GROWTH STATUS OF CHILDREN EXPOSED TO FALLOUT RADIATION ON MARSHALL ISLANDS

W. W. Sutow, M.D., R. A. Conard, M.D. and K. M. Griffith, M.D.

University of Texas M. D. Anderson Hospital and Tumor Institute, Houston, Texas, and the Medical Division, Brookhaven National Laboratory, Upton, Long Island, New York

On March 1, 1954, inhabitants of three atolls (Rongelap, Ailingnae, and Utirik) of the Marshall Islands were accidentally exposed to fallout radiation from the experimental detonation of a large thermonuclear device over Bikini Atoll. An unpredicted shift in wind at the time of detonation caused deposition of significant amounts of fallout on these nearby islands (see Table I). The inhabitants were subjected to whole body gamma radiation, irradiation of the skin (largely from beta particles in the fallout), and radiation from internal absorption of radionuclides following ingestion of contaminated food and water. About two days after the accident, the entire populations of the three atolls were evacuated by plane and ship to Kwajalein Atoll where complete examinations were carried out. After several months, the Utirik group was returned to its home island where radioactivity was considered to be low enough for safe habitation. The Rongelap and Ailingnae people were transferred to Majuro Atoll, several hundred miles to the south. By June, 1957, the radioactivity levels on Rongelap were considered low enough for the people to be moved back to the island.

Most of the people exposed on Rongelap experienced anorexia and nausea within the first 24 to 48 hours after exposure. Vomiting and diarrhea occurred in a few. Cutaneous lesions and alopecia developed about two weeks later in most of the exposed subjects. Leukopenia (white blood count less than 5,000) and thrombocytopenia (platelet count less than 100,000) were seen in a number (see Table II). None of the people exposed on Utirik developed alopecia, epilation, or other radiation symptoms.

Since the exposure, annual medical followup examinations have been conducted on these people. Detailed accounts of the hematological, clinical, and other data from these surveys have been published.[1-10] This report summarizes the findings from growth and development studies, for 1958 through 1963, of those who were in the pediatric age group (less than 20 years of age) at the time of exposure.

RADIATION EXPOSURE DATA

Table I shows the various island groups, distances from Bikini, and estimated whole body doses. On Rongelap atoll, 64 people received the calculated gamma dose in air of 175 r. Eighteen other Rongelap inhabitants who had been on the neighboring Ailingnae atoll were exposed to about 69 r. One hundred and fifty-seven inhabitants of Utirik atoll, farthest from Bikini, received the smallest dose of about 14 r. The integrated dosage calculations were rather complicated and involved survey instrument readings at the time of evacuation, film badge readings of a group of Americans on a nearby contaminated island, estimation of the time and extent of fallout, fallout decay, etc.[11] An accurate estimate of the beta radiation dose to the skin from radioactive material in contact with the dermal surface could not be made, but the development of skin lesions indicated that it must have been roughly 10,000 to 15,000 rads (largely low-energy beta).

Radiochemical analysis of urine samples from exposed persons showed some degree

(Submitted November 18, 1964; revision accepted for publication March 31, 1965.)

ADDRESS: (W.W.S.) University of Texas M. D. Anderson Hospital and Tumor Institute, Texas Medical Center, Houston, Texas; (R.A.C.) Brookhaven National Laboratory, Upton, Long Island, New York.

This work was supported by the U. S. Atomic Energy Commission.

TABLE I

EXPOSURE DATA* MARSHALL ISLAND INHABITANTS

Atoll	Distance from Bikini (Nautical Miles)	Exposure Dose (Whole Body Gamma Radiation)	Number of People Exposed	
			Total	Under Age 20 Years
Rongelap	105	175 r	64	31†
Ailingnae	80‡	69 r	18	7
Utirik	200	14 r	157	74

* 23 Japanese fishermen aboard the vessel "Lucky Dragon" near Rongelap and 28 American service men stationed at another atoll were also subjected to the fallout radiation on the same day.

† Four additional subjects were *in utero* at the time of exposure.

‡ Though Ailingnae was closer than Rongelap to Bikini it was more out of the pattern of heavy fallout.

of internal absorption of radioactive material, presumably from ingestion of contaminated food and water.[12] Body burdens of radio-nuclides have been measured by radiochemical urine analysis and gamma spectrographic analysis; the latter was done in a 21-ton steel room carried to the islands especially for this purpose. Cs^{137} and Zn^{65} have been the principal gamma emitters detected (residual fallout contamination). The highest levels of these isotopes averaged about 0.7 μc for $cesium^{137}$ and 0.4 μc for $zinc^{65}$ per individual, well below the accepted permissible levels, and imparting a dose of only about 100 mr annually (less than that normally received from natural gamma sources). During the first few days the radioisotopes of iodine exceeded the accepted permissible level (about 6.4 μc on the first day). It was estimated that the thyroid glands of the adults received 100 to 150 rads from the radioiodines (with somewhat higher values for the children). No acute effects were noted from these internal exposures.

