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ELEVATION OF SYSTOLIC AND DIASTOLIC BLOOD PRESSURE ASSOCIATED WITH MIGRATION: THE TOKELAU ISLAND MIGRANT STUDY

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Abstract—Cross-sectional univariate and multivariate analyses estimated differences between the blood pressure of adult Tokelauan migrants to New Zealand and non-migrants still living on three Polynesian atolls. Response rates were 97 and 99% in the two locations. Among males, the difference between migrants and non-migrants after adjustment for significant covariates was 7.2 mmHg systolic pressure ($p < 0.001$) and 8.1 mmHg diastolic pressure ($p < 0.001$). Among females, adjusted systolic pressure was not significantly higher in migrants compared to non-migrants (1.8 mmHg, $p = 0.065$) and diastolic pressure was only 3.0 mmHg higher ($p < 0.001$). Body mass is significantly correlated with blood pressure in this study group; nonetheless, differences in body mass explain only a small proportion of the observed migrant/non-migrant differential in blood pressure. Estimates of blood pressure differences preceeding migration are also reported. These indicate that blood pressure was neither consistently nor significantly higher among those who subsequently migrated. This report provides compelling evidence linking Westernization and the development of chronic disease.

INTRODUCTION

DESPITE decades of careful work, the relationship between blood pressure and social environmental factors such as urbanization and Westernization remains unclear. Studies of migrants from more traditional and rural societies with low blood pressures would seem to provide especially valuable insights; yet even here the evidence is equivocal. South African Zulus who migrated to urban centres demonstrated higher pressure than those remaining in rural areas [1]. Similarly, Stamler found the prevalence of elevated systolic pressure was higher among Blacks born and raised in Chicago than among recent Black immigrants from the rural American southeast [2]. After about a decade of life in Chicago, prevalence of hypertension among immigrants equalled that of the city-born blacks. It has also been shown that Polynesians living on Easter Island have somewhat lower blood pressures than migrants from the same island living in Chile [3]. Results of this study are of special interest as the authors found considerable genetic homogeneity across the two study groups. In a similar vein, examination of Irish-born sibships separated by migration also revealed a higher prevalence of hypertension among migrants to the United States than among non-migrants still in Ireland [4].

Other important studies of blood pressure in migrants have produced quite different results. In the New Hebrides, urban residents have blood pressures little different from those in traditional rural areas and in neither group did blood pressure rise much with age [5]. The NiHon-San study of Japanese men living in Japan, Hawaii, and California also failed to reveal a consistent relationship between migration and blood pressure [6]. Though the age-adjusted prevalence of hypertension was greater in California than Japan, Hawaiian Japanese (presumably intermediate in Westernization between Japan and California) had the lowest prevalence of all. Furthermore, intensive studies of individual acculturation status and blood pressure revealed no increase in blood pressure with Westernization in either California [7] or Hawaii [8].

On the whole, the reader is left with the disquieting impression that difficulties in the design of migrant studies may lead to such inconclusive or contradictory findings. In particular, unspecified and unquantifiable selection factors may produce rather dissimilar individuals in the migrant and non-migrant groups [9]. Concerns about sampling and non-participation also arise. Indeed, problems such as these may be sufficient to explain our current perplexities concerning migration and blood pressure. This report presents analyses of adult systolic and diastolic blood pressure among migrants and non-migrants from Tokelau to New Zealand. These data are a part of multidisciplinary, longitudinal study of migration and health which commenced in 1967 [10, 11]. The overall hypotheses being examined by the Tokelau Island Migrant Study deal with physical and sociocultural contribution to the development of chronic disease following migration; geneologies have been collected and a major pedigree file is being developed. Special features of this study were developed in response to the typical problems of migration studies discussed above. Since many individuals were examined prior to migration, selection for migration can be quantified and examined. Furthermore, the study includes virtually every Tokelauan living in New Zealand or on the atolls and non-participation rates are extremely low. In order to provide a context for analyses of migration and blood pressure it is important to describe the contrast between life before and after migration. Non-migrants continue to live on the three small atolls which make up the Tokelau Islands and are located approximately 480 km north of Samoa, 3200 km from New Zealand. At the time of these examinations the atolls were visited infrequently by ships, life followed stable and traditional patterns of social organisation that had been largely unchanged since the introduction of Christianity almost 100 yr ago [12]. Led by male elders who made major community decisions individuals functioned within cohesive family and kin-based work units, called *kaiga* [13]. Though there was a small cash sector, the economy was a subsistence one based on fishing and the harvesting of coconuts for food and copra. Money sent from migrants in New Zealand to relatives provided an important source of income for many families. There was a marked sex role differentiation; men fished and worked in the coconut groves while women remained in the villages tending to the responsibilities of home and family [14]. In Tokelau, the stable foods were coconut, fish, and breadfruit supplemented by imported flour, rice, and sugar. Fat intake, derived from coconut, was high and protein intake, though modest, was adequate.

