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Exposure Dosage Should be 0.5 mSv or Less, in Yearly Chest Fluorography for Students: Considerations of Risks and Benefits in Chest X-ray Examination

Takahiko NOHARA[1)], Masatoshi ASAI[2)] and Shuzo TANAKA[3)]

[1)]Health Administration Center Izumo, [2)]Center for Integrated Research in Science, [3)]Department of Life Science, Shimane University School of Medicine, Izumo 693-8501, Japan

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Although diagnostic X-rays provide benefits, their use should be avoided as much as possible. While the risk of X-ray examination may be not always surpassed the benefit in medical treatment, it may far exceed the benefit of health-check examination for well persons, because of the loss of life or life expectancy caused by radiation exposure. Therefore, it is necessary to define the risks and benefits of the chest fluororoentgenography in order to make an impartial evaluation. As digitizing the benefits of the chest X-ray examination are comparatively difficult, we consider the Mori's article with using the method of the Waaler's model, which was constructed by the epidemiology of tuberculosis. As to the risks of the examination, it is possible to digitize by measuring the radiation exposed dose at the time of a chest radiography. And the risk estimation model is obtained by the loss of life expectancy due to lethal cancer induced by radiation. Consequently, we perceived the risks and benefits are almost equal or the benefits surpassed the risks provided the radiation dose of the chest X-ray examination is 0.5 mSv or less. And further, it may be also expedient using a dose (= 1 mSv) as an upper limit which is the maximum permissible exposure to public radiation in a year recommended by the "International Commission on Radiological Protection".

Key words: risk and benefit, tuberculosis, radiation dose, fluororoentgenography, chest X-ray examination

Correspondence: Takahiko Nohara, M.D., Ph.D. Health Administration Center Izumo, Shimane University, School of Medicine, 89-1, Enya-cho, Izumo Shimane, Japan

Tel: +81-853-20-2099

Fax: +81-853-20-2097

E-male: nohara@med.shimane-u.ac.jp

INTRODUCTION

Chest fluororoentgenography (fluorography) has been used as a primary prevention measure of tuberculosis in Japan, following revision of the Tuberculosis Prevention Law in 1951. However, after the 8th report of the WHO Tuberculosis Special Committee in 1964, which indicated a decreasing detected frequency of tuberculosis in mass screening with a diminishing number of tuberculosis patients, criticism arose regarding the mass-screening standard. Subsequently, the 9th WHO report in 1974 stated that indiscriminate mass examination (ME) for tuberculosis with a mobile chest X-ray unit, i.e. mass miniature radiography (MMR), should be discontinued for three reasons: 1) the cost for fluorography ME is expensive, even when the prevalence of tuberculosis is high; 2) only a small portion of newly-infected patients are detected by ME; and 3) ME has little influence on the incidence of smear from sputum. In 1988, specific methods of reducing the effective radiation dose were reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), including switching from fluorography to direct radiography.

In 1993, criticism against fluorography accelerated, reflected in the following guidelines which were set force by the Tuberculosis Prevention Committee of the Council of Public Health in Japan: 1) Discontinuance of chest fluorography on tuberculin-reaction positive first grade elementary school children; 2) Discontinuance of periodic health examinations for the fourth grade elementary school children; 3) Discontinuance of chest fluorography on the tuberculin-reaction positive first grade junior high school children; 4) Discontinuance of chest fluorography for the second grade junior high school children; and 5)

Discontinuance of periodic health examination for the third grade junior high school children.

And further, in accordance with the revised Tuberculosis Prevention Law in Japan, chest fluorography examination is to be performed only once, upon the entrance of students to universities, high schools, technical colleges, and vocational schools, starting from the fiscal year 2005. But, the medical colleges of universities which are high-risk groups of tuberculosis must perform yearly chest X-ray examination as before (1).

CONSIDERATIONS

Although diagnostic X-ray provide great benefits, that their use involves some small risk of developing cancer is generally accepted (2). The chest radiography is indispensable in the general health examination, and X-ray films give us the useful pieces of information with the niduses or morbid conditions of patients. At the other extreme, cancer is one of the major concerns of radiation exposure (3), and the radiography examination is always beset with the risks of the X-ray exposure. So, we consider the risks and benefits exactly in order to avoid the excessive fear or underrating to the exposure by a fluorography.

Reasons cited by the Council of Public Health for such above mentioned changes included the risk of radiation exposure from chest fluorography, i.e., "the loss of life or life expectancy" caused by radiation exposure. Background information used for radiation risk evaluation is based on human epidemiological data, as animal experimental data is deemed unacceptable because of animals' shorter life-spans. However, epidemiological investigations do not include life-long follow-up data after radiation exposure, thus data is based on a predictive model.

