Sodium in drinking water and adolescent blood pressure

by Jean Charlotte Forseth

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF NURSING
Montana State University

Abstract:
The blood pressures of thirty-three healthy fourteen through sixteen year old high school students from a community with drinking water sodium of 378 mg/l were compared with blood pressures of thirty-four students of similar age and health from a control community that had 2.1 mg/l of sodium in the drinking water supply. Data were collected by questionnaire and measurement of variables known to affect blood pressure. Mean systolic and mean diastolic pressures for each group and for males and females were analyzed by t-test. Intervening variables were analyzed for correlation with blood pressure, then analysis of co-variance produced adjusted mean systolic and diastolic pressures for the two groups after controlling for the effect of the intervening variables. The high sodium group had higher systolic and diastolic means than the control group but only mean female diastolic pressure was significantly higher than the control group mean.

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Signature Jean C. Forseth

Date May 21, 1981

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by

JEAN CHARLOTTE FORSETH

A thesis submitted in partial fulfillment
of the requirements for the degree

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Approved:

Ruth Vandenhorst
Chairperson, Graduate Committee

Anna M. Shannon
Head, Major Department

Michael Malone
Graduate Dean

MONTANA STATE UNIVERSITY
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TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

The blood pressures of thirty-three healthy fourteen through sixteen year old high school students from a community with drinking water sodium of 378 mg/l were compared with blood pressures of thirty-four students of similar age and health from a control community that had 2.1 mg/l of sodium in the drinking water supply. Data were collected by questionnaire and measurement of variables known to affect blood pressure. Mean systolic and mean diastolic pressures for each group and for males and females were analyzed by t-test. Intervening variables were analyzed for correlation with blood pressure, then analysis of co-variance produced adjusted mean systolic and diastolic pressures for the two groups after controlling for the effect of the intervening variables. The high sodium group had higher systolic and diastolic means than the control group but only mean female diastolic pressure was significantly higher than the control group mean.

CHAPTER 1

INTRODUCTION

For many years, there has been controversy about the role of sodium in hypertension development. During clinical experience in a rural community, the investigator discovered that the water was very soft and tasted like sodium bicarbonate. In the course of ethnographic interviews with an elderly population sample, histories of hypertension were common. Hypertension prevalence increases with age, so many elderly persons with hypertension would not be an uncommon finding. Upon further investigation, water analysis (State Water Quality Bureau, 1977) revealed the drinking water sodium level to be 440 mg per liter which could provide a source of an additional gram of sodium per day. The water sodium level was not known by members of the health care professions or the public in that town. The American Heart Association in 1957 (Your 500 Milligram Diet) proposed a limit of 20 mg/l of sodium in drinking water to protect persons on low sodium diets from additional sources of sodium. Several studies have associated water sodium levels lower than 400 mg with elevated blood pressure in animals and humans.

Findings of a possible connection between water sodium and hypertension in this community stimulated investigation into the likelihood of water sodium's contribution to elevated blood pressures in a healthy sample of the population. The sample selected for study was a group of teenagers, 14 through 16 years old, because that age group would be less likely to have much chronic disease and medication use which could interfere with a study of blood pressure levels. Blood pressures of a healthy group of adolescents in a town with high drinking water sodium (experimental) were compared with a comparable group in a town with a low (2.5 mg/l) drinking water sodium level (control group).

A study of the effect of water sodium levels and blood pressure could have significance for the population of a town with high sodium in drinking water. If blood pressures were elevated in young healthy people, that effect could be expected to continue since blood pressure rises with age. More hypertension or stroke prevalence could be associated with water sodium intake. The effect of higher drinking water sodium levels than had been previously studied was the focus of this study. Sodium's effect on health was measured by blood pressure. Such a study could add to data about water sodium hazards and contribute to determination of the necessity for drinking water sodium standards. The findings could aid communities in providing public awareness of hidden sources of sodium and its effect on health.

The high sodium community's water supply comes from three deep wells. Water from shallow wells is usually mineralized with calcium and magnesium (hard water). In deep wells, higher sodium levels are found because calcium and magnesium are exchanged for sodium in rock formations as water seeps into the ground. If ion exchange materials are not available, or the rock is limestone in composition, levels of sodium in ground water are low (Calabrese and Tuthill, 1978).

