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Lung Cancer Mortality from Exposure to Indoor Radon (^{222}Rn) in Mexico

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Authors' contributions

This work was developed in collaboration by the both authors, who contributed equally to the literature review and writing of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

To evaluate lung cancer mortality in Mexico in the year 2012 attributable to exposure to the radioactive gas radon. Values of mortality from exposure to indoor ^{222}Rn are obtained by the application of a model of excess of relative risk for the average indoor ^{222}Rn concentration in Mexico taking into account values of lung cancer mortality statistics in Mexican population and smoking habits.
Lung cancer Mortality from exposure to ^{222}Rn is estimated, for Mexican Republic in year 2012, with an exposure to indoor ^{222}Rn for the last 35 years before 2012. The excess relative risk (ERR) model published in the BEIR VI report and modified by the USEPA was used with the Mexican population and lung cancer mortality rate data for both genders from the year 2012.
According to official statistics there were a total of 6,547 deaths from lung cancer in Mexico in 2012, of which 4,147 were of males and 2,400 of females. The general mortality rate was 5.67; the mortality rates for males and females were 7.4 and 4.1 respectively. The countrywide average

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indoor radon concentration was estimated to be 83.3 Bq/m^3. By calculating the excess relative risk (ERR) using the relevant mortality, demographic and smoking prevalence data, we were able to estimate that 3,041 male lung cancer deaths (73.3%) were attributable to causes other than radon exposure and that the remaining 1,106 lung cancer deaths (26.7%) were attributable to radon exposure. We estimate that 1,641 female lung cancer deaths (72.6%) were attributable to causes other than radon exposure and 619 (27.4%) were attributable to radon exposure. Lung Cancer Mortality rate from exposure to indoor ^{222}Rn in Mexican population is smaller than UK, American and Canadian population although the average value of ^{222}Rn in Mexico is larger than those countries, due to the small baseline of lung cancer in Mexican population.

Keywords: Radon; risk; mortalit; lung cance; Mexico.

1. INTRODUCTION

The BEIR VI [1] relative risk model was modified by the USEPA [2] and used to estimate that of 157,400 lung cancer (LC) deaths in the United States in 1995; up to 21,800 are attributable to radon exposure. This estimation is based on an average indoor radon concentration of 46.6 Bq/m^3. USEPA alert about the risk of lung cancer for radioactive radon gas exposure and published guide values to minimize the LC risk. Several studies have measured indoor radon concentrations at different locations in Mexico. The simple average of the results of these studies, 83.3 Bq/m^3, [3-7]. Average indoor radon concentration in Mexico is almost twice than EEUU, but actually, there is no official information about lung cancer mortality from ^{222}Rn exposure in Mexican population, no guide values for ^{222}Rn indoor concentrations like USEPA in EEUU therefore is important to have basic information to know the importance of ^{222}Rn as Mexican public health problem, nevertheless the risk of LC for indoor radon exposure must be calculated in base of Mexican parameters and that “risk values” could be too difference than EEUU. In advance, knowing the importance in risk of LC in EEUU for radon exposure and knowing that in Mexico the indoor radon concentration is larger than EEUU could be that the incidence and mortality for LC be an important public health problem. The aim of the analysis is to evaluate the number of lung cancer deaths in Mexico in 2012 that are attributable to indoor radon exposure. We use the method published in the BEIR VI report and modified by the USEPA, together with official demographic and lung cancer mortality data for the year 2012 [8]. It is well known that tobacco consumption [9] is the main cause of lung cancer; to take this into account the BEIR VI model requires smoking rates for both genders for the year which is anterior to the year of interest (2012) by half the difference between the average life expectancy in Mexico (77 years) and the minimum age at which lung cancer cases are observed (40 years). For the present study that year is 1995.

1.1 Demographics

Life expectancy in Mexico in the year 2012 was 71.6 years for males and 77.25 for females [10]. The population of Mexico in the same year was estimated based in the population censuses of 1990, 1995, 2000, 2005 and 2010. The total population in 2012 was estimated to be 115,445,227, comprising 56,351,357 males and 59,093,870 females [11]. The age distribution of the population is summarized in the population pyramid in Fig. 1.