A New Zealand dependancy since 1925, Tokelau became part of New Zealand in 1948, giving Tokelauans both New Zealand citizenship and the right of entry. This also clearly established New Zealand Government responsibility for Tokelau and its people. Following a devastating hurricane in 1966, a programme of assisted migration was established to bring those who wished from Tokelau to New Zealand [11]. Though comparatively few individuals were assisted in this way, a process of "chain migration" was established whereby those already in New Zealand brought over other family members from Tokelau or Samoa where many were working or studying. Eventually, about half the population of the atolls migrated to New Zealand. By the time of these examinations 1517 Tokelauan adults and children were living on the atolls while 2365 were in New Zealand. The New Zealand migrants settled in the large centres of a country with a modern western culture. Men, and some women worked for wages, largely in unskilled factory jobs. Diet in New Zealand was much more diversified; though fish was still frequently eaten, immigrants also used eggs, dairy products, and red meat. Simple carbohydrate and salt intake increased while fat supplied a smaller proportion of total energy [16]. On the whole, life for migrants was very different from that on the atolls. At the same time, the majority were still involved to varying degrees in Tokelauan community activities in New Zealand [15].

STUDY DESIGN AND METHODS

The criteria for inclusion in the study population, overall study design and details of examination methods have been described elsewhere [10, 11]. Examinations being reported here were conducted on adult males and females 15 yr of age or older during

1976 in Tokelau and during 1975–77 in New Zealand. In Tokelau, 807 individuals were examined and in New Zealand, 1181. This constitutes a 99% response rate on the atolls and a 97% response rate in New Zealand [16]. The analyses which follow are confined to adults under the age of 75, of whom 784 were in Tokelau and 1119 in New Zealand. Five men and 18 women on antihypertensive medications were excluded from the analyses, as were all pregnant women. Those examined in New Zealand had lived in that country for an average of 5.4 yr (median length of stay was also 5.4 yr). Blood pressures were determined by use of a random zero sphygmomanometer with the cuff placed on the participant's right arm while seated. Both 4th and 5th phase diastolic pressures were determined. Two pressures were obtained by different observers from each participant and results reported here are the average of the two readings. In defining hypertension WHO standard criteria have been applied: definite hypertension (systolic BP ⩾160 mmHg and/or diastolic BP ⩾95 mmHg) and borderline hypertension (systolic BP 140–159 mmHg or diastolic BP 90–94 mmHg) [17]. Height and weight were determined by use of standard scales and measurement techniques. Calibration of the scales was routinely checked against standards. The Quetelet body mass index was subsequently calculated as (weight/height^2). Blood specimens were obtained 1 hr after ingestion of 100 g glucose load; sera were frozen and subsequently analysed at the Epidemiology Unit laboratory in Wellington, New Zealand, which participates in the CDC Quality Control Program. Casual early morning urines were obtained and analysed for sodium and potassium in the same laboratory. Earlier work demonstrated that the correlation between urinary sodium determined in this fashion and blood pressure was at least as strong as that obtained using a 24 hr specimen [17]. Time in New Zealand was recorded as zero for those in Tokelau and decimal years for migrants. Marital status was a binary measure comparing the married with all others (single, widowed, divorced and separated).