Other sources of sodium in drinking water are artificial water softening, addition of large amounts of sodium hypochlorite for water disinfection, or sodium hydroxide to precipitate iron from the water. Road salting is another source of sodium contamination of drinking water and is in greatest use in large metropolitan areas of the northern United States (National Academy of Sciences, 1977). It is most likely that deep well ion exchange is mainly responsible for the high sodium level in the study community.

There has been no standard set for the level of sodium in drinking water nationally or on a state level. The Safe Drinking Water Act which became effective with Interim Primary Regulations in June 1977, did not list a maximum allowable level for sodium in drinking water. The Environmental Protection Agency did not include a standard for sodium because there were insufficient and conflicting studies about the effect of sodium on health on which to base a standard. It was also believed that the minority affected by salt restricted diets could be managed by their physicians without forcing the majority to pay for further water treatment (U. S. Environmental Protection Agency, 1971). A standard of 100 mg/l was suggested (National Academy of Sciences, 1977) to assure that less than 10% of dietary intake of sodium would be provided by drinking water. Montana has 40 communities with water sodium levels over 20 mg/l. Of these, 28 communities have water sodium levels over 270 mg/l, the level used by the Montana Water Quality Bureau (unknown year) to advise town mayors of potential harm to persons on sodium restricted diets. One town has water sodium of 798 mg/l. The problem is most prevalent in the eastern portion of the state.

A portion of the reluctance of Federal agencies to establish a standard for sodium in drinking water may be related to findings which have illustrated that most people consuming high sodium do not become hypertensive. Because it is difficult for persons culturally accustomed to high sodium intake to modify their diets, and desalinization of water is very expensive, some believe that it is not necessary to reduce sodium for an entire population. It may suffice to provide early detection and treatment for the minority of salt sensitive individuals (Abramowicz, 1980). If such individuals could be identified and receive follow up care prior to hypertension development, such an approach might be adequate. Without that ability, it seems necessary that investigation continue into hazards of high sodium intake and ways to reduce unnecessary sodium intake.

One such study demonstrated higher blood pressures in adolescents consuming 107 mg/l of sodium in community drinking water (Tuthill and Calabrese, 1979).

Nursing is a profession concerned with promotion of health and health-seeking behaviors. High sodium intake is of importance to nurses in teaching patients and families affected by hypertension, renal insufficiency, arteriosclerotic disease, congestive heart failure, liver failure and toxemia of pregnancy. Therefore, nurses, as well as other health professionals, should be aware of high water sodium levels and include such information in health promotion activities. Groups which could be affected by high sodium intake have been identified. Newborns fed formula diluted with high sodium concentration water could be at increased risk for the development of hypernatremia, especially when ill. The elderly population could be at higher risk for severe dehydration development when consuming high sodium water in the presence of the reduced kidney function which accompanies the aging process. In some schools in Montana, it is still common practice to distribute salt tablets to athletes with plenty of water intake during hot weather. In a high water sodium community, this practice could be quite dangerous. Those hazards of high sodium intake should certainly be addressed by those responsible for the provision and promotion of health.

In addition, if high water sodium content is shown to adversely affect the blood pressure of normal, healthy individuals, health teaching about the water sodium level and the necessity for decreasing dietary salt intake may be beneficial for the entire population from an early age. This study was done to add to knowledge about the risk from high sodium water to the healthy population. Studies of sodium risks may stimulate appropriate health interventions at the community level and within health care referral areas.

Hypotheses

The study was undertaken to answer this question. Are blood pressure levels higher in 14 through 16 year old healthy subjects exposed to high sodium in drinking water than a similar group which has low sodium in the drinking water? The following hypotheses were tested to address the question:

1. There will be an increase in the mean systolic and mean diastolic blood pressure values in the high sodium group over the low sodium group.
2. The upward shift in mean systolic and mean diastolic blood pressure values found will be proportionately higher than that found in Tuthill's (1979) study of high school sophomores. There will be a dose-response relationship between findings of the two studies.

3. There will be a higher prevalence rate of hypertension in the high sodium group than the low sodium group.

CHAPTER 2

LITERATURE REVIEW

Hypertension Epidemiology

Controversy has surrounded literature and research relating to hypertension in man for years. There has been no ongoing study of the incidence of hypertension over time. The prevalence rate of hypertension has not changed in recent years. The rate among adults was 18.1 per 100 population in the 1971-1974 National Health Survey and 18.2 in 1960-1962 (Borhani, 1979). Mortality from hypertension and hypertensive heart disease, however, has decreased dramatically from 1950 to 1976.

