ACCIDENTAL IONIZING RADIATION AND ITS IMPACT ON THE POPULATION#

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Abstract. A study of the influence of accidental ionizing radiation due to the nuclear explosion in Chernobyl in 1986 on Mureş County population was performed. We studied the annual incidence of acute leukemia in Mureş County between 1983–2002, according to gender, origin, and type of disease. This study is a cohort type, based on ecological preponderance. Due to the existence of incomplete records in some clinics, we could not study the incidence of disease for more than 3 years in pre-Chernobyl period (1983–1985). Thus, we have grouped the post-Chernobyl interval in 5 periods of 3 years, to calculate and compare the cumulative incidence values. Regarding the total incidence of acute leukemia, there is a statistically significant positive association between the exposure to the risk factor (ionizing radiation) and the disease throughout all the studied periods during 1986–2000. Previous conclusions are also supported by the results of data analysis in case of grouping data according to criteria regarding the type of the disease, as well as demographic criteria. The results appear to contest the existence of a dose-response type relationship in case of our study.

Key words: ionizing radiation, acute leukemia, statistical analysis.

INTRODUCTION

Ionizing radiation is a factor that is involved in the etiology of leukemia [1, 6, 10, 11, 12]. We considered the reference level of the nuclear accident in Chernobyl in 1986 and we performed a study of the incidence of this hematological disorder in pre and post-accident in order to judge the impact of ionizing radiation on the health status of Mureş County population as a result of this accident [5, 7].

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We considered this study of interest, since measurements performed by the Institute of Public Health – Radiation Hygiene Laboratory, Cluj-Napoca, in collaboration with the Radiation Hygiene Laboratory Târgu Mureş, show high values of effective dose equivalent in Mureş County [2, 3].

Acute leukemia (AL) is a neoplastic disease characterized by loss of differentiation and ripening ability of hematopoietic cells. Acute leukemia is classified in myeloid and lymphoblastic leukemia.

Acute myeloid leukemia (AML) is a clonal disease of [various types of] oriented myeloid hematopoietic stem cells characterized by their neoplastic aberrant proliferation, by obstructing differentiation and ripening.

Acute lymphoblastic leukemia (ALL) is a clonal neoplastic proliferation of lymphoid progenitor stem cells, characterized by the obstruction of differentiation and ripening. Malignant clone expansion gradually leads to bone marrow, lymph node and central nervous system invasion [4, 9].

We studied the incidence of acute leukemia in Mureş County on groups of patients admitted and investigated at the Hematology Department of Medical Clinic I, Department of Hematology and Stem Cell Transplant of Medical Clinic II, Department of Oncology of Pediatrics Clinic I, Târgu Mureş, in order to quantify the effects of accidental radiation resulted subsequent to the Chernobyl accident. We have to mention that, as far as we know, in Romania there is no published report to date about the effects of this accident on the population [13, 15].

MATERIALS AND METHODS

The performed study is of a cohort type, based on ecological preponderance, where the analysed units are whole populations or groups rather than individual subjects.

Regarding the sample size of this study, we investigated all cases of this type of illness found in the archives of Mureş County Clinics during 1983–2002. We determined the annual and cumulative incidence (for periods of 3 years), divided by the County population, according to demographic data.

We collected data concerning patients' age and gender, the year of the diagnosis, the type of acute leukemia, living conditions and geographical area they originated from. The study covered the period 1983–2002.

Due to the existence of incomplete records in some clinics, we could not study the incidence of malignant hemopathies for more than 3 years in pre-Chernobyl period (1983–1985). Therefore, we have grouped the post-Chernobyl interval in 5 periods of 3 years, to calculate and compare the cumulative incidence values. Although 2001, 2002 were taken initially into consideration, they could not be grouped in a comparative 3-year period; thus, analysis for this period could be performed only by using special statistical techniques (e.g. resampling) in order to provide the missing values. While most statistical books [8] recommend caution when applying such methods, we preferred to skip this period, to avoid affecting the objectivity of the conclusions.