Sr^{90}, a beta emitter which is selectively deposited in bones, was another consideration. Based on urinary excretion values[3,9,13] and bone analyses from autopsy specimens, the maximum Sr^{90} in the adult bones was calculated to be about 15 pc/gm Ca. Since this value was higher by a factor of about 10 in children, because of greater bone absorption, the value would be 150 pc/gm Ca. Using the assumptions accepted in the United Nations report,[14] this value corresponded to a dose to the children's bones

TABLE II

RADIATION SYMPTOMS IN RONGELAP CHILDREN

Age at Exposure (yr)	Sex	Number Exposed	Number with Radiation Symptoms						
			Nausea	Vomiting	Diarrhea	Epilation	Skin Lesion	Leukopenia	Thrombocytopenia
Under 2	M	5	4	1	1	4	4	5	
	F	3	2			3	3	2	2
2–3	M	3	1	1	1	2	3	3	
	F	4	3	1		3	4	4	3
4–6	M	2	2	1		2	2	2	1
	F	1					1		
7–10	M	3	1	1	1	2	3	3	1
	F	5	2			5	5	5	
11–15	M	2	1			2	2	2	
	F	6	6			3	5	5	4
16–20	M	1					1	1	1
	F	3	1			1	3	3	

of about 370 mr/yr or a total dose of about 3 rads over the 9-year period since the fallout.

PROCEDURES

Of the total population of 237 exposed to fallout radiation, 112 (47%) were under the age of 20 years (Table I). Although some attrition in number has resulted from inter-island migration and from "graduation" into the adult category, longitudinal data have become available for the majority of the children. This analysis, however, has been limited to growth data obtained from 1958 through 1963 on the 38 children exposed at Rongelap and Ailingnae atolls (Table III), 4 children exposed *in utero,* 67 unexposed comparison children, 39 children born to exposed parents, and 53 children born to unexposed parents on Rongelap subsequent to the radiation fallout.

When the Rongelap people were returned to their home island in 1957, they were accompanied by a group of relatives and former Rongelap residents who had not been exposed to the fallout. These added people are thought to be ethnologically comparable to the exposed group. Since these unexposed people, which included 69 in the pediatric age group, have continued to live and eat in the same environment as the exposed islanders, they have been used after 1957 as the comparison population. The age-sex statistics of the exposed and unexposed children are shown on Table IV.

TABLE III

Number of Children Examined Rongelap Series

Year of Examination	Exposed	Unexposed	Babies Born after December, 1954	
			To Exposed Parent(s)	To Unexposed Parent(s)
1954	38			
1958	39*	67	13	26
1959	34*	50	20	32
1960	36*		10	
1961	30*	50	24	39
1962	30*	43	37	53
1963	25*	36	35	53

* Includes 4 who were exposed *in utero.*

TABLE IV

Exposed and Unexposed Children Rongelap Series

Birth Year	Number of Boys		Number of Girls	
	Exposed	Unexposed*	Exposed	Unexposed
1954	3†	2	1†	7
1953	1	2		3
1952	4	2	3	4
1951		2	2	2
1950	3	3	2	4
1949	1			1
1948		4	1	2
1947	1	1	2	3
1946	1	5	1	1
1945	1	1	2	
1944		2		2
1943	1	4		
1942 & earlier	3	6	9	6

* Children born prior to December, 1954.
† Exposed *in utero.*

During the evacuation phase, the hospital and clinics at Kwajalein and Majuro were used for the medical surveys. Following repatriation, examination facilities were set up on Rongelap. Examinations, however, have been continued on Kwajalein and Majuro for those exposed islanders who had moved there.

Routine annual pediatric work-up on each child has consisted of interval medical history, physical examination, physical anthropometry, roentgenogram of left hand and wrist, complete blood count, and urinalysis. During the period covered by this analysis, ophthalmological studies were carried out in 1957, 1958, 1959, and 1962 and dental surveys in 1959 and 1961. Special laboratory studies for clinical indications and for survey purposes have included biochemical determinations on body fluids, parasitological surveys, chromosome studies, skin biopsy examinations, radionuclide body burden evaluations, immunoelectrophoretic analyses, and studies of genetically inherited characteristics of blood components and urine.

The routine anthropometric measurements consisted of stature, body weight, sitting height, head circumference, head width, head length, chest circumference, calf circumference, bisacromial diameter, and bicristal diameter. Weight was determined on a Fairbanks scale, beam balance. Stature was measured on a fixed wall scale using a right-angle square. Circumferences were determined by a flexible steel tape and diameters by Swan Tool spreading calipers. Techniques conformed basically to those used internationally in physical anthropometry.[15] The growth data used in this analysis were obtained by a single observer (W.W.S.) except in 1960 when only the heights and weights were determined on exposed children (by R.A.C.).

Evaluation of sexual maturation was done during the physical examination using standards described by Greulich *et al.*[16] and Reynolds and Wines.[17,18] Assessment of osseous development was carried out by a single evaluator (W. W. S.) using the technique of Greulich and Pyle.[19]

RESULTS

The pediatric study population was divided into four groups: (*a*) those exposed to radiation, including 4 children *in utero* at the time of exposure; (*b*) those born before the fallout but not exposed to radiation; (*c*) those born to exposed parents subsequent to the fallout; and (*d*) those born to unexposed parents subsequent to the fallout.