Hypertension is a very powerful risk factor for coronary heart disease. In recent years there has been a decrease in stroke mortality and the rate of mortality from coronary heart disease as well. In the Proceedings of the Conference on the Decline in Coronary Heart Disease Mortality (National Institutes of Health, 1979), changes in risk factors such as hypertension, physical activity, dietary patterns, smoking and changes in treatment were cited as having an effect on coronary heart disease mortality. Thus, multifactorial causes are possible explanations of the decline in vascular disease mortality. Public awareness, education, screening, and treatment of hypertension have increased in recent years. While disease prevalence has not changed, hypertension mortality has declined. It is suggested that is because of increased case finding and treatment.

Factors in Hypertension Development

Some basic mechanisms of hypertension in man have been described by Guyton (1976). One type of hypertension, volume loading hypertension, is caused by excess water and salt intake in patients with reduced kidney mass. The actual mechanism for this hypertension is the initial increased cardiac output caused by excessive water load which accompanies salt retention in the compromised kidney. Following continued salt loading (controlled administration of high saline dose), the total peripheral resistance increases. Since the basic mechanism of hypertension is either increased cardiac output or increased peripheral resistance, hypertension continues during the period of increase in volume. Guyton (1976) did experiments in animals in which he demonstrated that increased total salt in the body does not cause hypertension unless there is a concomitant rise in the fluid volume. As long as the kidneys are even partially functional and can excrete water, salt is the factor that determines the volume of extracellular fluid in the body.

Renal artery constriction with chronic renin secretion is another mechanism by which hypertension is caused. Renin is secreted which causes angiotensin (a powerful vasoconstrictor) to increase peripheral resistance. Over a period of time, excretion of water and salt is depressed, thus contributing further to increased cardiac output and long-term hypertension (Guyton, 1976).

Neurogenic factors have been proposed as a cause of hypertension through prolonged stimulation of the sympathetic nervous system. It is believed that abnormal sympathetic stimulation of the kidneys eventually causes a secondary renal abnormality which maintains the hypertensive state (Guyton, 1976). Diastolic pressure is a reflection of total peripheral resistance which is the mechanism in neurogenic hypertension (Groer and Shekleton, 1979).

Essential hypertension is a term used to describe hypertension of unknown origin. In persons with essential hypertension, the urinary output-pressure curve is shifted to a higher level; the arterial pressure must remain elevated in order to maintain the excretion of water and salt through the kidneys at an amount equal to intake. The cause of this shift in the pressure curve is unknown (Guyton, 1976). Several studies have attempted to explain this phenomenon on the basis of salt intake. This study also addressed the problem of essential hypertension development in relation to sodium intake.

Several theories have been proposed to partially explain a hypothesis of salt induced hypertension. Guyton (1976) believed that essential hypertension could be explained (as are many known causes of hypertension) by a kidney abnormality in regulation of salt and water. This theory was supported by findings of a shift in the urinary output-pressure curve in patients with essential hypertension. Urinary output levels can only be maintained if the blood pressure is high. When blood pressure falls, the urinary output drops to zero. He postulated the pathology was either thickened glomerular membranes which would reduce the glomerular filtration rate and increase tubular reabsorption of salt and water or increased afferent arteriolar resistance caused by vascular sclerosis. Neither theory has been directly verified in the literature. This pathology explanation does not clearly postulate salt as a cause of the hypertension; rather, salt intake would be a contributor to the development of hypertension following subtle kidney changes.

Animal Studies

Several studies have proposed and tested the theory that a mechanism for salt induced hypertension is an increase in intracellular sodium in the peripheral arterial wall (Tobian and Binion, 1952; Haddy, 1974; Edmondson, Hilton, Thomas, Jones, and Patrick, 1975; Madden, Smith, and Llaurado, 1979). Madden et al. (1979) demonstrated a net movement of sodium to a compartment in the mesenteric arterial wall in rats. The rats (not Dahl rats, the salt-sensitive genetic strain) had hypertension induced by substituting 2% sodium chloride for drinking water ad lib. The experimental rats in 8 weeks showed a 14% increase in blood pressure when compared with control animals. The researchers developed a model in which a sodium compartment within the cell was postulated to contain the excessive sodium. There was slowed sodium exchange in the mesenteric artery wall of salt-loaded rats, and decreased extracellular fluid to intracellular fluid ratio was indicative of intracellular sodium accumulation. The authors believed this shift could have a stiffening effect on the arterial walls leading to hypertension development.

