UDC 613.952: 614.876
DOI: 10.21668/health.risk/2022.1.04.eng

Read online

Research article

ANTHROPOMETRIC MEASUREMENTS IN NEWBORN CHILDREN OF PERSONNEL EMPLOYED AT RADIATION-HAZARDOUS PRODUCTION AS INDICATORS USED IN MONITORING OVER CONSEQUENCES OF PARENTAL EXPOSURE TO RADIATION

S.F. Sosnina, P.V. Okatenko, M.E. Sokolnikov

Southern Urals Biophysics Institute of FMBA of Russia, 19 Ozerskoe shosse, Ozersk, 456780, Russian Federation

Physical development of offspring can be an important criterion applied to assess effects produced by parental exposure. The cohort that includes workers employed at Mayak Production Association (PA), the first nuclear fuel cycle production facility in Russia, is a valuable information source for analyzing consequences of occupational exposure.

Our objective was to analyze somatometric parameters of newborn children of Mayak PA workers who were occupationally exposed to pre-conception external gamma-radiation.

We retrospectively analyzed anthropometric measurements of 13,880 newborn children, all born in 1949–1973; 9321 children were conceived by parents who were long-term occupationally exposed to radiation at Mayak PA. The analysis covered the core anthropometric elements including height, weight, head circumference, and chest circumference. Development proportionality was estimated by using Quetelet, Vervek – Vorontsov's, and Erismann indexes. We estimated a correlation between anthropometric measurements and accumulated parental pre-conception external gamma radiation dose and calculated relative risk coefficients and odds ratio with 95 % confidence interval.

We established that parents were exposed to a wide range of external gamma radiation doses, up to 4075.6 mGy to the ovaries and 5653.1 mGy to the testicles. There was a weak correlation between newborns' height and weight and parental exposure. We also detected a trend for a decrease in newborns' body mass with increasing accumulated pre-conception dose of external gamma radiation to the ovaries and, conversely, for an increase in it with a growing dose to the testicles. We revealed a statistically significant increase in height and weight among children conceived and born by Mayak PA workers, namely, a greater share of children with high body mass at birth. Analysis of children's somatotypes confirmed excessive values of proportionality indexes that showed height and weight measurements among children of exposed parents. Additional analysis of firstborns and children with proper duration of gestation produced the same results. Risk assessment indicated there was significant prevalence of children with high body mass among offspring of exposed people.

We also assessed physical development of Mayak PA workers' newborns taking into account the latest data on long-term occupational exposure; this assessment is vital for epidemiological monitoring over health of children born by personnel employed at radiation-hazardous production facilities.

Key words: *physical development, newborns, radiation-hazardous production facilities, pre-conception exposure, dose to the gonads, Mayak PA personnel, offspring, Quetelet index, Vervek – Vorontsov's index, Erismann index.*

Consequences of parental exposure for their offspring's health are an open issue that should be given attention by scientific experts [1, 2]. It particular, it is vital to directly assess risks of heritable effects [3, 4] since there are rather few research papers on the matter. Anthropometric measurements of offspring reflect a significant aspect in ontogenetic development and can be used as a valuable criterion in assessing effects produced by preconception exposure.

At present there are rather controversial estimates given to peculiar physical development of children born to parents who were exposed to radiation prior to conception. N.N. Evtushnko with colleagues [5] examined 653 infants who were born in families living in settlements alongside the Techa river and exposed to ioniz-

Svetlana F. Sosnina – Candidate of Medical Sciences, Senior Researcher at Radiation Epidemiology Laboratory (e-mail: sosnina@subi.su; tel.: +7 (35130) 71-652; ORCID: https://orcid.org/0000-0003-1553-0963).

Pavel V. Okatenko – Head of the group on hardware and software at Radiation Epidemiology Laboratory (e-mail: okatenko@subi.su; tel.: +7 (35130) 76-903; ORCID: https://orcid.org/0000-0002-8260-1808).

Mikhail E. Sokolnikov – Doctor of Medical Sciences, Head of Epidemiology Department (e-mail: sokolnikov@subi.su; tel.: +7 (35130) 71-652; ORCID: https://orcid.org/0000-0001-9492-4316).

ing radiation due to emergencies at nuclear productions. The authors described retarded physical development in 3-month infants in families where parents were exposed to higher doses (27.3 sSv to the gonads and 109 sSv to the hypophysis) against the offspring of unexposed parents. S. Chen and others [6] examined 92,492 infants; 9,275 of them had low birthweight. The authors detected that fathers' preconception exposure was the primary risk factor causing low birthweight among children (odds ratio (OR) was 1.537, confidence interval (CI) was 1.083–2.181). Besides, they noted that exposed fathers tended to have premature babies more frequently.

Similar trends were described by M.G. Andreassi with colleagues [7] when they assessed influence exerted by occupational exposure on reproductive outcomes among personnel working at a heart catheterization laboratory and exposed to an annual dose equal to 1–10 mSv/year. They showed that chronic occupational exposure of male workers correlated with higher prevalence of low birthweight among their offspring (OR = 2.7, CI 1.1–6.3).

N.P. Petrushkina performed a prospective complex assessment of physical development parameters among 606 children born by parents who were employed at a nuclear enterprise. She noted that "deteriorated physical development" was authentically more frequent among children with both parents being occupationally exposed and among children born by mothers with accumulated dose up to 100 sGy[1].

Meanwhile, Magnusson L.L. with colleagues [8] described disharmonic physical development and high birth weight among offspring of males who were occupationally exposed to radioactive isotopes in biomedical research laboratories (OR = 1.8, CI 1.0–3.2). T. Herrmann with colleagues [9] analyzed criteria of normal development and biological maturation terms in families where a parent had radiation therapy due to a malignant neoplasm with a dose to the gonads varying from 0.01 to 2 Gy. The authors detected a trend for preterm delivery (52.5 % children were born prematurely) but still, birthweight was normal in all cases and though the skeleton maturing was a bit retarded, otherwise children developed within physiological standards.