Because some of the distributions encountered in these data did not approximate normality or even symmetry of distribution, and because many of the groups were too small to justify making assumptions about the parameters of the populations from which the samples were drawn (and in many instances too small to permit calculations of any meaningful measure of variability), all data analysis was done by non-parametric statistical methods. All measures of central tendency were medians, and all graphic presentations comparing groups were plotted in terms of group medians. Descriptive differences reported as between groups were differences between medians. Significance of differences between groups, unless otherwise specified, was determined by the Kruskal-Wallis one-way analysis of variance.[20]

Height and weight data on unexposed children born before the fallout showed the expected pattern of pubertal growth spurt occurring earlier in girls than in boys and the eventual superiority in size of boys at maturity. Among the exposed children, there was a distinct tendency for boys exposed at ages 1 through 5 to be shorter than unexposed boys of the same age (Fig. 1). Although the differences were statistically significant at the 5% confidence level

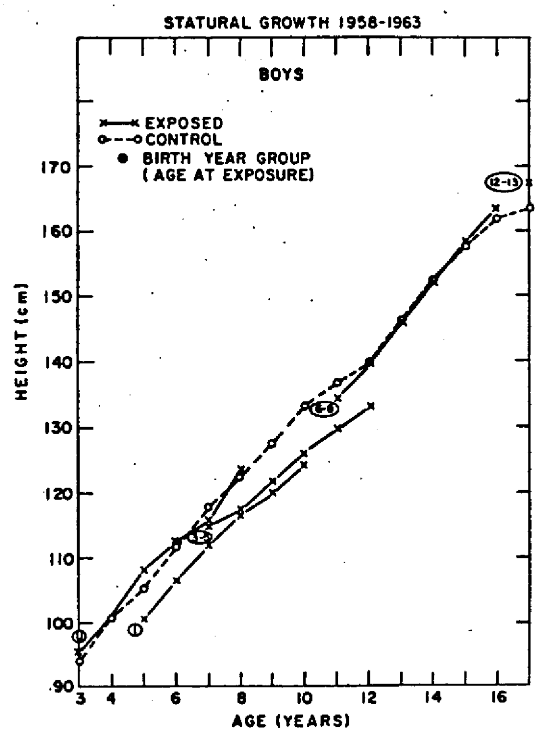


FIG. 1. Statural growth of boys, 1958 through 1963. Longitudinal growth curves showing median statures of groups of boys exposed at various ages, e.g., *in utero* (u) 3 boys; 12 to 24 months (1) 5 boys; 3 through 5 years (3–5) 4 boys; 6 through 8 years (6–8) 3 boys; and 12 through 13 years (12–13) 2 boys; indicate definite and continuing retardation in statural growth of boys exposed at ages 5 years or younger and particularly 12 to 24 months of age.

10827-64

5012568

only in the measurements at ages 6, 9, and 10 years for the boys exposed at age 1, and at age 11 for the boys exposed at ages 3 through 5 years, the retardation in stature of these boys exposed at an early age was apparent at all ages at which measurements were made. Two of the 9 boys exposed at ages 1 through 5 maintained statures comparable to the median statures of the unexposed boys of the same age while the other 7 showed varying degrees of retardation. No tendency toward diminution in the magnitudes of the differences was noted as the boys grew older.

In general, the boys exposed at age 5 years or below appear to have growth curves parallel to those of the unexposed group, but remain 5 to 10 cm shorter in stature than unexposed boys of the same age (Fig. 1). The notable exceptions to this generalization are 2 of the 4 boys exposed at 16 to 17 months of age. Both of these boys, at age 10 years, are roughly comparable in stature to the 6-year-old unexposed boy. Subject No. 3 was 6.8 cm below the median height for the unexposed

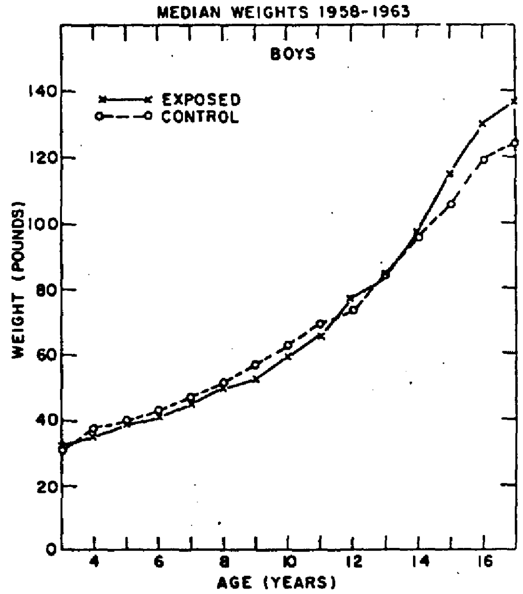


FIG. 3. Median weights of boys, 1958 through 1963. A trend, not statistically significant, for the younger boys of the exposed group to be lighter in weight in comparison with the control group is noted.

10-826-64

when he was 5 years old, and at age 10 he was 19.5 cm below the median height for the unexposed. Subject No. 5 was 9.6 cm below the median height for the unexposed at age 5 years, as compared with 22.9 cm at 10 years.

