Strontium-90 in Newborns and Childhood Disease

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ABSTRACT. Radioactive strontium-90 concentrations in baby teeth obtained from Suffolk County, New York, rose steadily during the 1980s. Recent levels of strontium-90 are similar to those reported for babies born in the late 1950s—at the height of atmospheric nuclear weapons testing in Nevada. Strontium-90 concentrations increased concomitantly with increases in cancer incidence among Suffolk children under the age of 5 y, a result that mimicked parallel trends observed in the 1950s and early 1960s. Given that effects of strontium-90 on developing cells are most pronounced during the fetal and infant periods, escalating levels should be viewed as a factor in the recent decline in various child health status measures.

THE IMPORTANCE of measuring radioactivity levels in humans was first recognized when atmospheric nuclear weapons testing in Nevada began in January 1951. Several subsequent studies focused on the radionuclide strontium-90 (Sr-90), which concentrates in bone where it damages stem cells of the bone marrow critical to reproduction of cells that mediate immune function. Sr-90 breaks down in the body to yttrium-90 (Y-90), which is also a radioactive beta particle emitter. Y-90 concentrates in the soft glandular tissues, including the pituitary gland, which controls hormonal function.[1,2] All forms of cancer can be induced by radiation, and cancer incidence increases with cumulative dose; the embryo, fetus, and infant are more sensitive to radiation than are adults.[3]

By July 1953, radioactive strontium had been detected in animal bones and milk products.[4] The following year, the U.S. Atomic Energy Commission began to measure Sr-90 in the vertebrae of healthy New York City residents (mostly adults) who died in accidents, and the program was extended to San Francisco residents in 1961.[5] In 1962, the U.S. Public Health Service established an expanded program of Sr-90 analysis of human vertebrae (mostly persons under age 25 y) in 34 U.S. cities.[6] Finally, a study of Sr-90 in 60,000 baby teeth in the St. Louis area commenced in 1958.[7] Each of these efforts revealed that Sr-90 levels rose steadily during atmospheric nuclear weapons testing, except during 1959–1961, at which time there was a decline during a testing moratorium. Peak levels were reached in 1964, shortly after the passage of the Limited Test Ban Treaty, and levels dropped rapidly thereafter.[8]

In a landmark 1958 study, investigators found an excess of childhood cancer deaths following pelvic x-rays in utero; this was the first time that susceptibility of the developing fetus to low levels of radiation had been demonstrated.[9] Subsequently, absorption of elevated levels of Sr-90 and other radionuclides in bomb test fallout was linked with increased disease risk in radiation-sensitive child health measures.[10–12] For example, U.S. childhood leukemia rates were correlated with levels of Sr-90 in milk from bomb test fallout.[13] Cancer incidence in children under the age of 5 y in Connecticut—the only state with an established cancer registry at that time—increased 40% from 1948–1950 to 1962–1964.[1] Once atmospheric bomb testing ceased, the rate quick-

ly fell 30% by 1967–1969, at which time it returned to the rate experienced during the pre-Nevada test era. These trends cast doubt on the theory that factors such as pesticides and other chemicals are the principal cause of childhood cancer.

Given that Sr-90 levels were dropping, all three baby teeth and vertebrae studies were terminated by various U.S. governmental agencies between 1970 and 1982. These studies ended despite the fact that declines in Sr-90 concentrations in the urban northeast United States had slowed after 1975, and they remained at 1957 levels. These patterns implied that another source of radioactivity—likely nuclear power reactors—was adding to Sr-90 levels in the American environment. Similar to bomb test fallout, researchers have linked radioactive emissions from reactors to elevated childhood leukemia rates in the United States[15] and abroad.[16] Moreover, in a recent report Mangano[17] showed that following the closure of 5 nuclear power plants, declines in local infant mortality ensued immediately, as did cancer in children less than 5 y of age in the most populated area.

An anomalous 37% nationwide increase in cancer incidence in children aged 0–9 y occurred from the early 1980s to the early 1990s.[18] This adverse trend has been accompanied by other declines in newborn and infant health status. Newborn hypothyroidism, a condition sensitive to radioactive iodine, jumped 47% from 1981 to 1994 in 30 states.[19] Asthma prevalence in 0- to 4-y olds rose 160% from 1980 to 1993–1994.[20] During the period from 1984 to 1992, ear infections in children aged 0–4 y rose 76%,[20] whereas premature births (i.e., gestation less than 37 wk) increased 14%.[21] Subsequent to 1986, the hospital admission rate for infants less than 1 y of age has stagnated[22]—in contrast to sharp reductions for all other ages. Each of these trends, illustrating potential malfunctions of the immune and/or hormonal system, represents an anomalous change from prior periods.