The analyses which follow address the null hypothesis that there is no difference between the blood pressure of migrants and non-migrants. Standard statistical programs generated by the Statistical Package for the Social Sciences [18] and the Statistical Analysis System [19] were used throughout.

RESULTS

Blood pressures among migrants and non-migrants are shown in Figs 1 and 2 for both men and women. An elevation associated with migration is more apparent in males than females; blood pressures among male migrants are higher than those of non-migrants at all ages while for females this is not true at the extremes of age. The mean systolic pressures in females 15–19 yr old were also found to be higher in Tokelau than New Zealand in the previous round of examinations [17]. The explanation for this is not clear.

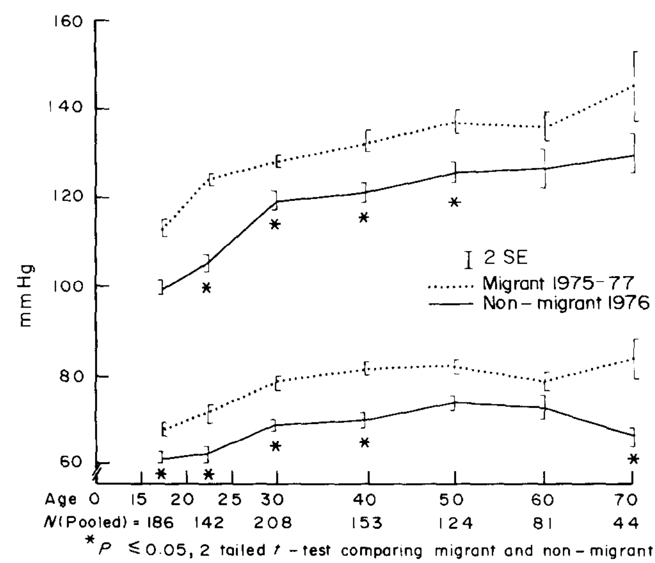

Fig. 1.

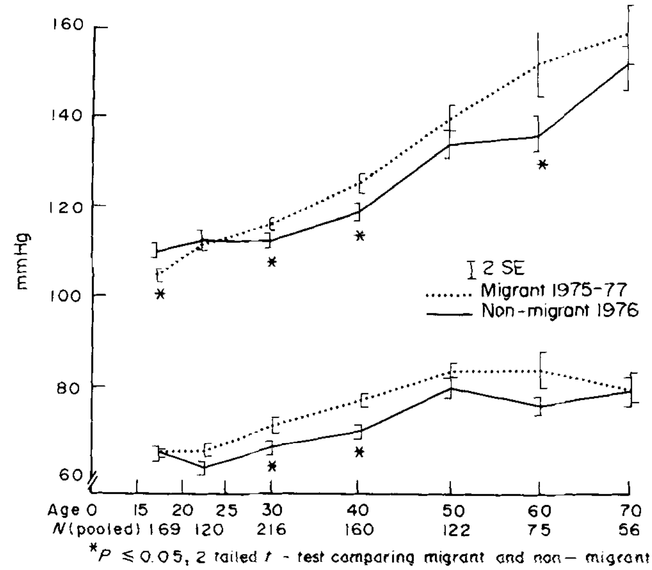

FIG. 2.