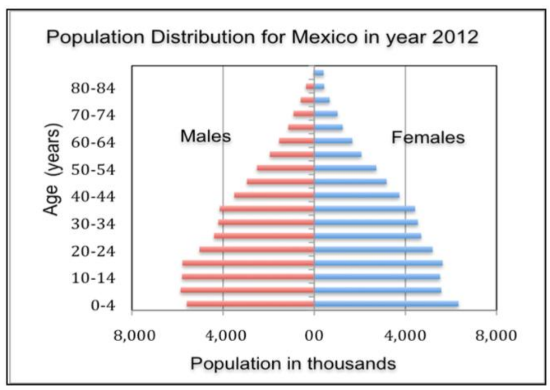

Fig. 1. Population pyramid of Mexico in 2012

1.2 Tobacco Smoking

Smoking rates for adult males and adult females in Mexico may be obtained from national surveys of smoking habits [12]. Rates for several years between 1993 and 2011 are shown in Table 1. From these data we estimate that in 1995, the smoking prevalence was of 40.6% amongst adult males and 15.3% amongst adult females.

1.3 Average Indoor ^{222}Rn Concentration in Mexico

The average indoor radon concentration in Mexico was estimated to be 83.3 Bq/m^3. This estimation is a simple average of results within a selection of studies which measured indoor radon concentrations at various locations in Mexico. The studies used for the analysis are shown in Table 2 [13-18].

Table 1. Smoking prevalence in Mexico for several years between 1993 and 2011

Smoking prevalence in Mexico (%)		
Year	**Males**	**Females**
1993	38.3	14.2
1998	42.9	16.3
2002	36.2	13.1
2008	29.9	11.8
2008	30.3	12.1
2011	31.4	12.6

Table 2. Indoor radon concentrations at various locations in Mexico used to estimate the countrywide average

City (State)	^{222}Rn (Bq/m^3)	City (State)	^{222}Rn (Bq/m^3)
Aguascalientes, (Aguascalientes)	61 (39-130)	Monterrey, (Nuevo León)	97 (45-280)
Aldama, (Chihuahua)	225 (29-448)	Morelia, (Michoacán)	45 (4-165)
Chihuahua, (Chihuahua)	135 (42-273)	Pachuca, (Hidalgo)	120 (20-187)
Guadalajara, (Jalisco)	117 (37-190)	Puebla, (Puebla)	54 (48-60)
Hermosillo, (Sonora)	91 (27-157)	Puebla, (Puebla)	72 (49-101)
León, (Guanajuato)	67 (20-130)	Querétaro, (Querétaro)	61 (4-163)
Mexico City	34 (4-296)	San Luis Potosí, (San Luis Potosí)	49 (4-148)
Mexico City	90 (55-300)	Toluca, (State of Mexico)	47 (11-440)
Mexico City	97 (45-280)	Zacatecas, (Zacatecas)	46 (14-86)
Mexico City	74 (41-136)		

1.4 Mortality Rates

Official statistics [18] indicate that there were 6,547 deaths from lung cancer in Mexico in 2012, of which 4,148 were of males and 2,400 of females. The general mortality rate was 5.67, for males and females the rates were 7.4 and 4.1 respectively. In agreement with WHO-IARC [19] Incidence of lung cancer in Mexico is of 5471 cases/year (8.3%) with a mortality of 4945 (12.8%) and prevalence (5-year) of 5249 (3.8%).

2. METHOD

We used the excess relative risk (ERR) model published by the BEIR VI Committee and modified by the USEPA.

The probability of contracting lung cancer caused by radon exposure is described using the concept of excess relative risk. In the general relative risk model, the lung cancer rate $r(x,z,w)$ is represented by the next formula $r(x,z,w) = r_0(x)RR(z,w)$, where $r_0(x)$ is the lung cancer rate in a non-exposed population and $RR(z,w)$ is the exposure-response function. In the linear model of relative risk, this function is expressed as

$$RR = 1 + \beta w$$

where βw estimates the excess relative risk (ERR), w is exposure and β represents the increase in ERR for a unit increase in exposure w. From this equation we see that $ERR = RR-1$.

