TECHNICAL REPORT
RERF TR 19-84
業績報告書

RELATIONSHIP OF HEIGHT, BODY WEIGHT, HEAD CIRCUMFERENCE, AND CHEST CIRCUMFERENCE AT AGE 18, TO GAMMA AND NEUTRON DOSES AMONG IN UTERO EXPOSED CHILDREN, HIROSHIMA AND NAGASAKI

18歳時の胎内被爆児の身長，体重，頭囲及び胸囲とガンマ線量，中性子線量との関係，広島及び長崎

TORANOSUKE ISHIMARU, M.D., M.P.H. 石丸寅之助
EIJI NAKASHIMA, M.S. 中島栄二
SADAHISA KAWAMOTO, M.D. 河本定久

In cooperation with 研究協力者：
NOBUKO SHIMBA 榛葉信子

放影研
RERF

RADIATION EFFECTS RESEARCH FOUNDATION
財団法人 放射線影響研究所
A Cooperative Japan - United States Research Organization
日米共同研究機関

ACKNOWLEDGMENT
謝　辞

The authors express their appreciation to Dr. William J. Schull, Professor of Population Genetics, the University of Texas Health Sciences Center at Houston for his advice. They are grateful to Mr. Kenji Joji, Chief, RERF Translation Section, for his editorial assistance in preparing the manuscript.

御助言をいただいた Houston 市 Texas 大学保健科学センター集団遺伝学教授の William J. Schull 博士に謝意を表す．本報英文の作成のため御援助をいただいた放影研翻訳室課長定地憲爾氏に対しても感謝する．

In the continued interest of accurately defining the late effects of the atomic bombs, the qualitative and quantitative characteristics of the A-bomb radiation exposure doses are periodically refined. If warranted by future dose assessments, the data reported here will be reanalyzed and subsequently reported.

原爆の後影響を引き続いて正確に究明する目的をもって，原爆放射線被曝線量の質的・量的特質について定期的に改良を加えている．今後線量評価によって，その必要性が起これば，本報の資料を再解析の上，改めて報告する．

RERF TECHNICAL REPORT SERIES
放影研業績報告書集

The RERF Technical Reports provide the official bilingual statements required to meet the needs of Japanese and American staff members, consultants, and advisory groups. The Technical Report Series is not intended to supplant regular journal publication.

放影研業績報告書は，日米専門職員，顧問，諮問機関の要求に応えるための日英両語による公式報告記録である．業績報告書は通例の誌上発表論文に代わるものではない．

The Radiation Effects Research Foundation (formerly ABCC) was established in April 1975 as a private nonprofit Japanese Foundation, supported equally by the Government of Japan through the Ministry of Health and Welfare, and the Government of the United States through the National Academy of Sciences under contract with the Department of Energy.

放射線影響研究所（元 ABCC）は，昭和50年4月1日に公益法人として発足したもので，その経費は日米両政府の平等分担により，日本は厚生省の補助金，米国はエネルギー省との契約に基づく米国学士院の補助金とをもって運営されている．

放影研 RERF RADIATION EFFECTS RESEARCH FOUNDATION
財団法人 放射線影響研究所

Research Project 研究課題 10-80

RELATIONSHIP OF HEIGHT, BODY WEIGHT, HEAD CIRCUMFERENCE, AND CHEST CIRCUMFERENCE AT AGE 18, TO GAMMA AND NEUTRON DOSES AMONG IN UTERO EXPOSED CHILDREN, HIROSHIMA AND NAGASAKI

18歳時の胎内被爆児の身長，体重，頭囲及び胸囲とガンマ線量，中性子線量との関係，広島及び長崎

TORANOSUKE ISHIMARU, M.D., M.P.H. (石丸寅之助)[1]; EIJI NAKASHIMA, M.S. (中島栄二)[1]; SADAHISA KAWAMOTO, M.D. (河本定久)[2]

In cooperation with
研究協力者:
NOBUKO SHIMBA (榛葉信子)[1]

RERF Department of Epidemiology & Statistics[1], and Matsuura Health Center, Nagasaki[2]
放影研疫学統計部[1]，長崎県松浦保健所[2]

SUMMARY

Based on the existing records, reanalysis was undertaken for the measurements of physical characteristics attained at age 18 of the in utero exposed children and their controls in Hiroshima and Nagasaki. To ascertain the relationship of height, bodyweight, head circumference, and chest circumference attained at age 18 to gamma ray and neutron doses received, a stepwise regression analysis was performed. Three dose-response models were examined on the data. When both gamma ray and neutron doses are significantly related to the growth and development of in utero exposed children, the model based on squared gamma dose dependence and linear neutron dose dependence best explains the effect of dose on height and head circumference. The relative biological effectiveness (RBE) of neutrons is estimated to be around $36.6/\sqrt{Dn}$ (Dn=neutron dose) for the effect on height, and around $39.0/\sqrt{Dn}$ for the effect on head circumference. The effect of dose on height is also best explained using the model involving a linear dependence on both gamma ray and neutron doses and in this case the estimated RBE is about 4.9.

要 約

既存の記録に基づき，広島・長崎の胎内被爆児とその対照者について，18歳時の身体計測値の再解析を行った．18歳時の身長，体重，頭囲及び胸囲とガンマ線量及び中性子線量との関係を確認するために，段階的回帰解析を行った．このデータに三つの線量反応モデルを適合させた．ガンマ線量と中性子線量の双方が胎内被爆児の成長・発育と有意に関係がある場合，ガンマ線量の二乗に依存し，中性子線量と線形に依存するモデルが，身長及び頭囲に対する線量影響を最も良く説明できた．この場合中性子線の相対的生物学的効果比（RBE）は身長については約$36.6/\sqrt{Dn}$（Dn＝中性子線量），頭囲については約$39.0/\sqrt{Dn}$と推定された．身長に対する線量影響はガンマ線量と中性子線量の双方に線形に依存するモデルでも良く説明され，この場合の推定 RBE 値は約4.9である．

INTRODUCTION

Wood et al[1] have reported that children exposed in utero within 1,500m of the hypocenter were less advanced in such growth parameters as head circumference, height, and body weight at age 17 than children exposed elsewhere, and Belsky and Blot[2] have shown that the average height among Hiroshima survivors whose age at the time of the bomb (ATB) was less than 6 and who received 100 rad or more was significantly less than controls. Recently, Ishimaru et al[3] have reported that the height attained by survivors whose age ATB was less than 10 decreases with an increase in dose; this decrease is directly proportional to neutron exposure but varies with the square of the gamma dose. Improved dose estimates have become available in Nagasaki based on a new epicenter proposed by Kerr and Solomon.[4] It is also now possible to estimate fetus dose based on the fetus dose/kerma dose conversion factors proposed by Kerr.[5] This report, therefore, attempts to examine growth and development of individuals exposed in utero and their controls in relation to fetus gamma and neutron doses.

