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Paper

Estimation of Heights and Body Masses of Tuberculosis Patients in the Canadian Fluoroscopy Cohort Study for Use in Individual Dosimetry

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Abstract—**This paper documents the estimation of mean heights and body masses, by age and sex, used in development of organ-specific dose conversion coefficients for external radiation for a historical cohort of about 64,000 patients from the Canadian Fluoroscopy Cohort Study. Patients were exposed to repeated fluoroscopy and chest radiography examinations in the course of treatment for tuberculosis in residential medical facilities throughout Canada between 1930 and 1969. Using Canadian national survey data and extensive literature review, mean heights and masses were obtained for the White population of Canada during the time period of interest, and the differences in mean body mass between tuberculosis patients and the general population were estimated. Results in terms of mean height and body mass of Canadian tuberculosis patients, with uncertainties, are reported for selected age groups (children of ages 1, 5, 10, and 15 y and adults age 20+) and for both sexes. Use of estimated average heights and body masses by age and sex permits the adjustment of computerized phantoms for body mass for a given age, thereby increasing the relevance of the organ-specific dose conversion coefficients for the cohort and improving the accuracy of the resulting estimated organ doses.**
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INTRODUCTION

In the first half of the 20th century, before the availability of antibiotics, treatment of pulmonary tuberculosis in North America centered on bed rest and collapse therapy (Oatway and Salkin 1962; Grzybowski and Allen 1999). Artificial pneumothorax (injection of air into the pleural cavity) and pneumoperitoneum (injection of air into the peritoneal cavity) were the most commonly used types of collapse therapy, which was intended to collapse all or part of a diseased lung. Lung collapse and refills of air were monitored using fluoroscopy, typically on a biweekly basis over a period of years.

The Canadian Fluoroscopy Cohort Study (CFCS) was designed to estimate excess risks of cancer and other diseases in tuberculosis patients due to repeated exposures to ionizing radiation from fluoroscopy procedures and chest radiographs during the course of treatment in government-funded tuberculosis sanatoria (Miller et al. 1989; Howe 1995; Howe and McLaughlin 1996; Zablotska et al. 2014; Borrego et al. 2019; Kocher et al. 2020). The time period of interest for the CFCS is 1930–1969; all patients entered the cohort between 1930 and 1952, when improved treatments became available, but use of pneumothorax or pneumoperitoneum and monitoring by fluoroscopy, and thus exposures to some members of the cohort, continued until the end of 1969. More than 28,000 patients (44%) in a total cohort of about 64,000 received radiation from fluoroscopy procedures, and more than 60,000 (94%) received chest radiographs (Borrego et al. 2019; Kocher et al. 2020); both types of radiation exposures are included in the analyses of the CFCS cohort.

Recent follow-up work on the cohort has included a substantial effort to revise and update the dosimetry. In particular, new sex- and age-specific computerized phantoms are being used to estimate organ-specific dose conversion coefficients for external radiation for the members of the study cohort, for the relevant age groups, and for each sex (Borrego et al. 2019). These hybrid phantoms allow both the anthropomorphic flexibility (i.e., changes in the position and shape of organs) of stylized phantoms and the anatomic realism and scalability with size of voxel phantoms. For example, age-specific features such as the spatial distribution of red bone marrow can be accounted for, and the phantoms can be scaled with body mass[3] for a given age. The use of these hybrid phantoms, by age group and sex, is expected to increase the accuracy of the estimated organ doses.

The CFCS includes patients of both sexes, aged 1–81 y at the time of first admission to a tuberculosis sanitorium. The median duration of monitoring by fluoroscopy was 2 y, but some patients were admitted several times, and some stayed as long as 35 y (Zablotska et al. 2014). Development of the dose conversion coefficients requires selection of appropriate heights and masses for each age group and sex (Lee et al. 2010; Geyer et al. 2014; Borrego et al. 2019). Estimation of doses to specific organs therefore presents the challenge of properly accounting for different heights and body masses of patients over the period of treatment.

In the absence of individual information on body mass and height of CFCS patients from medical records, average heights and masses by age and sex for the Canadian population during the time period of interest were obtained from the literature. Differences in mean body mass between tuberculosis patients and the general population were also estimated from the literature. Full details of the literature review, including results for all age groups, have been summarized by Thiessen (2017).

Information on race or ethnicity of individual patients was not available from the medical records. Census information (Basavarajappa and Ram 2014) indicates that minority groups (e.g., Native Indian or Inuit, Asian) comprised about 2% of the Canadian population in 1931 and 1941 and 3% in 1951; therefore, the review concentrated on information for the White population of Canada (i.e., those of British, French, or other European origin).