Materials and Method

In 1998, the Radiation and Public Health Project (RPHP) began studying Sr-90 concentrations in baby teeth, an approach that might help explain the decline in children's health. One can compare the project to the earlier St. Louis effort, as well as to a study by the Otto Hug Radiation Institute in Munich in which researchers showed that beta-emitting radioactivity in the teeth of German children increased nearly 10 times following the Chernobyl accident.[23] Investigators code deciduous teeth for blind testing with a scintillation counting technique to measure the ratio of Sr-90 to calcium (Ca) at birth (see Appendix). The scale of the RPHP study is far smaller than its counterpart performed in St. Louis 40 y earlier. The RPHP calculates Sr-90 concentrations for individual teeth, each of which carries a standard error of ± 0.7 picocuries (pCi) Sr-90/g Ca. Most teeth were submitted for study in special envelopes, which contained identifying information; the teeth were received in response to solicitations by mail to randomly selected households with children between the ages of 6 y and 18 y. Other teeth were submitted as a result of media coverage of the project (via a toll-free phone number [800-582-3716]) and a site on the world wide web (http://www.radiation.org).

As of January 1, 2000, RPHP has received approximately 1,700 teeth, of which 515 have been analyzed for Sr-90 content. Most teeth (n = 299) analyzed to date have been from Suffolk County, New York—the eastern portion of Long Island. Of the 299 teeth, all but 8 are from persons born between 1979 and 1993—roughly the period when no atmospheric nuclear tests were conducted worldwide (the last such detonation, by China, occurred in 1980). For approximately a decade, potential causes of the county's soaring breast cancer rate[24] have been the focus of extensive discussion. Suffolk County is the site of Brookhaven National Laboratories, which operated two or three research reactors for various periods, beginning in 1950. Much of the county also lies within 113 km (70 mi) of the Indian Point, New York, reactors (to the northwest) and the Oyster Creek, New Jersey, reactor (to the south-southwest). Prevailing winds propel airborne radioactive particles toward the county from Indian Point in the winter and from Oyster Creek in the summer.[25] In addition, Suffolk County is located as close as 18 km (11 mi) from the Millstone plant and 35 km (22 mi) from the Haddam Neck plant; both plants are in Connecticut. These installations are relatively old; Indian Point, Haddam Neck, Oyster Creek, and Millstone began operations in 1962, 1967, 1969, and 1970, respectively. Among U.S. nuclear plants, Oyster Creek and Millstone have emitted the second- and third-highest levels of airborne iodine-131 and other particulates since 1970.[26]

Before our study was initiated, evidence existed that local radioactivity levels had been escalating during recent years. Sr-90 levels in the bones of fish living in Suffolk County's Peconic River, measured annually by the New York State Department of Health, escalated from 125.3 pCi Sr-90/g Ca in 1990 to 211.3 pCi Sr-90/g Ca in 1991 and to 636.3 pCi Sr-90-g Ca in 1992; finally, in 1993 and 1994 there was a decrease.[27]

Among the items requested from tooth donors for data analysis, several suggest that the sample is representative of Suffolk County. Forty-five percent and 50% of mothers of tooth donors born between 1979 and 1993 were in their 20s or 30s at delivery, respectively, compared with 46% and 47% of mothers in the entire county. In addition, 6.76% (n = 19) of infants weighed less than 2,500 g at birth, compared with 5.84% for all infants of Suffolk County.

Results

The average radioactivity concentration in the teeth of 476 children (all geographic areas) born between 1979 and 1993, inclusive, was 1.50 pCi Sr-90/g Ca—a result similar to levels found in St. Louis children born in 1956. This level was well above the 0.20 pCi Sr-90/g Ca figure expected had the 1964–1970 decline in St. Louis teeth (after large-scale atmospheric nuclear weapons testing) had continued.

Table 1.—Strontium-90 Concentrations in Baby Teeth Obtained from Children Born between 1979 and 1990 vs. Cancer Incidence in 0–4-y-Olds during 1982–1993, in Suffolk County, New York

Birth period (teeth)	Diagnosis period (cancer)	High pCi Sr-90/g Ca	Ave. pCi Sr-90/g Ca	Cancer incidence* Ages 0–4 y
1979–1981	1982–1984	3.45	1.11 (11)†	17.40 (46)‡
1982–1984	1985–1987	2.60	1.26 (23)†	20.17 (55)‡
1985–1987	1988–1990	7.26	1.50 (70)†	25.52 (73)‡
1988–1990	1991–1993	7.86	1.45 (110)†	19.29 (58)‡

Notes: Sr-90 = strontium-90, and pCi Sr-90/g Ca = picocuries strontium-90 per gram calcium.
†Numbers of teeth analyzed in parentheses.
‡Numbers of cancer cases in parentheses.