Therefore, at present there are no unified conclusions with respect to assessing risks of somatometric deviations in children whose parents were exposed to radiation prior to conception. This proves the necessity to examine offspring's health involving assessment of contribution made by parental exposure.

"Mayak" Production Association ("Mayak" PA) is the first industrial nuclear facility. In 1948 the first uranium-graphite industrial reactor in Russia (and on the continent as well) was put into operation there and reached its planned operation capacity. Mayak PA personnel, the major part of them being at their reproductive age, might have been exposed to substantial doses at their workplaces. Examining health risks for offspring of people who are occupationally exposed to technogenic ionizing radiation seems interesting not only as a scientific issue but also as a vital aspect in regulating hygienic standards at radiation-hazardous production facilities.

Our objective was to analyze somatometric parameters of newborn children of Mayak PA workers who were occupationally exposed to preconception external gamma-radiation.

Materials and methods. Necessary data for a retrospective epidemiological study were taken from the Ozersk Children's Health Register. Ozersk is a closed town located in the vicinity of the nuclear enterprise. The register was created and has been kept at the Radiation Epidemiology Laboratory, Southern Urals Biophysics Institute of FMBA of Russia; it contains medical and social data from archive out-patient case histories of children living in Ozersk [10]. Data on parental individual occupational exposure were taken from the Mayak-2013 Workers Dosimetric System [11]. The system provides data on accumulated external gamma-radiation doses to the gonads and equivalents of photon radiation doses Hp (10).

[1] Petrushkina N.P. Zdorov'e potomkov (1-2-e pokoleniya) rabotnikov pervogo predpriyatiya atomnoi promyshlennosti – proizvodstvennogo ob"edineniya «Mayak» (kliniko-epidemiologicheskoe issledovanie) [Health of offspring (the 1st – 2nd generation) born by parents who were employed at Mayak PA, the first nuclear industrial enterprise in the country (clinical-epidemiological research)]: the thesis for the Doctor of Medical Sciences degree. Moscow, 2003, 371 p. (in Russian).

Table 1

Data taken from the Ozersk Children's Health Register (children born in 1949–1973)

Years of birth	A number of people in the Ozersk Children's Health Register										
	Male	Female	Total	Offspring of Mayak PA workers		Including measured accumulated occupational preconception exposure					
						Only father		Only mother		Both parents	
				abs.	%	abs.	%*	abs.	%*	abs.	%*
1949–1953	594	711	1305	539	41.3	193	35.8	97	18.0	58	10.8
1954–1958	1903	1880	3783	1619	42.8	753	46.5	257	15.9	391	24.2
1959–1963	3386	3151	6537	2877	44.0	1996	69.4	201	7.0	330	11.5
1964–1968	2596	2437	5033	2285	45.4	1691	74.0	103	4.5	157	6.9
1969–1973	2854	2771	5625	2001	35.6	1426	71.3	83	4.1	97	4.8
1949–1973	11,333	10,950	22,283	9321	41.8	6059	65.0	741	7.9	1033	11.1

Note: * means the shares from the number of Mayak PA workers' offspring.

The present work covers a 25-year observation period focusing on children living in Ozersk (born in 1949–1973) including the first generation of Mayak PA workers' offspring. Initial data are outlined in Table 1.

We created our examined groups as follows:

– the test group: we extracted data from the Ozersk Children's Health Register on the first generation of Mayak PA workers' offspring; workers were hired in 1948–1982 and were occupationally exposed to radiation prior to conception; children were born in Ozersk in 1949–1973. Our ultimate sampling to be examined amounted to 9321 children, 51.2 % (4776) boys and 48.8 % (4545) girls;

– the reference group: we extracted data from the Ozersk Children's Health Register on children born by non-exposed parents (parents had not been occupationally exposed prior to conception, had never taken part in eliminating consequences of radiation emergencies, and hadn't moved to the city from territories with radioactive pollution); children were born in Ozersk in 1949–1973. The reference group was made up of 4559 children, 43.8 % (1996) boys and 56.2 % (2563) girls.

Both groups were comparable as per years of birth, sex, and the place of birth being the same, Ozersk. We excluded children who weren't born in the city and came to live there in their childhood from our research. It was done to ensure that our analyzed groups had the same climatic and geographic living conditions and the same scope and quality of available medical services.

Somatometric parameters were estimated bearing in mind physiological norms for children development, both those that were applied in pediatrics during the first decades in the observation period[2] and established later [12–14]. We examined the core anthropometric elements of newborns including weight, height, head circumference, and chest circumference. Development proportionality was estimated by calculating the following indexes:

– Quetelet index I or weight-height index (QI):

$$QI = \frac{\text{weight (g)}}{\text{height (cm)}}$$

– Vervek – Vorontsov's index (VVI):

$$VVI = \frac{\text{height (cm)}}{2 \cdot \text{weight (kg)} + \text{chest circumference (cm)}}$$

– Erismann index (EI):

$$EI = \text{chest circumference (cm)} - \frac{\text{height (cm)}}{2}$$

[2] Rukovodstvo po pediatrii: v 10 t. [Guide on pediatrics: in 10 volumes]. In: A.F. Tur ed. Moscow, Medgiz, 1960, vol. 1, Anatomo-fiziologicheskie osobennosti detskogo vozrasta [Anatomic and physiological peculiarities of children], 576 p. (in Russian); Mazurin A.V., Vorontsov I.M. Propedevtika detskikh boleznei [Preliminary study of children diseases]. Moscow, Meditsina, 1985, 432 p. (in Russian).

The data were statistically analyzed with Statistica Version 10 software package (StatSoft, USA). We applied Kolmogorov – Smirnov test to check whether distribution was normal. Descriptive statistics for normally distributed indicators was given as mean values (*M*) ± standard quadratic deviation (*s*); in case distribution wasn't normal they were given as median (*Me*) and interquartile range (25-th and 75-th percentiles). When comparing values in two groups that were not normally distributed, we applied non-parametric Kolmogorov – Smirnov and Mann – Whitney tests. We determined statistical significance of differences between the analyzed groups using χ^2 test.