This paper provides the average heights and body masses for specific age groups (ages 1, 5, 10, and 15 y, and adults) and both sexes, along with multiplicative scaling factors (with uncertainties) used to adjust the body masses for each group to account for the effects of tuberculosis. The adjusted body masses and heights were then used to select the proper phantom size by age and sex. The dose coefficients account for masses and sizes of organs in tuberculosis patients, who, on average, exhibit lower whole-body masses. The organs of main interest for the CFCS are located within the incident beam, and estimated dose coefficients account for changes in organ position.

[3]Much of the literature cited in this paper uses the terms "weight" or "body weight" rather than "mass" or "body mass."

AVERAGE HEIGHTS AND BODY MASSES FOR THE CANADIAN POPULATION

A number of Canadian data sets for heights and body masses during the first half of the 20th century were reviewed (Table 1). The review focused on data sets that provided average heights and masses by age and sex; data reported only in terms of mass for a given height were not useful for the present purpose. Data sets not considered in detail included those that contained only a few age groups or were limited to single regions, those with uncertain dates of measurement or dates outside the time period of interest, and those that were not representative for the Canadian White population. Data sets that included both US and Canadian individuals but did not report the Canadian data separately were also not considered in detail (ALIMD/ASA 1912; Davenport 1923; Dublin and Marks 1937; McLester 1943; Hathaway and Foard 1960).

Two Canadian data sets were identified for use in developing dose conversion coefficients. Data for ages 2 to 65+ y are weighted averages for the Canadian population in 1953, taken from Pett and Ogilvie (1956, 1957). Data for birth to 18 mo were taken from Demirjian et al. (1983) and are based on French Canadians in Montreal born in 1975–1976. Table 2 summarizes the reported average heights and body masses of Canadians by age and sex for the age groups of interest in the CFCS.

1953 survey of the Canadian population

Heights and body masses for the Canadian general population (ages 2 to 65+ y) were compiled in 1953 by the Nutrition Division of the Department of National Health and Welfare (Pett 1955a and b; Pett and Ogilvie 1956, 1957). No comprehensive or properly documented statistics for the Canadian population predate this effort (Pett 1952; Pett and Ogilvie 1957), although some regional information was available. The 1953 sampling involved close to 22,000 Canadians out of a population of about 14 million (1951 census; Basavarajappa and Ram 2014).

Participants were selected by an area stratification plan, proportionate to population density, developed by the Dominion Bureau of Statistics using 1951 census data (Pett 1955b; Pett and Ogilvie 1956, 1957). The goal was to collect heights and masses for a representative sample of the entire Canadian population, from which tables of average mass for height, age, and sex would be developed (Pett and Ogilvie 1956, 1957). The sample was expected to be representative for such things as socioeconomic status, climate, and geographic conditions, and results were expressed as weighted means to account for the sampling procedure (Pett and Ogilvie 1957). For each measurement, a weighting factor was assigned based on the population represented by a given individual in his or her area (the ratio of the sample to the total population in the sampling area); the areas were weighted in proportion to total population when the sample was selected (Pett and Ogilvie

Table 1. Summary of reported information on population average heights and body masses in Canada.