Boys exposed at ages 6 to 12 years showed no differences in stature from unexposed boys of the same age. Since there were only 2 boys exposed in the 12- through 13-year-age range, the data available did not justify any conclusion regarding the effect of exposure about the time of puberty.

There is no evidence of retardation of stature of the exposed girls as compared with the unexposed group, regardless of age at exposure (Fig. 2). There are no statistically significant differences between the two groups of girls with respect to stature at any age at which measurements were made, nor are there any individuals who might be described as staturally retarded.

The trends for weights of exposed and unexposed children (Fig. 3 and 4) are

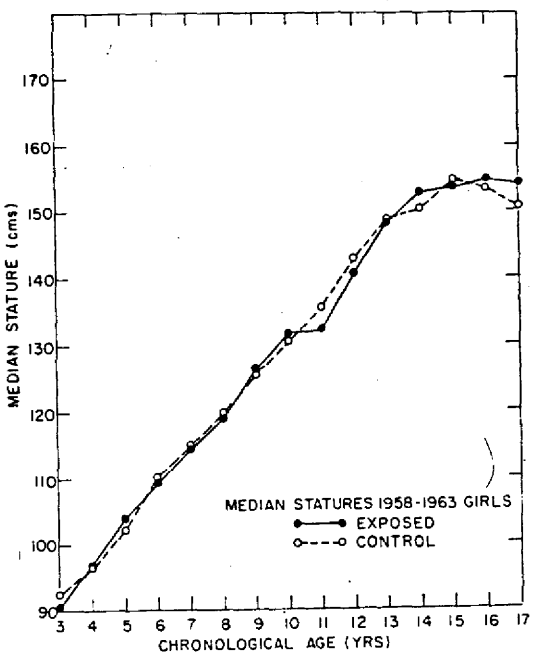


FIG. 2. Statural growth of girls, 1958 through 1963. No significant differences exist between the exposed and non-exposed groups of girls.

1-59-64

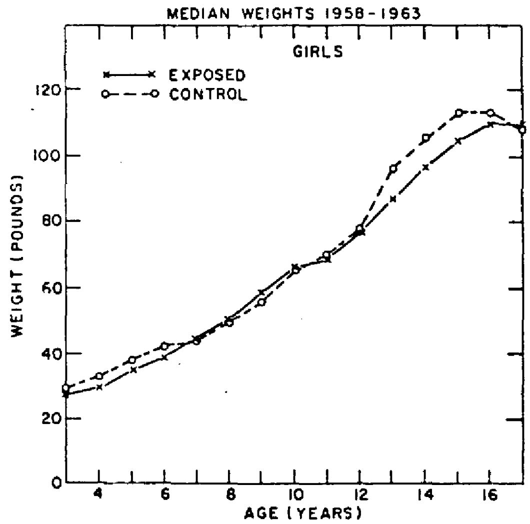


FIG. 4. Median weights of girls, 1958 through 1963. No difference in the weight curves is apparent between exposed and non-exposed groups of girls.

10-825-64

similar to those observed in the statures, but the differences were smaller and none were statistically significant. Even subjects No. 3 and 5, who are approximately 4 years

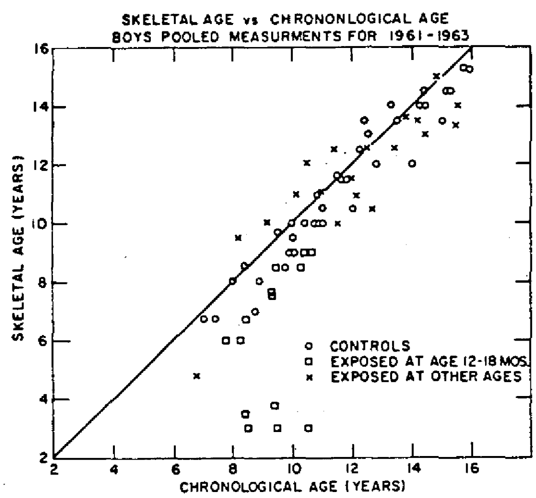


FIG. 5. Skeletal age versus chronological age in boys, 1961 through 1963. Scattergram of pooled skeletal age assessment data from three separate examinations show general retardation (though not statistically significant over-all) of exposed boys compared to the non-exposed. The measurements on the boys exposed to fallout radiation at 12 to 18 months of age are represented by open squares and indicate continued failure in skeletal maturation. The standard curve derived from Marshall Islands data is represented by the solid line.

10-830-64

behind their peers in stature, are only 1 to 2 years behind in weight.

Neither the boys nor the girls have showed any significant differences between exposed and unexposed groups with respect to head circumference.

Skeletal ages, based on the standards of Greulich and Pyle,[19] paralleled the statural development of the children. The scattergrams of skeletal ages versus chronological ages (Figs. 5 and 6) represent the pooled measurements for 1961, 1962, and 1963. Thus, the same individual may be shown at three different chronological age levels on the graph. The solid line on each scattergram is a least squares fitting to the points representing the measurements on the unexposed children. Both the exposed and unexposed Marshallese children tended to be less mature skeletally at comparable chronological ages than the norms published by Greulich and Pyle. However, the boys were somewhat less mature skeletally than the girls, being on the average 8 months retarded, as compared with 3 months for the girls. Also, the exposed children, both boys and girls, were somewhat less mature skeletally than the unexposed. The median skeletal retardation of the exposed children was 9 months, as compared with 3 months for the controls.