We estimated correlations between anthropometric measurements and parental accumulated preconception exposure dose of external gamma-radiation using Spearman's rank correlation coefficient. A share of dispersion that could be explained was calculated as per the following formula: $r^2 \times 100$ (%). Differences were considered statistically significant at $p < 0.05$. We calculated relative risk (RR) and odds ratio (OR) of deviations in physical development among offspring of exposed and non-exposed parents with 95 % confidence interval (CI).

Results and discussion. Mayak PA workers might have been exposed to excessive radiation at their workplaces during the first years of the facility operations since they had to manufacture ionizing radiation sources for industrial and military use in a short time, they lacked necessary experience in working with such materials, technologies were rather underdeveloped, and radiation safety standards existing at the moment were also inadequate.

We analyzed accumulated preconception exposure in parents employed at Mayak PA and detected apparent spread in values caused by variable occupational exposure scenarios (Table 2). Overall, paternal preconception exposure was higher than maternal exposure according to dosimetric data on a range of accumulated technogenic external gamma-radiation. At the same time there were only slight differences in medians of parental doses both to the gonads and individual equivalents of photon radiation doses Hp (10).

We comparatively analyzed data taken from children's out-patient case histories and revealed certain differences in newborns' clinical records between the groups. According to data on gestation, a specific share of children with normal gestation was similar in both groups and amounted to 84.8 % (7903 children) in the test group and 84,5 % (3851 children) in the reference group, $p > 0.05$. But at the same time premature children were significantly more frequently detected in the reference group against the test one (4.7 % (214 children) against 3.4 % (319) accordingly, $p < 0.01$) as well as postmature children (0.7 % (34 cases) against 0.4 % (41) accordingly, $p = 0.02$). There were no archive data regarding gestation age on 1058 children (11.4 %) in the test group and 460 (10.1 %) in the reference one ($p = 0.025$).

Majority of children in both groups were born in single pregnancies and only a very small share were born in multiple ones, 1.3 % (119) in the test group and 1.2 % (54) in the reference group, $p > 0.05$.

Compromised obstetric-gynecological case history was detected significantly more frequently in mothers of children from the test group, 33.7 % (3143 against 30.1 % (1373) in the reference group, $p < 0.01$. Induced abortion prevailed among such pathologies and it could probably be due to underdeveloped contraceptive techniques, especially during the first years of the observed period. Two and more medical abortions were detected in 19.3 % cases (1799 mothers) in the test group and in 17.4 % (791 mothers) in the reference one, $p > 0.05$.

Besides, we can't exclude a probable risk of miscarriage caused by occupational exposure. It is well-known, that exposure of the female reproductive system and a mother's body as a whole can not only induce mutations in ovules and their predecessors but also result in distorted intrauterine development due to changes in the physiological condition of the reproductive organs, placenta, and organs responsible for neuroendocrine regulation as well as due to a decrease in adaptive capabilities of the body [15]. However, it is impossible to spot out miscarriages caused by occupational exposure in obstetric-gynecological case histories since there are no available data on the matter.

Table 2

Accumulated parental preconception doses of external gamma-radiation

Preconception doses	Range of doses	*M* ± *s*	*Me* [Q25; Q75]
Mother preconception exposure			
Doses to the ovaries, mGy	0.01–4075.6	385.9 ± 525.3	166.1 [37.0; 540.5]
Hp (10) doses, mSy	0.01–6697.3	564.6 ± 788.2	235.1 [51.4; 782.3]
Father preconception exposure			
Doses to the testicles, mGy	0.01–5653.1	422.9 ± 634.6	168.4 [45.6; 510.0]
Hp (10) doses, mSy	0.01–6918.3	489.9 ± 723.4	195.8 [48.2; 600.3]

Note: *M* is mean value, *s* is standard deviation; *Me* is sampling median, [Q25; Q75] is interquartile range.

Table 3

Parameters of newborn's physical development

Parameters	*M* ± *s*			*Me* [Q25; Q75]		
	Total	Boys	Girls	Total	Boys	Girls
Test group						
BW, kg	3.47 ± 0.52*	3.54 ± 0.52*	3.39 ± 0.5*	3.5 [3.2; 3.8]	3.55 [3.23; 3.86]	3.4 [3.1; 3.7]
H, cm	51.7 ± 2.5*	52.1 ± 2.5	51.3 ± 2.43*	52 [50; 53]	52 [51; 54]	51 [50; 53]
HC, cm	35.6 ± 1.5*	35.9 ± 1.5*	35.4 ± 1.43	36 [35; 36]	36 [35; 37]	35 [35; 36]
CC, cm	34.7 ± 1.6	34.9 ± 1.6	34.4 ± 1.52	35 [34; 36]	35 [34; 36]	35 [34; 35]
Reference group						
BW, kg	3.39 ± 0.53	3.47 ± 0.54	3.33 ± 0.52	3.4 [3.1; 3.7]	3.5 [3.15; 3.8]	3.35 [3.03; 3.65]
H, cm	51.4 ± 2.5	51.9 ± 2.61	51.1 ± 2.4	52 [50; 53]	52 [50; 53]	51 [50; 52]
HC, cm	35.5 ± 1.5	35.75 ± 1.53	35.25 ± 1.5	36 [35; 36]	36 [35; 37]	35 [35; 36]
CC, cm	34.5 ± 1.6	34.78 ± 1.68	34.3 ± 1.6	35 [34; 35]	35 [34; 36]	34 [34; 35]

Note: BW is body weight, H is height, HC is head circumference; CC is chest circumference; *M* is mean value, *s* is standard deviation; *Me* is sampling median, [Q25; Q75] is interquartile range; * means difference between the groups are significant.