Date	Population	Content	References
1953	Survey of Canadian general population based on 1951 census; excluded children <2 y old, military personnel in camp or barracks, native populations on reservations, disabled and ill people; survey sample statistically representative of Canadian population based on 1951 census; nearly all of European ancestry; measured in indoor clothing without shoes.	Mean height and body mass by age and sex (ages 2 to 65+ y); percentiles of height and mass by age and sex (ages 2 to 65+ y); Mean mass height ratios by age and sex (ages 15+ y).	Pett (1952, 1955a and b); Pett and Ogilvie (1956, 1957)
1975–1979	Longitudinal survey of French Canadian children born in Montreal in 1975–1976; followed to age 3 y; dress not specified (but not likely to have included shoes).	Mean height and body mass by age and sex (ages 0 to 36 mo); percentiles of height and mass; comparisons of mass as a function of height.	Demirjian et al. (1983)
1892, 1939	Surveys of Toronto schoolchildren (public schools in 1892, public and parochial schools in 1939); measured without shoes.	Medians and percentiles of heights of children (ages 6–14 y).	Meredith and Meredith (1944); Helmuth (1983)
1923, 1939	Toronto schoolchildren; dress not stated here, but reported elsewhere as without shoes.	Mean heights and body masses for children (ages 5–15 y).	Pett (1955b)
1933–1945	Ottawa children, reported separately for higher and lower socioeconomic status; measured without shoes.	Mean heights and body masses for children (ages 6–12 y).	Hopkins (1947)
Not stated	Convenience samples of Ontario residents (life insurance applicants, university students, employees of a public utility and a textile factory, driver's license applicants); 8,075 males and 4,318 females; measured for most groups, self-reported for driver's license applicants; possibility exists for inclusion in more than one group; not considered representative for Canada; probably with shoes but not stated ("customary indoor clothing"); no information on race or socioeconomic status.	Mean heights of adults by age group (ages 15 to 50+ y); insufficient information on body masses for the current study (average mass height ratio for one age group of males).	McHenry et al. (1947)
1947–1956	Central Vancouver Island (British Columbia); 12,116 boys and 11,453 girls; 1–18 measurements per child over the time period (average about 5 per child); measured in indoor clothing without shoes.	Median heights and body masses for children (ages 6–18 y).	Best and Doughty (1963); Stennett and Cram (1969); Helmuth (1983)
1967–1969	Public school students in London, Ontario; approximately 16,000 boys and 16,000 girls; measured in indoor clothing without shoes.	Median heights and body masses for children (ages 6–18 y).	Stennett and Cram (1969)
1969	French Canadian children in Montreal; 2,722 boys and 2,332 girls; dress not stated.	Mean heights and body masses for children (males ages 6–17 y; females ages 6–16 y).	Demirjian et al. (1972)
1964–1973	Longitudinal survey of English-speaking children in Saskatoon, started in 1964 (103 of 207 boys still in study in 1973) and 1965 (100 girls); dress not stated.	Mean heights and body masses for children (ages 7–15 y).	Demirjian et al. (1976)
1970–1972	Data from a national anthropometry report by Demirjian (1980); Canadian children; no details available regarding locations or number of individuals; dress not stated.	Heights and body masses for children (ages 6–20 y).	Demirjian (1980), as reported by Helmuth (1983)
1974–1976	Children in Toronto (schools and area recreation camps) and Montreal (one school); approximately 50 children per age group and sex; representative distribution of ethnic origin; measurements of children lightly clad and without shoes; potentially biased for upper ages (children remaining in school past age 16 y).	Heights (means) and body masses (geometric means) for children (ages 6–18 y).	Farkas and Wood (1982)

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Table 1. *(Continued)*

Date	Population	Content	References
1981	French Canadians from 11 regions in Quebec; 2,555 boys and 2,407 girls; measured in sport clothes without shoes.	Mean heights and body masses for children (ages 6–17 y).	Léger and Lambert (1983, 1985)
1981–1982	High school students and Trent University students, Peterborough, Ontario; no details available regarding number of individuals; dress not stated.	Heights and body masses for children and young adults (ages 14–23 y).	Helmuth (1983)
Various	Canadian Native or Inuit populations; various ages.	Not relevant for the current study.	Partington and Roberts (1969); Demirjian et al. (1976); Lee and Birkbeck (1977); Coodin et al. (1980); Helmuth (1983)

1956, 1957). Thus, the results were reported as weighted means intended to represent the entire Canadian population.

The 1953 survey of the Canadian population excluded pregnant women, children < 2 y old, military personnel in camp or barracks, native populations on reserves, disabled people, and people who were confined to bed due to illness (Pett 1955b; Pett and Ogilvie 1956). The data summarized by Pett and Ogilvie (1956) and Pett (1955a and b) should thus be representative for the general healthy population of Canada at the time of the survey, apart from these exclusions. The vast majority (97%) of the 1951 population were of British, French, or other European ancestry, while people of other origins (e.g., Native Indian and Inuit, Asian) together constituted 3% (Basavarajappa and Ram 2014). Thus, while the 1953 survey sample may not have been composed exclusively of people of European origin (Whites), it would have been composed almost entirely of Whites and can be expected to be representative for the White population of Canada in 1953. People of European origin constituted nearly 98% of the population in the 1931 and 1941 censuses, essentially no different from the 1951 census. Thus, the population sample included in the 1953 survey should be sufficiently representative of the patient population in the CFCS.

Table 2. Mean height and body mass of Canadians by age and sex, with estimated mean body mass for Canadian tuberculosis patients.

