Cytogenetic monitoring of medical staff professionally exposed to Gamma and X radiation

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The intention of the study was to find out whether in spite of carrying out the required protection measures in using therapeutic and diagnostic machines there is an increased frequency of structural chromosome aberrations in medical staff professionally exposed to ionizing radiation. The other objective was to find out whether there are consequential differences in exposure to Gamma and X radiation. The classic genotoxic method of analyzing chromosome aberrations in peripheral blood lymphocytes was used and 200 metaphases per examinee were analyzed. Twenty-five staff members of Oncology Department exposed to Gamma radiation were examined by that method, 22 of Radiology Department exposed to X radiation, as well as 20 unexposed medical employees. The results have shown that chromatid breaks (CB) differ significantly in the three examined groups ($p<0.05$). The difference is even more significant in acentric fragments (AC), ($p<0.001$). The highest values are in the group of gamma radiation exposure. Translocational aberrations (DIC) and tetraradiuses (TET) occured in the group exposed to Gamma radiation, while in other two groups that was not the case. There was a considerable positive correlation between the years of exposure to ionizing radiation and occurrence of acentric fragments. Aberration analysis per cell showed the highest frequency of structural aberrations in examinees exposed to Gamma radiation. It seems that protection measures in Gamma radiation departments are not always satisfactory. Furthermore, continual monitoring of Radiology Department staff exposed to X radiation is necessary, as their aberration frequency is higher than the control, the unexposed group of examinees.

Key words: chromosome aberrations, ionizing radiation, continual monitoring

Every radiation is potentially dangerous. That is also true of non-ionizing radiation in case of long-term exposure, when the source of radiation is in immediate vicinity and when protection is inadequate [4, 17, 21, 27]. The standard cellular phone frequencies have not so far caused chromosomal aberrations [40]. Generally speaking, chromosomal aberrations are the best biomarkers of exposure to radiation [2]. Chromosomal aberrations are the best guidance in explaining carcinogenesis [20, 22]. Ionizing radiation can be of great danger, particularly professionally used Gamma and X radiation, irrespective of the source of radiation being the nucleus or electronic field. They lead to genetic instabilities, DNA breaks and chromosomal translocations [11, 15, 28, 29, 37].

Everyone on earth is exposed to a broad spectrum of electromagnetic waves. Even living and staying in contaminated buildings (radioactive building material) may pose a certain risk [6]. The problem is the increasing number of occupations in which people are professionally exposed to radiation. Demand for energy is growing, the number of nuclear power plants is on the rise but so is the number of people overexposed to radiation [7], not to mention radiation at the time of nuclear disasters like Chernobyl in 1986, of which consequences are still felt [14, 31]. Even nowadays the aftereffects of Gamma and neutron radiation are observed in survivors of Hiroshima and Nagasaki bombing [34].

The need for rapid transportation is on the increase, pilots and crews fly on ever higher altitudes where there is danger of cosmic radiation [32, 43]. Professional exposure to depleted uranium, that is respirable particles in the air which appear when missiles fired from tanks and other weapons hit the armor causing radioactive contamination. The occurrence of leukemia and malignant tumors seems to be more frequent among the Balkan and the Gulf war veterans [36].

A particular case of professional exposure to ionizing radiation is that of medical staff continually exposed to low doses of gamma and X radiation, with the purpose of diagnosing and treating various diseases [24, 39]. The studying of such groups have shown an increase in lymphocytes aberrations, although some studies report of no statistical significance in relation to unexposed population.

The aim of this study was is to find out whether there is in medical staff exposed to ionizing radiation a statistically significant increase of structural chromosome aberrations frequency in comparison to unexposed staff, and whether on the basis of biodosimeter analysis there is consequential difference of exposure to Gamma and X radiation in such persons.

Material and methods

The study includes blood samples of 25 medical staff exposed to Gamma radiation employed in the Department of Oncology, of Hospital in Rijeka, and blood samples of 22 medical staff of Radiology Department exposed to X radiation as well as 20 blood samples of unexposed staff of the Hospital Center.

In the group exposed to Gamma radiation 23 were women and 2 men. Their mean age was 41.64 years (range 23–58). Film dosimeters were used for all subjects to work out the annual mean dose of received ionizing radiation.

In the group exposed to X radiation there were 18 women and 4 men. Their mean age was 37.95 years (range 23–49).