L. K. Dahl has been a persistent advocate of the role of salt in hypertension development since the 1950's. In the intervening years, he developed a genetic strain of salt-sensitive rats which have served as subjects in much hypertension animal research. Genetic factors were demonstrated to play a part in the development of essential hypertension in rats. Dahl (1972) found that the salt-sensitive strain developed hypertension with high salt intake while the control strain did not display elevated blood pressures.

Evidence that the genetic fault is in the kidneys as postulated by Guyton was provided in a recent study (Tobian, 1977). Bianchi (1974) and Dahl (1972) independently demonstrated hypertension may be caused by a renal defect in sodium excretion.

Definitive physiologic and histologic studies of the pathology of salt induced hypertension are not possible in humans. Corbet, Kuller, Blaine and Damico (1979) studied the effects of a high salt diet in swine to demonstrate a model of its occurrence in man. Swine were chosen because of their sedentary and obese features; they were believed to be similar to man in that regard. Serum cholesterol, potassium, sodium, gross pathology and histology of the aortic vessels, heart walls and vessels, kidneys, and adrenal glands were utilized to study the high salt diet effect in experimental and control animals. Unfortunately, urinary excretion of sodium and water were not measured, nor were extracellular-intracellular fluid ratios. The 3% salt diet used was quite high in comparison with American diets. Both systolic and diastolic blood pressures were elevated in the experimental animals, 7-12 mm over the control animals' values. There was no difference between groups in the variables weight, serum sodium, potassium or cholesterol. The report did not discuss results of gross pathology and histology studies which may have added to knowledge about mechanisms of salt induced hypertension.

Human Studies

In studies of humans, genetic factors have been implicated which consistently demonstrate decrease in sodium excretion in black males given a sodium load. In the discussion of one study, (Luft, Grim, Fineberg, and Weinberger, 1979a) the genetic stimulus was speculated to be an adaptive response to originally living in areas with high temperature where dietary sodium was not readily available. The black race exhibits more efficient means of temperature regulation in secretion of less sweat per hour than whites performing the same work load, so it is conceivable that they and other peoples originating in semitropical areas may have developed more efficient mechanisms of sodium conservation. Such mechanisms of sodium conservation could be hazardous to blacks living in America or other countries with excessive salt intake.

Pickering (1980, p. 13) wrote a critical review of some research which has supported the role of salt in hypertension. He restated the theory of autoregulation first proposed by Guyton:

> According to the argument, excessive intake of salt increases extracellular fluid volume, plasma volume and cardiac output. This leads to an increase in arterial pressure, which in turn leads

> to adaptive changes in peripheral blood vessels, some effected through the baroreceptor reflexes. This vasoconstriction results in an increased peripheral resistance that eventually maintains the arterial pressure as the cardiac output returns to normal.

The portion of the autoregulation theory which he omitted in his restatement was that the increased pressure then becomes essential for the maintenance of normal urinary/sodium excretion balance with intake (Guyton, 1976; Coleman, Samar, Murphy, 1979). Pickering then concluded that excessive salt intake is not the cause of essential hypertension by citing data from a study (Framingham Heart Study Data displayed by Dauber et al., 1967) which showed no significant elevation of blood pressure in persons whose urinary sodium excretion varied between 8 and 13 Gm. The percentage of persons with high blood pressure increased from 20% at less than 8 Gm sodium excretion to 36% at greater than 13 Gm representing twice as many hypertensive subjects in 44-45 year olds. Since sodium excretion is equal to sodium intake on a 24 hour basis, the study Pickering utilized lends some support to the salt hypothesis rather than definitely refuting it as was his intent.