The following factors were screened by use of a step-wise multiple regression procedure for their relationship to both diastolic and systolic pressure within sexes: age; the sum of subscapular and triceps skin folds; Quetelet body mass index; serum cholesterol; early morning urinary sodium; the ratio of early morning urinary sodium and potassium; marital status. On the basis of these preliminary analyses, the following conclusions were derived. In both sexes, age and body mass index are significant covariates of systolic and diastolic pressure. Among women only, marital status and serum cholesterol are also related to both systolic and diastolic blood pressure. More specifically, women with lower serum cholesterol have lower blood pressure and married women have lower blood pressure than the single, widowed, or divorced. Migration was considered as a binary variable representing residence in Tokelau (scored 0) or New Zealand (scored 1). These factors were considered in an analysis of covariance, the results of which are shown in Table 1 (males) and Table 2 (non-pregnant females). The estimated increase in blood pressure among migrants was obtained by calculating the difference between blood pressure among those in New Zealand and those in Tokelau. Both the unadjusted difference and the difference adjusted for the significant covariates described above are reported.

Among men, systolic and diastolic pressures were significantly higher among migrants than non-migrants after controlling for the effects of age and body mass; systolic pressures were 7.2 mmHg higher ($p < 0.001$) and diastolic pressures 8.1 mmHg higher ($p < 0.001$). It is apparent that though differences in age structure and body mass are contributing to the observed increase, they explain relatively little.

TABLE 1. UNADJUSTED AND ADJUSTED MEAN DIFFERENCE BETWEEN MIGRANT AND NON-MIGRANT BLOOD PRESSURES: RESULTS OF ANALYSIS OF COVARIANCE FOR MALES

	Mean difference (mmHg)	95% confidence interval	p
Systolic pressure			
Unadjusted	8.5	6.3–10.7	<0.001
Adjusted for:			
Age	10.7	8.7–12.7	<0.001
Age & body mass	7.2	5.2–9.2	<0.001
Fourth phase diastolic pressure			
Unadjusted	9.6	8.0–11.2	<0.001
Adjusted for:			
Age	10.9	9.3–12.5	<0.001
Age & body mass	9.1	6.7–9.5	<0.001

TABLE 2. UNADJUSTED AND ADJUSTED MEAN DIFFERENCE BETWEEN MIGRANT AND NON-MIGRANT BLOOD PRESSURES: RESULTS OF ANALYSIS OF COVARIANCE FOR NON-PREGNANT FEMALES

	Mean difference (mmHg)	95% confidence interval	p
Systolic pressure			
Unadjusted	−1.2	−3.9–1.4	0.353
Adjusted for:			
Age	2.4	0.2–4.6	0.027
Age and body mass	1.0	−1.0–3.0	0.326
Age, body mass & marital status	1.9	−0.1–3.9	0.055
Age, body mass, marital status & serum cholesterol	1.8	−0.2–3.8	0.065
Fourth phase diastolic pressure			
Unadjusted	2.3	0.7–3.9	0.005
Adjusted for:			
Age	3.8	2.3–5.4	<0.001
Age and body mass	2.7	1.3–4.1	<0.001
Age, body mass, & marital status	3.0	1.6–4.4	<0.001
Age, body mass, marital status & serum cholesterol	3.0	1.5–4.3	<0.001

Among women, the relationship between migration and blood pressure is less dramatic. As shown in Table 2, the increase in systolic blood pressure among migrants does not achieve statistical significance. Adjusted 4th phase diastolic pressure is 3 mmHg higher among migrants ($p < 0.001$), less than half the increase seen in males. Furthermore the effects of adjustment for covariates is different from that found in men. Among women the adjusted estimates are actually higher than the unadjusted. It should also be noted that these estimates are influenced by the inclusion of the youngest women in whom the impact of migration on blood pressure is negligible. Exclusion of women less than 20 would produce an estimated difference in both systolic and diastolic pressure of almost 4 mmHg after adjustment for covariates.

Further examination of Tables 1 and 2 suggests that differences in body mass explain some of the increase in blood pressure associated with migration among both men and women in this study group. In order to explore this factor further, sex and age-specific comparisons of body mass in migrants and non-migrants are shown in Figs 3 and 4.