The control group consisted of persons who came for preliminary checkup at the Industrial Medicine Surgery before being employed in the ionizing radiation zone. There were 11 women in the group and 9 men. Their mean age was 28.05 (range 22–41).

Chromosome aberration analysis. A genotoxic analysis was performed by conventional metaphase analysis of peripheral blood lymphocytes, stained by Giemsa techniques. Briefly, short-term lymphocyte cultures were prepared using Gibco F 10 Medium, which was supplemented with 20% foetal calf serum, antibiotics and phytohaemagglutinin (Murex, Biotech ltd, Dartford, England). Two cultures of each sample were prepared. The cells were harvested at 48 h following stimulation. Colchicine (0.004%) (Sigma, Chemical Co., St. Louis, MO) was added 3 h before harvest. The cultures were centrifuged and subjected to a hypotonic shock (20 min, 0.0075 M KCl) at 37 °C. The lymphocytes were then fixed in acetic acid-methanol (1:3) and air-dried and stained with 5% aqueous Giemsa solution for 10 min. Two hundred metaphases were analyzed, seeking for structural aberrations such as chromatid and chromosome breaks, acentric and dicentric fragments, tetraradiuses as well as for double minutes and gaps.

The radiation emitters specifications. The sources of Gamma radiation at the Department of Oncology from 1999 have been the Cobalt unit and the Curietron. The Cobalt unit ("Cirus", CIS Biointernational, France, 1999) had nominal activity 239,681 TBq. Until 1999, the Canadian Cobalt unit "Theratron" was used, manufactured in 1965, nominal activity about 150 TBq. The Curietron for intracavitary afterloading was manufactured in 1987 in France, from CGR. Sources of low dose rate have been also in use, active length 1.4 to 7 cm, activity 1.5 to 5 GBq.

The sources of X radiation at the Department of Radiology were different types of X-ray instruments: Siemens "Tridors 5 S", Germany, 1980; "Superix 1000", Yugoslavia, 1985; "Housing Model Type Opti 100 L", USA, 1985; maximal intensities 150 kV. Two Siemens instruments have been used for diascopy: "Sireskop Cx SYS I", Germany, 1994 and 1998, maximal intensities 150 kV. "Polydoros 80 – Angio", Siemens 1994, maximal intensity 125 kV, has been used for angiographic examinations.

Results

Results have shown a considerable statistical difference in frequency of chromatid breaks occurrence in 3 studied groups ($p<0.05$) with highest values in Gamma radiation. The difference is even more significant in acentric fragments ($p<0.001$), (Fig. 1). Acentric fragments are the most dominant types of structural aberrations in persons exposed to both types of ionizing radiation.

The years of exposure and frequency of acentric fragments have shown a substantial positive correlation (Fig. 2).

The work in Gamma radiation zone has caused the highest frequency of chromosome aberrations. Fifty percent of examinees had five or more aberrations in 200 metaphases (Tab. 1 – shadowed boxes). Conditions in X radiation zone proved to be much better where 4 out of 22 examinees had five or more aberrations in 200 metaphases (Tab. 2 – shadowed boxes). Unexposed population had the best findings where only one person had 5 aberrations in 200 metaphases (Tab. 3).

The analysis of chromosome aberration frequencies per cell has clearly shown the results for all structural chromosome aberrations. For persons exposed to Gamma radiation frequency for chromatid breaks was $0.5x10^{-3}$, $1.24x10^{-3}$ for acentric fragments, $0.88x10^{-3}$ for gaps, $0.12x10^{-3}$ for dicentrics and $0.04x10^{-3}$ for tetraradiuses expressed per cell.

That frequency is higher than in persons exposed to X radiation, which was $0.3x10^{-3}$ for chromatid breaks, $0.5x10^{-3}$ for acentric fragments and $0.7x10^{-3}$ for gaps expressed per cell, and much higher than in unexposed persons (Tab. 4). Dicentrics and tetraradiuses appeared only in persons exposed to Gamma radiation. According to the analysis results persons working with sources of 60 Co Gamma radiation received the average 642.80 μSv, while persons working with X radiation sources received the average of 536.56 μSv doses of ionizing radiation.