The stipulated statistical analysis consisted in calculating the expected relative risk (RR) and the related confidence interval (CI). RR and CI were calculated using the CHI^2 test, which was applied using the YATES correction, and not the Fisher test, because of the ecological character of this study, which resulted in greater values in the contingency tables.

RESULTS

The number of registered acute leukemia cases in Mureş County amounted to 218 patients, out of whom 108 (49.54%) were males and 110 (50.46%) females. We followed up the number of acute leukemia cases for each year by gender, age groups, origin, and the type of leukemia. Concerning the origin of patients, we found 116 cases (53.21%) from urban area and 102 cases (46.79 %) from rural area.

Simultaneously we studied the type of acute leukemia in the 218 investigated patients; it turned out that 95 of the patients were diagnosed with acute myeloid leukemia and 123 with acute lymphoblastic leukemia. Acute lymphoblastic leukemia was found in 56.42% of the cases, whereas acute myeloid leukemia in 43.58% of the cases. Regarding the type of acute leukemia retrieved in the studied group during 1983–2002, we determined the rate of acute leukemia in Mureş County. Out of the total of 156 adults, 74 had acute myeloid leukemia and 88 acute lymphoblastic leukemia.

We calculated the incidence of acute leukemia during the pre and post-Chernobyl period for each year of the interval 1983–2002, by corroborating, analyzing and processing the descriptive data appropriate to the group of studied patients. At the same time we determined the incidence of AL based on gender, age, origin and type of acute leukemia as shown in Figures 1, 2, and 3.

During the period before the Chernobyl nuclear accident, the incidence of acute leukemia in Mureş County oscillated at values below $1^0/_{0000}$ inhabitants. According to the attained results there was an increased incidence after 1986, reaching $2.433^0/_{0000}$ in 1987, staying high in 1988 too, at $2.425^0/_{0000}$, so that in the following years these values gradually decreased. Ten years after the accident we recorded a further increase in the incidence of AL, peaking in 1997 and remaining at high levels in the following years; consequently, in 2002 these values reached $3.098^0/_{0000}$ inhabitants. Taking into account the distribution by gender of the AL incidence, the results show approximately equal percentages of affected patients of both genders in 1987, and predominantly affected male population in 1988, 1997, 1999 and 2002.

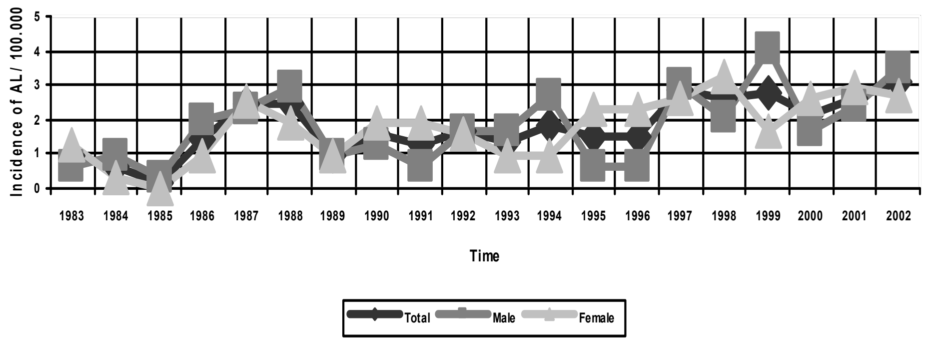

Fig. 1. The incidence by gender of acute leukemia in Mureş County during the period 1983–2002.

The calculated average annual incidence shows increased values in the urban population in 1987, 1992, 1993, 1996 and 2000. High values of the AL incidence in the rural areas were found in 1989, 1995 and 1997.