A degree of uncertainty has arisen regarding the T65-revised dose (T65DR) system of dosimetry, both with regard to the quality and the quantity of radiation released by the two nuclear devices used on Hiroshima and Nagasaki.[6-8] Therefore, it is not altogether timely to report the analysis of growth and development of in utero exposed children in relation to gamma ray and neutron doses, estimated by the T65DR system. However, the present research protocol was approved before recognition of this uncertainty in the T65DR dosimetry system.

MATERIALS AND METHODS

Subjects Height, body weight, head circumference and chest circumference have been recorded for individuals who were exposed in utero and their controls. These individuals were measured for these parameters until they were 18 years old, as part of an annual health examination administered at ABCC under the PE86 project. The data are available in the files of the Department of Epidemiology and Statistics at RERF. In 1964 annual health examinations were suspended for a variety of administrative reasons. However, biennial health examinations were instituted in 1978 for a smaller sample of in utero exposed individuals.

緒　言

Woodら[1]は，爆心地から1,500m以内で胎内被爆した子供の17歳時における頭囲，身長及び体重等の成長パラメーターがこの距離以遠で被爆した子供よりも低いことを報告し，Belsky及びBlot[2]は，原爆時年齢が6歳未満で，被曝線量が100rad以上であった広島の被爆者の平均身長は対照者よりも有意に低いことを示した．最近石丸ら[3]は，原爆時年齢が10歳未満の被爆者の身長は線量の増加に伴い減少すること，また，この減少は中性子線量に比例するが，ガンマ線量の二乗とともに変化することを報告した．長崎の改訂線量推定値は，KerrとSolomon[4]が提案した新しい爆央に基づいて得られた．Kerr[5]によって提案された胎児線量/kerma線量変換係数に基づき胎児線量を推定することも可能である．したがって本報では，胎内被爆児及びその対照者の成長・発育と胎児のガンマ線量及び胎児の中性子線量との関係を調べた．

広島・長崎に使用された二つの核爆弾から放出された放射線の質及び量の双方について，1965年暫定改訂線量（T65DR）システムに若干の不確実性が生じた．[6-8] したがって，胎内被爆児の成長・発育とT65DRシステムにより推定されたガンマ線量及び中性子線量との関係についての解析を報告するのは必ずしも時宜を得ているとはいえない．しかし，この研究計画書はT65DRシステムによる線量推定の不確実性が認められる以前に承認されたものである．

材料及び方法

対象者　胎内被爆者及びその対照者について身長，体重，頭囲及び胸囲を記録してきた．これらのパラメーターについての記録は，PE86課題に基づきABCCが行った年1回の検診の一環として，対象者を18歳まで計測したものである．このデータは放影研疫学統計部のファイルに収められている．1964年にはこの年1回の検診は，運営上の諸事情のため中止された．しかし，1978年に胎内被爆者の小規模サンプルについて2年ごとの検診を開始した．表1は

Table 1 shows the distribution of the 1,080 subjects of this study by city and total fetus dose, 830 subjects in Hiroshima and 250 in Nagasaki.

広島830名，長崎250名から成る本調査の対象者1,080名の分布を都市別，胎児総線量別に示したものである．

TABLE 1 IN UTERO EXPOSED CHILDREN AND CONTROLS DISTRIBUTED BY CITY AND TOTAL FETUS DOSE
表1　胎内被爆児及び対照者の分布，都市別及び胎児総線量別

City	Total fetus dose in rad				Total
	Control*	1-24	25-49	50+	
Hiroshima	554	231	26	19	830
Nagasaki	179	41	12	18	250
Total	733	272	38	37	1080

*0 rad and not-in-city ATB groups.
0 rad 及び原爆時市内不在群

Dosimetry Individual fetus dose estimates have been calculated using the fetus dose/kerma dose conversion factors proposed by Kerr.[5]

線量推定　Kerr[5]が提案した胎児線量/kerma線量変換係数を用いて，個人別胎児線量推定値を計算した．

Statistical analysis First, to ascertain the relationship of height, body weight, head circumference, and chest circumference to fetus dose, the differences in average height, body weight, head circumference, and chest circumference were examined in relation to total fetus dose, city, and sex. Second, to determine the relationship of each of the four measurements to fetus gamma and neutron doses, the following three dose-response models were applied to the data:

統計的解析　まず，身長，体重，頭囲及び胸囲と胎児線量との関係を確認するために，身長，体重，頭囲及び胸囲の平均値の差を胎児総線量別，都市別及び性別に調べた．次に，四つの計測値各々と胎児ガンマ線量及び中性子線量との関係を決定するために，以下の三つの線量反応モデルをデータに適用した．

Model I Linear dependence on both gamma and neutron dose:

モデルI　ガンマ線量及び中性子線量双方に線形的に依存する：

$$Y=a+b_1X_1+b_2X_2+b_3X_3+b_4D\gamma+b_5Dn$$

Model II Squared gamma dose dependence and linear dependence on neutron dose:

モデルII　ガンマ線量の二乗に依存し，中性子線量に線形的に依存する：

$$Y=a+b_1X_1+b_2X_2+b_3X_3+b_4D\gamma^2+b_5Dn$$

Model III Linear and squared gamma dose dependence and linear dependence on neutron dose:

モデルIII　ガンマ線量に線形的及びその二乗に依存し，中性子線量に線形的に依存する．

$$Y=a+b_1X_1+b_2X_2+b_3X_3+b_4D\gamma+b_5D\gamma^2+b_6Dn$$

where, in each case, Y is a vector specified by measurements of height(cm), body weight(kg), head circumference(cm), and chest circumference(cm). While a, X_1, X_2, and X_3 are, respectively, a constant, city, sex, and weeks of gestation. Dγ and Dn are the gamma and neutron doses in rad. A stepwise regression analysis[9] which treats each measurement as a continuous phenomenon was used.