The purpose of tuberculosis screening is the reduction of morbidity and mortality rates through the prevention of infection, along with early detection for successful treatment. Therefore, "effectiveness = ben efit" is shown by the difference between the prognosis for early-diagnosed patients and the prognosis for tuberculosis patients who underwent no screening. Models of public health measures are frequently applied for disease detection and prevention. For tuberculosis, the model (Fig. 1) used in the serial studies of Waaler, H.T. has been applied since 1968 (4).

The following is a transition probability matrix that was calculated for the following six categories of patients, supposing the transition probability at "n" years later: 1) infectious case, 2) non-infectious case, 3) non-infectious case undergoing treatment, 4) recovered case (treated), 5) recovered case (untreated), and 6) deceased case.

1) Transition probability matrix

State (S_1): infectious case
State (S_2): non infectious case
State (S_3): non infectious, treated, previously infectious case,
State (S_4): recovered, treated case
State (S_5): recovered, not treated case
State (S_6): deceased case

Supposing P_{jk} shows the transition probability of within 1 year from state S_1 to S_k, the transition probability matrix is shown as follows:

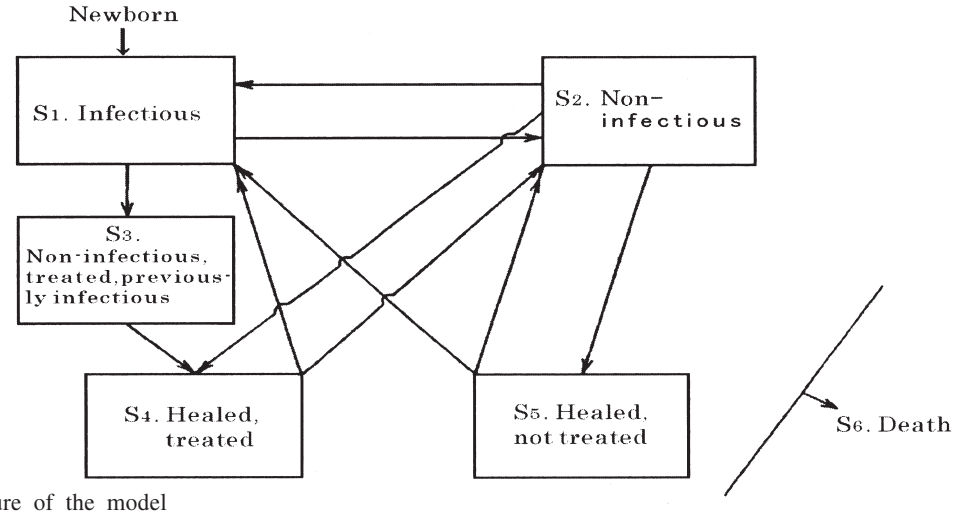

Fig. 1. Structure of the model

T = ・・・・・・・(where Σ Pjk = 1) is obtained.

$$T = \begin{pmatrix} P11 & P12 \cdots\cdots\cdots & P16 \\ P21 & P22 \cdots\cdots\cdots & P26 \\ P31 & P32 \cdots\cdots\cdots & P36 \\ \cdots & \cdots \cdots\cdots & \cdots \\ P61 & P62 \cdots\cdots\cdots & P66 \end{pmatrix} \quad \left(\text{where } \sum_{k=1}^{6} Pjk = 1 \text{ is obtained} \right)$$

2) Calculations of P_{jk}, the transition probability matrix based on parameters, are as follows.

A: Detection rate in patients

B: Case finding (CF) value: input variables showing the diffusion rate of local clinical service. Detection of patients through routine clinical examination, excluding screening examination versus including screening.

C: Death rate, remission rate, deterioration rate.

The actual parameter value, which is the base for probability of transition from one state to another, is defined separately. Besides the parameter value, input variables include the local clinical service diffusion rate (shown as high CF and low CF in the Tables) and detection rate of patients by current screening. Table 1 shows the benefits section of the "mathemat ical model" of Mori (5-7) which is based on Walle r's earlier model (4).

On the other hand, the risk of chest fluorography, is considered to be "loss of life or loss of life expe ctancy" caused by radiation exposure. Namely, the risk of tuberculosis screening is the probability of cancer death during a lifetime, or a shortened life expectancy due to radiation-induced cancer. Therefore, a risk predictive model (including non-radiation induced cancer) is shown as loss of life expectancy, calculating the difference between the average life expectancy in general death (including non-radiation induced cancer death) and the average life expectancy, including the risk of radiation exposure.