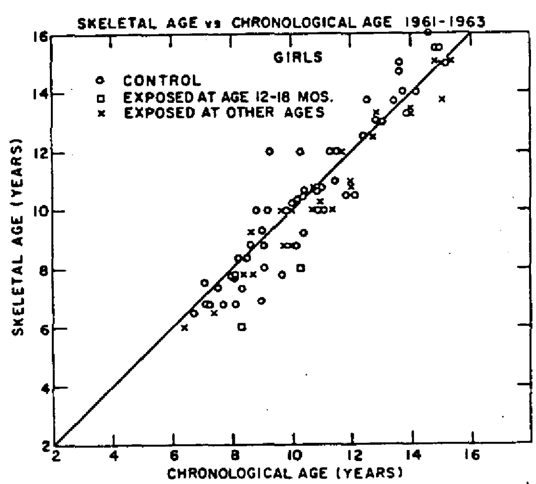


FIG. 6. Skeletal age versus chronological age in girls, 1961 through 1963. No significant over-all difference is apparent between exposed and non-exposed groups of girls.

10-829-64

However, these differences were not statistically significant.

The retardation of skeletal maturation of subjects No. 3 and 5, the 2 boys exposed at 16 to 17 months of age, is even more extreme than the retardation in their statural growth. Their skeletal maturation has fallen progressively farther behind the standards of Greulich and Pyle each year, and they are now approximately 6 years retarded according to these norms. One of these boys (No. 3) is shown with his younger (larger) sib (No. 83) in Figure 7. The roentgenograms of the wrist (Fig. 8) as well as the graphic presentation of the osseous development (Fig. 9) indicate the magnitude of retardation in this particular boy.

The exposed girls did not differ significantly from the unexposed girls with respect to skeletal maturation, but it is perhaps of interest to note that the girl who has consistently been the most retarded in skeletal maturation (27 months below Greulich and Pyle standards), and the smallest for age of the exposed girls, was exposed at 15 months of age. This would be consistent with the viewpoint that children are most susceptible to the effects of exposure in the 1-year-old age range, but that girls are less susceptible than boys.

There were no significant differences between the children born to exposed parents and the children born to unexposed parents with respect to stature, weight, head circumference, or skeletal maturation.

Although the exposed category consisted of 31 children who had received 175 r and 7 who had received 69 r, there was no difference in the growth patterns of the children receiving the two different doses of irradiation. Therefore, the two groups were combined in the analytic procedures.

COMMENTS

Among the most prominent findings of the present study has been the age and sex dependence of the effects on growth of the Marshallese children. Boys appeared to be more adversely affected than the girls; the retardation was noted among boys exposed at ages below 5 years. Those who were 12 to 18 months old at the time of exposure to fallout radiation have shown the greatest deviations in growth patterns.

FIG. 7. Brothers. Marked retardation in statural growth is shown by the older (shorter) brother (No. 3 on the right) who was exposed at age 4 months. The younger, by 21 months (No. 83 on the left), is taller by 13 cm. The retarded boy showed no evidence of hypothyroidism or skeletal disease clinically other than markedly delayed osseous maturation. 10-549-64

From a preliminary survey in 1947 and 1948 of children who were exposed to the atomic bomb in Nagasaki and Hiroshima, Japan, Greulich *et al.*[21] reported that the growth and development of the surviving children were retarded. They also found that the boys tended to be more affected than the girls. This sex-connected inferiority in adjusting to stress situations had been noted in earlier studies on Guamanian children by Greulich.[22]

In a broad program of medical observations, the Atomic Bomb Casualty Commission (ABCC) has continued to study the