The BEIR VI model uses a relative risk function of the form

$$RR = 1 + \beta(w_{5-14} + \theta_{15-24} w_{15-24} + \theta_{25+} w_{25+})\phi_{age}\gamma_z$$

Excess relative risk is thus

$$ERR = \beta(w_{5-14} + \theta_{15-24} w_{15-24} + \theta_{25+} w_{25+})\phi_{age}\gamma_z$$

where the total exposure w is divided into three time windows: exposure that occurred from 5 to 14, 15 to 24, and 25 or more years before the year of interest. The exposures in these windows are designated w_{5-14}, w_{15-24} and w_{25+} respectively. The parameters θ_{5-14}, θ_{15-24} and θ_{25+} describe the relative importance of the exposure windows (by convention θ_{5-14} is set equal to unity).

The BEIR VI Committee proposes two equally valid models which differ only in their interpretation of the parameter γ_z. In the duration model the parameter represents exposure duration; in the concentration model it represents the average concentration over the exposure time. The parameter ϕ_{age} describes the effect of age on ERR. The parameters of both models are shown in Table 3.

As a function of age, ERR is continuous (and increasing) until 54 years of age; it then decreases in a series of steps (Fig. 1).

The model used by the USEPA was based on the concentration model. The parameter β was adjusted to 0.0634. Given that for indoor exposures the exposure rate is less than 0.5 WL, the parameter γ was set at 1.0. In the modified model, the expression for ERR is thus

$$ERR = \beta^{*}(w_{5-14} + 0.78w_{15-24} + 0.51w_{25+})$$

where

$$\beta^{*} = 0.0634 \ \ for \ \ age < 55\,years$$
$$\beta^{*} = 0.0361 \ for \ age \ \ 55 < 65\,years$$
$$\beta^{*} = 0.0184 \ \ for \ age \ \ 65 < 75\,years$$
$$\beta^{*} = 0.0057 \ \ for \ age \ \ x \geq 75\,years$$

Table 3. Parameters of the BEIR VI exposure and concentration models

Duration model		Concentration model	
β^{b}x 100	0.55	βx 100	7.68
Relative importance of exposure windows			
θ_{5-14}	1		1
θ_{15-24}	0.72		0.78
θ_{25+}	0.44		0.51
Age			
$\phi_{<55}$	1		1
ϕ_{55-64}	0.52		0.57
ϕ_{65-74}	0.28		0.29
ϕ_{75+}	0.13		0.09
Exposure duration (years)		**Exposure rate (WL)**	
$\gamma_{<5}$	1.0	$\gamma_{<0.5}$	1.0
γ_{5-14}	2.78	$\gamma_{0.5-1.0}$	0.49
γ_{15-24}	4.42	$\gamma_{1.0-3.0}$	0.37
γ_{25-34}	6.62	$\gamma_{3.0-5.0}$	0.32
$\gamma_{<35+}$	10.2	$\gamma_{5.0-15.0}$	0.17
		$\gamma_{15.0+}$	0.11

Excess relative risk is then smoothed as a function of age (Fig. 2).

According to national statistics the general lung cancer mortality rate in 2012 was 5.67 (1/100,000). Lung cancer mortality rates for males and females were 7.4 and 4.1 respectively. Fig. 3 shows the lung cancer mortality rates for Mexican males and females in 2012 as a function of age.

The lung cancer mortality rate of never-smokers (NS) of age *x* is

$$h_{NS}(x) = h_{pop}(x)\left[(1 - p(x)) + p(x)RR\right]^{-1}$$

where $h_{pop}(x)$ is the mortality rate of the general population of age *x*, $p(x)$ is the proportion of ever-smokers (ES) of age *x*, and *RR* is the ratio of the mortality rate of ever-smokers to that of never-smokers. The mortality rate of ever-smokers of age *x* is thus

$$h_{ES}(x) = RRh_{NS}$$

If we assume that smoking rates for males and females, and the ratio *RR*, are age-independent, then we can calculate the lung cancer mortality rate as a function of age for both ever- and never-smokers for both genders.