The average for the 291 teeth for children born in Suffolk County was 1.33 pCi Sr-90/g Ca. Only 89 of the 291 teeth (31%) registered the expected concentration of 0.20 pCi Sr-90/g Ca. Conversely, 64 teeth (22%) had concentrations that exceeded 2.00 pCi Sr-90/g Ca; these concentrations were at least 10 times greater than the minimum detectable level. The highest reading in Suffolk was 9.29 pCi Sr-90/g Ca for a 1992 birth, whereas the highest overall reading (17.87 pCi Sr-90/g Ca) in the study was from a child born in Miami in 1988.

Radioactivity in Suffolk baby teeth increased steadily from 1.11 pCi Sr-90/g Ca to 1.50 pCi Sr-90/g Ca ($p < .08$) for children born 1979–1981 and 1985–1987, respectively. Given that Sr-90 does not exist in nature, and because no atmospheric bomb tests were conducted, the source of these elevated levels is likely nuclear power plant emissions. The 1988–1990 average dropped slightly to 1.45 pCi Sr-90/g Ca (Table 1). Most teeth received recently (and expected in the future) have been from children born after 1990; therefore, any reporting of radioactivity levels for births during the 1990s would be premature.

Sr-90 increases were followed by a 47% rise (17.40 to 25.52 cases per 100,000) in the Suffolk cancer incidence rate for ages 0-4 y 3 y later. The reduced average level of Sr-90 during 1988–1990 was followed by a lower cancer incidence rate. This 3-y latency corresponds to the principle that cancers in young children, most frequently diagnosed between the ages of 2 y and 4 y, result from altered or mutated genes acquired during the fetal period.[28] This pattern of dual increases in Sr-90 and childhood cancer was observed previously in the 1950s and early 1960s; these increases were followed by declines in both measures after U.S. and Soviet atmospheric nuclear tests were halted.

Subsequent to the 1960s, the highest annual concentrations of Sr-90 in Suffolk baby teeth were found in 1979 (2.25 pCi Sr-90/g Ca [$n = 3$]) and 1986 (1.85 pCi Sr-90/g Ca [$n = 21$]). In these years, the worst nuclear accidents in the United States (i.e., Three Mile Island) and the world (i.e., Chernobyl) occurred. Linkages have been demonstrated between radioactivity from these events and childhood cancer. In three central Pennsylvania counties, the cancer mortality rate for children between 0 and 9 y of age moved from one-third below to one-third above the U.S. rate between 1970–1974 (i.e., before Three Mile Island opened) and 1980–1984 (i.e., after the accident).[29] Investigators have linked excess childhood leukemia with fallout from the Chernobyl accident in West Germany, Greece, and the United States.[30–32] In New York City milk, which is shipped from the same areas as Long Island's supply, Sr-90 levels in July of 1979 were 50% greater than during the previous 2 y. In addition, the average of seven May, June, and July 1986 milk measurements was 20% greater than the average for measurements during July 1984 and 1985[33]—a result that was similar to the 25% excess of Sr-90 in baby teeth.

Given that approximately one-third of the 291 Suffolk teeth have minimum detectable levels of Sr-90, and another one-fifth have readings ranging from 2.00 pCi Sr-90/g Ca to 9.29 pCi Sr-90/g Ca, the frequency distribution is asymmetrical, rather than Gaussian bell-shaped. Although our report is preliminary, it is evident that this distribution changes little as more teeth are analyzed. Given that the frequency distribution is asymmetrical and that the selection of households that received requests for teeth was random, we are confident that the frequency distribution of our sample generally represents that of the county's population.

Sr-90 concentrations in teeth from 16 children born in the New York metropolitan area from 1957–1970 were approximately 30% below matching birth cohorts from the St. Louis tooth study, approximating Sr-90 differences in milk from the two cities during that time.[34] Sr-90 levels in both New York and St. Louis teeth peaked in the mid-1960s, and later in the decade they were sharply reduced. These similarities point to the accuracy of RPHP measurements of Sr-90.