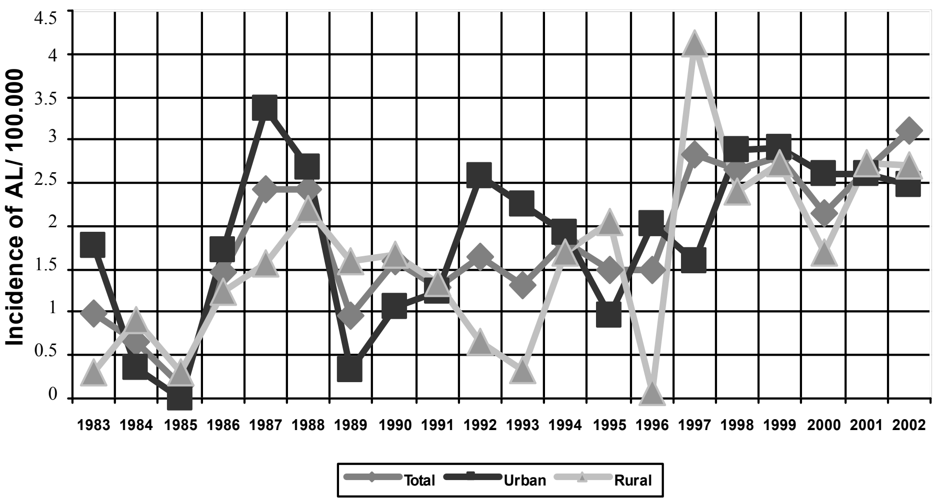

Fig. 2. The incidence by the origin of acute leukemia in Mureş County.

Until 1986 the incidences of AML and ALL were less than $1^{0}/_{0000}$, but after 1986 they increased, especially for ALL in 1987, 1988, 1997, 1998, 1999, resting at about $1^{0}/_{0000}$ inhabitants in the following period. In case of AML, the incidence increased in 1986, 1988, 1989, 1993, 1996, with a peak in 1987 and another in 2002.

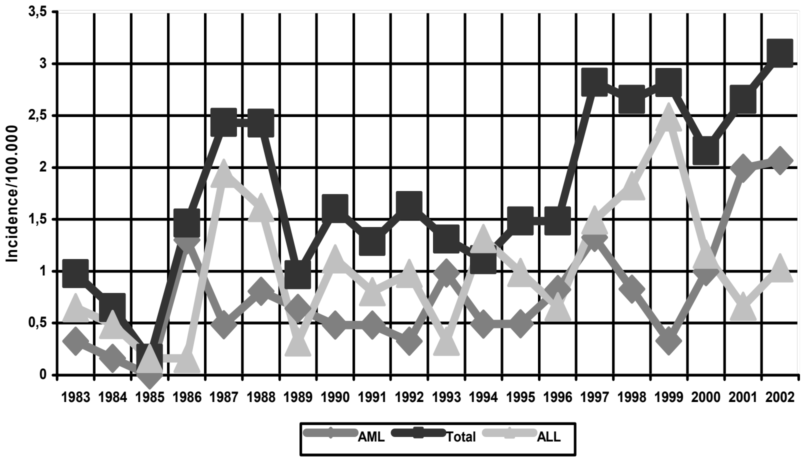

Fig. 3. The incidence of AL by type of disease in Mureş County.

Table 1

Statistical parameters of acute leukemia in Mureş County

Period	**Number of AL cases**	**Number of population exposed to risk**	**Relative risk (RR)** (CI 95 %)	**Chi^2 Test**	**P**	**CI (3 years)** /10^5 inhabitants	**Attribut-able risk**
1983–1985 (no exposure)	**11**	**614296**				**1.791**	
1986–1988	39	614725	3.543 (1.814;6.919)	14.562	0.0001	6.344	4.554
1989–1991	24	621246	2.157 (1.057;4.405)	3.981	0.046	3.863	2.073
1992–1994	29	612521	2,653 (1.321;5.294)	7.275	0.007	4.735	2.944
1995–1997	35	606777	3.221 (1.636;6.344)	11.786	0.0006	5.768	3.978
1998–2000	46	602721	4.262 (2.207;8.230)	20.935	0.0001	7.632	5.841

We performed a statistical analysis of the association between the exposure to the risk factor (ionizing radiation due to Chernobyl accident) and the disease throughout all studied periods (5 periods lasting 3 years each during 1986–2000) as shown in Table 1.