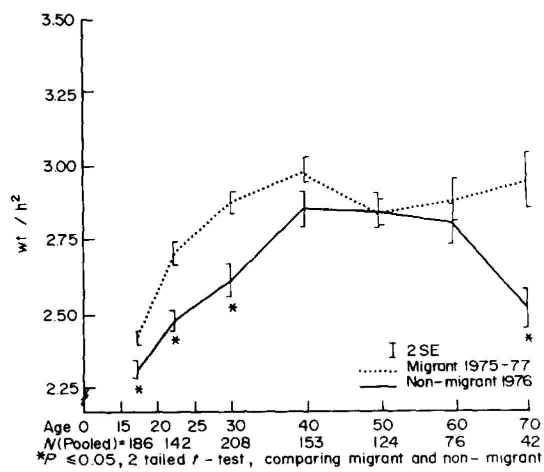

FIG. 3.

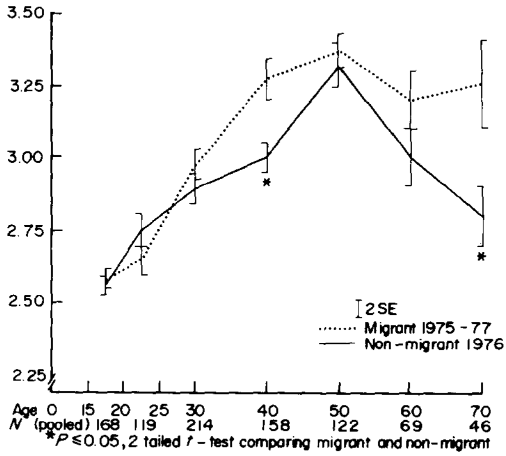

FIG. 4.

Body mass in both sexes tends to increase until midlife when it again declines. For males this peak occurs among 35–44 yr olds, while among females it is seen a decade later. In both sexes body mass is much greater among the elderly in New Zealand. In addition to age, these differences in body mass appear to be the most important factor associated with blood pressure. This relationship was more specifically explored by examining the correlation between blood pressure and body mass while controlling for age. The partial correlations thus obtained ranged from 0.39 to 0.51 ($p < 0.001$ for each comparison).

Like body mass, sodium intake has also been suggested as an important determinant of blood pressure [20, 21]. In this study, urinary electrolytes were estimated for each individual by analysis of the early morning voided specimen. As mentioned earlier, both urinary sodium and the ratio of sodium to potassium were screened for their relationship to blood pressure; on the basis of these results neither factor was considered in the analysis of covariance. This is not surprising as a single determination is probably insufficient to provide a stable estimate of individual electrolyte excretion [22, 23]; individual variability is sufficiently great that multiple determinations are required. Nonetheless, it is also possible to use data collected in this study to estimate group means for migrants and non-migrants. Shown in Table 3 are age-adjusted means for urinary electrolytes in the two environments. These values are largely unchanged since determinations 3–5 yr earlier [17]; it is likely that the higher levels in New Zealand are a

TABLE 3. EARLY MORNING URINARY ELECTROLYTE CONCENTRATIONS: AGE-ADJUSTED MEANS AND STANDARD ERRORS

	Sodium (mEq/l)	Potassium (mEq/l)	Sodium/potassium
Males			
Tokelau			
Mean	69.24	89.64	0.83
SE	1.07	1.29	0.02
New Zealand			
Mean	110.33	51.71	2.62
SE	0.96	0.51	0.30
Females			
Tokelau			
Mean	63.79	91.04	0.89
SE	0.92	1.01	0.14
New Zealand			
Mean	90.91	54.03	2.28
SE	1.06	0.61	0.03

consequence of Westernization, especially dietary changes. Such data are consistent with the hypothesis that sodium levels are related to blood pressure levels and that changing sodium and potassium intakes could be factors contributing to the higher blood pressure levels in the migrant.