ここで，いずれのモデルにおいても，Yは身長(cm)，体重(kg)，頭囲(cm)及び胸囲(cm)の計測値により特定化されるベクトルである．a，X_1，X_2 及びX_3 はそれぞれ定数，都市，性及び胎児週齢である．Dγ及びDn はrad を単位とするガンマ線量及び中性子線量である．各計測値を連続現象として処理する段階的回帰解析[9] を用いた．

RESULTS

Relationship of Body Parameters Measured to City, Sex, and Total Fetus Dose

Table 2 shows the mean and standard deviation of height, body weight, head circumference, and chest circumference of subjects by city, sex, and dose, and the results of tests of homogeneity of variance for the four total fetus dose groups by city and sex. Average height tends to decrease with an increase in dose for both sexes and both cities, but the variances in height do not differ significantly by dose. Average body weight also tends to decrease as dose increases for both sexes and both cities, and again, the variances do not differ significantly by dose, except for Nagasaki males. Average head circumference tends to decrease as dose increases for both sexes and both cities. The variance in head circumference differs significantly by dose for both sexes in Hiroshima, but it does not differ significantly by dose for either sex in Nagasaki. Again, average chest circumference tends to be smaller as dose increases for both sexes and both cities. The variance in chest circumference differs significantly by dose for males in both cities, but not for females in either city.

Table 3 gives the results of two-way analyses of variance for height, body weight, head circumference, and chest circumference in relation to sex and dose by city. Height is significantly different by sex and dose in Hiroshima, and by sex but not dose in Nagasaki. Body weight is significantly different by sex and dose for both cities. Head circumference is also significantly different by sex and dose. However, chest circumference is significantly different by sex for both cities, but not by dose for either city. To summarize, height (except in the case of Nagasaki), body weight, and head circumference all appear to be dose-related in both cities, but no effect of dose on chest circumference has been found.

結　果

身体計測パラメーターと都市，性及び胎児総線量との関係

表2に都市，性及び線量別にみた対象者の身長，体重，頭囲及び胸囲の平均及び標準偏差と，都市別，性別にみた四つの胎児総線量群に関する分散の均質性検定の結果を示した．身長の平均値は，男女及び両市ともに線量の増加に伴い減少する傾向にあるが，身長の分散は線量別にみて有意差はない．体重の平均値は，男女及び両市ともに線量の増加に伴って減少する傾向があるが，分散は長崎の男性を除き，線量別にみて有意差を示さない．頭囲の平均値は，男女及び両市ともに線量の増加に伴い減少する傾向にあるが，頭囲の分散は，広島の男女に関しては線量別にみて有意差があるが，長崎の男女においては線量別に有意差はない．更に，胸囲の平均値は，男女及び両市ともに線量の増加に伴い減少する傾向がある．胸囲の分散は，両市の男性に線量別の有意差が認められるが，両市の女性は有意差は認められない．

表3は都市別にみた身長，体重，頭囲及び胸囲の分散と性及び線量との関係の2元分析の結果を示した．身長は広島では性別，線量別にみて有意差があり，長崎では性別では有意差があるが，線量別では認められない．体重は両市とも性別，線量別に有意差がある．頭囲は性別，線量別に有意差がある．しかし，胸囲は両市とも性別にみると有意差があるが，線量別にみると有意差はない．要約すると，身長(長崎の場合は除外する)，体重及び頭囲はすべて，両市とも線量と関連があるように思われるが，胸囲に及ぼす線量の影響は認められない．

TABLE 2 MEAN AND STANDARD DEVIATION OF HEIGHT, BODY WEIGHT, HEAD CIRCUMFERENCE, AND CHEST CIRCUMFERENCE FOR IN UTERO EXPOSED CHILDREN AND CONTROLS AT AGE 18 BY DOSE, CITY, AND SEX

表 2　胎内被爆児及び対照者の18歳時の身長，体重，頭囲及び胸囲の平均及び標準偏差，線量別，都市別及び性別

	Total tissue dose in rad					Homogeneity test of variance
	Control	1-24	25-49	50+	Total	
Height (cm)			Hiroshima, Male			(df)
No.	288	117	13	11	429	
Mean	166.0	165.0	163.5	162.3	165.0	$\chi^2_{(3)}$=.382
SD	5.77	5.82	5.80	6.57	5.84	P>.10, NS
			Hiroshima, Female			
No.	266	114	13	8	401	
Mean	154.1	153.2	153.2	149.1	153.7	$\chi^2_{(3)}$=3.448
SD	5.34	5.55	4.78	7.88	5.47	P>.10, NS
			Nagasaki, Male			
No.	95	26	6	8	135	
Mean	165.0	162.8	165.8	160.5	164.4	$\chi^2_{(3)}$=5.031
SD	6.20	7.90	3.97	7.58	6.63	P>.10, NS
			Nagasaki, Female			
No.	84	15	6	10	115	
Mean	153.6	154.0	153.8	151.6	153.5	$\chi^2_{(3)}$ = 1.404
SD	5.02	4.14	4.54	5.74	4.93	P>.10, NS
Body Weight (kg)			Hiroshima, Male			
No.	288	117	13	11	429	
Mean	55.0	53.7	52.8	53.5	54.5	$\chi^2_{(3)}$=5.953
SD	6.49	7.59	6.51	8.87	6.88	P>.10, NS
			Hiroshima, Female			
No.	266	114	13	8	401	$\chi^2_{(3)}$=2.054
Mean	49.2	47.9	48.3	43.7	48.7	P>.10, NS
SD	5.97	6.34	5.71	7.99	6.16	
			Nagasaki, Male			
No.	95	26	6	8	135	
Mean	54.4	53.6	58.9	50.4	54.2	$\chi^2_{(3)}$=8.679
SD	6.06	8.25	8.60	10.36	6.99	P>.05, *
			Nagasaki, Female			
No.	84	15	6	10	115	
Mean	48.5	48.8	50.6	45.0	48.4	$\chi^2_{(3)}$=.742
SD	5.29	5.62	6.67	5.67	5.48	P>. 10, NS
Head circumference (cm)			Hiroshima, Male			(df)
No.	288	117	13	11	429	
Mean	55.4	55.0	54.1	54.0	55.2	$\chi^2_{(3)}$=9.607
SD	1.38	1.70	1.56	1.97	1.52	P<.05, *
			Hiroshima, Female			
No.	266	114	13	8	401	
Mean	54.3	53.8	53.6	52.2	54.1	$\chi^2_{(3)}$=15.935
SD	1.46	1.63		2.65	1.61	P<.01,**