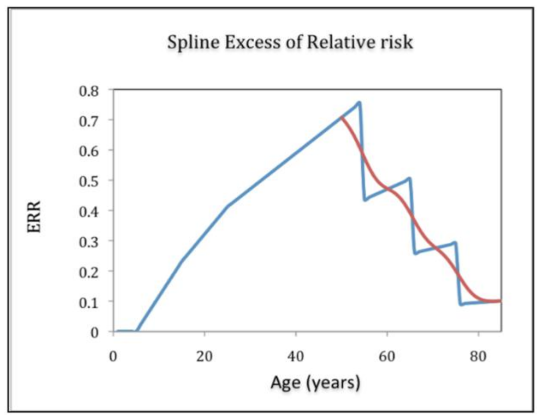

Fig. 2. Excess relative risk (ERR) as a function of age before and after smoothing

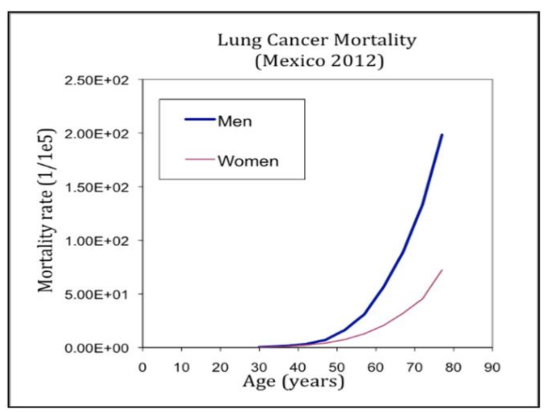

Fig. 3. Lung cancer mortality rates for Mexican males and females in 2012 as a function of age

2.6 Application of the BEIR VI-USEPA Method

To calculate mortality using the BEIR-USEPA method we make the following considerations:

1. The average indoor radon concentration in Mexico was a constant 83.3 Bq/m^3 throughout the period from 1975 to 2012.
2. The lung cancer mortality rate in the Mexican population is from the year 2012.
3. The smoking rates used (40.6% for adult males and 15.3% for adult females) are from the year 1995, this year being anterior to 2012 by half the difference between the minimum age at which cases of lung cancer appear (40 years) and the average life expectancy in the Mexican population (77 years).
4. Ever-smokers are at greater risk of contracting lung cancer than never-smokers: for males the risk is 14 times greater, for females 12 times.
5. ERR is calculated using the BEIR VI model modified by the USEPA.

We perform calculations for ages up to the 99th percentile life expectancy: 77 years for males and 80 years for females.

3. RESULTS AND DISCUSSION

3.1 Results

We used the values of ERR for each year of age (beginning at 40) for both genders to obtain the values of RR. We used the lung cancer mortality rate as a function of age to calculate the number of lung cancer deaths of never-smokers and ever-smokers of both sexes attributable to radon exposure and the number due to other causes. The results of the calculations are shown in Figs. 4 and 5. We estimate that 3,041 male lung cancer deaths (73.3%) were due to causes other than radon exposure and that the remaining 1,106 deaths (26.7%) are attributable to radon exposure. For females, we estimate that 1,641 lung cancer deaths (72.6%) were due to other causes, while 619 (27.4%) are attributable to radon exposure.

In agreement with publication Beir VI, the uncertainty in this model is about 30%, while the uncertainties in the single values from the measurements of Rn in Mexico are about 6% to 7% and the average value in Radon concentration have an uncertainty of 15%, because that the uncertainty in the mortality average values is about 33.5%:

3.2 Comparison with Mortality Rates in Other Countries

The lung cancer rate mortality values for a country present important differences in agreement with the consulted source, due to that issue we have considered in addition to national statistics, the values published for WHO-IARC [20]. For comparison, the Table 4 presents lung cancer mortality rates for the United States, England, Canada and Mexico [21-24].