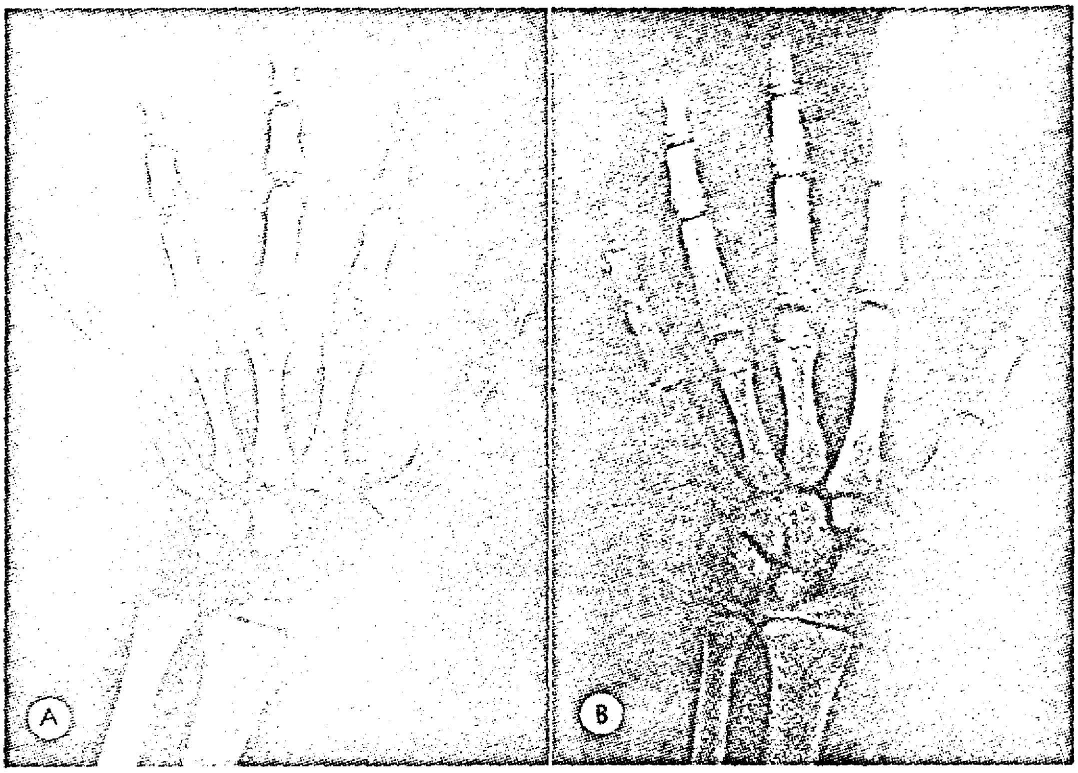


FIG. 8. Skeletal age roentgenograms of left wrists and hands. (A) Subject No. 3 shows marked retardation in skeletal maturation at chronological age of 10 years 6 months. (B) Subject No. 83, younger brother of No. 3, has normal osseous development at chronological age of 8 years 8 months.

not BNL reg

exposed Japanese populace.[23] Reynolds[24] examined the growth data obtained from 1951 through 1953 on the Hiroshima children and reported a trend in the direction of inferior physical status in the exposed as compared to the control children. He further interpreted the data as demonstrating a tendency among children exposed closer to the hypocenter to be physically smaller than those exposed farther away. Similarly, inferior growth status was more marked in those children with histories of more severe radiation symptoms.

Recently, Nehemias[25] utilized multivariate techniques with twelve anthropometric variables to analyze the 1951–1953 ABCC growth data. He concluded that there were trends "in the direction of decreasing size with increasing degree of radiation exposure." It was noted that the differences in size were physically small, not detectable for the most part in the age-sex-specific tests. Correlation analyses indicated that "the effect tended to be most marked at the older and younger age groups," i.e., in children who were "either in infancy at the time of the bomb or in the 12- and 13-year-age range".

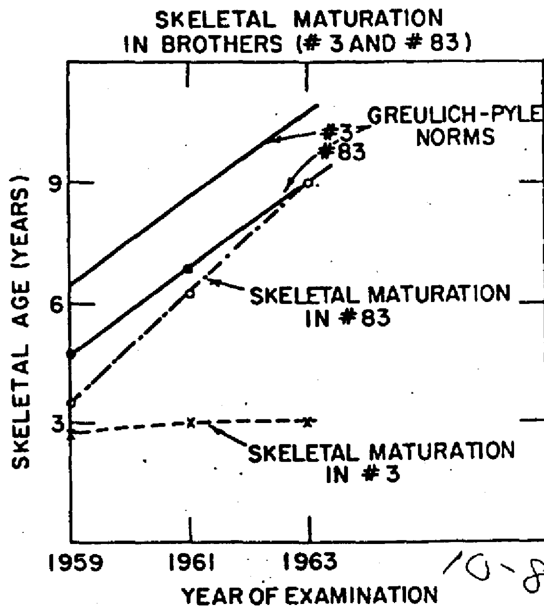
Even in the large-scale ABCC program, the problems related to the selection of a control population for purposes of comparison have been difficult to solve.[23-25] Although quantitative differences in growth between exposed and unexposed children can be shown to exist statistically, the causal relationship of the biological effect of radiation to the noted difference remains to be proved.[25] Factors such as physical and psychic trauma added to nutritional deficiencies could have influenced growth and development in the Japanese children. These factors that complicated the interpretation of growth data in the ABCC program would seem to be of minimal importance in the Marshall Island study. Significant socioeconomic differences do not exist on the Rongelap atoll as they did in Japan. The level and availability of medical care are uniform for all inhabitants. Great variations in food habits do not occur and food deprivation is a community and not an individual problem.

The size of the exposed group as well as the nearly uniform exposure did not permit stratification by dose groups of Rongelap people. Fortunately, the influx of unexposed relatives and former inhabitants of the Rongelap atoll have provided an unexpectedly stable comparison group.

The virtual absence of locally recorded vital statistics data as well as the incomplete and frequently inaccurate information filed centrally at Trust Territory Headquarters introduced uncertainty regarding the birth dates of many of the children in the study. This necessitated a painstaking reconstruction of the birth chronology of the childhood population of Rongelap. Birth order and spacing of sibs as well as coincidental births in neighboring families provided useful information. Where conflicting birth dates were given, one most consistent with circumstantial evidence and biologic compatibility was selected as the presumptive birth date. As expected, the recorded information on birth dates checked out validly only in the younger children.