Sir George Pickering also cited three studies (Thomas, Ledingham and Beilin, 1978; Simpson, Waal-Manning and Bolli, 1978; and Bing, Thurston and Swales, 1979) which demonstrated that persons with highest blood pressures in a population excrete the same amount of sodium in 24 hours as those with low pressures. That statement was intended to prove that sodium intake had no effect on hypertension but the populations sampled were not defined as having high sodium intake. Following further literature review, he stated that it seemed reasonable to conclude that humans, like Dahl rats, may vary in their salt sensitivity.

Another critical review by Coleman, Samar, and Murphy, (1979) discussed studies which have conflicting results in findings related to blood flow; an increase in blood flow precedes a peripheral resistance increase in the autoregulation theory. They concluded that the lack of direct experimental evidence is prolonging controversy surrounding the theory of salt induced hypertension.

Some experimental studies in humans have been completed recently. The giving of an 800 mEq sodium load (in great excess of that consumed by Western societies) resulted in a mean blood pressure (calculated from summation of 1/3 of the pulse pressure and the diastolic pressure) increase from 83.3 to 100.3 in fourteen men. Failure to use a control group which was not salt loaded opened the study to criticism. The effect of testing blood and urine and I.V. fluid administration was unknown. Controls were included for intake of potassium, phosphorus and drinking water sodium (Luft, et al., 1979b)

A study utilizing similar methodology, smaller sample size and no control group failed to demonstrate any increase in blood pressure (Romoff, Keusch, Campese, et al., 1979).

Epidemiological Studies

Papers presented at the Joint U.S.-U.S.S.R. Symposium on Hypertension reported on an investigation of a population living in a region in Russia where two to five times more salt than normal (values not given) was present in the drinking water. This sample was divided into those who consumed excessive dietary salt (more than 350 mEq/day) and those who did not (150-180 mEq/day). The two groups were further split into healthy and hypertensive sub-groups. Hypertension was found four times more often in individuals who consumed excessive dietary salt. These groups were then subjected to experimental treatment; placed in the hospital where all received diets of 9 Gm salt per day. Intravenous salt load and subsequent diuresis with Furosemide caused decreased sodium and water excretion in the hypertensive group who had used excessive salt. This did not occur in persons with hypertension who consumed normal amounts of salt (Nekrasova, Gazaryan, Fatula, Suvorov, Zhemerikina and Chernova, 1978). Changes in prostaglandins and renin were seen in healthy high salt consumers when compared with their low salt control group. The report was a translation from Russian and difficult to understand.

Thus, it would appear that experimental physiologic studies are still limited in number, scope and consistency of findings in demonstrating any conclusive evidence that sodium intake is a factor in the development of essential hypertension. Few studies considered control for many possible intervening variables. Much more evidence supporting sodium's role in hypertension than refuting it has been published in the last 20 years, however. Interested public health professionals are continuing to develop studies to demonstrate the effect of sodium on the mean blood pressure of normal community samples.

In an epidemiological study (combined with physiological parameters) seven areas with soft water were compared with six areas having hard water supplies. Mean systolic blood pressure, plasma cholesterol and serum sodium were elevated in areas with higher sodium-calcium ratios. Validation of higher sodium intake by measuring urinary sodium excretion was not done, however. The researcher demonstrated significant negative correlation between hard water (containing low sodium) and death rates from cardiovascular disease. _Cebus_ monkeys were studied and found to develop high serum sodium levels when given soft drinking water for 8 weeks (Toutounchian, 1977).

Tuthill and Calabrese (1979) published a report of their continuing studies aimed at documenting the need for a national standard for drinking water sodium. High school sophomores were compared in a community with 107 mg/l drinking water sodium content with a matched community having a sodium level of 8 mg/l. It is generally accepted that patients on a sodium restricted diet would be harmed by the additional unknown intake of over 200 mg per day of sodium in drinking water which contains 100 mg/l sodium. The purpose of Tuthill and Calabrese's studies was to determine effects of additional sodium intake on normal healthy human populations. Communities in the study were similar in size, median family income, education, and ethnic composition which was believed to control dietary, genetic, and stress factors. Blood pressures were compared in 300 white sophomores. Many variables were studied by questionnaire. An upswing in blood pressure was demonstrated in the high sodium community with the increase higher in females than males. Female systolic and diastolic means were 5.11 mm higher in the high sodium community. Male values were 3.58 mm higher for systolic pressure and 2.69 mm higher for diastolic pressures. Using one way analysis of covariance, values were adjusted in relation to the 18 variables studied by questionnaire. In males, the difference in diastolic pressure means decreased to nonsignificance with the main effect coming from the variable "time since last meal". Females' systolic and diastolic and male systolic readings remained highly significant following the adjustment. Two way analysis of covariance did not change those results except that the decrease in mean difference in males' diastolic values disappeared. Further studies are planned with third graders in which salt intake will be verified by sodium excretion.

