THE CHERNOBYL ACCIDENT, THE MALE TO FEMALE RATIO AT BIRTH AND BIRTH RATES

Victor Grech

Department of Paediatrics, Mater Dei Hospital, Malta

Summary: Introduction: The male:female ratio at birth (male births divided by total live births – M/T) has been shown to increase in response to ionizing radiation due to gender-biased fetal loss, with excess female loss. M/T rose sharply in 1987 in central-eastern European countries following the Chernobyl accident in 1986. This study analyses M/T and births for the former Soviet Republics and for the countries most contaminated by the event. Methods: Annual birth data was obtained from the World Health Organisation. The countries with the highest exposure levels (by ^{137}Cs) were identified from an official publication of the International Atomic Energy Agency. All of the former Soviet states were also analysed and the periods before and after 1986 were compared. Results: Except for the Baltic States, all regions in the former USSR showed a significant rise in M/T from 1986. There were significant rises in M/T in the three most exposed (Belarus, Ukraine and the Russian Federation). The birth deficit in the post-Soviet states for the ten years following Chernobyl was estimated at 2,072,666, of which 1,087,924 are accounted by Belarus and Ukraine alone. Discussion: Chernobyl has resulted in the loss of millions of births, a process that has involved female even more than male fetuses. This is another and oft neglected consequence of widespread population radiation contamination.

Key words: *USSR; Birth Rate/*trends; Chernobyl Nuclear Accident; Infant; Newborn Sex Ratio; Radiation; Ionizing*

Introduction

The exposure to ionizing radiation has deleterious effects on offspring, such as a higher rate of birth defects and congenital malformations (1–3).

The male to female ratio of live births is expressed as the ratio of male live births divided by total live births (M/T), and for humans, this is expected to approximate 0.515 (4). M/T has been mooted as a unique indicator with regards to biological radiation interactions as maternal exposure results in a different effect from paternal exposure (5).

Irradiated men sire an excess of males (6). Occupational studies among workers in the nuclear industry support this, including a study wherein workers at the nuclear reprocessing plant in Sellafield were shown to sire children with a higher M/T, and this was dose dependent (7). On the other hand, irradiated women give birth to an excess of females (8). When both genders within a population are approximately equally exposed, an overall increase in M/T is produced since more females than males are lost in-utero due to lethal mutations (9).

Major industrial accidents, when the exposure status of large populations with respect to toxins changes rapidly and can be measured, provide useful ground for the analysis of the effects of M/T at birth.

The Chernobyl incident in April 1986 produced major biological effects, such as an excess of thyroid cancer (10). The explosion and resulting fire from the stricken reactor released large airborne quantities of nuclear fuel and radionuclides from fission products. These included primarily plutonium, caesium-137, iodine-131, strontium-90 and iodine-131. Some of these had relatively short half-lives (e.g. just eight days for iodine-131) while others formed heavier particulates and were deposited close to Chernobyl (11).

^{137}Cs has a half-life of 30 years, decaying by beta emission to barium-137, which in turn has a half-life of 153 seconds and is responsible for all of the gamma ray emissions resulting from this decay sequence. Caesium is quite chemically reactive and very water soluble as caesium hydroxide, with the biological behaviour of potassium and rubidium. The biological half-life of caesium is 70 days. For this reason, it has been closely studied as this particular radio-isotope is relatively easy to measure. All extant ^{137}C is anthropogenic, occurring solely in nuclear fission processes (11).

Earlier studies have shown that for the Czech Republic, Denmark, Finland, Germany, Hungary, Norway, Poland, and Sweden, M/T rose significantly in 1987, superimposed on a decreasing secular trend (9). In a second and larger study, the same authors showed this same trend in Western Europe overall, with an absence of any such effects in the United States (12). In the same study, the authors showed that the M/T reduction between 1950–64 and the increase between 1964–1975 may have been associated with delayed global atomic bomb test fallout released prior to the Partial (atmospheric) Test Ban Treaty in 1963 (12). The subsequent downward secular trend was interrupted by a sharp

ACTA MEDICA (Hradec Králové) 2014; 57(2):62–67
http://dx.doi.org/10.14712/18059694.2014.41

rise following Chernobyl (12). The authors concluded that this implies a global deficit of births in the range of several millions. Interestingly, in the same paper, the authors also showed a strong link between an increased M/T and living within 35 kilometers of a normally functioning nuclear power plant (12).