A point of genetic significance that needs further evaluation is the degree of inbreeding that may exist in the population. Schull[26] has reported a significant association between inbreeding and anthropometric measures of growth and development. In a rigidly controlled Child Health Survey on Japanese children, he found that 10 body measurements including height and weight were all depressed in proportion to the child's coefficient of inbreeding.

Complete genealogical information on the Rongelap population is now being tabulated. In the meantime, previously accumulated data on a number of families permits speculations concerning the extent of consanguineous marriages on the island. Among parents of 33 exposed children,



10-824-64

FIG. 9. Skeletal maturation in brothers (Nos. 3 and 83). The older brother (No. 3) has failed to show any significant skeletal development during three successive examinations at 2-year intervals. His younger brother (No. 83) is developing normally and is now about 6 years ahead of his older brother in bone maturation.

there were 5 third cousin, 3 second cousin, and no first cousin marriages. Among 19 paternal and 34 maternal grandparents as well as among 64 great-grandparents of these children, there were no first, second, or third cousin marriages. In contrast, among the unexposed control children, there were 8 first cousin marriages among 23 parents. Among 20 maternal grandparents there were 6 first cousin marriages. No first, second, or third cousin marriages were noted among 25 paternal grandparents and 24 great-grandparents. These preliminary observations suggest that a greater degree of parental inbreeding does not exist among the exposed children.

If the difference in growth noted in this study is the result of exposure to radiation, important questions are raised concerning the mechanisms by which the retardation was brought about. Clinical and biochemical evaluations have demonstrated no apparent abnormalities in endocrine function or mineral metabolism. The beta irradiation delivered to the thyroid did not result in any clinically apparent metabolic dysfunctions and repeated determinations of the serum protein-bound iodine values have been about the same in exposed and unexposed Rongelap children. Persistent environmental factors are eliminated since both exposed and control populations live under identical condition. Thus, it is believed that in these Marshall Islands children any radiation effect on bone growth must have resulted from penetrating gamma radiation at the time of original exposure. As pointed out above, the accumulated dose to the bones from absorbed radionuclides, such as Sr^{90}, is believed to be negligible compared with the dose of gamma radiation originally received. However, the dose of penetrating radiation received was much lower than that expected to produce retardation by direct effect on osseous growth. In rabbits, D'Angio and co-workers[27] found that a dose of 400 r to the entire extremity was required before any grossly observable inhibition of bone growth occurred. The possibility that radiation exposure may produce some indirect, abscopal effect on bone growth has been examined by Conard,[28] who demonstrated in weanling rats a retardation effect on bone growth of shielded legs when the animals were exposed to 300 to 600 rads. This effect was largely accounted for by radiation-induced lowered food intake and weight loss, though preliminary experiments indicated that the abdominal area might be the site of an additional abscopal effect. It was noted that in 25 of 31 exposed Rongelap children, in whom weights were documented, a weight loss of several pounds each occurred during the first 6- to 8-week period following exposure.[1,2] This may have been a reflection of radiation effect on metabolism, but effects of change of environment cannot be ruled out.

SUMMARY

Longitudinal studies on 38 children who were exposed to fallout radiation on Rongelap and Ailingnae atolls, Marshall Islands, in March, 1954, have shown retardation in both statural growth and skeletal maturation among the exposed boys as compared to non-exposed comparison children. The retardation was noted among boys who were under 5 years of age when exposed to the fallout, being most prominent among those who were 12 to 18 months old at time of exposure. No statistically significant differences were noted in the growth patterns between the exposed and the non-exposed group of girls and between 39 children born to exposed parents subsequent to fallout and 53 children born to non-exposed parents.

REFERENCES

1. Cronkite, E. P., Bond, V. P., and Dunham, C. L.: Some Effects of Ionizing Radiation on Human Beings. A report on the Marshallese and Americans accidentally exposed to radiation from fallout and a discussion of radiation injury in the human being. U.S. Atomic Energy Commission TID 5358, Washington, D.C.: U.S. Government Printing Office, 1956, 106 pp.
2. Cronkite, E. P., Dunham, C. L., Griffin, D., McPherson, S. P., and Woodward, K. T.: Twelve-month post-exposure survey on Marshallese exposed to fallout radiation. Brookhaven National Laboratory (BNL) Technical Bulletin 384 (T-71), 1955.
3. Conard, R. A., Huggins, C. E., Cannon, B., Lowrey, A., and Richards, J. B.: Medical survey of Marshallese two years after exposure to fallout radiation. J.A.M.A., 164: 1192, 1957.
4. Conard, R. A., Meyer, L. M., Rall, J. E., Lowrey, A., Bach, S. A., Cannon, B., Carter, E. L., Eicher, M., and Hechter, H.: March 1957 medical survey of Rongelap and Utirik people three years after exposure to radioactive fallout. BNL 501 (T-119), 1958, 26 pp.
5. Conard, R. A., Robertson, J. S., Meyer, L. M., Sutow, W. W., Wolins, W., Lowrey, A., Urschel, H. C., Jr., Barton, J. M., Goldman, M., Hechter, H., Eicher, M., Carver, R. K., and Potter, D. W.: Medical survey of Rongelap people, March 1958, four years after exposure to fallout. BNL 534 (T-135), 1959, 36 pp.
6. Conard, R. A., Meyer, L. M., Robertson, J. S., Sutow, W. W., Wolins, W., and Hechter, H.: Effects of fallout radiation on a human population. Radiat. Res., Supplement 1, p. 280, 1959.
7. Conard, R. A., Macdonald, H. E., Lowrey, A.,

Meyer, L. M., Cohn, S., Sutow, W. W., Blumberg, B. S., Hollingsworth, J. W., Lyon, H. W., Lewis, W. H., Jr., Jaffe, A. A., Eicher, M., Potter, D., Lanwi, I., Riklon, E., Iaman, J., and Helkena, J.: Medical survey of Rongelap people five and six years after exposure to fallout (with an addendum on vegetation). BNL 609 (T-179), 1961, 86 pp.

