary of the main indicators reflecting the state of nephrological care and RRT in the Russian Federation in 2024 is presented in Table 5.

The authors declare no conflict of interest.

Table 4

Recommendations from the Shumakov National Medical Research Center of Transplantology and Artificial Organs on the organization of dispensary follow-up for patients with CKD stages 1–5 and kidney transplant recipients

S/N	ICD-10 Code	Chronic condition / functional disorder requiring regular medical follow-up	Minimum frequency of follow-up visits (examinations, consultations)	Health indicators monitored under regular medical follow-up	Follow-up duration	Remarks
Medical follow-up is carried out by a general practitioner						
1	N18.1, N18.2, N18.3	Chronic kidney disease (CKD) stages 1, 2, and 3a (glomerular filtration rate [GFR]: 45–60 mL/min)	At least twice a year, in accordance with clinical guidelines	Blood creatinine with GFR calculation (at least twice a year), albuminuria (at least twice a year), complete blood count (at least twice a year)	Lifelong, until initiation of renal replacement therapy	Appointment (examination or consultation) with a nephrologist as clinically indicated, in accordance with clinical guidelines
Medical follow-up is carried out by a nephrologist						
2	N18.3, N18.4	CKD stage 3b (GFR: 30–45 mL/min)	At least four times a year, in accordance with clinical guidelines	Blood creatinine with GFR calculation (at four times a year), blood potassium (at least 4 times a year), albuminuria (at least 4 times a year), complete blood count (at least twice a year)	Lifelong, until initiation of renal replacement therapy	
3	N18.5	CKD stage 5 prior to the initiation of renal replacement therapy (RRT)	At least once a month, in accordance with clinical guidelines	Blood creatinine with GFR calculation (at least 12 times a year), blood urea (at least 12 times a year), blood potassium (at least 12 times a year), complete blood count (at least twice a year)	Lifelong, until initiation of renal replacement therapy	
4	Z94.0	Presence of a functioning transplanted kidney	At least four times a year, in accordance with clinical guidelines	Complete blood count (at least 4 times a year), comprehensive metabolic panel (at least 4 times a year), drug level monitoring of tacrolimus/cyclosporine, everolimus (at least 4 times a year)	Lifelong, until graft failure or loss of function	

Note. The frequency of medical examinations (check-ups and consultations) is determined in accordance with the following clinical guidelines: “Chronic Kidney Disease (CKD)”, Ministry of Health of the Russian Federation (URL: https://cr.minzdrav.gov.ru/recomend/469_2); KDIGO 2017 Clinical Practice Guideline Update for the Diagnosis, Evaluation, Prevention, and Treatment of Chronic Kidney Disease–Mineral and Bone Disorder (CKD-MBD). Kidney International Supplements (2017) 7, 1–59; KDIGO Clinical Practice Guideline for Anemia in Chronic Kidney Disease. Kidney International Supplements (2012) 2.

Table 5

Key indicators of nephrological care for patients with CKD and those receiving RRT in 2024 (based on data from 89 Federal Subjects of the Russian Federation)

Renal replacement therapy (RRT)	
Number of patients on RRT (abs.)	72,672
RRT coverage per million population	557.0
Number of patients on hemodialysis (HD, abs.)	56,134
HD coverage per million population	459.6
Number of patients on peritoneal dialysis (PD, abs.)	1,850
PD coverage per million population	12.7
Number of patients with functioning kidney transplant (KT, abs.)	14,688
KT coverage per million population	84.6
Number of KT centers	49

End of Table 5

Hemodialysis / HD centers	
Hemodialysis / HD centers	674
<i>of which are state-owned</i>	274
Number of dialysis stations (abs.)	21,372
Availability of dialysis stations per million population	179.14
Number of doctors in dialysis centers/departments (abs.)	2,670
Number of nurses in dialysis centers/departments (abs.)	5,774
Number of hemodialysis machines	14,458
Outpatient nephrology services	
Number of nephrologists' offices in outpatient care	537
Number of nephrologists in outpatient care (abs.)	690
<i>Of these, trained in managing patients with a transplanted kidney</i>	86
Availability of outpatient nephrologists per 50,000 registered population	0.27
Inpatient nephrology services (nephrology departments)	
Number of departments providing nephrology care (abs.)	263
Number of nephrology beds (abs.)	5,039
Number of nephrology beds per 10,000 population	0.35
Number of nephrologists in inpatient care (abs.)	783
<i>Of which trained in the management of kidney recipients</i>	187
Total number of nephrologists	4,143