1) Probability of lethal cancer incidence induced from radiation is calculated using the hazard exponential as a hazard rate. The mortality due to radiation-induced cancer in "*t*" years depends on the amount of the radiation exposure dose, and is calculated by the following equation according to the recommendation of the International Committee of Radiation Protection (ICRP) in 1990 (8), following the report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

$$\lambda_r(t) = \kappa \cdot D \cdot \lambda_0(t)$$

(κ : risk factor, D : radiation exposure dose)

$$\int_{t_0}^{\infty} \lambda_r(t) \cdot \phi_r(t) \cdot \phi(t) \cdot dt$$

$$= \sum_{k=1}^{\infty} \frac{\phi_r^{(k-1)} - \phi_r^{(k)}}{\phi_r^{(k)}} \int_{t_0}^{\infty} \delta(t - t_0 - k) \phi_r(t) \phi(t) \cdot dt$$

$$= \sum_{k=1}^{\infty} (\phi_r^{(k-1)} - \phi_r^{(k)}) \cdot \phi^{(k)}$$

$\lambda_r(t)$: Cancer death rate due to radiation exposure in *t* years

λ_0 : Death rate not related to radiation exposure

$\delta(t - t_0 - k)$ δ Exponential

$\phi_r(t)$: Hazard exponential in cancer death due to radiation exposure

$\phi(t)$: Hazard exponential in death not related to radiation exposure

Table 1. Saving Life due to MMR (by T. Mori in 1982)

		Lives saved in persons per 100,000 examinees of MMR		Lives extended in person years per 100,000 examinees of MMR	
Age	Sex	High CF	Low CF	High CF	Low CF
15-1	M	0.105	0.243	6.0	13.7
	F	0.129	0.299	7.3	16.8
20-2	M	0.182	0.425	8.6	19.9
	F	0.150	0.348	7.1	16.4
30-3	M	0.300	0.708	11.6	26.5
	F	0.158	0.367	6.0	13.7
40-4	M	0.926	1.541	16.9	40.3
	F	0.311	0.374	8.0	18.6
50-5	M	1.419	3.137	30.4	65.3
	F	0.749	1.602	15.0	31.1
60 <	M	0.572	1.326	9.7	22.3
	F	0.343	0.739	5.0	10.3

CF: Case-findings

High/Low CF: High/Low coverage of case-finding in routine clinical service

MMR: Mass miniature radiophotography

2) Loss of life expectancy due to radiation exposure.

Loss of life expectancy per 100,000 people = {average life span (general death) - life expectancy (general death + cancer death due to radiation exposure)} x 100,000

① Average life expectancy due to causes not related to radiation exposure.

$$\int_{t_0}^{\infty} \phi(t) \cdot dt = \sum_{k=1}^{\infty} (1 - P_{k-1})$$

($1 - P_{k-1}$: Probability of survival, P_{k-1}: probability of death)

② Average life expectancy including a risk of radiation exposure.

$$\int_{t_0}^{\infty} \phi_r(t) \cdot \phi(t) \cdot dt = \sum_{k=0}^{\infty} \chi^{(k)}$$

($\chi^{(k)}$: Probability of survival, including the risk of radiation exposure)

Therefore, the loss of life expectancy occurring due to chest X-ray examination is calculated using the following formula:

$$\sum_{k=1}^{\infty} (1 - P_{k-1}) - \sum_{k=0}^{\infty} \chi^{(k)}$$

In the above mentioned λr (t), the values at 1 mSv and 0.5 mSv (dose per year) are interpolated, based on the multiplication model of "conditioned mortality in full years: G_0 (u)", according to the recommendation of ICRP in 1990 (8). Table 2 further compares the benefit value for the range of 20-29 year olds in

The yearly radiation dose in the above mentioned "conditioned mortality in full years" of ICRP is calculated assuming the radiation exposure to the whole body, although the difference between the directions of radiation exposure is not specified (whether from all directions or from one direction). In cases of chest radiography, the radiation field is limited in less than a quarter of the body, and radiation is given from the back only; thus, we need to take account of the area of the radiation field, namely, the X ray exposure field. We calculated the X-ray exposure field, assuming the area of the bone marrow which is considered most susceptible to radiation exposure effect, although this is a rough inference (or supposition).

Table 5 and 6 show data when the radiation field is assumed to be 1/2 and 1/3 of the whole body.