(Continue 続く)

TABLE 2 (Continued 続き)

	Total tissue dose in rad					Homogeneity test of variance
	Control	1-24	25-49	50+	Total	
			Nagasaki, Male			
No.	95	26	6	8	135	
Mean	55.2	54.9	54.8	52.8	55.0	$\chi^2_{(3)}=3.177$
SD	1.41	1.60	1.50	2.11	5.59	P<.10, NS
			Nagasaki, Female			
No.	84	15	6	10	115	
Mean	54.4	54.7	54.1	53.7	54.3	$\chi^2_{(3)}=1.547$
SD	1.36	1.32	1.17	1.00	1.33	P>.10, NS
Chest circumference (cm)			Hiroshima, Male			
No.	288	117	13	11	429	
Mean	79.1	78.5	78.8	77.7	78.9	$\chi^2_{(3)}=12.423$
SD	4.02	5.12	4.54	5.88	4.41	P<.01, **
			Hiroshima, Female			
No.	266	114	13	8	401	
Mean	74.4	74.2	75.1	71.8	74.3	$\chi^2_{(3)}=1.525$
SD	4.87	4.85	4.23	6.19	4.87	P>.10, NS
			Nagasaki, Male			
No.	95	26	6	8	135	
Mean	81.4	81.3	83.4	78.6	80.7	$\chi^2_{(3)}=1.525$
SD	4.77	6.93	5.73		7.61	P<.05, *
			Nagasaki, Female			
No.	84	15	6	10	115	
Mean	79.2	78.7	79.4	76.4	78.9	$\chi^2_{(3)}=1.250$
SD	4.45	4.95	5.47	5.41	4.66	P>.10, NS

TABLE 3 TWO-WAY ANALYSES OF VARIANCE FOR HEIGHT, BODY WEIGHT, HEAD CIRCUMFERENCE, AND CHEST CIRCUMFERENCE IN IN UTERO EXPOSED CHILDREN AND CONTROLS IN RELATION TO SEX AND DOSE BY CITY
表3 胎内被爆児及び対照者の身長，体重，頭囲及び胸囲の分散と性及び線量との関係の2元分析，都市別

	SS	DF	MS	F	P
Height			Hiroshima		
Sex	29034	1	29034	915.95	<.01 **
Dose	492.9	3	164.31	5.18	<.01 **
Interaction	24.44	3	8.15	0.26	>.05 NS
Between	29521	7	4217.3	133.05	<.01 **
Within	26056	822	31.70		
Total	55576	829			

(Continue 続く)

TABLE 3 (Continued 続き)

	SS	DF	MS	F	P
			Nagasaki		
Sex	7278.2	1	7278.2	210.07	<.01 **
Dose	201.53	3	67.18	1.94	>.05 NS
Interaction	75.90	3	25.30	0.73	>.05 NS
Between	7634.8	7	1090.7	31.48	<.01 **
Within	8384.5	242	34.65		
Total	16019	249			
Body weight			Hiroshima		
Sex	7126.6	1	7126.6	167.88	<.01 **
Dose	432.41	3	144.14	3.40	<.05 *
Interaction	85.15	3	28.38	0.67	>.05 NS
Between	7647.7	7	1092.5	25.74	<.01 **
Within	34896	822	42.45		
Total	42543	829			
			Nagasaki		
Sex	2050.0	1	2050.0	51.90	<.01 **
Dose	371.85	3	123.95	3.14	<.05 *
Interaction	30.37	3	10.12	0.26	>.05 NS
Between	2508.2	7	358.32	9.07	<.01 **
Within	9559.4	242	39.50		
Total	12068	249			
Head circumstances			Hiroshima		
Sex	265.97	1	265.97	113.04	<.01 **
Dose	86.50	3	28.84	12.26	<.01 **
Interaction	4.30	3	1.43	0.61	>.05 NS
Between	355.68	7	50.81	21.60	<.01 **
Within	1934.1	822	2.75		
Total	2289.7	829			
			Nagasaki		
Sex	23.53	1	23.53	11.69	<.01 **
Dose	35.92	3	11.98	5.95	<.01 **
Interaction	14.93	3	4.98	2.47	>.05 NS
Between	77.74	7	11.11	5.52	<.01 **
Within	487.16	242	2.01		
Total	564.90	249			
Chest circumstances			Hiroshima		
Sex	4274.6	1	4274.6	198.54	<.01 **
Dose	86.81	3	28.94	1.34	>.05 NS
Interaction	16.63	3	5.54	0.26	>.05 NS
Between	4369.0	7	624.14	28.99	<.01 **
Within	1769.7	822	21.53		
Total	2200.6	829			
			Nagasaki		
Sex	324.96	1	324.96	16.50	<.01 **
Dose	147.30	3	49.10	2.51	>.05 NS
Interaction	10.09	3	3.36	0.17	>.05 NS
Between	500.80	7	71.54	3.65	<.01 **
Within	4738.1	242	19.58		
Total	5238.9	249			

Sex (M,F), Dose (Control, 1-24, 25-49, and 50+ rad).