3.3 DISCUSSION

By summing our male and female estimates, we obtain an estimate for the total number of lung cancer deaths in Mexico in 2012 attributable to radon exposure: 1,725. This corresponds to a mortality rate of 1.5 (1/100 000). Mexico's radon-related lung cancer mortality rate is thus comparable to that of England (2.0), and much lower than those of the United States (6.4) and Canada (8.7). It is notable that the mortality rates for radon exposure of the United States and Canada are at least four times greater than that of Mexico. We estimate that 26% of lung cancer deaths in Mexico are attributable to radon exposure; this compares with 12% in the United States, 16% in Canada and 5.3% in England. This percentage values are in direct relation with indoor radon concentration, modified for others parameters like tobacco habits; in that sense, the lung cancer rate percentage values in Table 6 are logical and normal. Mexico's average radon concentration of 83.3 Bq/m^3 is much higher than the average concentrations of the United States (46.6 Bq/m^3), Canada (41.9 Bq/m^3) and England (20.0 Bq/m^3). When only the radon concentration is considered, the lung mortality rates for radon indoor exposure are apparently inconsistent but is important to emphasize that the model BEIR VI-USEPA predict the excess of relative risk (ERR), that is a relative risk as function to baseline mortality rate with no radon exposure in a population under study. The lung cancer mortality baseline value in EEUU is about 47.0 and in Mexico is about 4.0, ten times less than in EEUU, therefore 12% of 47 is larger than 26% of 4, and when the absolute mortality values are obtained obviously in Mexico are much less than the same one in EEUU.

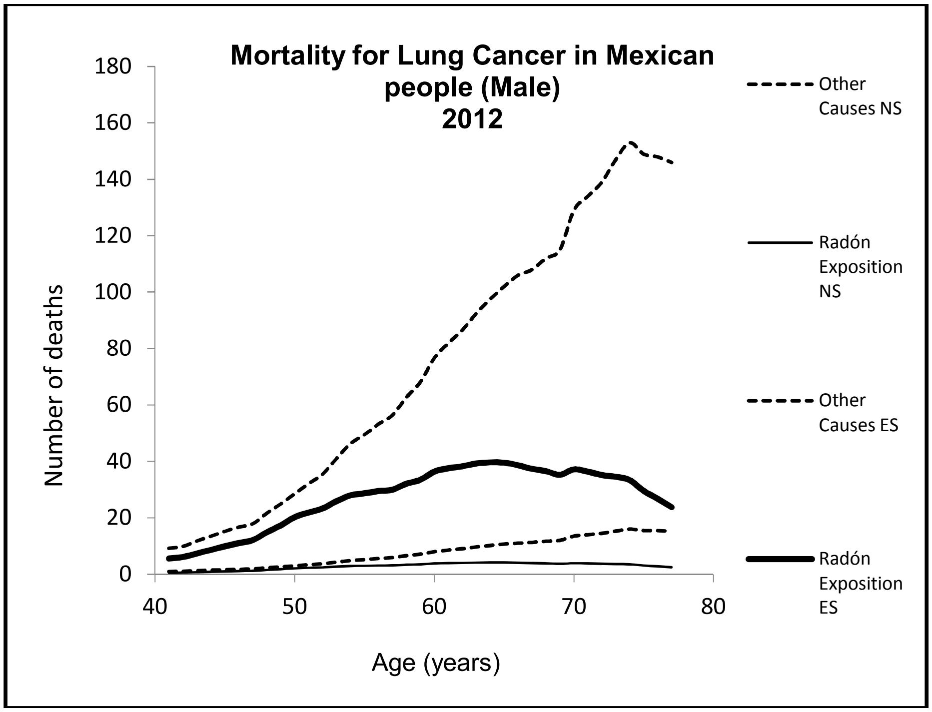

Fig. 4. Mortality rates in the male Mexican population in the year 2012, obtained from the BEIR-USEPA model