Table 2

Statistical evaluation of acute myeloid leukemia in Mureş County

Period	**Number of AML cases**	**Number of population exposed to risk**	**Relative risk (RR)** (CI 95 %)	**Chi^2 Test**	**P**	**CI (3 years)** /10^5 inhabitants	**Attributable risk**
1983–1985 (no exposure)	**3**	**614296**				**0.488**	
1986–1988	16	614725	5.33 (1.553;18.297)	7.571	0.006	2.603	2.114
1989–1991	10	621246	3,296 (0.907;11.980)	2.702	0.100	1.610	1.121
1992–1994	13	612521	4.346 (1.238;15.256)	5.089	0.024	2.122	1.634
1995–1997	16	606777	5.400 (1.573;18.536)	7.728	0.0054	2.637	2.149
1998–2000	13	602721	4.417 (1.258;15.504)	**5.236**	0.022	2.157	1.669

Table 3

Statistical analysis of acute lymphoblastic leukemia in Mureş County

Period	**Number of ALL cases**	**Number of population exposed to risk**	**Relative risk (RR)** (CI 95 %)	**Chi^2 Test**	**P**	**CI (3 years)** /10^5 inhabitants	**Attributable risk**
1983–1985 (no exposure)	**8**	**614296**				**1.302**	
1986–1988	23	614725	2.873 (1.285;6.424)	6.313	0.012	3.742	2.439
1989–1991	14	621246	1.730 (0.726;4.126)	1.081	0.299	2.254	0.951
1992–1994	16	612521	2.006 (0.858;4.688)	2.062	0.151	2.612	1.310
1995–1997	19	606777	2.404 (1.052;5.494)	3.828	0.050	3.131	1.829
1998–2000	33	602721	4.204 (1.942;9.104)	14.511	0.0001	5.475	4.173

Subsequently, we performed a statistical analysis related to the incidence of acute leukemia by representing the studied groups in tables according to the following criteria: type of disease (AML/ALL), demographic data (urban/rural, male/female) as seen in Tables 2 and 3.

The comparison of the results for the two diseases is presented in Fig. 4.

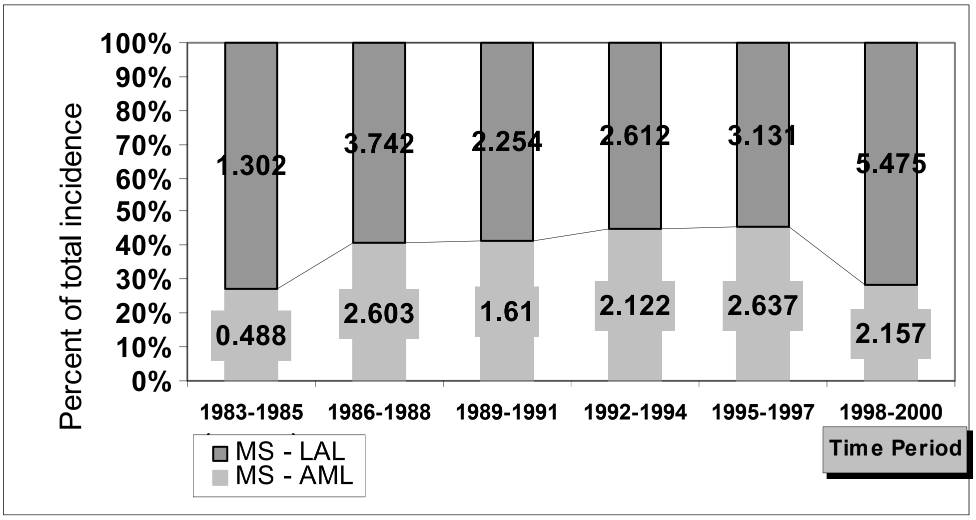

Fig. 4. The rate of total incidence of AML compared to ALL during the studied periods, in Mureş County.

Table 4

Statistical parameters of acute leukemia in urban areas of Mureş County

Period	Number of AL cases (urban)	Number of population exposed to risk	Relative risk (RR) (CI 95 %)	Chi^2 Test	P	CI (3 years) $/10^5$ inhabitants	Attributable risk
1983–1985 (no exposure)	**6**	**282898**				**2,121**	
1986–1988	23	291162	3.725 (1.516;9.149)	8.375	0.004	7.899	5.778
1989–1991	10	309481	1.524 (0.554;4.193)	0.326	0.568	3.231	1.110
1992–1994	21	310680	3.187 (1.286;7.898)	6.021	0.014	6.759	4.638
1995–1997	15	314305	2.250 (0.873;5.801)	2.271	0.132	4.772	2.652
1998–2000	26	310920	3.943 (1.6232;9.581)	9.580	0.002	8.362	6.241

We found a relative increase of the AML incidence during the first 4 intervals, compared to the pre-Chernobyl period – as can be seen in Table 4, which represents the relative risk (much increased in case of AML), although the absolute incidence is higher in case of ALL.