A number of stillbirths was comparable in both groups, 1.7 % (160 cases) in the test group and 1.6 % (74 cases) among offspring of unexposed parents, the reference group, $p > 0.05$.

We detected a statistically significant difference between the groups in distribution of pregnancies as per their ordinal number. Secundiparas were more frequent in the test group (42.3 % cases or 3940 women), whereas there were only 37 % such cases in the reference group (1687), $p < 0.001$. Average age of a mother at the moment of birth amounted to 25.9 years in the test group and to 25.1 in the reference group; average age of a father, 27.1 and 25.1 years accordingly.

Parameters of newborns' physical development are comparatively described in Table 3.

Our analysis of somatometric parameters revealed statistically significant differences between the groups as per the following anthropometric measurements: weight, height, and head circumference. Figure 1 shows graphic description of birthweight.

Despite apparent similarities and relatively close values, newborn's weights were still significantly higher in the test group than in the reference one, both totally ($p < 0.001$), and when distributed as per sex ($p < 0.001$).

Newborns' heights had a wider spread of values among offspring of Mayak PA workers, a higher median value (Figure 2) and were statistically significantly different from values detected in the reference group, both totally ($p < 0.001$) and among girls ($p < 0.001$).

We established a small but still statistically significant difference in head circumference among offspring of exposed parents, both in the whole group ($p < 0.001$) and among boys ($p = 0.02$). A range of head circumference values was wider in the reference group where we detected the maximum values in children with hydrocephaly. Minimal values of head circumference were detected among Mayak PA workers' children; however, a number of newborns with head circumference being lower than the 10-th percentile (less than 33 cm) was significantly higher in the reference group, 5.6 % (254) against 4.4 % (410) in the test group, p = 0.0024.We comparatively analyzed gestation age of these children and didn't establish any significant differences ($p > 0.05$).

There were slight differences in chest circumference between the groups, and, as a rule, the parameter corresponded to physiological standards of newborns development. Having compared the parameters between the groups, we didn't detect any statistically significant differences.

Table 4 provides data on estimates of development proportionality with determined anthropometric indexes.

Orientation estimates of somatotype with Erismann index didn't detect any significant differences between the two groups and in general conformed to age standards. At the

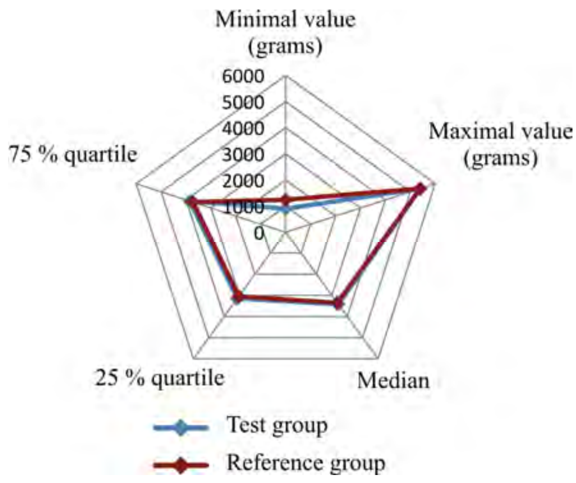

Figure 1. Description of newborns' birthweight in the groups

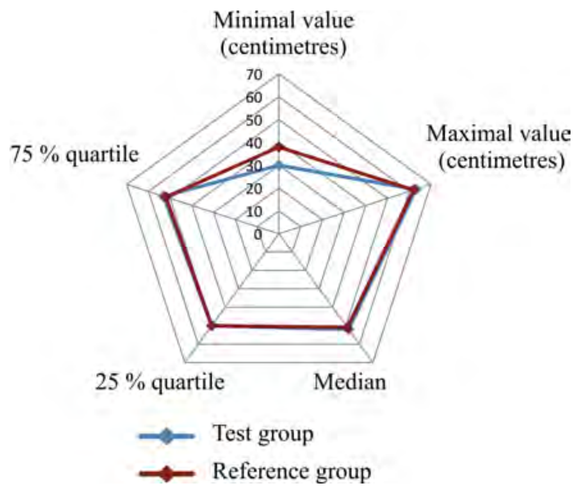

Figure 2. Newborns' heights in two groups

Table 4

Comparative characteristics of proportionality indexes

Index	*M* ± *s*			*Me* [Q25; Q75]		
	Total	Boys	Girls	Total	Boys	Girls
The test group						
QI	66.9 ± 7.9*	67.7 ± 7.8*	66.0 ± 7.8*	67.3 [62.0; 71.8]	68.2 [63.0; 72.5]	66.5 [61.2; 71]
VVI	1.24 ± 0.05*	1.24 ± 0.04*	1.25 ± 0.05	1.24 [1.22; 1.27]	1.24 [1.21; 1.27]	1.24 [1.22; 1.27]
EI	8.79 ± 0.01	8.85 ± 0.02	8.75 ± 0.02	9.0 [8.0; 9.5]	9.0 [8.0; 9.5]	9.0 [8.0; 9.5]
The reference group						
QI	65.6 ± 8.1	66.6 ± 8.2	64.9 ± 8.0	66.0 [60.8; 70.6]	67.3 [61.8; 71.6]	65.4 [60.0; 70]
VVI	1.25 ± 0.05	1.25 ± 0.04	1.25 ± 0.05	1.24 [1.22; 1.27]	1.24 [1.22; 1.27]	1.24 [1.22; 1.28]
EI	8.8 ± 0.02	8.84 ± 0.04	8.78 ± 0.03	9.0 [8.0; 9.5]	9.0 [8.0; 9.5]	9.0 [8.0; 9.5]

Note: *M* is mean value, *s* is standard deviation; *Me* is sampling median, [Q25; Q75] is interquartile range; * means difference between the groups are significant.

same time, higher values of Vervek – Vorontsov's index were authentically more frequent among unexposed parents' offspring, both in the group as a whole ($p = 0.013$), and among boys as well ($p = 0.033$). This is additional evidence that birthweight values were higher in the test group than in the reference one.