	General Population[a]		Tuberculosis patients[b]		
Age	Height (cm)	Mass (kg)	Mass (kg)	Range (kg)	Uncertainty[c]
Males					
1 y	75.6	9.9	9.9	9.4–9.9	−5% to 0%
5 y	106.4	18.1	18.1	17.2–18.1	−5% to 0%
10 y	135.9	31.8	28.6	27.0–30.2	−6% to 6%
15 y	164.3	54.0	48.6	45.9–51.3	−6% to 6%
Adult	170.2	73.3	66.0	62.3–69.6	−6% to 6%
Females					
1 y	74.3	9.4	9.4	8.9–9.4	−5% to 0%
5 y	106.2	18.6	18.6	17.7–18.6	−5% to 0%
10 y	135.4	31.3	28.2	26.6–29.7	−6% to 6%
15 y	158.0	50.8	45.7	43.2–48.3	−6% to 6%
Adult	156.8	61.2	55.1	52.0–58.1	−6% to 6%

[a]Data from Pett and Ogilvie (1956, 1957); Demirjian et al. (1983).
[b]Estimated body masses as described in the text.
[c]Uncertainty in the estimated mean body mass of tuberculosis patients, as a range of percentages of the estimated mean body mass.

Measurements were made in English units [inches to the nearest 0.25 inch (0.64 cm); pounds to the nearest 0.5 lb (0.23 kg)] while participants wore usual indoor clothing but with shoes removed (Pett and Ogilvie 1956, 1957). The masses include approximately 2.0 lb (0.91 kg) of clothing for women, 3.0 lb (1.4 kg) for men, and 1.0–3.0 lb (0.45–1.4 kg) for children, depending on the size of the child.

1975–1976 study of French Canadian children

The primary source of data for children < 2 y old is a longitudinal study of approximately 400 French Canadian children born in Montreal in 1975–1976 (Demirjian et al. 1983). French Canadians or residents of Quebec tended to be smaller than residents of the rest of Canada (Pett and Ogilvie 1957; Stoudt et al. 1960, 1965). However, the Montreal data are very close to US data (1930s–1950s; Stoudt et al. 1960) for children up to age 2 y, and similar to data from the 1953 Canadian data set for children of age 2 y; for the youngest ages, any differences between the Montreal data and the Canadian general population are not expected to be important.

General representativeness of the selected Canadian data sets

The 1953 Canadian data set (Pett and Ogilvie 1956, 1957) was obtained close to the end of the entry period for the fluoroscopy study (1930-1952). The survey was designed to be geographically representative of the whole Canadian population, includes an age range from 2 y through adulthood, and benefits from consistent measurement techniques throughout the sample. The sample itself included approximately 0.16% of the Canadian population at the time and consisted almost totally of people of European origin. The survey was held up as an example of how such population surveys should be performed (Stoudt et al. 1960, 1965).

For ages < 2 y, the only available Canadian data set is for French Canadians born in the 1970s (Demirjian et al. 1983). This data set is reasonably consistent with the 1953 data in the region of overlap, and these data were used only for ages up to 18 mo.

Other Canadian data sets (Table 1) are much more limited in their age range and their geographical scope than the 1953 survey. The only other Canadian study to include adults was self-described as not representative (McHenry et al. 1947), and no other Canadian data sets at all are available for children ages 3–5 y.

Geographical representativeness of the selected Canadian data sets

The 1953 survey was designed to be representative of the Canadian population, based on the 1951 census. However, the CFCS patients might not be geographically representative with respect to the Canadian population of their time. The 1953 data are not available by province, so it is not possible to select average heights and masses by age for each province. Pett and Ogilvie (1957) provided a breakdown for Quebec and for Canada excluding Quebec, for ages 5 y through adult. While Quebeckers, especially males, are noticeably smaller than other Canadians (Pett and Ogilvie 1957; Cranfield and Inwood 2007), non-Quebec Canadians are not much taller or heavier on average than all Canadians combined. Given that the data for all Canadians includes the Quebeckers, use of those averages to generate one set of dose conversion coefficients for all Canadians was considered sufficient.

Temporal representativeness (secular trend) of the selected Canadian data sets

The main survey data were obtained in 1953, close to the end of the entry period for the cohort (1930–1952); thus, the suitability of the 1953 data for later years is less important. Populations do change over time, and differences among populations may be due to both temporal changes and regional differences in such things as socioeconomic circumstances, growth patterns, degree of urbanization, and immigration patterns. In contrast to the nearly complete national data set for 1953 (Pett and Ogilvie 1956, 1957), regional data sets for earlier or later time periods are incomplete with respect to age groups. The single data set for height of adults in Ontario is described by its authors as not representative, and its dates are uncertain (McHenry et al. 1947). However, the mean heights reported by McHenry et al. (1947), when adjusted for height of shoes, are generally similar to the 1953 national data set, suggesting that the national data set is probably sufficiently representative for Ontario during the time period of interest. For school-age children, several earlier data sets (e.g., Toronto in 1939 and Ottawa 1933-1945; Hopkins 1947; Pett 1955b) are also generally similar to the national data in 1953.