8. Conard, R. A., Macdonald, H. E., Meyer, L. M., Cohn, S., Sutow, W. W., Karnofsky, D., Jaffe, A. A., and Riklon, E.: Medical survey of Rongelap people seven years after exposure to fallout. BNL 727 (T-260), 1962, 88 pp.
9. Conard, R. A., Meyer, L. M., Sutow, W. W., Moloney, W. C., Lowrey, A., Hicking, A., and Riklon, E.: Medical survey of Rongelap people eight years after exposure to fallout. BNL 780 (T-296), 1963, 74 pp.
10. Conard, R. A., Meyer, L. M., Sutow, W. W., Moloney, W. C., Cannon, B., Hicking, A., and Riklon, E.: Medical survey of the people of Rongelap and Utirik Islands, nine years after exposure to fallout radiation (March, 1963). Interim report. BNL 7766, 1964, 20 pp.
11. Sondhaus, C. A., Sharp, R., Bond, V. P., and Cronkite, E. P.: Radiation characteristics of the fallout material and the determination of the dose of radiation. In reference 1, p. 1.
12. Cohn, S. H., Rinehart, R. W., Gong, J. K., Robertson, J. S., Milne, W. L., Bond, V. P., and Cronkite, E. P.: Internal deposition of radionuclides in human beings and animals. In Reference 1, p. 65.
13. Woodward, K. T., Schrodt, A. G., Anderson, J. E., Claypool, H. A., and Hartgering, J. B.: The determination of internally deposited radioactive isotopes in the Marshallese people by excretion analysis. DASA 1180, 1959.
14. Environmental contamination, annex D. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. General Assembly Official Records, Supplement No. 17 (A/3838), 1958, p. 98.
15. Stewart, T. D.: Hrdlicka's Practical Anthropometry. Philadelphia: Wistar Institute of Anatomy and Biology, 1947, 230 pp.
16. Greulich, W. W., Dorfman, R. I., Catchpole, H. R., Solomon, C. I., and Culotta, C. S.: Somatic and Endocrine Studies of Puberal and Adolescent Boys. Society for Research in Child Development. Washington, D.C.: National Research Council, 1942, 85 pp.
17. Reynolds, E. L., and Wines, J. V.: Individual differences in physical changes associated with adolescence in girls. Amer. J. Dis. Child., 75:329, 1948.
18. Reynolds, E. L., and Wines, J. V.: Physical changes associated with adolescence in boys. Amer. J. Dis. Child., 82:529, 1951.
19. Greulich, W. W., and Pyle, S. I.: Radiographic Atlas of Skeletal Development of the Hand and Wrist. 2nd Ed. Stanford, California: Stanford University Press, 1959, 256 pp.
20. Kruskal, W. H., and Wallis, W. A.: Use of ranks in one-criterion variance analysis. J. Amer. Stat. Ass., 47:583, 1952.
21. Greulich, W. W., Crismon, C. S., Turner, M. A., Greulich, M. A., and Okumoto, Y.: The physical growth and development of children who survived the atomic bombing of Hiroshima or Nagasaki. J. Pediat., 43:121, 1953.
22. Greulich, W. W.: The growth and developmental status of Guamanian children in 1947. Amer. J. Phys. Anthro., N. S. 9:55, 1951.
23. Sutow, W. W.: Summary of medical studies on Hiroshima children exposed to the atomic bomb, 1951–1953. Atomic Bomb Casualty Commission, NYO-4478, 1957, 97 pp.
24. Reynolds, E. L.: Growth and development of Hiroshima children exposed to the atomic bomb. Three year study (1951–1953). Atomic Bomb Casualty Commission, Technical Report 20-59, 1954, 157 pp.
25. Nehemias, J. V.: Multivariate analysis and the IBM 704 Computer applied to ABCC data on growth of surviving Hiroshima children. Health Phys., 8:165, 1962.
26. Schull, W. J.: Inbreeding and maternal effects in the Japanese. Eugen. Quart., 9:14, 1962.
27. D'Angio, G. J., Jung, J., Wright, K. A., and Cohen, J.: Disturbance in bone growth produced by 3.5 Mev electron irradiation of young rabbit limbs. Amer. J. Roentgen., 91: 1132, 1964.
28. Conrad, R. A.: Indirect effect of X-radiation on bone growth in rats. Ann. N.Y. Acad. Sci., 114:335, 1964.

Reprinted from *Pediatrics*, Vol. 36, No. 5
November, 1965