In case of AL, as well as for AML or ALL, we can notice an increase of the RR values during the first period of post-accident (1986–1988) and the last two studied periods (Tables 1, 2, and 3).

Relative increase means an increasing modification of the $CI_{3yearsAML}/CI_{3yearsALL}$ ratio. Thus, we can notice an increase in percentage of AML in comparison with the sum of the AML + ALL incidences during that period (in this case that amount is exactly the total incidence of AL). According to the graph in Figure 4, we obtain the percentage $CI_{3yearsAML} = CI_{3yearsAML}/(CI_{3yearsAML} + CI_{3yearsALL}) = 0,488/(0,488 + 1,302) = 0,272$ or 27.2% of the "sum of the two incidences" during the first period (1983–1985), compared to the second period (1986–1988) where the percentage $CI_{3yearsAML} = CI_{3yearsAML}/(CI_{3yearsAML} + CI_{3yearsALL}) = 2.603/(2.603+3.742) = 0.410$ or 41%.

Table 5

Statistical parameters of acute leukemia in rural areas of Mureş County

Period	**Number of AL cases (rural)**	**Number of population exposed to risk**	**Relative risk (RR)** (CI 95 %)	**Chi^2 Test**	**P**	**CI (3 years)** /10^5 inhabitants	**Attributable risk**
1983–1985 (no exposure)	**5**	**331398**				**1.509**	
1986–1988	16	323563	3.278 (1.200;8.949)	5.005	0.025	4.945	3.436
1989–1991	14	311765	2.976 (1..072;8.266)	3.878	0.049	4.491	2.982
1992–1994	8	301841	1.750 (0.575;5.371)	0.524	0.469	2.650	1.142
1995–1997	20	292472	4.533 (0.701;12.080)	9.723	0.002	6.838	5.330
1998–2000	20	291801	4.543 (1.705;12.108)	9.760	0.002	6.854	5.345

The comparison of the results for the two areas of origin is represented in Figure 5.

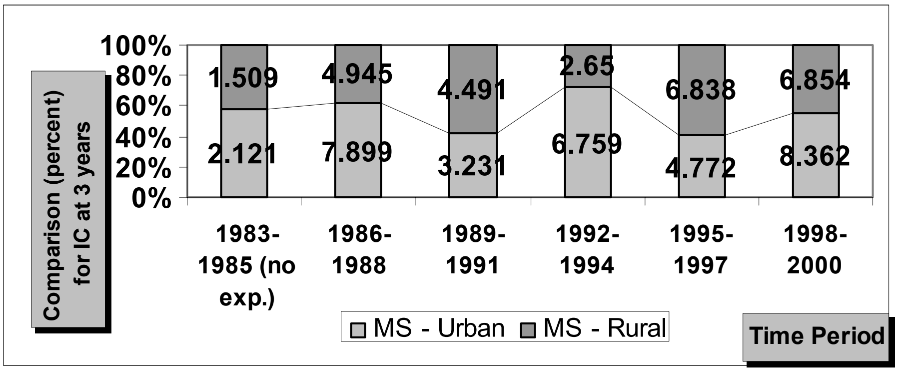

Fig. 5. Graphics of cumulative incidence of AL in urban *versus* rural areas for the studied period in Mureş County.

We found a relative increase in incidence in rural areas *versus* urban areas, compared to the pre-Chernobyl period in 3 out of the 5 studied intervals: 1989–1991, 1995–1997, 1998–2000 (marked increases during the last 2 intervals). The interval immediately following the accident, 1986–1988, shows an increase of the incidence values for both total cases and cases from the two groups of population (urban and rural).