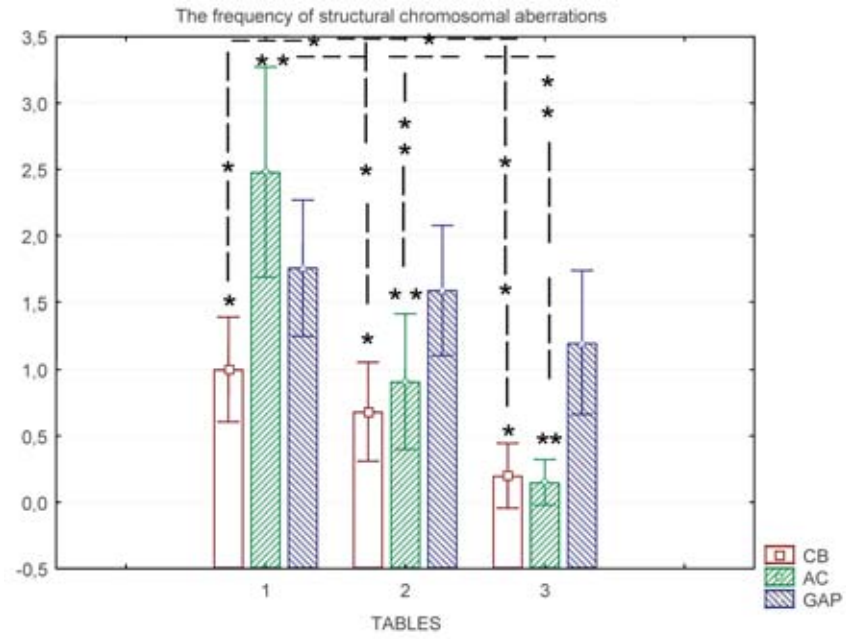

Figure 1. Comparison of three groups of examinees. The frequency of structural chromosomal aberrations after exposure to Gamma radiation (1), X radiation (2), and the Control group (3) of examinees. CB – chromatid breaks, AC – acentric fragment, GAP – chromatid gap. *p<0.05; **p<0.001.

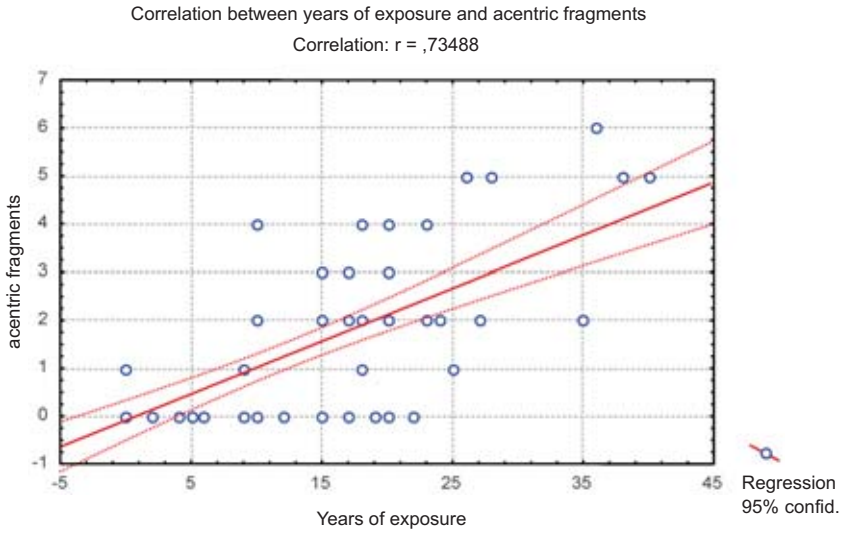

Figure 2. Correlation between years of exposure and acentric fragments. The strong positive correlation is found between years of exposure and acentric fragments.

Discussion

"Dose effect" dependence curve that indicates chromosome aberrations gives the most accurate results in majority of cases [3]. Higher radiation doses, particularly doses by which patients with radiosensitive malignant diseases are treated, provoke a higher cell response [18, 25, 41]. With higher Gamma radiation doses even inter-cellular chromosome aberrations – dicentrics (DIC) occur [16].

Industrial Medicine monitoring professionally exposed staff is specially interested in exposures to low doses of ionizing radiation. The extended exposure to low doses of Cobalt 60 Gamma rays results in the increase of acentrics and dicentrics [1, 12, 35], leading to elevated frequency of inter-chromosome changes [5]. In such extended and low exposures to Gamma rays DNA breaks are significantly elevated [38].