With the 1953 survey data, it was possible to compare birth cohorts (age groups) who are assumed to have reached their full adult height (ages 20+). Differences in average heights were about 1 cm for a 20-y difference in age group and 4–5 cm for a 40-y difference. However, all of these adults were included in the averages for adults (ages 20+) provided with the 1953 survey results, and use of average values for all adults (ages 20+) in generation of dose conversion coefficients minimizes differences among these birth cohorts.

A bigger concern is whether children of a given age in 1953 were substantially different in size from same-aged children in 1930. Farkas and Wood (1982) suggest that the secular trend is more important for children than for adults and for the adolescent growth spurt more than for preadolescents. Some of the comparisons between the 1953 data and later data sets (e.g., Stennett and Cram 1969) are consistent with this. While the differences between 1953 and 1892 or 1923 could be important, differences between 1953 and the 1930s or 1940s are likely to have been less important and are within the observed ranges of regional and other differences during the overall time period. For example, Ottawa data (Hopkins 1947) show trends between 1933 and 1945, but the differences over time are less than the differences between above-average and below-average socioeconomic status. Helmuth (1983) suggested that the lack of increase between 1939 Toronto and 1953 Canada represented a stalling or possible reversal of the secular trend, which he attributed to wartime conditions in Canada during the 1940s.

Farkas and Wood (1982) also suggest that secular trends have progressed at different rates in different countries and may reflect migration patterns and socioeconomic changes more than ethnic origins. None of the available surveys included birthplace (an indicator of immigration; Cranfield and Inwood 2007). Meredith (1976), in reviewing studies back to the 1800s in several countries (including Canada), concluded that the increase in mean height per decade was about 1.3 cm in late childhood, 1.9 cm in mid-adolescence, and 0.6 cm in early adulthood; the larger differences observed during childhood and adolescence are not maintained into adulthood. Based on Meredith's findings, an increase in height of about 1.3 to 3.8 cm, depending on age, could be expected for a time period of two decades or so in Canada. Examination of the 1953 survey data by birth cohort indicates that the actual increases in adult height per decade among the Canadian population between the 1890s and the early 1930s were smaller than Meredith's predictions. Cranfield and Inwood (2007) report a decline in average stature of Canadians during the 19th century, with a substantial trend upward during the 20th century as a whole. They also describe the differences in size and differences in rates of change of size among regional populations.

Overall, the information described above indicates that height of older children and adults increases with later birth year (birth cohort) among Canadians, but the increase during the years affecting the CFCS appears to have been relatively small. Although larger increases can be observed during the years after 1953, increases during the first part of the 20th century appear not to have been large, likely due to the combined effects of two world wars, the depression, and substantial immigration.

DECREASED BODY MASS AMONG TUBERCULOSIS PATIENTS

A decrease in body mass ("weight loss") is a common, although nonspecific, symptom of tuberculosis (e.g., Schuit 1979; Long and Cowie 1999; Marais et al. 2004, 2005a and b, 2006; Schaaf et al. 2007; Cruz et al. 2013; Dizdar et al. 2014), and a low mass:height ratio is often associated with the presence of tuberculosis or an increased susceptibility to tuberculosis (Weber and Kirkness 1909; Reed and Love 1933; Britten 1933; Berry and Nash 1955; Long and Jablon 1955; Palmer et al. 1957; Karpinos 1958; Edwards et al. 1971; Snider 1987; Tverdal 1986, 1988; Lönnroth et al. 2010). With respect to the CFCS, the concern is that below-average body masses among tuberculosis patients might require different dose conversion coefficients than those used for the general population. This section summarizes available information on reported body masses of tuberculosis patients and the percentage differences from normal or control body masses.

Adult tuberculosis patients

Several studies have reported heights and body masses for groups of adult tuberculosis patients, including comparisons with relevant control or normal groups, or with former "healthy" masses for the same individuals (Table 3). Mean percent differences between patient masses and normal masses ranged from -2.5% to -16.5%. These studies are based on US and English populations, which would have been reasonably similar to the Canadian population of the same time period (first half of the 20th century) in terms of race, ethnicity, lifestyle, and socioeconomic status. No corresponding Canadian studies were located.