Discussion

The unexpected increase in in vivo Sr-90, occurring at a time of rising childhood cancer rates, repeats patterns found in the era of atmospheric nuclear weapons testing. Current concentrations of Sr-90 in Suffolk County and other American children correspond roughly to concentrations found in St. Louis children born in

1956—5 y after atmospheric nuclear testing in Nevada commenced. In fact, the concentrations far exceed levels expected had declines after the large-scale American and Soviet atmospheric tests continued. Thus, another source of fission products must be contributing to the current levels; most likely, these are emissions from nuclear reactors.

Potential contributors to the current childhood cancer epidemic include environmental factors.[35] One of these etiologies is exposure to radioactive emissions from nuclear power plants.[36] For the first time, an association has been found between in vivo levels of radioactivity—not just plant emissions or dietary levels—and childhood cancer. Moreover, rising childhood cancer is linked with relatively modest increases in radioactivity, from accidents like Three Mile Island and Chernobyl and from routine emissions from power plants. This association supports the comparable findings of numerous epidemiological studies mentioned in this report.

One troubling finding in our study involved persons with exceptionally high Sr-90 concentrations, such as the 13 (5%) children with levels above 4.00 pCi Sr-90/g Ca. The mean concentration for this group (5.80 pCi Sr-90/g Ca) exceeded all years covered in the St. Louis study, except for the peak period of 1963–1966. Therefore, an adverse combination of Sr-90 from the maternal diet, maternal bone stores, birth location, and time of pregnancy can result in high Sr-90 levels, as well as increased risk of childhood cancer and other diseases. These at-risk children number at least 1,000 of the 20,000 births in Suffolk County each year.

Initial results of the baby tooth study represent the beginning of an assessment of radioactivity's effects on not just cancer but on a variety of declines in U.S. child health. The study may provide the researchers with valuable information to assess this potential linkage, particularly as more teeth are analyzed in a variety of geographic areas.

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Appendix
Determination of Sr-90 to Calcium Ratio

Sr-90 in deciduous teeth was determined under the direction of Hari D. Sharma, Professor Emeritus of Radiochemistry and president of REMS, Inc., Waterloo, Ontario, Canada, who recommended use of the procedure described below.

A tooth is dried for 12 h at 110 °C and then ground to a fine powder. Approximately 0.1 g of the powder is weighed in a vial and then digested with 0.5 ml of concentrated nitric acid for a few hours, along with solutions containing 5 mg strontium^{++} (Sr^{++}) and 2 mg yttrium^{+++} (Y^{+++}) carriers at approximately 110 °C on a sand bath. The solution is not evaporated to dryness. The digested powder is transferred by rinsing with tritium-free water to a centrifuge tube. Carbonates of Sr, Y, and calcium (Ca) are precipitated by the addition of a saturated solution of sodium carbonate and then centrifuged. The carbonates are washed repeatedly with a dilute solution of sodium carbonate, thus removing any coloration from the precipitate. The precipitate is dissolved in hydrochloric acid, and the pH is adjusted to a range of 1.5–2 to make a volume of 2 ml, of which 0.1 ml is set aside for determination of calcium. The remaining 1.9 ml are mixed with 9.1 ml of scintillation cocktail Ultima Gold AB supplied by Packard Bioscience BV in a special vial for counting. A blank with appropriate amounts of Ca^{++}, Sr^{++}, and Y^{+++} is prepared for recording the background.

The activity in the vial with the dissolved tooth is counted four times for 100 min each time, for a total of 400 min, with a Wallac WDY 1220X Quantulus low-level scintillation spectrometer. The spectrometer has special features so that the background count rate in the 400–1000 channels is 2.25 ± 0.02 counts/min. The background has been counted for more than 5,000 min; therefore, the error associated with the background measurement is approximately 1%. The overall uncertainty or one sigma associated with the measurement of Sr-90/g Ca is ± 0.7 pCi/g Ca.

The efficiency of counting was established with a calibrated solution of Sr-90/Y-90 obtained from the National Institute of Standards and Technology. The calibrated solution was diluted in water containing a few milligrams of Sr^{++} solution, and the count rate from an aliquot of the solution was recorded in channel numbers ranging from 400 to 1,000, thus enabling the determination of the counting efficiency for the beta particles emitted by Sr-90 and Y-90. It was ensured that the Y-90 was in secular equilibrium with its parent Sr-90 in the solution. The counting efficiency was 1.67 counts per decay of Sr-90 with 1.9 ml of Sr-90/Y-90 solution with the amounts of 25 mg Ca^{++}, 5 mg of Sr^{++}, 2 mg of Y^{+++}, and 9.1 ml of the scintillation cocktail.

The calcium content was determined with a Varian A-A 1475 atomic absorption spectrophotometer by flame spectroscopy at a wave length of 422.7 nanometers, using acetylene plus air as fuel.

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