Vervek – Vorontsov's index shows how proportionate development is if taken as per ratio of lateral and longitudinal sizes. Having comparatively analyzed its structure as per its numeric values, we didn't detect any significant differences. There were no newborns with the index being lower than 0.85 (indicating brachymorph, that is lateral sizes being greater than longitudinal ones) in either group. Mesomorph type (0.85–1.25 VVI) was detected in more than a half children in each group, 58.4 % (3694) in the test group and 57.6 % (1844) in the reference one, $p > 0.05$. There wasn't any statistically significant difference in a number of newborns with VVI value exceeding 1.25 (which indicates dolichomorphic body type or moderate prevalence of longitudinal sizes) either.

We detected the most significant differences between the two groups when comparing Quetelet I index that reflected weight and height and allowed determining whether a child had good nutrition during its antenatal life. There was a great variability in the index values in the test group (Figure 3). And though average values of the index in both groups generally conformed to the standards of newborns' physical development, our comparative analysis established significant higher Quetelet I index values in children born in families of Mayak PA workers, both in the group as a whole ($p < 0.001$) and distributed as per sex ($p < 0.001$).

Long-term observations over people who lived on territories alongside the Techa river with considerable radioactive pollution [16] established that in general physical development of offspring in that exposed population was within its physiological standards. Still, there was a trend for growing frequency of newborns with high birth weight and "low birthweight" ones.

Table 5 provides data on distribution of newborns in the analyzed groups as per their weights: low birthweight (500–2499 grams), normal weight (2500–3499 grams) and high birthweight (3500 grams and more) with calculated median of parental preconception occupational exposure doses for each interval. There were data on birthweight of 8480 children in the test group (51.2 % (4339) boys and 48.8 % (4141) girls) and 4186 children in the

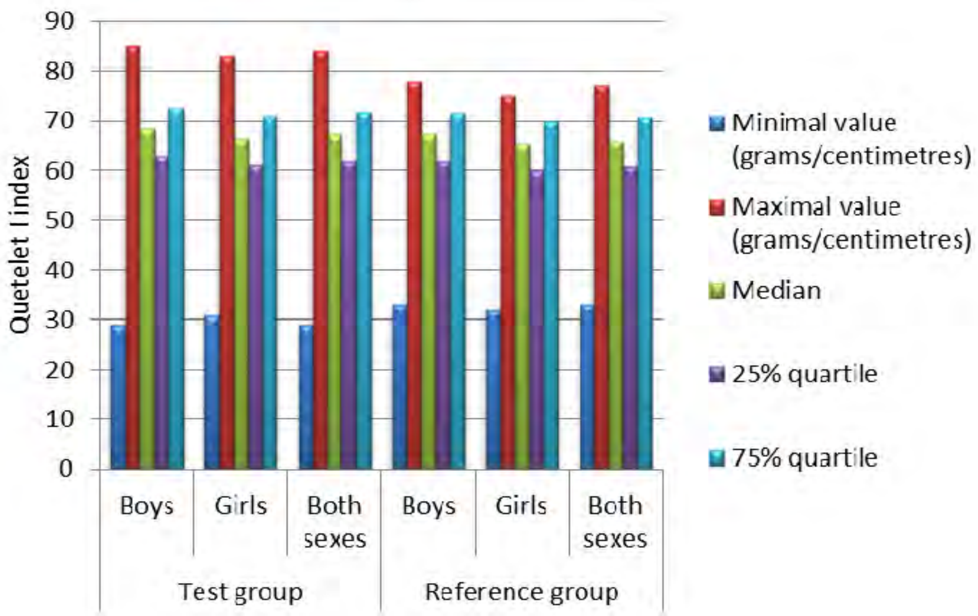

Figure 3. Quetelet I index in the groups

Table 5

Newborns distributed as per birthweight

Sex	Low birthweight (500–2499 grams)			Normal birthweight (2500–3499 grams)			High birthweight (3500 and more)		
	Abs. (%)	Mother dose	Father dose	Abs. (%)	Mother dose	Father dose	Abs. (%)	Mother dose	Father dose
Test group (n = 8480)									
Total	278* (3.3)	189.1	134.5	3926* (46.3)	167.4	145.4	4276* (50.4)	153.6	184.9
Boys	114* (1.3)	85.4	129.3	1784* (21)	161.2	143.4	2441* (28.8)	149.1	188.9
Girls	164 (2.0)	190.2	134.5	2142* (25.3)	180.4	150.5	1835* (21.6)	159.4	179.4
Reference group (n = 4186)									
Total	188 (4.5)	–	–	2117 (50.6)	–	–	1881 (44.9)	–	–
Boys	72 (1.7)	–	–	816 (19.5)	–	–	949 (22.7)	–	–
Girls	116 (2.8)	–	–	1301 (31.1)	–	–	932 (22.3)	–	–

N o t e : Dose is a median of accumulated external gamma-radiation to the gonads prior to conception, mGy; * means differences from the reference group are statistically significant.

reference group (43.9 % (1837) boys and 56.1 % (2349) girls). Data on the remaining children were missing due to absence of information about physical development during the neonatal period in some archive case histories.

Development of newborns estimated as per birthweight had statistically significant differences in the analyzed groups. Thus, a share of newborns with their birthweight exceeding 3500 grams was higher in the test group than in the reference one (50.4 % and 44.9 % accordingly, $p < 0.001$). The same statistically significant prevalence of high birthweight babies was detected among boys in the test group against the reference one (28.8 % and 22.7 % accordingly, $p < 0.001$). At the same time a number of low birthweight newborns with prenatal hypotrophy was higher in the reference group among boys (p = 0,008) and in the whole group ($p < 0.001$).

Normally developed children significantly prevailed among unexposed parents' offspring, both in the group as a whole and among girls ($p < 0.001$ and $p = 0.005$ accordingly) whereas a number of newborn boys with normal development was significantly higher in the test group ($p = 0.017$).