Studies in other countries after the time period of interest for the CFCS have consistently reported lower mean body masses for tuberculosis patients than for control patients (Sidhu and Sodhi 1975; Cameron and Scheepers 1986; Harries et al. 1988; Sharma et al. 2008; Mupere et al. 2010; PrayGod et al. 2011). In addition, Van Lettow et al. (2004) reported decreased body mass index (BMI, kg m^{-2}) with increasing severity of tuberculosis, Villamor et al. (2006) reported lower BMI among tuberculosis patients than among the general population of the same city (based on Bovet et al. 2002), and Ladefoged et al. (2011) reported lower median BMI for tuberculosis patients than for matched controls.

Child tuberculosis patients

Very little information is available for masses of pediatric tuberculosis patients compared with healthy children for any population. The best data available are those of Spaulding (1933), who reported average heights and masses, by age and sex, for approximately 600 children (ages 5 to 16 y) admitted to two treatment facilities in Minnesota between 1922 and 1932. Measurements were made at admission. Most of the age groups included 15–40+ children, but the youngest and oldest groups (ages 5 and 15 y) each included <10 children.

Height, mass, and BMI for the Minnesota patients were compared with summary information for the US population

Table 3. Body mass for adult tuberculosis patients as a percentage change from normal or control masses.

Country/description	Sex	Age range	Number	% change	Notes	Reference
England					a	Weber and Kirkness (1909)
Sputum positive	Male	25+	500	−12.2%		
Sputum positive	Female	25+	100	−10.8%		
Sputum negative ("old pulmonary tuberculosis")	Male	29+	100	−9.1%		
U.S. (New York)	Male	16–42	31	−14.8%	b	Garvin et al. (1918a and b)
	Female	16–39	20	−16.5%		
U.S. (Army recruits; September 1, 1917 to April 1, 1918)	Male	21–30	4,653	−6.95%	c	Love (1929); Davenport and Love (1921)
U.S. (Selective Service registrants; January 1943-January 1944; whites)	Male	18–37	Not given	−2.5%	d	Karpinos (1958)

[a]Masses at admission, percent change from reported former masses (former masses were close to "reference" masses).

[b]Ranges −36.6% to −5.6% (male); −23.0% to −6.2% (female). Percent difference of recorded lowest masses (usually around time of start of treatment) from recorded highest masses (usually after treatment) for individuals.

[c]−5.8% for height of 60 inches to −9.9% for height of 78 inches. Early or incipient TB cases from 868,445 men sent to camp (more advanced cases were probably rejected before being sent to camp).

[d]Includes essentially all registrants (385,937 Whites), both those inducted and those disqualified. The number of tuberculosis cases was not provided. The data exclude institutionalized tuberculosis cases.

(Stoudt et al. 1960). The average heights for age among the Minnesota tuberculosis patients (especially boys) were close to the estimated heights for age for the general US population, while the average masses for age among the patients were substantially lower than those estimated for the general US population after about age 6 (boys) or 7 (girls). BMI for the patients was substantially lower than for either general population, except at the youngest ages.

Fig. 1 shows the mass height ratio (kg cm^{-1}), by age, for the US general population (estimates from Stoudt et al. 1960) and the Minnesota tuberculosis patients (Spaulding 1933). Except for the youngest ages, the mass:height ratio in the general US population is clearly greater than that found among the patients. The calculated percentage difference in the mass:height ratio between the Minnesota patients and the US general population averaged -9.4% for boys (ages 7–14 y) and -10.1% for girls (ages 8–14 y). Below ages 7 (boys) or 8 y (girls), the percentage difference was small. The mass for age data from Spaulding (1933) show small standard deviations at these ages but much larger standard deviations for older ages, consistent with a smaller variability in size at younger ages.

Other studies reporting heights and masses of children with tuberculosis were considered inadequate for the CFCS purposes due to lack of information on time of measurements with respect to start of treatment, lack of control or comparison groups, small sample sizes, or unrepresentativeness (Topper and Rosenberg 1936; Topper and Shore 1939; Topper 1939; Topper and Rubin 1939, 1940; Chavalittamrong et al. 1987).