A significant peak in Down's syndrome births was also noted in January 1987 in Berlin and Belarus (13, 14).

An M/T rise was also noted in Cuba after 1987, and while the original authors ascribed socio-economic reasons for this (15), others have argued that this may have been produced by the heavy importation of contaminated foodstuffs from the USSR with Cs-137 and Sr-90 (16).

The former Soviet republics (also known as the post-Soviet states or the former Soviet Union) comprise 15 independent states that seceded from the Union of Soviet Socialist Republics (USSR) in its dissolution in December 1991. Chernobyl is situated in this region and these countries suffered significant radiation exposure from fallout. The former Soviet republics may be divided into the Russian Federation and four regions, the Baltic States (Estonia, Latvia and Lithuania), Eastern Europe (Belarus, Moldova and Ukraine), the Southern Caucasus (Armenia, Azerbaijan and Georgia) and Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan).

Secular trends and latitude gradients for M/T in this region have been previously described (17). This study was carried out in order to ascertain whether the Chernobyl accident influenced M/T in the former Soviet republics and in countries known to have been most exposed, and to what extent this effect occurred in the more severely affected countries. Quantification is also attempted.

A potential limiting factor of this study is that this region experienced widespread socio-economic changes and disruptions that may have independently shifted birth demographics (18). In addition, Chernobyl was a psychological disturbing agent that may have further aggravated birth demographics (19).

Methods

Exposure levels

The seven countries with the highest exposure levels (as measured using ^{137}Cs) were identified from an official publication of the International Atomic Energy Agency (11). These were Belarus, Ukraine, Russia, Sweden, Finland, Austria and Norway (Table 1).

Statistics

Excel was used for data entry and analysis. The quadratic equations of Fleiss were used for exact calculation of 95% confidence intervals for ratios (20).

Chi tests for trend were used for annual male and female births. These were performed using the Bio-Med-Stat Excel add-in for contingency tables. This add-in is based on the original work by Cochran and Armitage (Dr. Peter Slezák, Institute of Normal and Pathological Physiology, Slovak Academy of Sciences, personal communication), (21, 22).

Correlation was carried out in SPSS using Spearman's rho. A p value ≤ 0.05 was taken to represent a statistically significant result.

Regions and eras

Annual male and female live births were obtained directly from the World Health Organisation. The former Soviet republics were analysed by comparing the 5 years prior to 1986 (1981–85) with the two following five year periods (1986–90 and 1991–95). These comparisons were also made for the seven most affected countries. Short (five year) periods were used for comparison in order to minimise the possibility that changes seen would not be solely due to the broad secular trends in M/T that all countries and regions exhibit (23).

Utilizing 5 year periods increases the robustness of the study but also limits trend analysis as opposed to 1 year analyses. The data for the year 1984 was not available for

Tab. 1: European countries most contaminated with ^{137}Cs.

Exposure	37–185 kBq/m²		185–555 kBq/m²		555–1480 kBq/m²		>1480 kBq/m²	
Country	**km²**	**% of country**	**km²**	**% of country**	**km²**	**% of country**	**km²**	**% of country**
Belarus	29.900	14.4	10.200	4.9	4.200	2.00	2.200	1.1
Ukraine	37.200	6.2	3.200	0.53	900	0.15	600	0.1
Russia	49.800	0.29	5.700	0.03	2.100	0.01	300	0.002
Sweden	12.000	2.7	–	–	–	–	–	–
Finland	11.500	3.4	–	–	–	–	–	–
Austria	8.600	10.3	–	–	–	–	–	–
Norway	5.200	1.3	–	–	–	–	–	–

Modified from the Report of the Chernobyl Forum Expert Group 'Environment' table 3.2 (p. 23). (Xxcfegereport) analysis for all post-Soviet states except for the Russian Federation and Latvia.

Results

For all regions, annual number of births were steady for period 1981–1986/7. After this period, annual births steadily declined for all regions.

Except for the Baltic States, all regions showed a significant rise in M/T after 1986 (comparison of male and female births – Table 2). Analysis of the countries most irradiated showed significant rises in M/T after 1986 only in the three most exposed countries, namely Belarus, Ukraine and the Russian Federation (Table 3 and Figure 1).