Relationship of Body Parameters Measured to Gamma and Neutron Exposure

Table 4 summarizes the stepwise regression analysis of the relationships of height, body weight, head circumference, and chest circumference to gamma and neutron doses and such concomitant factors as city, sex, and gestational age ATB for three dose-response models. The first assumes a linear dependence of each measurement on both gamma and neutron doses (Model I); the second assumes a squared term dependence on gamma rays and a linear term dependence on neutrons (Model II); and the third assumes a linear and squared term dependence on gamma rays and a linear term dependence on neutrons (Model III).

身体計測パラメーターとガンマ線及び中性子線被曝との関係

表4は，三つの線量反応モデルについて，身長，体重，頭囲及び胸囲とガンマ線量，中性子線量並びに都市，性及び原爆時胎児週齢等の随伴因子との関係について段階的回帰解析を行ったものを要約した．第1のモデルは，各計測値がガンマ線量及び中性子線量に線形に依存すると仮定し（モデルI），第2のモデルは，計測値がガンマ線の二乗に依存し，中性子線に線形に依存すると仮定しており（モデルII），また，第3のモデルは，計測値がガンマ線に線形にも，その二乗にも依存し，中性子線に線形に依存すると仮定した（モデルIII）．

TABLE 4 SUMMARY OF THE STEPWISE REGRESSION ANALYSIS OF HEIGHT, BODY WEIGHT, HEAD CIRCUMFERENCE, AND CHEST CIRCUMFERENCE IN RELATION TO CITY, SEX, GESTATIONAL AGE, GAMMA DOSE, AND NEUTRON DOSE

表4　身長，体重，頭囲及び胸囲と都市，性，胎児週齢，ガンマ線量，中性子線量との関係の段階的回帰解析の要約

	Regression Coefficients	Standard error	Partial F-test	P
Model I: $Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4D_\gamma + b_5Dn$				
X_1 = City, X_2 = Sex, X_3 = Gestational age in weeks, D_γ = Gamma dose, Dn = Neutron dose				
Y = Height (cm)				
Sex	11.5783	0.3437	1134.60	<.01**
Gestation week	0.0477	0.0171	7.72	<.01**
D_γ	−0.0464	0.0087	28.67	<.01**
Constant	153.1			
Percentage of variation explained: R^2 = 52.2%				
Unrelated variables: City and Dn				
Y = Body weight (kg)				
Sex	5.8120	0.3892	223.04	<.01**
Gestation week	0.0858	0.0194	19.48	<.01**
D_γ	−0.0417	0.0098	18.04	<.01**
Constant	47.3			
Percentage of variation explained: R^2 = 19.6%				
Unrelated variables: City and Dn				
Y = Head circumference (cm)				
Sex	1.0145	0.0916	122.61	<.01**
Gestation week	0.0068	0.0046	2.25	>.05NS
D_γ	−0.0147	0.0026	32.72	<.01**
Dn	−0.0722	0.0305	5.61	<.05*
Constant	54.1			
Cov. D_γ. Dn = -0.34161×10^{-4}, RBE=4.9 [95% confidence limits: 1.8~13.7]				
Percentage of variation explained: R^2 = 14.9%				
Unrelated variable: City				

(Continue 続く)

TABLE 4 (Continued 続き)

	Regression Coefficients	Standard error	Partial F-test	p
Y = Chest circumference (cm)				
D_γ	−0.0246	0.0071	12.16	<.01**
City	−3.5675	0.3318	115.59	<.01**
Sex	4.0000	0.2767	208.97	<.01**
Gestation week	0.0695	0.0138	25.27	<.01**
Constant	76.97			
Percentage of variation explained: $R^2 = 25.4\%$				
Unrelated variable: Dn				
Model II: $Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4D_\gamma^2 + b_5Dn$				
X_1 = City, X_2 = Sex, X_3 = Gestational age in weeks, D_γ^2 = Squared gamma dose, Dn = Neutron dose				
Y = Height (cm)				
City	0.6752	0.4156	2.64	>.05NS
Sex	11.5776	0.3440	1132.76	<.01**
Gestation week	0.0498	0.0172	8.40	<.01**
D_γ^2	−0.00021	0.000061	12.15	<.01**
Dn	−0.2819	0.1076	6.86	<.01**
Constant	152.4			
Cov. $D_\gamma^2 \cdot Dn = 0.18084 \times 10^{-5}$, RBE = $36.6/\sqrt{Dn}$ [95% confidence limits: $21.5/\sqrt{Dn} \sim 61.7/\sqrt{Dn}$]				
Percentage of variation explained: $R^2 = 52.3\%$				
Y = Body weight (kg)				
Sex	5.8187	0.3897	222.99	<.01**
Gestation week	0.0856	0.0195	19.36	<.01**
D_γ^2	−0.00026	0.000066	15.33	<.01**
Constant	47.1			
Percentage of variation explained: $R^2 = 19.4\%$				
Unrelated variables: City and Dn				
Y = Head circumference (cm)				
Sex	1.0139	0.0921	121.16	<.01**
Gestation week	0.0080	0.0046	2.31	>.05NS
D_γ^2	−0.000073	0.000016	20.97	<.01**
Dn	−0.1145	0.0285	16.09	<.01**
Constant	54.1			
Cov. $D_\gamma^2 \cdot Dn = -0.12982 \times 10^{-6}$, RBE = $39.0/\sqrt{Dn}$ [95% confidence limits: $26.9/\sqrt{Dn} \sim 56.5/\sqrt{Dn}$]				
Percentage of variation explained: $R^2 = 14.0\%$				
Unrelated variable : City				
Y = Chest circumference (cm)				
D_γ^2	−0.00016	0.00005	12.29	<.01**
City	−3.5549	0.3312	115.17	<.01**
Sex	4.0045	0.2767	209.46	<.01**
Gestation week	0.0695	0.0138	25.26	<.01**
Constant	76.9			
Percentage of variation explained: $R^2 = 25.4\%$				
Unrelated variable: Dn				