Estimates of the reduction in body mass for tuberculosis patients

Based on the findings described above, a downward adjustment of 10% (range 5 to 15%) on average adult body masses was selected to account for the decreased body mass of tuberculosis patients. While average reductions in body mass appear to be more than 10% for patients entering treatment, average reductions for patients in treatment or for less severe cases appear to be less than 10%. Use of a 10% reduction in average adult body mass for all adult tuberculosis patients thus seems to be a reasonable estimate, based on the available information.

For children in the age range for which information is available (ages 5–16 y), the difference in average mass between the Minnesota patients and the US general population, above about age 8 y, approximates that seen between adult patients and controls, around 10% less in patients. Therefore, a downward adjustment of 10% (range, 5 to 15%) on average body masses for children at least 8 y old was selected to account for the decreased body mass of tuberculosis patients. For younger children (ages 5 y for males, 5–7 y for females), no adjustment on the body masses for the general population was made in estimating the body mass of tuberculosis patients (range, 0 to 5%). For 6- and 7-y-old males, an intermediate downward adjustment of 5% (range, 0 to 10%) was used, reflecting a difference in body mass greater than that observed for 5-y-old males and less than that observed for males ages 8+ y.

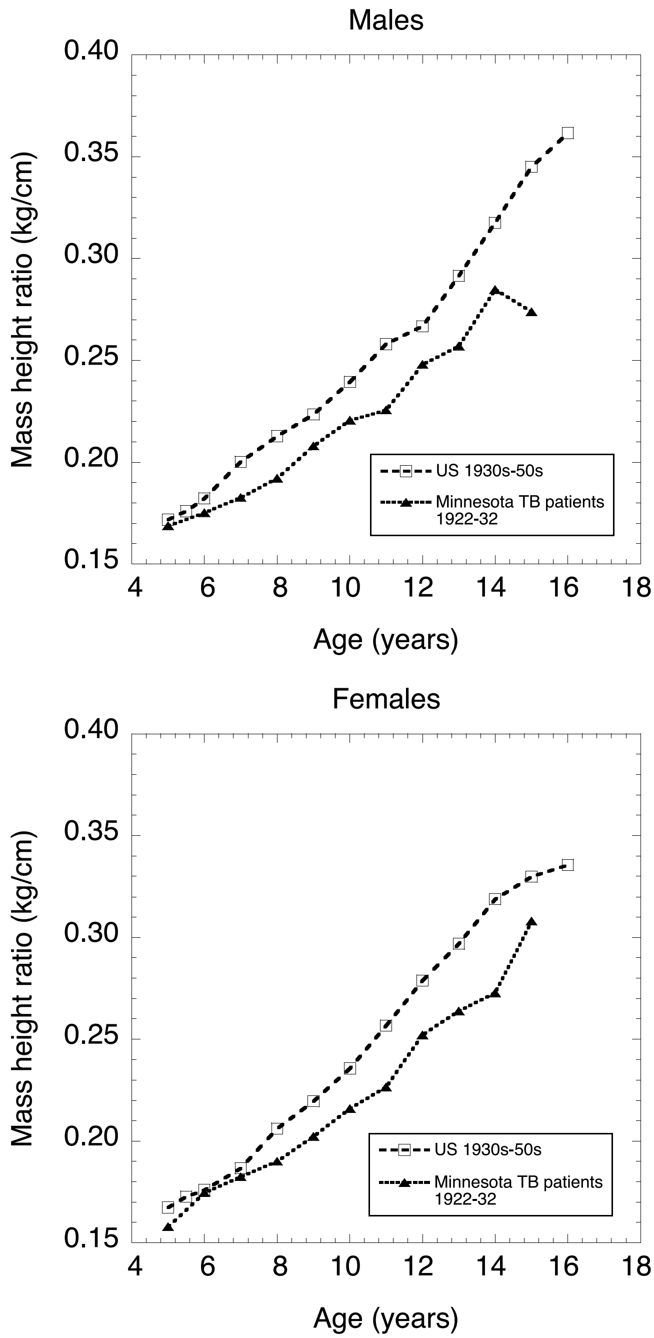

Fig. 1. Comparison of the mass height ratio (kg cm^{-1}) for age for the Minnesota tuberculosis patients (Spaulding 1933) and the estimated U.S. population (Stoudt et al. 1960), shown separately for males (top) and females (bottom).

In the absence of specific information for patients younger than 5 y, and based on the smaller variability in size at the youngest ages for which any information is available, the mass:height ratio of patients less than 5 y was assumed to be the same as that for the general population of the same age (no adjustment, range 0 to 5%).