"Dose effect" dependence curve may also be used in X radiation. Only the use of small dental RTG equipment has not caused an increase in chromosome aberrations [26]. When other RTG equipments are used, even in industry when they are used to identify the structure of specific minerals, with very little exposure, aberration frequency is somewhat higher than in unexposed persons [19]. Medical staff exposed to X rays is often subjected also to other detrimental factors such as anesthetic fumes in operation theatres [10, 33]. Experiments have proved that detrimental cofactors together with radiation diminish adaptive response of exposed persons [30, 42].

To estimate the received dose also in medical staff of Clinical Hospital Center Rijeka we decided on chromosome aberration analysis as the most sensitive and the most accurate method [23]. In medical staff of Clinical Hospital center Rijeka employed in Oncology Department, exposed to Gamma radiation (Cobalt bomb, Cesium 137) there was a considerable increase in acentric fragments frequency which differed significantly compared to Radiology Department staff and unexposed employees. In staff exposed to Gamma radiation there were also incidences of translocational chromosome aberrations, dicentrics (DIC) and tetraradiuses (TET). Their incidence was however low. This is also due to hereditary selective mechanisms which act against translocational aberrations and diminish their number with time of exposure [9]. As the doses of received ionizing radiation for staff in X and Gamma radiation zone were practically equivalent, it is hard to conclude with certainty why

Table 1. The professional exposure to Gamma rays

No	Sex	Age exposure	Years of in 1 year	Doses (μSv)	CB	AC	GAP	DIC	TETRA	All/ 200 cells	% All
1	F	49	27	560	2	2	1	2	1	8	4.0
2	F	30	10	240	0	0	2	0	0	2	1.0
3	F	32	10	350	1	4	2	0	0	7	3.5
4	F	22	2	540	1	0	2	0	0	3	1.5
5	F	40	15	480	0	2	0	0	0	2	1.0
6	F	39	17	910	2	2	4	2	0	10	5.0
7	F	25	4	180	1	0	2	0	0	3	1.5
8	F	42	20	510	1	3	3	2	0	9	4.5
9	F	23	5	380	2	0	3	0	0	5	2.5
10	F	30	10	720	2	2	1	0	0	5	2.5
11	F	35	15	490	0	2	2	0	0	4	2.0
12	F	37	18	930	2	4	0	0	0	6	3.0
13	F	57	36	950	3	6	2	0	0	11	5.5
14	F	27	5	560	0	0	2	0	0	2	1.0
15	F	42	20	470	2	4	1	0	0	7	3.5
16	M	46	23	660	0	2	3	0	0	5	2.5
17	F	38	19	570	1	0	1	0	0	2	1.0
18	M	57	27	720	2	2	3	0	0	7	3.5
19	F	46	28	1960	0	5	4	0	0	9	4.5
20	F	49	25	940	2	1	2	0	0	5	2.5
21	F	57	38	590	0	5	1	0	0	6	3.0
22	F	58	40	190	0	5	3	0	0	8	4.0
23	F	53	23	990	0	4	0	0	0	4	2.0
24	F	53	26	930	0	5	0	0	0	5	2.5
25	F	54	35	240	1	2	0	0	1	4	2.0

CB – chromatid break, AC – acentric fragment, DIC – dicentric; TETRA – tetraradius. Shadowed boxes – 5 or more chromosome aberrations found on 200 metaphases.

Table 2. The professional exposure to X-rays

No	Sex	Age exposure	Years of in 1 year	Doses(μSv)	CB*	AC	GAP	DIC	TETRA	All/ 200 cells	%All
1	F	39	19	560	1	0	1	0	0	2	1.0
2	F	47	15	490	0	3	1	0	0	4	2.0
3	F	46	18	330	0	1	4	0	0	5	2.5
4	F	34	12	550	1	0	1	0	0	2	1.0
5	M	34	10	480	1	0	4	0	0	5	2.5
6	M	42	17	1250	3	0	0	0	0	3	1.5
7	F	47	20	480	0	2	1	0	0	3	1.5
8	M	49	20	590	0	2	2	0	0	4	2.0
9	F	37	9	350	0	1	3	0	0	4	2.0
10	F	23	4	580	1	0	1	0	0	2	1.0
11	F	47	18	450	0	2	0	0	0	2	1.0
12	F	43	20	490	0	0	2	0	0	2	1.0
13	F	29	6	440	0	0	1	0	0	1	0.5
14	F	28	6	540	0	0	1	0	0	1	0.5
15	F	32	10	530	1	0	1	0	0	2	1.0
16	F	38	18	620	0	1	3	0	0	4	2.0
17	F	35	15	420	1	0	2	0	0	3	1.5
18	F	32	9	460	1	0	1	0	0	2	1.0
19	M	47	24	580	2	2	1	0	0	5	2.5
20	F	44	20	390	0	3	2	0	0	5	2.5
21	F	49	17	930	2	3	1	0	0	6	3.0
22	F	43	22	290	1	0	2	0	0	3	1.5