Tab. 2: M/T and births in regions comprising the former Soviet republics, 1981–1991.

		1981–85	1986–90	1991–95
Baltic States (Estonia, Latvia & Lithuania)	**M**	261,167	314,268	235,951
	F	248,583	297,258	223,825
	T	509,750	611,526	459,776
	UCI	0.5137	0.5152	0.5146
	M/T	0.5123	0.5139	0.5132
	LCI	0.5110	0.5127	0.5117
	1981–85 vs 86–90		1986–90 vs 91–95	
	x	2.7		0.5
	p	0.1		0.5
Eastern Europe (Belarus, Moldova & Ukraine)	**M**	2,067,607	2,505,210	1,897,375
	F	1,962,650	2,368,173	1,789,003
	T	4,030,257	4,873,383	3,686,378
	UCI	0.5135	0.5145	0.5152
	M/T	0.5130	0.5141	0.5147
	LCI	0.5125	0.5136	0.5142
	1981–85 vs 86–90		1986–90 vs 91–95	
	x	9.5		3.4
	p	0.002		0.06
Southern Caucasus (Armenia, Azerbaijan & Georgia)	**M**	700,448	917,453	774,753
	F	662,493	860,842	719,130
	T	1,362,941	1,778,295	1,493,883
	UCI	0.5148	0.5167	0.5194
	M/T	0.5139	0.5159	0.5186
	LCI	0.5131	0.5152	0.5178
	1981–85 vs 86–90		1986–90 vs 91–95	
	x	12.3		23.7
	p	<0.0001		<0.0001
Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, & Uzbekistan)	**M**	2,867,760	3,976,874	3,674,940
	F	2,743,404	3,782,424	3,513,345
	T	5,611,164	7,759,298	7,188,285
	UCI	0.5115	0.5129	0.5116
	M/T	0.5111	0.5125	0.5112
	LCI	0.5107	0.5122	0.5109
	1981–85 vs 86–90		1986–90 vs 91–95	
	x	27.4		24.9
	p	<0.0001		<0.0001
Russian Federation	**M**	6,058,393	5,893,395	3,848,248
	F	5,769,342	5,590,405	3,635,204
	T	11,827,735	11,483,800	7,483,452
	UCI	0.5125	0.5135	0.5146
	M/T	0.5122	0.5132	0.5142
	LCI	0.5119	0.5129	0.5139
	1981–85 vs 86–90		1986–90 vs 91–95	
	x	22.1		19.7
	p	<0.0001		<0.0001

Chi test analysis compared male and female births.

Correlation was carried out between M/T and annual births for the period 1986–95 for the countries most affected. Statistical significance was only reached or approached for the three most exposed countries: Ukraine ($\rho = -0.66$, $p = 0.038$), Belarus ($\rho = -0.34$, $p = 0.33$) and the Russian Federation ($\rho = -0.58$, $p = 0.08$).

Birth deficits were calculated by taking the expected annual birth rate as the annual average of the years prior to 1986 (1981–3 and 1985) except for Central Asia. This region exhibited a rising number of births and for this reason, 1985 alone was chosen as the expected annual number of births. The birth deficit is estimated at 2,072,666, of which 1,087,924 are accounted by Belarus and Ukraine alone (Table 4).

Discussion

Ionizing radiation as a toxin has a unique deleterious effect on M/T in that its effect differs in male and female parents. Irradiated men sire an excess of males (6) and irradiated females give birth to an excess of females (8). This is attributed to the hypothesis that if an X-linked recessive lethal gene is induced in a mother's germ cell line by ionizing radiation, it would have no effect on a heterozygous daughter but would be lethal to a hemizygous male zygote. X-linked dominant lethal mutations in mothers would be equally lethal to both genders (24). X-linked dominant mutations induced in fathers would suppress only female offspring. Recessive X-linked lethal mutations in fathers

Tab. 3: M/T in the countries most exposed as per table 1, 1981–1994.