Not only blood pressure, but the clinical problem of hypertension was also investigated in this study. Standard WHO blood pressure criteria were applied to systolic and diastolic pressure to identify both borderline and definite hypertension [17]. Individuals currently on antihypertensive medication were included as definite hypertensives in the calculations which follow. As shown in Table 4, the age-adjusted prevalence of both borderline and definite hypertension is higher among migrants than non-migrants. (Age-specific rates of hypertension are given in Appendix 1.) Though this categorical measure of hypertension status is less sensitive than a continuous measurement of blood pressure it nonetheless reflects something of the clinical sequelae and risk status following migration in this study group.

In summary, these analyses demonstrate a significant elevation in both systolic and diastolic blood pressure associated with migration. Among men this increase was originally estimated to be about 9 mmHg, but after adjustment for significant covariates fell to between 7 and 8 mmHg. Among women the increase is less than half that observed in males. Age and body mass were the most important factors influencing blood pressure in both sexes; clinically, both definite and borderline hypertension were more apparent among migrants than non-migrants.

DISCUSSION

The possibility exists that these findings do not represent an underlying difference between migrants and non-migrants, but instead result from some systematic bias. This seems unlikely for several reasons. Response rates were remarkably high among both migrants and non-migrants and the non-response of a few individuals is unlikely to explain these relatively large differences in blood pressure. Measurement of blood pressure itself was standardized by use of random zero sphygomanometer and two observers; a systematic bias of many mmHg is unlikely to occur under these circumstances. Finally, it is theoretically possible that systematic selection results in migration by individuals whose blood pressure is higher than those of non-migrants. In such a case, observed differences would reflect selection for migration instead of the consequences of migration. It is this possibility which the Tokelau Migrant Study was designed to examine. Previous work has examined blood pressure and health prior to migration (and in most cases even prior to the decision to migrate from Tokelau to New Zealand). These analyses are reviewed in Table 5. Among males, younger pre-migrants had slightly higher blood pressures and older pre-migrants slightly lower blood pressures than those who remained in Tokelau. Except at the youngest ages, female pre-migrants did not differ in any way from non-migrants before migration. It seems likely, then, that the elevation of blood pressure described here is not the result of non-response, biased assessment, or selection. These results therefore, provide important evidence linking migration and Westernization to the development of chronic disease in this study group. It is apparent that some of this change is due to physiologic sequelae of weight gain but much of it remains unexplained. Both cross-sectional and longitudinal studies of Tokelauan children have also demonstrated higher pressures among those living in New Zealand [25, 26]. This suggests that migration has a general effect on blood pressure at virtually every age.

TABLE 4. AGE-ADJUSTED PREVALENCE (PER HUNDRED) OF HYPERTENSION

	Males		Females	
	Migrants	Non-migrants	Migrants	Non-migrants
Borderline	16.6	6.4	10.6	4.6
Definite	9.4	2.6	10.3	7.6

TABLE 5. MEAN BLOOD PRESSURE AMONG NON-MIGRANTS AND PRE-MIGRANTS IN TOKELAU, 1968

		Systolic		Diastolic	
	N	X̄	SE	X̄	SE
15–19					
Males					
NM	31	111.7	2.2	64.6	2.2
PM	38	117.9	2.3	66.5	2.0
Females					
NM	46	123.0	2.0	76.4	1.4
PM	35	118.8	1.9	72.3	1.9
20–24					
Males					
NM	17	120.1	2.8	67.8	3.3
PM	9	124.1	4.3	68.7	2.9
Females					
NM	28	115.4	2.4	74.1	1.6
PM	13	116.3	2.7	77.8	1.9
25–34					
Males					
NM	38	119.9	2.3	71.5	2.0
PM	19	127.6	4.4	70.3	2.4
Females					
NM	57	119.5	1.6	74.3	1.4
PM	17	116.2	3.6	76.2	2.3
35–44					
Males					
NM	44	127.1	2.1	78.4	1.6
PM	31	124.9	2.2	74.5	1.5
Females					
NM	65	127.9	3.2	79.6	1.7
PM	21	132.6	4.1	78.4	3.1
45–54					
Males					
NM	35	136.8	5.7	81.9	3.7
PM	29	123.9	2.4	72.8	1.5
Females					
NM	40	140.2	2.3	86.2	2.2
PM	23	142.8	6.9	84.5	3.2
55–64					
Males					
NM	20	134.4	4.9	78.8	3.5
PM	15	134.2	6.2	77.9	3.5
Females					
NM	34	144.9	4.4	83.7	2.4
PM	18	146.1	5.3	86.6	4.2