APPLICATION TO THE CFCS

Mean heights for the tuberculosis patients were assumed to be the same as for the general population of the same age and sex (Pett and Ogilvie 1956, 1957; Demirjian et al. 1983). Uncertainties on the mean heights were assumed to be 0, since the values were based on measurements of a large population sample representative of the time period of interest.

Multipliers based on the estimated percentage differences in body mass between tuberculosis patients and healthy individuals described above were used to adjust mean body masses for the general population (Pett and Ogilvie 1956, 1957; Demirjian et al. 1983) to estimate mean body masses for the corresponding population of tuberculosis patients. Selected values were 1.0 (range, 0.95–1.0; ages 0–5 y for males, 0–7 y for females), 0.95 (range, 0.9–1.0; ages 6–7 y for males), and 0.9 (range, 0.85–0.95; males and females ages 8–15 y and adults). The resulting estimated average body masses for age for Canadian tuberculosis patients relative to the general population in 1953 are shown in Fig. 2 (all ages) and Table 2 (selected age groups, corresponding to the ages considered in the CFCS). Table 2 also provides the uncertainty on the mean body masses of tuberculosis patients, shown both as estimated ranges for the mean body masses and as ranges of percentages of the mean body mass. The mean heights and body masses of tuberculosis patients (Table 2) were then used for selection of appropriate computational phantoms for calculation of the organ-specific dose conversion coefficients used in the CFCS (Borrego et al. 2019).

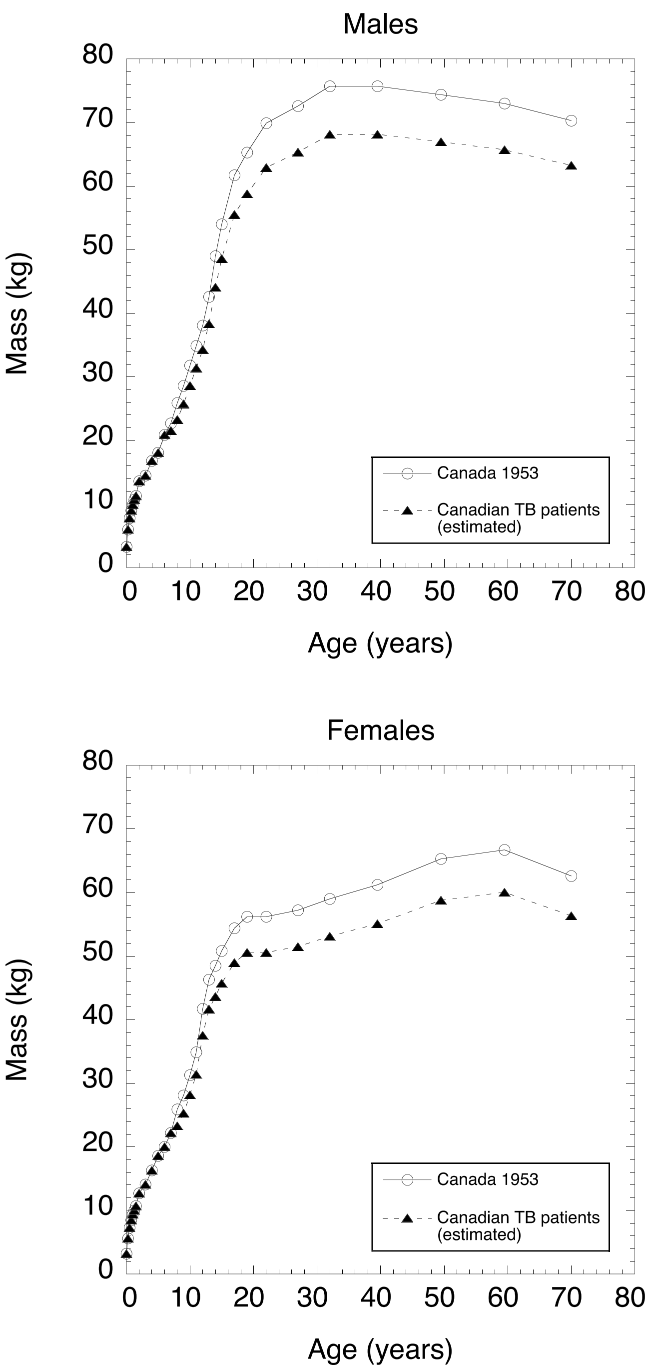

Fig. 2. Estimated average body masses for age for Canadian tuberculosis patients, compared with the general population of Canada (Pett and Ogilvie 1956, 1957; Demirjian et al. 1983), shown separately for males (top) and females (bottom).

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