CB – chromatid break; AC – acentric fragment; DIC – dicentric; TETRA – tetraradius. % All – percent of aberrations found on 200 metaphases. Shadowed boxes – 5 or more chromosome aberrations found on 200 metaphases.

Table 3. The control group of examinees

No	Sex	Age	Years of exposure	Doses (μSv) in 1 year	CB	AC	GAP	DIC	TETRA	All/ 200cells	% All
1	F	32	0	0	0	0	1	0	0	1	0.5
2	F	25	0	0	0	0	1	0	0	1	0.5
3	F	35	0	0	0	0	4	0	0	4	2.0
4	M	37	0	0	0	1	0	0	0	1	0.5
5	F	26	0	0	0	0	0	0	0	0	0.0
6	M	38	0	0	0	0	1	0	0	1	0.5
7	M	41	0	0	0	0	2	0	0	2	1.0
8	M	28	0	0	0	0	1	0	0	1	0.5
9	M	26	0	0	0	0	0	0	0	0	0.0
10	F	24	0	0	1	0	1	0	0	2	1.0
11	M	27	0	0	0	1	2	0	0	3	1.5
12	M	24	0	0	0	0	0	0	0	0	0.0
13	F	23	0	0	0	0	1	0	0	1	0.5
14	M	22	0	0	0	1	0	0	0	1	0.5
15	F	25	0	0	0	0	3	0	0	3	1.5
16	F	25	0	0	0	0	2	0	0	2	1.0
17	F	29	0	0	2	0	3	0	0	5	2.5
18	M	24	0	0	1	0	1	0	0	2	1.0
19	M	23	0	0	0	0	0	0	0	0	0.0
20	F	27	0	0	0	0	1	0	0	1	0.5

CB – chromatid break, AC – acentric fragment, DIC – dicentric, TETRA – tetraradius. % All – percent of aberrations found on 200 metaphases. Shadowed boxes – 5 or more chromosome aberrations found on 200 metaphases.

Table 4. The frequency of chromosome aberrations expressed per cell

	CB x 10^{-3}	AC x 10^{-3}	GAP x 10^{-3}	DIC x 10^{-3}	TET x 10^{-3}
Gamma radiation	0.5	1.24	0.88	0.12	0.04
X radiation	0.3	0.5	0.75	0.0	0.0
Control group	0.1	0.07	0.60	0.0	0.0

CB – chromatid break, AC – acentric fragment, DIC – dicentric, TETRA – tetraradius.

there were incidences of translocational aberrations in staff in Gamma radiation zone, but not in staff in X radiation zone, and why the overall chromosome aberration frequency was nevertheless the highest in staff in the zone of ionizing Gamma radiation.

The age of both groups of examinees exposed to ionizing radiation was about the same. The staff exposed to Gamma radiation was employed on the average five years longer in ionizing radiation zone. The research has shown positive correlation between incidence of acentric fragments and years of exposure to ionizing radiation. It is probable that longer employment, though not much longer, is one of the many cofactors causing translocational aberrations in people exposed to Gamma radiation. Furthermore, Oncology Department staff uses 60 Co Gamma radiation for therapeutic purposes (entering frequently the Cobalt bomb room, positioning and turning patients, often unable or hardly able to move). At that time radiation is switched off but the air is ionized and the patient's body also emits radiation. Radiology Department staff use X radiation for diagnostic purposes only.

To conclude, the research shows higher aberration frequency in persons exposed to Gamma rays than in those exposed to X rays. The group exposed to X rays had a higher frequency than the control, unexposed group. That calls for regulatory measures shortening working hours and improving protection from radiation, besides the existing safety at work measures.

In that way Industrial Medicine, monitoring the exposed persons and suggesting implementation of new safety measures, hinders the radiation induced mutations and prevents possible radiation carcinogenesis [8, 13].

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