These conclusions should be regarded in the context of exposure to the risk factor, exposure which in Mureş County was much stronger in rural than in urban areas (about 3.38 times), as shown in Table 6 [2, 3].

Table 6

The equivalent of the effective dose (ED) due to soil contamination with Cs-134 and Cs-137 in the first year after contamination

County	ED (µSv), in 1986						
	Urban			**Rural**			**Total**
	Cs-137	Cs-134	**Total**	Cs-137	Cs-134	**Total**	
Mureş	4	4	**8**	13	14	**27**	**35**

These findings determined us to study the possibility of a dose-response type relationship (a correlation between exposure gradient and gradient of risk – in our case a possible correlation between higher levels of exposure in rural areas and increased incidence of acute leukemia in this area). The existence of such type of relationship is crucial to validate a statistically significant association type as a cause-effect relationship [14]. The results of this analysis are summarized in Table 7.

Table 7

Statistical analysis of acute leukemia in Mureş County, urban areas compared to rural areas

Period	Cumulative incidence at 3 years AL/Urban (low exposure)	Cumulative incidence at 3 years AL/Rural (high exposure)	Relative risk (RR) (CI 95 %)	Chi^2 Test	P
1983–1985 (no exposure) ***control period***	2.121	1.509	0.711 (0.217;2.332)	0.069	0.793
1986–1988	7.899	4.945	0.773 (0.408;1.464)	0.399	0.527
1989–1991	3.231	4.491	1.410 (0.626;3.176)	0.397	0.529
1992–1994	6.759	2.650	0.392 (0.174;0.885)	4.626	0.032
1995–1997	4.772	6.838	1.433 (0.734;2.799)	0.791	0.374
1998–2000	8.362	6.854	0.820 (0.458;1.468)	0.273	0.601

A negative association, although not statistically significant, between greater exposure to risk factor (ionizing radiation due to Chernobyl accident) and disease over 2 of the 5 periods studied (1986–1988, 1998–2000) can be observed. This association is identical in type and magnitude with the one observed during the control period (1983–1985, a period characterized by the lack of exposure to risk factor). Moreover, there is a statistically significant negative association between exposure and disease during 1992–1994, which confirms the above-mentioned tendency.

Table 8

Statistical evaluation of acute leukemia in males in Mureş County

Period	Number of AL cases (males)	Number of population exposed to risk	Relative risk (RR) (CI 95%)	Chi^2 Test	P	CI (3 years) $/10^5$ inhabitants	Attributable risk
1983–1985 (no exposure)	**6**	**304170**				**1.973**	
1986–1988	22	304263	3.666 (1.486;9.042)	8.031	0.005	7.231	5.258
1989–1991	9	307328	1.485 (0.528;4.172)	0.246	0.62	2.928	0.956
1992–1994	18	302687	3.015 (1.196;7.596)	5.096	0.024	5.947	3.974
1995–1997	13	298763	2.206 (0.838;5.805)	2.004	0.157	4.351	2.379
1998–2000	23	295759	3.942 (1.605;9.684)	9.284	0.002	7.777	5/804

Table 9

Statistical evaluation of acute leukemia in females in Mureş County

Period	Number of AL cases (females)	Number of population exposed to risk	Relative risk (RR) (CI 95%)	Chi^2 Test	P	CI (3 years) /10^5 inhabit-ants	Attributable risk
1983–1985 (no exposure)	**5**	**310126**				**1.612**	
1986–1988	17	310462	3.396 (1.253;9.208)	5.488	0.019	5.476	3.863
1989–1991	15	313918	2.964 (1.077;8.157)	3.942	0.047	4.778	3.166
1992–1994	11	309834	2.202 (0.765;6.339)	1.567	0.211	3.550	1.938
1995–1997	22	308014	4.430 (1.677;11.701)	9.592	0.002	7.143	5.530
1998–2000	23	306962	4.647 (1.766;12.227)	10.497	0.001	7.493	5.881

The other two intervals (1989–1991, 1995–1997) present a slight positive association between exposure and disease, lacking statistical significance.