Table 7 and 8 show data when the radiation field

Table 2. Risks and benefits due to radiation exposure based on the mortality with 20 year olds

	Number of saved lives per 100,000 population		Number of cancer deaths in lifetime per 100,000 population	
	High CF	Low CF	0.5 mSv	1 mSv
Male	0.18	0.43	0.89	1.80
Female	0.15	0.35	1.23	2.45

mSv: millisievert; a unit of radiation exposed dose

Table 3. Risks and benefits of chest X-ray examination based on loss of life expectancy with 20 year olds

	Prolongation of life expectancy per 100,000 population (years)		Loss of expectancy per 100,000 population	
	High CF	Low CF	0.5 mSv	1 mSv
Male	8.6	19.9	14.5	29
Female	7.1	16.4	21.5	43

Table 4. Area of X-ray exposure

	Bodyweight(kg)	Height(cm)	Body surface area(S)
Women of smallest stature	36	145	1.2260 m^2
One side (front or back) =1/2			1.2260 m2 / 2 = 0.6130 m^2
Area of bone marrow = 1/3			1.2260 m2 / 3 = 0.4087 m^2
1/2 x 1/3 = 1/6			1.2260 m2 / 6 = 0.2043 m^2
Chest X-ray radiation filed			45(cm)×45(cm) = 0.2025 m^2

Table 5. Risks of chest X-ray examination based on mortality with 20 year olds (radiation field: 1/2 and 1/3)

	Number of cancer deaths in lifetime per 100,000 population (case of 1/2)		Number of cancer deaths in lifetime per 100,000 population (case of 1/3)	
	0.5 mSv	1 mSv	0.5 mSv	1 mSv
Male	0.45	0.90	0.30	0.60
Female	0.62	1.25	0.41	0.83

Table 6. Risks of chest X-ray examination based on loss of life expectancy with 20 year olds (radiation field: 1/2 and 1/3)

	Loss of expectancy per 100,000 population (case of 1/2)		Loss of expectancy per 100,000 population (case of 1/3)	
	0.5 mSv	1 mSv	0.5 mSv	1 mSv
Male	7.5	14.5	5.0	9.7
Female	11.0	21.5	7.3	14.3

Table 7. Risks and benefits of chest X-ray examination based on mortality with 20 year olds (radiation: 1/2×1/3 = 1/6)

	Number of saved lives per 100,000 population		Number of cancer deaths in lifetime per 100,000 population	
	High CF	Low CF	0.5 mSv	1 mSv
Male	0.18	0.43	0.15	0.30
Female	0.15	0.35	0.21	0.83

Table 8. Risks and benefits of chest X-ray examination based on loss of life expectancy with 20 year olds (radiation field: 1/2×1/3 = 1/6)

	Prolongation of life expectancy per 100,000 population (years)		Loss of expectancy per 100,000 population	
	High CF	Low CF	0.5 mSv	1 mSv
Male	8.6	19.9	2.5	4.83
Female	7.1	16.4	3.7	7.17

is assumed to be 1/6 (= 1/2×1/3) of the whole body.

From these results, we found that when the radiation dose of the chest X-ray examination is 0.5 mSv or less, the risks and benefits are almost equal or the benefits exceed the risks.

DISCUSSION

From fiscal 2004, health administration centers of former national universities were required to administer safety and health care for university employees in accordance with Industrial Safety and Health Law. Health administration centers of universities thus became responsible for the health care of the entire employees as well as the students. While, this included chest X-ray examination for students upon admission and for employees as a part of their periodical health check, risks associated with chest radiography must be considered for all students and employees undergoing the examination by those in charge of such programs. Therefore, knowledge of correct radiation exposure dosage for chest radiography is indispensable (1, 9).

The number of incidence and morbidity rate of tuberculosis have been decreasing gradually in Japan except for during the 3-year between 1996 and 1997 (Table 9). For Japan, it is apparent that risk of the tuberculosis infection in a specific geographic area or age-group is not so declining, as evidenced by the increasing incidence of mass infection (Table 10) and by the stationary percentage of 20 year-old tuberculosis patients in major cities until 2000. As a consequence, our university health care center, which handles such high-risk groups and are positioned to promote tuberculosis infection prevention measures, decides it is necessary to conduct chest X-ray examination despite the above mentioned risks and benefits.

The value of "Saving life" in the Table 1 and 2, and "prolongation of life expectancy" in the table 1 and 3 were based on "detection rate in patients and case finding value" above mentioned, and they were decided by the incidence rate in the yearly numbers of tuberculosis patients (Table 9). Incidentally, for the 1961～1965 year the Waaler's model established, the average of tuberculosis morbidity and mortality in U.S.A. were 27.34 and 4.76 respectively (Reported Tuberculosis in The USA CDC 20001) (10). Therefore, the case findings (CF) must be comparable in Japan at this time to U.S.A. at that time.