When we tried to determine any correlations between accumulated parental preconception doses of external gamma-radiation and newborns' weights, we had rather ambiguous results. Thus, as accumulated doses to the ovaries grew, there was a trend for decreasing birthweight both in the group as a whole and among girls whereas low birthweight among boys was associated with low preconception exposure of mothers. Meanwhile, all the correlations between paternal preconception exposure and newborns' weight had the same directions: as an accumulated preconception dose of external gamma radiation to the testicles grew, there was an apparent trend for a growing birthweight of offspring.

Growing birth parity is likely to result in higher birthweight and this can be a reason of greater weight-height parameters in newborns. Since there was a significantly higher number of secundiparas in the test group ($p < 0.001$), we analyzed anthropometry among newborns again, having excluded children who were born in the second delivery (Table 6).

Average age of parents when their firstborns were born amounted to 23.2 years among mothers in the test group and 22.5 years in the reference group; 24.5 years and 22.3 years among fathers accordingly. Just as before, the comparative analysis showed that heights and weights were significantly greater among firstborns in the test group, both in the group as a whole and among girls. At the same time there was no difference in anthropometric measurements of boys, and we didn't find any

Table 6

Parameters of physical development estimated only among firstborns

Parameters	$M \pm s$			Me [Q25; Q75]		
	Total	Boys	Girls	Total	Boys	Girls
	Test group (n = 4058)					
BW, kg	3.37 ± 0.47*	3.44 ± 0.48	3.31 ± 0.46*	3.4 [3.1; 3.68]	3.45 [3.15; 3.71]	3.3 [3.0; 3.6]
H, cm	51.5 ± 2.3*	51.8 ± 2.2	51.2 ± 2.31*	52 [50; 53]	52 [50; 53]	51 [50; 53]
HC, cm	35.5 ± 1.4	35.7 ± 1.3	35.2 ± 1.35	36 [35; 36]	36 [35; 37]	35 [34; 36]
CC, cm	34.5 ± 1.5	34.7 ± 1.5	34.3 ± 1.44	35 [34; 35]	35 [34; 36]	34 [33; 35]
	Reference group (n = 2282)					
BW, kg	3.32 ± 0.49	3.41 ± 0.51	3.26 ± 0.47	3.35 [3.0; 3.64]	3.43 [3.1; 3.7]	3.3 [3.0; 3.55]
H, cm	51.3 ± 2.4	51.7 ± 2.44	50.9 ± 2.2	51 [50; 53]	52 [50; 53]	51 [50; 52]
HC, cm	35.4 ± 1.5	35.66 ± 1.47	35.17 ± 1.4	35 [35; 36]	36 [35; 37]	35 [34; 36]
CC, cm	34.4 ± 1.6	34.67 ± 1.67	34.2 ± 1.6	35 [34; 35]	35 [34; 36]	34 [33; 35]

Note: BW is body weight, H is height, HC is head circumference; CC is chest circumference; M is mean value, s is standard deviation; Me is sampling median, [Q25; Q75] is interquartile range; * means difference between the groups are significant.

confirmation of group differences as per newborns' head circumference ($p > 0.05$).

We also additionally compared anthropometric measurements of children with proper gestation, having excluded children born in a premature or retarded birth; the results were similar: significantly greater body weight and height of children in the test group, both as a whole ($p < 0.001$ and $p < 0.025$ accordingly) and among girls ($p < 0.05$).

Therefore, having analyzed somatometry, we established significantly greater weight and height among offspring of Mayak PA workers with long-term preconception occupational exposure. We also performed a correlation analysis to quantitative estimate correlations between parental doses and newborns' anthropometric measurements (Table 7).

Correlations between newborns' heights and weights and maternal doses of occupational exposure were characterized with authentic significance levels both for girls and boys; however, correlation coefficients were rather low (0.036–0.051). A weak, though statistically significant correlation was detected between birthweight and paternal accumulated doses of occupational exposure in the test group as a whole and among boys. We didn't detect any correlations between newborns' height and doses of external gamma-radiation accumulated by fathers.

A share of dispersion that could be explained as per the maximum value of the coefficients didn't exceed 0.3 %. Therefore, our analysis established a weak correlation between height and weight at birth and accumulated doses of parental preconception occupational exposure to external gamma radiation.

We estimated risk coefficients with respect to deviations in anthropometric measurements of newborns born by exposed and intact parents. The estimations confirmed all the aforementioned peculiarities (Table 8).

Babies of high birth weight were statistically significantly more frequently detected in families of Mayak PA workers: RR 1.12 (CI 1.08–1.17), OR 1.25 (1.16–1.34). This regularity was authentic both among boys: RR 1.09 (1.03–1.15), OR 1.2 (1.08–1.34), and among girls: RR 1.12 (1.05–1.19), OR 1.21 (1.09–1.34). Low and normal weights were significantly less frequent among newborns of parents with preconception occupational exposure. The lowest risk of low birthweight was detected for boys of exposed parents: OR 0.66 (0.49–0.89).

Undoubtedly, it would be a mistake to assume that newborns' physical development is associated solely with parental preconception exposure. There is a great variety of factors that determine how a fetus grows and develops, including genetic and biological ones, trace element deficiency, antenatal pathologies, infectious and somatic pathologies of a fetus [17, 18]. It is rather difficult to spot out

Table 7

Correlations between parental preconception exposure and newborns' height and weight

Sex	Mother's preconception exposure				Father's preconception exposure			
	Dose to gonads		Hp (10) dose		Dose to gonads		Hp (10) dose	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Birthweight								
Boys	0.051	< 0.001	0.051	< 0.001	0.041	< 0.01	0.04	< 0.01
Girls	0.036	0.019	0.036	0.019	0.022	> 0.05	0.022	> 0.05
Both sexes	0.043	< 0.001	0.043	< 0.001	0.033	< 0.01	0.032	< 0.01
Height at birth								
Boys	0.037	0.016	0.037	0.016	0.024	> 0.05	0.022	> 0.05
Girls	0.038	0.016	0.038	0.017	0.01	> 0.05	0.01	> 0.05
Both sexes	0.038	< 0.001	0.038	< 0.001	0.017	> 0.05	0.016	> 0.05

Note: *r* is correlation coefficient; *p* is the significance level.