Summary

There are a large number of variables known to affect blood pressure. The development of hypertension is probably of multifactorial causation. The theoretical framework of this study is based upon findings that high sodium intake is one of the factors contributing to the development of hypertension and investigates the relationships between sodium levels in drinking water and blood pressure levels in a young, normal population.

CHAPTER 3

METHODOLOGY

Introduction

The methodology of this study was patterned after that of Tuthill and Calabrese (1979) to allow comparisons between findings as much as possible. Methods were not rigorously replicated, however. To answer the question whether 14 to 16 year olds drinking high sodium water in the community supply would have higher blood pressures than a control group, blood pressures were measured and information on other factors was collected by a two-part questionnaire. The study design was pre-experimental in nature and consisted of measurement of the dependent variable, blood pressure and selected intervening variables. The independent variable, drinking water sodium level, had been present for years in the high sodium town (High Na). The town selected for sample comparison of blood pressure means had low drinking water sodium. In other words, the study used post-test only, nonequivalent control group design (Waltz and Bausell, 1981).

Three measures of blood pressure for each consenting 14 through 16 year old high school student were obtained in December 1980. Measurement of blood pressures for each of the sample groups was done on subsequent days and testing was begun and ended at the same time of day for both groups to provide for testing day internal validity. The groups were tested under similar conditions so far as possible. The data collectors were not aware what independent variable was being studied. Subjects were not made aware of the experimental-control group differences between water sodium levels although such knowledge could not be ruled out.

Additional measures for control of possible intervening variables were obtained by questionnaire. Some items were sent home for parental assistance; others were completed at the time of blood pressure measurement for independent student responses. Height and weight were measured at the time of blood pressure recording. Significant intervening variables were controlled by post hoc statistical analysis.

Definition of Terms

For the purposes of this study, the following definitions were used:

Subjects: High school students who had attained their fourteenth birthday but not their seventeenth birthday when the first questionnaire was distributed.

Adolescent hypertension: Subjects 14-16 years old with sustained blood pressure values exceeding or equal to

140 mm systolic or 90 mm diastolic in three repetitions as measured in this study (Weidman, 1979).

Systolic blood pressure: That pressure recorded upon auscultation of the first Korotkoff sound at the point where the first of two consecutive sounds was heard.

Diastolic blood pressure: That pressure recorded at the disappearance of sound; the fifth Korotkoff sound.

Prevalence of hypertension: The rate of students found in screening to have adolescent hypertension per 100 students.

Community Characteristics

The communities selected for the study differed in drinking water sodium levels. Characteristics of the communities were compared prior to community selection to assure similarity on as many variables as possible. The high sodium community was at 4245 feet elevation; the control community was 5280 feet in altitude. Acclimatization to high altitude may be related to lower blood pressures (Slonin, 1974) but no evidence was found to associate differences in blood pressure with the altitude levels between the study communities. Table 1 displays population distribution for the two communities from 1980

Census of Population and Housing Advance Reports.

Table 1

Community Population Characteristics

	Low Na[a]	High Na[b]
County Population	2154	2359
Town Population	1302	1182
White	1297	1171
Blacks	0	0
American Indian	2	5
Asian	0	2
Other	3	3
Housing Units	574	592

[a] Sodium level in drinking water 2.1 mg/l taken during data collection (State Water Quality Bureau)

[b] Sodium level in drinking water 378 mg/l taken during data collection (State Water Quality Bureau)

Since 1970, population in the low sodium community increased by 8.5% (102 persons) and the high sodium community decreased by 14.1% (194 persons). A major portion of the population loss for the experimental community occurred when the Milwaukee Railroad ceased operations in the town in March,1980. The economic loss to the community could affect the blood pressures of that community's children since stress and lower socioeconomic status have been associated with hypertension. Data about county economic condition is presented in Table 2 from the Montana Employment and Labor Force Monthly Report (August 1980). The study towns are the major population concentration for their respective counties.