The results appear to contest the existence of a dose-response type relationship for our study. In other words, we have no reason to believe that exposure to higher levels of radiation due to the Chernobyl nuclear accident in rural areas of Mureş County caused statistically significant increases in the incidence of acute leukemia compared to urban areas of the same County.

A comparison of the results for the two genders can be seen in Figure 6.

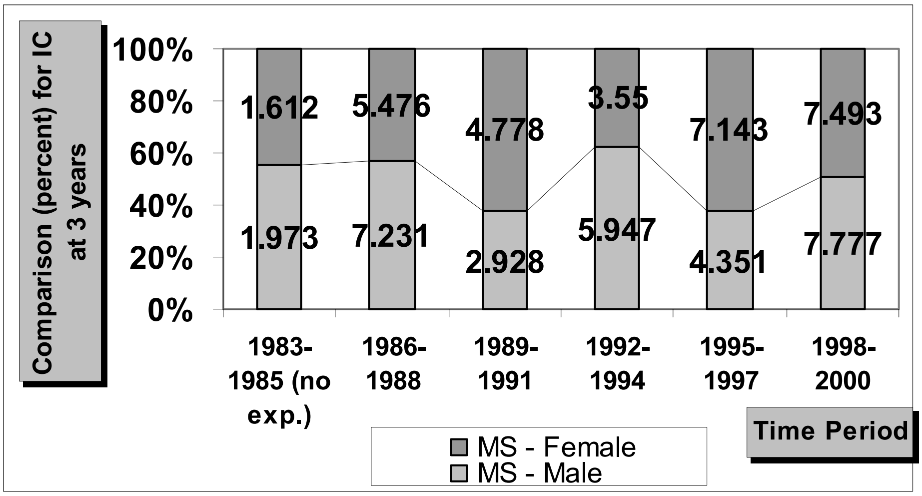

Fig. 6. Cumulative AL incidence in males compared to females, for the studied period, in Mureş County.

We can observe a relative increase in the incidence of acute leukemia in the female population *versus* male population, compared to the pre-Chernobyl period, in 3 of the 5 studied intervals: 1989–1991; 1995–1997; 1998–2000. The interval immediately following the accident, 1986–1988, shows an increase in the incidence of acute leukemia (and RR) for all studied cases, as well as for the two groups of people (males and females). The last 2 periods (1995–1997, 1998–2000) are characterized by an evident increase in RR, especially in the female population.

CONCLUSIONS

Analysing the results of our study about the influence of the radiation exposure due to the nuclear accident at Chernobyl on the incidence of acute leukemia in Mureş County, we can conclude the following:

The total incidence of acute leukemia: there is a statistically significant positive association between the exposure to the risk factor (ionizing radiation due to the Chernobyl accident) and the disease throughout all the studied periods (5 periods of 3 years duration each during 1986–2000). The statistical association is strong ($2.157 < RR < 4.262$). This conclusion is in agreement with the results of other similar studies on the biological effects of the Chernobyl nuclear accident, and at the same time with the results of the studies performed after the bombings of Hiroshima and Nagasaki [10].

The relative risk recorded increased values ($RR > 3$) during 1986–1988, 1995–1997, and 1998–2000.

Previous conclusions are also supported by the results of data analysis in case of grouping data according to criteria regarding the type of disease (AML/ALL), as well as demographic criteria (urban/rural, male/female), with the following peculiarities:

- All analyses performed on the studied population group resulted in a statistically significant positive association in at least 3 out of the 5 studied intervals.
- AML/ALL: one can observe a relative increase in AML incidence compared to the pre-Chernobyl period, even though absolute incidence values are higher for ALL.
- Urban/Rural: We found a relative increase in the incidence of acute leukemia in rural areas *versus* urban areas, compared with the pre-Chernobyl period, in 3 of the 5 periods studied: 1989–1991, 1995–1997, 1998–2000 (last 2 intervals with a marked increase).
- Male/Female: We detected a relative increase in the incidence of acute leukemias in the female population *versus* male population, compared to the pre-Chernobyl interval, in 3 out of the 5 studied periods: 1989–1991; 1995–1997; 1998–2000.

- The results appear to contest the existence of a dose-response type relationship in case of our study.

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