(Continue 続く)

TABLE 4 (Continued 続き)

	Regression Coefficients	Standard error	Partial F-test	P
Model III: $Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4D_\gamma + b_5D_\gamma^2 + b_6Dn$				
X_1 = City, X_2 = Sex, X_3 = Gestational age in weeks, D_γ = Gamma dose, D_γ^2 = Squared gamma dose, Dn = Neutron dose				
Y = Height (cm)				
Sex	11.5783	0.3437	1134.60	<.01**
Gestation week	0.0477	0.0172	7.72	<.01**
D_γ	−0.0464	0.0087	28.67	<.01**
Constant	153.1			
Percentage of variation explained: R^2 = 52.2%				
Unrelated variables: City, D_γ^2, Dn				
Y = Body weight (kg)				
Sex	5.8120	0.3892	223.04	<.01**
Gestation week	0.0858	0.0194	19.43	<.01**
D_γ	−0.0417	0.0098	18.04	<.01**
Constant	47.3			
Percentage of variation explained: R^2 = 19.6%				
Unrelated variables: City, D_γ^2 and Dn				
Y = Head circumference (cm)				
Sex	1.0145	0.0916	122.61	<.01**
Gestation week	0.0069	0.0046	2.25	>.05NS
D_γ	−0.0147	0.0026	32.71	<.01**
Dn	−0.0722	0.0305		<.05*
Constant	54.1			
Percentage of variation explained: R^2 = 14.9%				
Unrelated variables: City and D_γ^2				
Y = Chest circumference (cm)				
D_γ^2	−0.00016	0.00005	12.29	<.01**
City	−3.5545	0.3312	115.17	<.01**
Sex	4.0045	0.2767	209.46	<.01**
Gestation week	0.0695	0.0138	25.26	<.01**
Constant	76.9			
Percentage of variation explained: R^2 = 25.4%				
Unrelated Variables: D_γ and Dn				

According to Model I, height and body weight vary significantly with sex, gestational age, and gamma dose, but are not significantly related to city and neutron dose. Head circumference varies significantly with sex, gamma dose, and neutron dose, but is not significantly related to gestational age or city. The estimated RBE for the effect of diminished head circumference is calculated to be 4.9 (95% confidence limits: 1.8~13.7). Chest circumference varies significantly with city, sex, gestational age, and gamma dose, but is not significantly related to neutron dose.

モデルIによると，身長及び体重は性，胎児週齢及びガンマ線量に関して有意差を示すが，都市及び中性子線量との関係は有意でない．頭囲は性，ガンマ線量及び中性子線量に関して有意差を示すが，胎児週齢又は都市との関係は有意でない．頭囲の減少の影響に関する推定 RBE は，4.9 (95%信頼限界：1.8～13.7) と計算された．胸囲は都市，性，胎児週齢及びガンマ線量に関して有意差を示すが，中性子線量との関係は有意でない．

According to Model II, height varies significantly with sex, gestational age, gamma dose squared, and neutron dose. When height is examined in relation to both kinds of radiation, Model II was found to explain the data better than either Model I or III. The estimated RBE is calculated to be $36.6/\sqrt{Dn}$ (95% confidence limits: $21.5/\sqrt{Dn}$~$61.7/\sqrt{Dn}$). Body weight varies significantly with sex, gestational age, and gamma dose squared, but is not significantly related to city and neutron dose. Head circumference varies significantly with sex, gamma dose squared, and neutron dose, but is not significantly related to gestational age and city. The estimated RBE for the effect of diminished head circumference is calculated to be $39.0/\sqrt{Dn}$ (95% confidence limits: $26.9/\sqrt{Dn}$~$56.5/\sqrt{Dn}$). Chest circumference varies significantly with city, sex, gestational age, and gamma dose squared, but is not significantly related to neutron dose.

モデルIIによると，身長は，性，胎児週齢，ガンマ線量の二乗及び中性子線量に関して有意差を示す．身長と2種類の放射線との関係を調べる場合，モデルIIはモデルI又はIIIのいずれよりも良くデータを説明することが判明した．推定RBEは$36.6/\sqrt{Dn}$（95%信頼限界：$21.5/\sqrt{Dn}$～$61.7/\sqrt{Dn}$）と算定された．体重は性，胎児週齢及びガンマ線量の二乗に関して有意差を示すが，都市及び中性子線量との関係は有意でない．頭囲は性，ガンマ線量の二乗及び中性子線量に関して有意差を示すが，胎児週齢及び都市との関係は有意でない．頭囲の減少の影響に関する推定RBEは，$39.0/\sqrt{Dn}$（95%信頼限界：$26.9/\sqrt{Dn}$～$56.5/\sqrt{Dn}$）と計算された．胸囲は都市，性，胎児週齢及びガンマ線量の二乗に関して有意差を示すが，中性子線量との関係は有意でない．

According to Model III, height varies significantly with sex, gestational age, and gamma dose, but is not significantly related to city, gamma dose squared, nor neutron dose. Body weight varies significantly with sex, gestational age, and gamma dose, but it is not significantly related to city, gamma dose squared, nor neutron dose. Head circumference varies significantly with sex, gamma dose, and neutron dose, but it is not significantly related to gestational age, city, nor gamma dose squared. Chest circumference varies significantly with city, sex, gestational age, and gamma dose squared, but it is not significantly related to gamma dose nor to neutron dose. Thus, Model III does not explain the data for height, body weight, head circumference, and chest circumference in relation to both kinds of radiation.