Up to this time, it has been valid the current, '1990' Recommendation (Publication 60) adopted by the ICRP, until the next Recommendation would be launched. For the general public, the ICRP restricts, the exposure to manmade radiation to 1 mSv (100 mrem) per year. In this case, the limit is absurdly low. It is less than one half of the average individual dose of natural radiation received by the world popula tion, currently estimated at 2.4 mSv (240 mrem), and at least 10 times lower than the natural background radiation dose in many region of the world (11).

Below dose of a few hundred mGy, statistical power is progressively lost and direct estimates of cancer risk in a population of all ages becomes increasingly difficult and then impossible. So, at levels of controllable of the order of a few millisieverts, the exposures should not be of great concern from the point of view of an individual's health. ICRP recommendations, in the context of the use of radionuclides, have been for the control of protection from

Table 9. Yearly numbers of tuberculosis patients by age groups

year / age	1996 (%)	1997 (%)	1998 (%)	1999 (%)	2001 (%)	2003 (%)	2005 (%)
Total	42,472(100)	42,715(100)					
	except the mycobacteriosis →		41,033(100)	43,818(100)	35,489(100)	31,638(100)	28,319(100)
incidence rate	33.7	33.9	32.4	34.6	27.9	24.8	22.2
mortality rate	2.2	2.2	2.2	2.0	2.1	1.9	1.8
0～4	131(0.3)	128(0.3)	119(0.3)	134(0.3)	75(0.2)	72(0.2)	56(0.1)
5～9	69(0.2)	58(0.1)	67(0.2)	52(0.1)	48(0.1)	24(0.1)	22(0.1)
10～14	101(0.2)	99(0.2)	88(0.2)	97(0.2)	72(0.2)	31(0.1)	39(0.1)
15～19	557(1.3)	515(1.2)	505(1.2)	545(1.1)	421(1.2)	306(1.0)	284(1.0)
20～29	3,862(9.1)	3,855(9.0)	3,928(9.6)	4,052(8.4)	3,157(8.9)	2,798(8.8)	2,303(8.1)
30～39	3,263(7.7)	3,202(7.5)	3,165(7.7)	3,527(7.3)	3,041(8.6)	2,803(8.9)	2,677(6.5)
40～49	5,235(12.3)	4,765(11.2)	4,272(10.4)	4,511(9.3)	3,012(8.5)	2,457(7.8)	2,220(7.8)
50～59	6,678(15.7)	6,568(15.3)	6,318(15.4)	7,357(15.2)	5,383(15.2)	4,428(14.0)	3,676(13.0)
60～69	9,093(21.4)	8,821(20.7)	8,205(20.0)	9,144(18.9)	6,218(17.5)	5,133(16.2)	4,328(15.3)
70～79	13,483(31.7)	14,704(34.4)	8,641(21.1)	9,877(22.5)	7,901(22.3)	7,293(23.1)	6,332(22.4)
80 ≧			5,725(14.0)	6,694(15.3)	6,161(17.4)	6,293(19.9)	6,382(22.5)

Table 10. Incidence of tuberculosis mass infection

year / place	1994	1995	1996	1997	1998	total
total	11	15	20	42	44	132
hospitals	2	5	7	10	8	32
institutions	0	1	0	0	5	6
offices	2	4	8	14	11	39
regions	0	2	0	6	3	11
colleges and vocational schools	3	1	1	3	3	11
high schools and preparatory schools	3	0	3	6	8	20
junior-high schools	1	2	0	2	6	11
elementary schools and kindergartens	0	0	1	1	1	2

single sources by optimization within the individual maximum dose constraint of 0.3 mSv per year (12).

It is extremely difficult to assess the potential low-level radiation-induced health effects (3). In a recent investigation of the biological systems, at the level of DNA and biological organization, exposed to radiation, it follows that the net radiation cancer risk dose not rise linearly with dose in the low-dose region (13). Another investigation of using hematopoietic lines of mice revealed that chronically preirradiated mice acquired radioresistance of the granulocytopoietic system (14). In addition, a different study noted that living organisms possess the ability to respond to low-dose radiation in very sophisticated ways (15).

Incidentally, as the diagnostic X-ray provides us the information with the chest diseases, for example, pneumothorax, pulmonary tumors and heart diseases, other than tuberculosis, the benefits may be superior to the risks of the radiation suffered from the chest X-ray examination.

We believe the following to be worthwhile considerations for increasing the safety of the screening process: 1) improvements in imaging modalities and scanning methods; and 2) Assessment of radiation dosages to reduce them.

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