	Belarus			**Ukraine**			**Russian Federation**					
	1981–85	**1986–90**	**1991–95**	**1981–85**	**1986–90**	1991–95	1981–85	1986–90	1991–95			
M	333,688	408,394	304,043	1,556,358	1,873,621	1,423,724	6,058,393	5,893,395	3,848,248			
F	317,358	384,963	285,100	1,477,226	1,772,043	1,343,447	5,769,342	5,590,405	3,635,204			
T	651,046	793,357	589,143	3,033,584	3,645,664	2,767,171	11,827,735	11,483,800	7,483,452			
UCI	0.5138	0.5159	0.5174	0.5136	0.5144	0.5151	0.5125	0.5135	0.5146			
M/T	0.5125	0.5148	0.5161	0.5130	0.5139	0.5145	0.5122	0.5132	0.5142			
LCI	0.5113	0.5137	0.5148	0.5125	0.5134	0.5139	0.5119	0.5129	0.5139			
	1981–85 vs 86–90			1981–85 vs 86–90			1981–85 vs 86–90					
x	7.1			5.2			22.1					
p	0.008			0.02			<0.0001					
	1986–90 vs 91–95			1986–90 vs 91–95			1986–90 vs 91–95					
x	2.3			2.1			19.7					
p	0.1			0.1			<0.0001					
	Sweden			**Finland**			**Austria**			**Norway**		
	1981–85	**1986–90**	**1991–95**	**1981–85**	**1986–90**	**1991–95**	**1981–85**	**1986–90**	**1991–95**	**1981–85**	**1986–90**	**1991–95**
M	242,264	287,039	297,639	165,894	160,265	165,829	233,028	226,158	239,299	130,057	145,768	154,967
F	228,681	271,651	282,280	158,445	152,924	159,489	222,546	214,574	226,943	123,241	138,541	146,012
T	470,945	558,690	579,919	324,339	313,189	325,318	455,574	440,732	466,242	253,298	284,309	300,979
UCI	0.5158	0.5151	0.5145	0.5132	0.5135	0.5115	0.5130	0.5146	0.5147	0.5154	0.5145	0.5167
M/T	0.5144	0.5138	0.5132	0.5115	0.5117	0.5097	0.5115	0.5131	0.5133	0.5135	0.5127	0.5149
LCI	0.5130	0.5125	0.5120	0.5098	0.5100	0.5080	0.5101	0.5117	0.5118	0.5115	0.5109	0.5131
	1981–85 vs 86–90			1981–85 vs 86–90			1981–85 vs 86–90			1981–85 vs 86–90		
x	0.4			0			2.4			0.3		
p	0.5			0.9			0.1			0.6		
	1986–90 vs 91–95			1986–90 vs 91–95			1986–90 vs 91–95			1986–90 vs 91–95		
x	0.3			2.5			0.0			2.7		
p	0.6			0.1			0.9			0.1		

Chi test analysis compared male and female births.

Tab. 4: Estimated birth deficits for affected regions and countries.

	Belarus	Ukraine	Russian Fed.	Baltic	East. Eur.	S. Caucasus	Cent. Asia
Average 1981–85/ annum	162,761.5	758,396.0	2,354,530.3	117,225.8	1,007,564	340,735.3	1,503,447
Expected 1986–95	1,627,615	7,583,960	23,545,303	1,172,258	10,075,643	3,407,353	15,034,470
Observed	1,444,403	6,679,248	23,311,535	1,071,302	8,559,761	3,272,178	14,947,583
Deficit	183,212	904,712	233,768	100,955.5	1,515,882	135,174.5	86,887
Total est. deficits, 1986–95		1,087,924					2,072,666

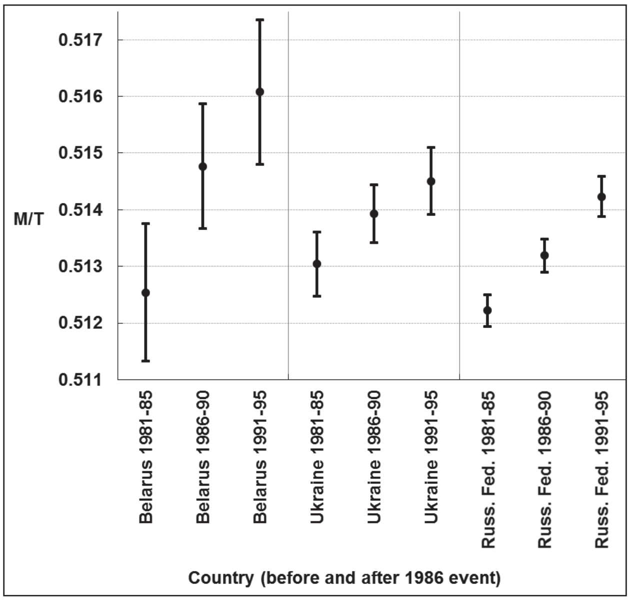

Fig. 1: M/T for Belarus, Ukraine and the Russian Federation, 1981–1991.