Table 8

Relative risk (RR) and odds ratio (OR) of deviations in birthweight

Birthweight	Group	Outcome		RR (95 % CI)	OR (95 % CI)
		Yes	No		
Boys					
Low weight	Exposed*	114	4225	0.67 (0.5–0.9)	0.66 (0.49–0.89)
	Non-exposed	72	1765		
Normal weight	Exposed	1784	2555	0.93 (0.87–0.98)	0.87 (0.78–0.97)
	Non-exposed	816	1021		
High weight	Exposed	2441	1898	1.09 (1.03–1.15)	1.2 (1.08–1.34)
	Non-exposed	949	888		
Girls					
Low weight	Exposed	164	3977	0.8 (0.64–1.01)	0.79 (0.62–1.01)
	Non-exposed	116	2233		
Normal weight	Exposed	2142	1999	0.93 (0.89–0.98)	0.86 (0.78–0.96)
	Non-exposed	1301	1048		
High weight	Exposed	1835	2306	1.12 (1.05–1.19)	1.21 (1.09–1.34)
	Non-exposed	932	1417		
Both sexes					
Low weight	Exposed	278	8202	0.73 (0.61–0.87)	0.72 (0.6–0.87)
	Non-exposed	188	3998		
Normal weight	Exposed	3926	4554	0.91 (0.88–0.95)	0.84 (0.78–0.91)
	Non-exposed	2117	2069		
High weight	Exposed	4276	4204	1.12 (1.08–1.17)	1.25 (1.16–1.34)
	Non-exposed	1881	2305		

Note: * means children whose parents were occupationally exposed prior to conception.

a leading factor that makes for developing ontogenetic disorders.

Previously we assessed physical development of newborns born by female Mayak PA workers with preconception occupation exposure to external gamma-radiation by performing a factor analysis. Apart from maternal exposure to radiation (15.3 % of dispersion) the analysis highlighted antenatal factors (13.8 %), obstetric-gynecologic case history (13.5 %), and mothers having bad habits (9.7 % of dispersion) [19]. Besides, a great contribution to children's physical development could be made by medical and social peculiarities of families living in the analyzed closed town [20]. This requires certain attention and further investigation and analysis including those focused on estimating contributions made by non-occupational parental exposure.

Conclusion. Anthropometric measurements are among the most significant parameters of a fetus and a newborn and they can be valuable for assessing effects produced by preconception exposure. We performed this retrospective analysis of newborns' anthropometric measurements covering data on 13,880 children born in Ozersk in 1949–1973, 9321 of them being born by parents with long-term preconception occupational exposure at Mayak PA.

Our overall research results indicate that, together with significant differences between the groups as per gestation age, birth parity, and mothers' reproductive health, height and weight at birth were significantly higher among newborns of Mayak PA. Distribution as per different birthweight categories revealed a greater contribution made by babies of a high birth weight (more than 3500 grams) among offspring of people with preconception occupational exposure against the reference group, $p < 0.001$. We comparatively assessed somatotypes using proportionality indexes and established both significance of anthropometric measurements showing height and weight parameters and their higher values among children of Mayak PA workers.

Having examined possible correlations between anthropometric measurements and dosimetric characteristics of parental exposure, we established an apparent trend for growing birthweight with increasing accumulated preconception doses of external gamma-radiation to the testicles and a trend for decreasing birthweight with growing accumulated preconception doses to the ovaries. At the same time quantitative assessment of an association between parental preconception occupational exposure and newborns' height and weight showed a statistically significant but rather weak correlation.

Our assessment of risk coefficients showed that low birthweight and normotrophy were statistically significantly less frequent among offspring of Mayak PA workers. At the same time, newborns of high birth weight (more than 3500 grams) significantly prevailed in this group and this fact confirms all our previous calculations.

By using a cohort including offspring of Mayak PA workers, we obtained an up-to-date estimation of anthropometric measurements at birth taking into account updated data on doses of long-term parental occupational exposure. The established peculiarities of newborns' physical development can enhance our overview of trends in epidemiologic monitoring over health of children born by workers employed at radiation-hazardous productions and determine new prevention strategies.

Funding. The work has been accomplished within the State Contract No. 11.314.20.2 signed on June 03, 2020. "Medical outcomes of exposure to ionizing radiation for population health and offspring of people living close to objects that are a part of nuclear legacy in the Russian Federation".

Conflict of interests. The authors declare there is no any conflict of interests.

References

1. UNSCEAR. Sources, Effects and Risks of Ionizing Radiation. UNSCEAR 2013 Report. Volume II. Scientific annex B: Effects of radiation exposure of children. New York, 2013, 284 p.

2. Tatsukawa Y., Cologne J.B., Hsu W.L., Yamada M., Ohishi W., Hida A., Furukawa K., Takahashi N. [et al.]. Radiation risk of individual multifactorial diseases in offspring of the atomic-bomb survivors: a clinical health study. *J. Radiol. Prot.*, 2013, vol. 33, no. 2, pp. 281–293. DOI: 10.1088/0952-4746/33/2/281

3. ICRP Publication 103. The 2007 Recommendations of the International Commission on Radiological Protection. In: J. Valentin ed. *Annals of the ICRP*, Elsevier, 2007.

4. Ozasa K., Cullings H.M., Ohishi W., Hida A., Grant E.J. Epidemiological studies of atomic bomb radiation at the Radiation Effects Research Foundation. *Int. J. Radiat. Biol.*, 2019, vol. 95, no. 7, pp. 879–891. DOI: 10.1080/09553002.2019.1569778

5. Evtushenko N.N., Volosnikov D.K., Akleev A.V. Fizicheskoe razvitie detei pervogo goda zhizni, roditeli kotorykh podvergalis' khronicheskomu radiatsionnomu vozdeistviyu [Physical development of children during the first year of life whose parents were chronically exposed to radiation]. *Pediatriya*, 2010, vol. 89, no. 6, pp. 52–57 (in Russian).