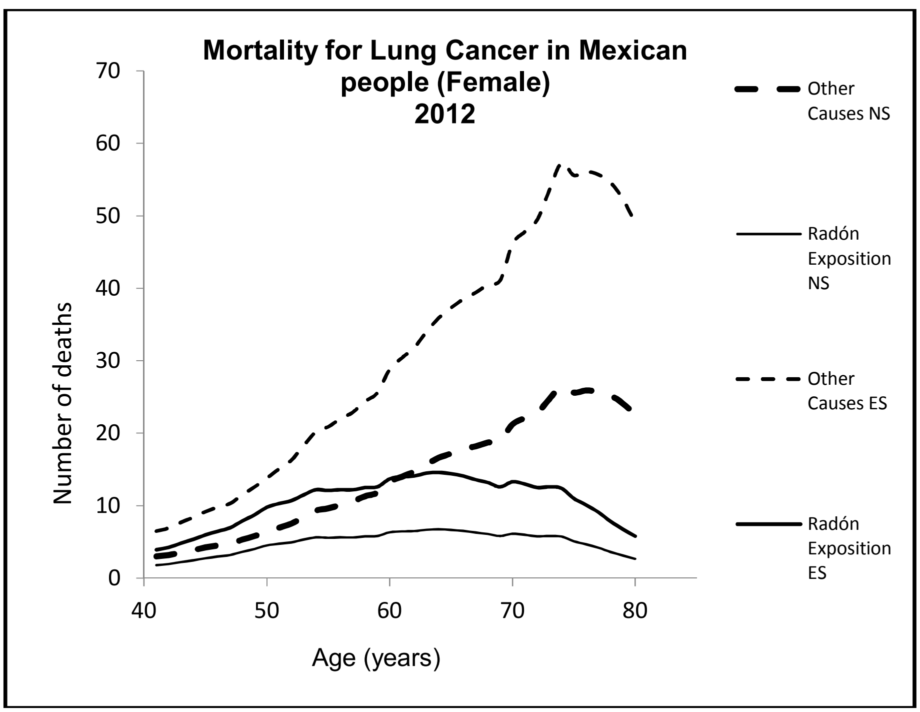

Fig. 5. Mortality rates in the female Mexican population in the year 2012, obtained from the BEIR-USEPA model

Table 4. Lung cancer mortality rates in a selection of countries

Country	Year	Lung cancer mortality rate (general)	Lung cancer mortality rate (NS)	Lung cancer mortality rate (ES)	Prevalence of tobacco smoking (%)	Lung cancer mortality rate (radon exposure)	Average indoor radon concentra-tion (Bq/m^3)
U.S.	1995	58.7	15.3	43.5	37.4	7.9 (13%)	46.6
U.S.	2012	53.05*	7.9	45.2	24.4	6.4 (12%)	46.6
Mexico	2012	5.7 (6.5)*	0.99	4.66	27.6	1.5 (26%)	83.3
England	2012	37.6 (56.6)*	2.4	35.2	20.0	2.0 (5.3 %)	20.0
Canada	2011	60.1 (58.0)*	9.0	51.1	31.0	8.7 (16.0 %)	41.9

**WHO-IARC*

4. CONCLUSION

Although the average indoor radon concentration in Mexico is almost double the concentrations in the United States and Canada, and almost four times the concentration in England, Mexico's radon-related lung cancer mortality rate is lower than the rates of the United States, Canada and England. This is because the baseline lung cancer mortality rate in Mexico is lower than in the other countries; in particular, it is low enough to more than offset the effect of Mexico's higher average indoor radon concentration, and the correspondingly higher percentage of lung cancer deaths attributable to radon exposure. The baseline lung cancer mortality rate is one of the main parameters for calculation of lung cancer for radon exposure by BEIR VI-USEPA model, due to in Mexico the lung cancer mortality baseline is low (4) then lung cancer mortality for radon exposure, is low too. In agreement with statistics published in EEUU [25] regarding the population analysis of that country, the proportional lung cancer incidence is of 61.0, if principal human races are considerate the incidence is 61.7 in white people; 64.0 in black people and 32.2 in Hispanic people, mortality rates are 46.0, 46.7, 49.3 and 19.9, in the same order, therefore one of important reasons for the difference in the baseline lung cancer mortality is the race and is clearly notorious in the lung cancer mortality for exposure to radon, but this fact does not explain completely the 4:1 proportion in both mortality rates and others parameters must be taken in count to explain that differences.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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