would not influence M/T as sons do not receive the paternal X-chromosome and daughters carry (and are protected by) a second X-chromosome from their mother (24). M/T is therefore influenced through increased but gender-biased fetal mortality. It has been hypothesised that the skew toward higher female mortality may be due to the fact that the X chromosome contains more genetic material and is larger, and hence, may be physically more easily struck by ionizing radiation. Another possibility is that ova and sperm afford their genetic material different levels of protection (12, 24).

The International Nuclear Event Scale (ranging in level from one to seven) has been in use at nuclear power plants since 1990 and was broadened in scope in 2001 to cover radioactive materials transport. The scale is logarithmic and each higher scale indicates a ten times higher event severity (25). Chernobyl was a level seven event, resulting in a very large release of radioactive material with widespread health and environmental effects, requiring implementation of planned and extended countermeasures. It has been estimated that there were 56 direct deaths as well as 4000 additional cancer fatalities among exposed individuals. The city of Chernobyl (population 14,000) was largely abandoned and the larger city of Pripyat (population 49,400) was completely abandoned. A permanent exclusion zone of 30 km was established around the reactor (26).

M/T has been mooted as a sentinel health indicator. This paper confirms that ionizing radiation can have significant and measurable effects on populations including a fall in births and M/T shifts. These occur possibly through the induction of lethal mutations that reduce the numbers of both male and female births, with the latter being effected more than the former. Furthermore, this paper also attempts to quantify the repercussions *vis-à-vis* birth reductions, and confirms that these are likely to have been in the millions region (12). The chosen 5-year period analysis method is more robust but less powerful than 1-year trend analysis, or even monthly trend analysis and hence, other significant shifts in M/T in countries other than Belarus, Ukraine, and Russia cannot be excluded. Moreover, the observed decline in births may have also been caused by altered reproductive behaviour that is not directly or even indirectly related to the Chernobyl event.

The biological effects of Chernobyl should wear off in the near future since by 2005 most of the radionuclides released in this accident had already decayed to below levels of health concerns, while remaining measurable in soils and some foods in many parts of Europe (11).

The only other level seven incident to date was the Fukushima Daiichi nuclear disaster of March 2011. This event released an estimated 10–30% of the environmental radiation contamination of the Chernobyl accident and resulted in a temporary exclusion zone of 20 km and a voluntary 30 km evacuation zone (27). The long term effects of this accident are still to be discovered.

In conclusion, birth rates are greatly reduced and the M/T ratio is skewed upward significantly with population exposure to ionizing radiation, even at great distances from major nuclear events.