モデルIIIによると，身長は性，胎児週齢及びガンマ線量に関して有意差を示すが，都市，ガンマ線量の二乗及び中性子線量との関係は有意でない．体重は性，胎児週齢及びガンマ線量に関して有意差を示すが，都市，ガンマ線量の二乗，中性子線量との関係は有意でない．頭囲は性，ガンマ線量及び中性子線量に関して有意差を示すが，胎児週齢，都市，ガンマ線量の二乗との関係は有意でない．胸囲は都市，性，胎児週齢及びガンマ線量の二乗に関して有意差を示すが，ガンマ線量及び中性子線量との関係は有意でない．したがって，モデルIIIでは身長，体重，頭囲及び胸囲と2種類の放射線との関係が説明されなかった．

Comparison of Height and Body Weight Between Age 18 and 35

A check was made on individuals having records of height and body weight measurements taken at ages 18 and 35, which included 134 subjects with a record of height and 140 individuals with a record of body weight at both ages. Table 5 compares average height and body weight for paired samples at ages 18 and 35. It appears that height nearly had attained a maximum at age 18, whereas body weight had significantly increased from age 18 to age 35. This suggests that body weight had changed with time,

18歳時と35歳時の身長及び体重の比較

18歳及び35歳時の身長及び体重の計測値の記録がある者についての調査では，両年齢時の身長が記録されていた134名と体重が記録されていた140名を対象とした．表5は，18歳と35歳時における対のサンプルの身長と体重の平均値の比較を示した．身長は18歳でほぼ最高に達する．他方，体重は18歳から35歳まで有意に増加したように思われる．これは体重が，恐らく栄養，社会経済的状態及びその他の

presumably due to improvements in nutrition, socioeconomic status, and other factors.

因子の改善により時間の経過とともに変化したことを示唆していると思われる.

TABLE 5 COMPARISON OF AVERAGE HEIGHT AND BODY WEIGHT AMONG IN UTERO EXPOSED CHILDREN AND CONTROLS AT AGES 18 AND 35

表5　胎内被爆児及び対照者の18歳時と35歳時の身長及び体重の平均値の比較

Height		
No. of pairs		134
Average height (cm)	Age 18	153.4
	Age 35	154.0
Statistical test of the difference		
$t = 1.02$, $P > .05$		
Body weight		
No. of pairs		140
Average body weight (kg)	Age 18	54.1
	Age 35	61.0
Statistical test of the difference		
$t = 6.46$, $P < .001$		

DISCUSSION

Wood et al[1] have reported diminished height, body weight, and head circumference among in utero exposed children of A-bomb survivors of Hiroshima and Nagasaki exposed within 1,500m of the hypocenter. They have suggested that a general reduction in growth occurred in children exposed in utero within 1,500m.

It is well known that the two A-bombs differed considerably in radiation released. Hiroshima survivors were exposed to a mixture of gamma and neutron radiation, but Nagasaki survivors received largely gamma radiation, with little neutron exposure even in the high dose region. Therefore, it is essential that the effects of radiation exposure be studied using precisely quantified estimates of gamma and neutron radiation, taken separately. The precision of such estimates is enhanced using fetus dose/kerma dose conversion factors as reported by Kerr[5] in calculating fetal tissue dose, as in the present study.

Our analysis is restricted to the four physical measurements taken at age 18 on in utero exposed children. We assumed that such

考察

Wood ら[1]は，爆心地から1,500m以内で被爆した広島・長崎の被爆者の胎内被爆児における身長，体重及び頭囲の減少を報告した．彼らは，1,500m以内の胎内被爆児は成長の全般的低下が認められることを示唆した．

二つの原爆により放出された放射線が相当異なっていたことはよく知られている．広島の被爆者はガンマ線と中性子線の両方に被曝したが，長崎の被爆者は主としてガンマ線を受け，高線量地域でさえも中性子線にはほとんど被曝しなかった．したがって，ガンマ線及び中性子線の正確に定量化された推定値を使用して，放射線被曝の影響を別々に調べることが肝要である．本調査で行っているように，Kerr[5]によって提案された胎児線量/kerma 線量変換係数を用いた胎児組織線量を使用すれば，この推定値の正確性が向上する．

我々の解析は，胎内被爆児における18歳時の四つの身体計測値に限定した．栄養，社会経済的状態，その他の随伴因子は線量に関係なく調査対象者全員に等しく影響を及ぼすと仮定した．まず，胎児総線量

concomitant factors as nutrition, socioeconomic status, and others affected all subjects studied equally, regardless of dose. First we examined the effects of radiation on these four growth parameters in relation to total fetus dose, and second, the effects on growth of gamma and neutron exposure, taken separately.

The present analysis suggests that average height, body weight, and head circumference decrease with increase in dose for both sexes and both cities, except for height in Nagasaki females. Variations by dose in head circumference in both sexes in Hiroshima and chest circumference in males for both cities were found to be significant. It appears that variation in head circumference in Hiroshima is greater in the higher dose categories. These findings suggest a difference in effect by city due to difference in radiation quality as manifested in diminished growth and development among children who had been exposed in utero. Three simple, commonly proposed dose-response models[10] were applied to the data. This analysis clearly demonstrates that height and head circumference of in utero exposed individuals decrease as a function of the neutron dose and the square of the gamma dose. The estimated RBE values for the effects of radiation in diminishing height and head circumference, respectively, are approximately $36.6/\sqrt{Dn}$ (95% confidence limits: $21.5/\sqrt{Dn}$~$61.7/\sqrt{Dn}$) and $39.0/\sqrt{Dn}$ (95% confidence limits: $26.9/\sqrt{Dn}$~$56.5/\sqrt{Dn}$). The estimated dose-dependent RBE values are quite similar for both height and head circumference. However, the present analysis also shows that the head circumference of in utero exposed individuals depends linearly on both gamma and neutron dose. In this instance, the estimated RBE is calculated to be approximately 4.9 (95% confidence limits: 1.8~13.7).

Although the average body weight was found to be significantly lower with increase in dose, the present analysis failed to produce a significant dose-response function for gamma and neutron radiation in relation to body weight under any of the three models. This is probably due to the fact that body weight depends more on nutrition and socioeconomic status than on dose. It was determined that body weight did not reach a fixed level at age 18, as shown in Table 5.