REFERENCES

- Hill NR, Fatoba ST, Oke JL, Hirst JA, O'Callaghan CA, Lasserson DS et al. Global prevalence of chronic kidney disease – a systematic review and meta-analysis. *PloS One*. 2016; 11: e0158765. doi: 10.1371/journal.pone.0158765.
- Sundström J, Bodegard J, Bollmann A, Vervloet MG, Mark PB, Karasik A et al. Prevalence, outcomes, and cost of chronic kidney disease in a contemporary population of 2.4 million patients from 11 countries: The CaReMe CKD study. *Lancet Reg Health Eur*. 2022 Jun 30; 20: 100438. doi: 10.1016/j.lanepe.2022.100438.
- Santos-Araújo C, Mendonça L, Carvalho DS, Bernardo F, Pardal M, Couceiro J et al. Twenty years of real-world data to estimate chronic kidney disease prevalence and staging in an unselected population. *Clin Kidney J*. 2022. 12; 16 (1): 111–124. doi: 10.1093/ckj/sfac206.
- Heaf J. The Danish Renal Biopsy Register. *Kidney Int*. 2004; 66 (3): 895–897. doi: 10.1111/j.1523-1755.2004.00832.x.
- Cunningham A, Benediktsson H, Muruve DA, Hildebrand AM, Ravani P. Trends in Biopsy-Based Diagnosis of Kidney Disease: A Population Study. *Can J Kidney Health Dis*. 2018; 5: 2054358118799690. doi: 10.1177/2054358118799690.
- Fiorentino M, Bolignano D, Tesar V, Pisano A, Van Biesen W, D'Arrigo G et al. Renal Biopsy in 2015 – From Epidemiology to Evidence-Based Indications. *Am J Nephrol*. 2016; 43 (1): 1–19. doi: 10.1159/000444026.
- Amodu A, Porteny T, Schmidt IM, Ladin K, Waikar SS. Nephrologists' Attitudes Toward Native Kidney Biopsy: A Qualitative Study. *Kidney Med*. 2021; 3 (6): 1022–1031. doi: 10.1016/j.xkme.2021.06.014.
- Molnár A, Thomas MJ, Fintha A, Kardos M, Dobi D, Tislér A et al. Kidney biopsy-based epidemiologic analysis shows growing biopsy rate among the elderly. *Sci Rep*. 2021; 11 (1): 24479. doi: 10.1038/s41598-021-04274-9.
- ERA Registry Annual Report 2022; <https://www.era-online.org/wp-content/uploads/2024/09/ERA-Registry-Annual-Report2022.pdf>.
- Kotenko ON, Omelyanovsky VV, Ignatyeva VI, Yagnenkova EE, Rumyantseva EI. The cost of chronic kidney disease in the Russian Federation. *Clinical nephrology*. 2021; 4: 30–38. doi: 10.18565/nephrology.2021.4.30-38.
- Bello AK, Okpechi IG, Osman MA, Cho Y, Htay H, Jha V et al. Epidemiology of haemodialysis outcomes. *Nat Rev Nephrol*. 2022; 18 (6): 378–395. doi: 10.1038/s41581-022-00542-7.
- Andrusev AM, Tomilina NA, Peregodova NG, Shinkarev MB. Kidney replacement therapy for end Stage Kidney Disease in Russian Federation, 2015–2019. Russian National Kidney Replacement Therapy Registry Report of Russian Public Organization of Nephrologists “Russian Dialysis Society”. *Nephrology and Dialysis*. 2021; 23 (3): 255–329. doi: 10.28996/2618-9801-2021-3-255-329.
- Ficociello LH, Busink E, Sawin DA, Winter A. Global real-world data on hemodiafiltration: An opportunity to complement clinical trial evidence. *Semin Dial*. 2022; 35 (5): 440–445. doi: 10.1111/sdi.13085.
- Vernooij RWM, Hockham C, Strippoli G, Green S, Hegbrant J, Davenport A et al. Haemodiafiltration versus haemodialysis for kidney failure: an individual patient data meta-analysis of randomised controlled trials. *Lancet*. 2024 Oct 25; S0140-6736(24)01859-2. doi: 10.1016/s0140-6736(24)01859-2.

15. Guimarães MGM, Tapioca FPM, Dos Santos NR, Tourinho Ferreira FPDC, Santana Passos LC, Rocha PN. Hemodiafiltration versus Hemodialysis in End-Stage Kidney Disease: A Systematic Review and Meta-Analysis. *Kidney Med.* 2024; 6 (6): 100829. doi: 10.1016/j.xkme.2024.100829.
16. https://cr.minzdrav.gov.ru/preview-cr/469_3.
17. <https://usrds-adr.niddk.nih.gov/2024/end-stage-renal-disease/3-clinical-indicators-and-preventive-care>.
18. Amaral S, Hwang W, Fivush B, Neu A, Frankenfield D, Furth S. Serum albumin level and risk for mortality and hospitalization in adolescents on hemodialysis. *Clin J Am Soc Nephrol.* 2008; 3 (3): 759–767. doi: 10.2215/CJN.02720707.
19. Leon JB, Albert JM, Gilchrist G, Kushner I, Lerner E, Mach S et al. Improving albumin levels among hemodialysis patients: a community-based randomized controlled trial. *Am J Kidney Dis.* 2006; 48 (1): 28–36. doi: 10.1053/j.ajkd.2006.03.046.
20. Macedo E, Karl B, Lee E, Mehta RL. A randomized trial of albumin infusion to prevent intradialytic hypotension in hospitalized hypoalbuminemic patients. *Crit Care.* 2021; 25 (1): 18. doi: 10.1186/s13054-020-03441-0.
21. Writing Group for the CKD Prognosis Consortium; Grams ME, Coresh J, Matsushita K, Ballew SH, Sang Y, Surapaneni A et al. Estimated Glomerular Filtration Rate, Albuminuria, and Adverse Outcomes: An Individual-Participant Data Meta-Analysis. *JAMA.* 2023; 330 (13): 1266–1277. doi: 10.1001/jama.2023.17002.

The article was submitted to the journal on 27.06.2025