References

1. Scherb H, Weigelt E. Congenital Malformation and Stillbirth in Germany and Europe Before and after the Chernobyl Nuclear Power Plant Accident. Environ Sci & Pollut Res. 2003; 1: 117–125.
2. Lazjuk GI, Nikolaev DL, Novikova IV. Changes in registered congenital anomalies in the Republic of Belarus after the Chernobyl accident. Stem Cells 1997; 15(Suppl 2): 255–60.
3. Wiesel A, Spix C, Mergenthaler A, Queisser-Luft A. Maternal occupational exposure to ionizing radiation and birth defects. Radiat Environ Biophys 2011; 50: 325–8.
4. James WH. The human sex ratio. Part 1: A review of the literature. Hum Biol 1987; 59: 721–752.
5. Neel JV, Schull WJ, et al. Implications of the Hiroshima-Nagasaki genetic studies for the estimation of the human "doubling dose" of radiation. Genome 1989; 31: 853–9.
6. James WH. Ionizing radiation and offspring sex ratio. J Epidemiol Community Health 1997; 51: 340–1.
7. Dickinson HO, Parker L, Binks K, Wakeford R, Smith J. The sex ratio of children in relation to paternal preconceptional radiation dose: a study in Cumbria, northern England. J Epidemiol Community Health 1996; 50: 645–52.
8. Schull WJ, Neel JV. Radiation and the sex ratio in man. Science 1958; 128: 343–8.
9. Scherb H, Voigt K. Trends in the human sex odds at birth in Europe and the Chernobyl Nuclear Power Plant accident. Reprod Toxicol 2007; 23: 593–9.
10. Ron E. Thyroid cancer incidence among people living in areas contaminated by radiation from the Chernobyl accident. Health Phys 2007; 93: 502–11.
11. Chernobyl Forum Expert Group. Environmental Consequences of the Chernobyl Accident and their Remediation: Twenty Years of Experience. Vienna: International Atomic Energy Agency 2006.
12. Scherb H, Voigt K. The human sex odds at birth after the atmospheric atomic bomb tests, after Chernobyl, and in the vicinity of nuclear facilities. Environ Sci Pollut Res Int 2011; 18: 697–707.
13. Sperling K, Pelz J, Wegner RD, Dorries A, Gruters A, Mikkelsen M. Significant increase in trisomy 21 in Berlin nine months after the Chernobyl reactor accident: temporal correlation or causal relation? BMJ 1994; 309: 158–62.
14. Zatsepin IO, Verger P, Robert-Gnansia E, Gagniere B, Khmel RD, Lazjuk GI. Cluster of Down's syndrome cases registered in January 1987 in Republic of Belarus as a possible effect of the Chernobyl accident. Int J Radiat Med 2004; 6: 57–71.
15. Venero Fernandez SJ, Medina RS, Britton J, Fogarty AW. The association between living through a prolonged economic depression and the male:female birth ratio – a longitudinal study from Cuba, 1960–2008. Am J Epidemiol 2011; 174: 1327–1331.
16. Scherb H, Kusmierz R, Voigt K. Increased sex ratio in Russia and Cuba after Chernobyl: a radiological hypothesis. Environ Health 2013 Aug 15; 12: 63. doi: 10.1186/1476-069X-12-63.
17. Grech V. Secular trends and latitude gradients in sex ratios at birth in the former Soviet republics. Acta Medica (Hradec Kralove) 2013; 56: 162–166.
18. Pridemore WA1, Chamlin MB, Cochran JK. An Interrupted Time-Series Analysis of Durkheim's Social Deregulation Thesis: The Case of the Russian Federation. Justice Q 2007; 24: 271.
19. Bromet EJ. Mental health consequences of the Chernobyl disaster. J Radiol Prot 2012; 32: 71–5.
20. Fleiss JL. Statistical methods for rates and proportions. 2nd ed. New York: John Wiley and Sons 1981: 14–15.
21. Cochran WG. Some methods for strengthening the common chi-squared tests. Biometrics 1954; 10: 417–451.
22. Armitage P. Tests for Linear Trends in Proportions and Frequencies. Biometrics 1955; 11: 375–386.
23. Gini C. Sulla probabilita che termini di una serie erratica sieno tutti crescenti (o non decrescenti) ovvero tutti decrescenti (o non crescenti) con applicazioni ai rapporti dei sessi nascite umane in intervalli successivi e alle disposizioni dei sessi nelle fratellanze umane. Metron 1955; 17: 1–41.
24. Vogel F, Motulsky AG. Human genetics. 2nd ed. Berlin: Springer 1986.
25. International Atomic Energy Agency. The International Nuclear and Radiological Event Scale. Vienna: International Atomic Energy Agency 2010.
26. Chernobyl Forum: 2003–2005. Chernobyl's Legacy: Health, Environmental and Socio-economic Impacts and Recommendations to the Governments of Belarus, the Russian Federation and Ukraine. Vienna: International Atomic Energy Agency 2006.
27. von Hippel FN. The radiological and psychological consequences of the Fukushima Daiichi accident. Bull Atomic Scientists 2011; 67: 27–36.

Received: 19/02/2014
Accepted in revised form: 16/05/2014

Corresponding author:

Prof. Victor Grech, Department of Paediatrics, Mater Dei Hospital, Malta; e-mail: victor.e.grech@gov.mt