6. Chen S., Yang Y., Qv Y., Zou Y., Zhu H., Gong F., Zou Y., Yang H. [et al.]. Paternal exposure to medical-related radiation associated with low birthweight infants: A large population-based, retrospective cohort study in rural China. *Medicine (Baltimore)*, 2018, vol. 97, no. 2, pp. e9565. DOI: 10.1097/MD.0000000000009565

7. Andreassi M.G., Borghini A., Vecoli C., Piccaluga E., Guagliumi G., Del Greco M., Gaita F., Picano E. Reproductive outcomes and Y chromosome instability in radiation-exposed male workers in cardiac catheterization laboratory. *Environ. Mol. Mutagen.*, 2020, vol. 61, no. 3, pp. 361–368. DOI: 10.1002/em.22341

8. Magnusson L.L., Bodin L., Wennborg H. Adverse pregnancy outcomes in offspring of fathers working in biomedical research laboratories. *Am. J. Ind. Med.*, 2006, vol. 49, no. 6, pp. 468–473. DOI: 10.1002/ajim.20317

9. Herrmann T., Thiede G., Trott K.R., Voigtmann L. Offsprings of preconceptionally irradiated parents. Final report of a longitudinal study 1976–1994 and recommendations for patients' advisory. *Strahlenther. Onkol.,* 2004, vol. 180, no. 1, pp. 21–30. DOI: 10.1007/s00066-004-1223-4 (in German).

10. Sosnina S.F., Kabirova N.R., Okatenko P.V., Rogacheva S.A., Tsareva Yu.V., Gruzdeva E.A., Sokolnikov M.E. Ozyorsk Children's Health register: development results, management guidelines, potential and prospects. *Meditsina ekstremal'nykh situatsii,* 2017, vol. 61, no. 3, pp. 95–103 (in Russian).

11. Napier B.A. The Mayak Worker Dosimetry System (MWDS-2013): an introduction to the documentation. *Radiat. Prot. Dosimetry*, 2017, vol. 176, no. 1–2, pp. 6–9.

12. Grantz K.L., Hediger M.L., Liu D., Buck Louis G.M. Fetal growth standards: the NICHD fetal growth study approach in context with INTERGROWTH-21st and the World Health Organization Multicentre Growth Reference Study. *Am. J. Obstet. Gynecol.*, 2018, vol. 218, no. 2S, pp. S641–S655.e28. DOI: 10.1016/j.ajog.2017.11.593

13. Kildiyarova R.R. Assessing physical development of children with percentile diagrams. *Voprosy sovremennoi pediatrii*, 2017, vol. 16, no. 5, pp. 431–437. DOI: 10.15690/vsp.v16i5.1808 (in Russian).

14. Chernaya N.L., Maskova G.S., Ganuzin V.M., Ermolina E.A. Comparative evaluation of postnatal growth of premature babies using different regulations and standards. *Prakticheskaya meditsina*, 2018, vol. 16, no. 8, pp. 79–83 (in Russian).

15. Pastukhova E.I., Shalaginov S.A., Akleev A.V. Chislo beremennostei i rodov u zhenshchin, podvergshikhsya deistviyu khronicheskogo ioniziruyushchego izlucheniya na reke Teche [The number of pregnancies and births in women exposed to chronic ionizing radiation on the Techa river]. *Vestnik Chelyabinskogo gosudarstvennogo universiteta*, 2013, vol. 298, no. 7, pp. 82–84 (in Russian).

16. Akleev A.V., Krestinina L.Yu., Varfolomeeva T.A., Ostroumova E.V., Pushkarev S.A., Shalaginov S.A., Khudyakova O.I., Veremeeva G.A. [et al.]. Mediko-biologicheskie effekty khronicheskogo vozdeistviya ioniziruyushchei radiatsii na cheloveka [Medico-biological effects of chronic exposure to ionizing radiation on humans]. *Meditsinskaya nauka i obrazovanie Urala*, 2008, vol. 9, no. 2 (52), pp. 8–10 (in Russian).

17. C A.K., Basel P.L., Singh S. Low birth weight and its associated risk factors: Health facility-based case-control study. *PLoS One,* 2020, vol. 15, no. 6, pp. e0234907. DOI: 10.1371/journal.pone.0234907

18. Sirotina Z.V., Sokolov V.N. High risk factors for fetal development (clinical lecture). *Zdravookhranenie Dal'nego Vostoka*, 2020, vol. 84, no. 2, pp. 59–65 (in Russian).

19. Sosnina S.F., Okatenko P.V. Physical development of newborns of female radiation workers. *Profilakticheskaya i klinicheskaya meditsina*, 2017, vol. 64, no. 3, pp. 14–20 (in Russian).

20. Volosnikov D.K., Sosnina S.F. Mediko-sotsial'naya kharakteristika semei, prozhivayushchikh v zakrytom administrativnom territorial'nom obrazovanii (g. Ozersk), imeyushchikh detei podrostkovogo vozrasta [The medical and social characteristics of families with children of adolescent age residing in the closed administrative territorial formation Ozersk]. *Sotsiologiya meditsiny*, 2010, no. 2, pp. 59–61 (in Russian).

Sosnina S.F., Okatenko P.V., Sokolnikov M.E. Anthropometric measurements in newborn children of personnel employed at radiation-hazardous production as indicators used in monitoring over consequences of parental exposure to radiation. Health Risk Analysis, 2022, no. 1, pp. 36–47. DOI: 10.21668/health.risk/2022.1.04.eng

Received: 12.01.2022
Approved: 25.01.2022
Accepted for publication: 11.03.2022