These results also highlight important and intriguing sex differences. Among both migrants and non-migrants, blood pressure in females rises more steeply than that of males between ages 20 and at least 50. This leads to the well-described "cross-over" effect with female pressures rising above those of males during mid-life. This cross-over actually occurs considerably later in migrants (at about age 45) than in non-migrants (at about age 30); it seems likely that this difference in timing is explained by the impact of migration on male blood pressure; increased pressure in male migrants would logically postpone the age at which female pressures could overtake theirs. More intriguing still, it appears that in this group migration has less effect on the blood pressure of females than of males. It would be tempting to explain this differential by a kind of "saturation" effect: because even in the atolls female blood pressure rises more steeply than that of males from about age 30 it is unable to respond further following migration. No major additional increase is physiologically possible and thus migration appears to have less effect. Unfortunately, this relatively straightforward explanation is not consistent with observed facts. If "saturation" were explaining the minimal female response, one would expect a more pronounced response to occur wherever possible, e.g. at younger ages and in the diastolic component of blood pressure. Yet this is not the case and a "saturation" effect seems less compelling an explanation given this inconsistency. In this regard, it is interesting to note again the consistently higher pressures found among young females in Tokelau when compared to New Zealand. The social anthropologists have suggested that the behaviour of the non-migrant young females may be particularly constrained by family and social pressures when compared with young males.

In addition to such sex differences, these analyses also point to differences in the character of systolic and diastolic pressures. Among both males and females, diastolic pressure responds more to the effects of migration. These findings are consistent with recent work which appeared to demonstrate a greater role for environmental control of diastolic than systolic pressure [27].

In conclusion, it seems that three observations emerge from this work:

(1) Blood pressure is higher among migrants than non-migrants;
(2) Blood pressure response among migrants is greater in males than females;
(3) Diastolic pressure of migrants responds more sharply to migration than does sys-systolic.

At this point these observations cannot be "explained". They provide evidence, however, that a complex of interrelated biological and environmental factors may be implicated in the development of hypertension. The longitudinal epidemiological and genetic analyses of this study group currently in progress are intended to provide more complete examination of these unresolved questions. In this way the Tokelau Island Migrant Study continues to investigate issues raised by the late John Cassel [28].

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APPENDIX

TABLE A1. AGE-SPECIFIC PREVALENCE (PER HUNDRED) OF DEFINITE AND BORDERLINE HYPERTENSION

	15–19	20–24	25–34	35–44	45–54	55–64	65–74
Males							
Migrants							
Borderline	6.5	6.7	15.3	23.8	27.4	38.8	30.8
Definite	0.9	3.8	8.2	15.2	16.4	12.8	23
(*N*)	(108)	(104)	(170)	(105)	(73)	(39)	(13)
Non-Migrants							
Borderline	0	0	7.9	14.6	15.7	9.5	16.1
Definite	0	2.7	0	2.3	2.4	11.9	12.9
(*N*)	(78)	(38)	(38)	(48)	(51)	(42)	(31)
Non-pregnant females:							
Migrants							
Borderline	0	0	5.0	21.5	18.0	25.0	21.1
Definite	0	1.2	2.2	5.0	24.6	33.3	47
(*N*)	(92)	(81)	(139)	(79)	(61)	(24)	(19)
Non-Migrants							
Borderline	0	0	0	4.9	13.1	13.0	21.6
Definite	0	0	1.3	4.0	21.3	17.4	40.5
(*N*)	(77)	(39)	(77)	(81)	(61)	(46)	(37)