に関して放射線がこれら四つの成長パラメーターに及ぼす影響を調べ，次に，ガンマ線及び中性子被曝の成長に及ぼす影響を別々に調べた．

本解析では，長崎の女性の身長を除いて，男女及び両市ともに，身長，体重及び頭囲の平均値は線量の増加とともに減少することが示された．広島の男女の頭囲及び両市の男性の胸囲における線量による変動は有意であることが認められた．広島における頭囲の変動は高線量カテゴリーで大きいように思われる．これらの所見は，胎内被爆児の成長，発育の低下で明らかなように，放射線の線質が都市により異なるためであることを示唆している．一般に提案されている三つの単純な線量反応モデル[10]を用いデータに適用した．この解析は，胎内被爆児の身長及び頭囲が中性子線量及びガンマ線量の二乗の関数として減少することを明瞭に立証した．身長及び頭囲の減少に対する放射線の影響に及ぼす推定 RBE 値は，それぞれ約$36.6/\sqrt{Dn}$（95%信頼限界：$21.5/\sqrt{Dn}$～$61.7/\sqrt{Dn}$）及び$39.0/\sqrt{Dn}$（95%信頼限界：$26.9/\sqrt{Dn}$～$56.5/\sqrt{Dn}$）である．身長及び頭囲の線量依存 RBE 推定値は，全く類似している．しかしながらこの解析は，胎内被爆児の頭囲がガンマ線量及び中性子線量に線形に依存することも同時に示している．この場合，推定 RBE は約4.9（95%信頼限界：1.8～13.7）と計算された．

体重の平均値は線量の増加に伴い有意に低下することが判明したが，本解析では，三つのモデルのいずれに基づいても，ガンマ線及び中性子線と体重との関係について有意な線量反応関係を提示することはできなかった．これは恐らく，体重が線量よりも栄養や社会経済的状態に依存するためであろう．表5で示したように，体重は18歳で固定したレベルに達しないことが確認された．

Principal component analysis was also carried out for the six variables of height, weight, chest circumference, sitting height, intercristal diameter, and head circumference for 1,080 subjects, although we did not show the results of this analysis in this report. The analysis showed that approximately 86% of the variations in growth parameters can be explained by the first principal component (size factor), together with the second and third principal components (shape factors). When stepwise regression analysis was carried out for each principal component under the L-L model (Model I), the Q-L model (Model II), and the L-Q-L model (Model III), it was discovered that the Q-L model is the most suitable one for the first principal component. In this case, the value of RBE is estimated to be approximately $32.7/\sqrt{Dn}$ (95% confidence limits: $13.4/\sqrt{Dn}$~$79.6/\sqrt{Dn}$).

The reassessment of A-bomb radiation dosimetry is now in progress.[11,12] It appears that a degree of uncertainty was recognized regarding both the quality and the quantity of T65DR system. Therefore, the data reported here should be reanalyzed after the reassessment of dosimetry, since the present report was prepared merely as a record of our effort.

1,080名の対象者に対して身長，体重，胸囲，座高，稜間直径及び頭囲の六つの変数の主成分解析も行った．しかし，本報には解析結果を示さなかった．この解析では，成長パラメーターの変動の約86%が第二，第三の主成分(形態の因子)とともに第一主成分(大きさの因子)により説明可能であることを示した．L-Lモデル(モデルI)，Q-Lモデル(モデルII)及びL-Q-Lモデル(モデルIII)に基づいて各主成分の段階的回帰解析を行った場合，Q-Lモデルが第一主成分に最適であることが分かった．この場合，RBE値は約$32.7/\sqrt{Dn}$ (95%信頼限界: $13.4/\sqrt{Dn}$~$79.6/\sqrt{Dn}$と推定された．

原爆放射線線量の再評価は現在進行中である．[11,12] T65DRシステムの質及び量の双方に関して若干の不確実性が指摘されている．したがって，本報は単に我々の努力の記録として作成したものであるから，ここで報告されたデータは，再評価された新しい改定線量を用いて再解析すべきである．

REFERENCES
参考文献

1. WOOD JW, KEEHN RJ, KAWAMOTO S, JOHNSON KG: The growth and development of children exposed in utero to the atomic bomb in Hiroshima and Nagasaki. Am J Public Health 57:1374-80, 1967 (ABCC TR 11-66)

2. BELSKY JL, BLOT WJ: Adult stature in relation to childhood exposure to the atomic bombs of Hiroshima and Nagasaki. Am J Public Health 65:489-94, 1975 (ABCC TR 35-71)

3. ISHIMARU T, AMANO T, KAWAMOTO S: Relationship of stature to gamma and neutron exposure among atomic bomb survivors aged less than 10 at the time of the bomb, Hiroshima and Nagasaki. RERF TR 18-81

4. KERR GD, SOLOMON DL: The epicenter of Nagasaki weapon: A reanalysis of available data with recommended values. ORNL-TM-5139 Oak Ridge National Laboratory, 1976

5. KERR GD: Organ dose estimates for Japanese atomic bomb survivors. Health Phys 37:487-508, 1979

6. LOEWE WE, MENDELSOHN E: Revised estimates of dose at Hiroshima and Nagasaki and possible consequences for radiation-induced leukemia. Lawrence Livermore National Laboratory Technical Report D-80-14, Livermore, 1980

7. KERR GD: Findings of recent ORNL review of dosimetry for the Japanese atomic-bomb survivors. ORNL/TM8087, 1981

8. KERR GD: Review of dosimetry for the atomic bomb survivors. Proceedings of the 4th Symposium on Neutron Dosimetry, Munich-Neuhenberg, 1-5 June 1981

9. DRAPER NR, SMITH H: Applied regression analysis, selecting the "Best" regression equation. New York, London, Sydney, John Wiley & Sons Inc., 1966. pp163-216

10. DIVISION OF MEDICAL SCIENCES, NAS-NRC: The Effects on Populations of Exposure to Low Levels of Ionizing Radiation: Report of the Advisory Committee on the Biological Effects of Ionizing Radiations, 1980. Washington, D.C., National Academy Press, 1980

11. US-Japan Joint Workshop for Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki. Proceedings of workshop held at Nagasaki, Japan, 16-17 February 1983, RERF, 1983

12. Second US-Japan Joint Workshop for Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki with Special Reference to Shielding and Organ Doses. Proceedings of a workshop held at Hiroshima, Japan, 8-9 November 1983, RERF, 1984