Table 2

County Economic Comparisons

	Low Na	High Na
Labor Force	1195	1245
Unemployment Rate	4.0	3.1
6 Month Unemployment Insurance Paid	$41,567	$15,815

As can be seen from Table 2, although population and a major source of employment dropped in the high sodium community, unemployment was higher in the low sodium community in the quarter prior to this study. If unemployment had an effect on adolescent blood pressure, it would be in a direction opposite the hypothesis of this study.

Other statistics about the counties are of interest to the hypothesis that sodium in drinking water contributes to elevated blood pressure in normal individuals. The death rate from heart disease in 1976 in the high sodium county was 240 per 100,000 population. The low sodium county had a heart disease death rate of 227 per 100,000 population comparisons of death rates for cerebrovascular disease (stroke) were even more significant to a study of hypertension. In the high sodium county, the death rate for stroke was 160 per 100,000 population; whereas in the low sodium county, that rate was 45.5 per 100,000 (Montana Vital Statistics, 1976).

Sample

The sample was drawn from two rural Montana communities which are 58 road miles apart. Potential subjects were fourteen through sixteen year old high school students whose parents consented to allow participation. Three years of age were used to produce an adequate sample size in these rural towns. Following data collection, subjects were further screened for home drinking water not provided by the community supply, for the presence of diabetes, heart or kidney disease, history, medication use, or use of bottled water. The elimination of those cases resulted in a sample size of 33 in the high water sodium community and 34 in the low water sodium community. To form the final sample of healthy subjects whose home was supplied by city water, cases were eliminated as shown in Table 3.

Table 3

Cases Which Did Not Meet Sample Selection Criteria

	Low Sodium Town	High Sodium Town
Non-city water supply	17	21
Bottled water	0	2
History heart disease	4	6
Diabetes	0	1
History kidney disease	4	0
Current medication use	4*	4*

* Some subjects eliminated for more than one reason.

Of 97 questionnaires distributed in class in the control group, 61 were returned and 58 students completed the blood pressure testing and completed part two of the questionnaire. In the high sodium town, 78 questionnaires were distributed, 74 were returned. There were 67 subjects in the experimental town who completed part two and had their blood pressures taken (two of these were eliminated following discovery of lack of parental consent).

Procedure

Portions of a questionnaire developed by Tuthill and Calabrese (1979) were used in development of the two-part questionnaire used for data collection. The first part of the questionnaire was sent home with students, two to three weeks prior to data collection. The second part was completed at the time of blood pressure screening. A copy of both parts of the questionnaire comprise Appendix A.

Part One Questionnaire

Demographic data were obtained in the first portion of the questionnaire as were those questions in which parental assistance would improve accuracy. In the interest of brevity, items on Tuthill and Calabrese's instrument relating to prior experience with blood pressure taking, number of cups of hot chocolate consumed per week (may be milk or water based) and glasses of water consumed with lunch were deleted. The last page of Tuthill and Calabrese's instrument was deleted because students given a pilot test (*n*-5) had difficulty completing it without great assistance from the researcher. Some questions students had difficulty with were, for example: "Have you ever been troubled by 'cold sweats'?", "Do you feel that you are bothered by all sorts (different kinds) of ailments in different parts of your body?" Association with blood pressure was unclear for some of those questions.

Items added to the questionnaire sought further information about family history of hypertension, black licorice use and the source of the home drinking water supply. The items consisted of mixed multiple-choice and fill-in-the-blank questions. Questions sought information about gender, grade in school, living situation, head of household education and occupation, age, and length of time lived in the town. General health, physical activity, recent gain or loss of weight, specific diseases and medication use were reported. The student was asked to estimate the amount of salt added to meals, salty snacks, soft drinks, coffee or tea and water consumption. Part one of the questionnaire was returned in a sealed envelope to the school, then the entire group of returned questionnaires was sealed and sent to the researcher. Confidentiality of response was assured and maintained throughout the study by identification of each section of data collection by identification number.

Part Two Questionnaire

Other variables have been mentioned in the literature as having an effect upon blood pressure. Personality factors of anger and anxiety were shown to be associated with hypertension in adults (Baer, Collins, Bourianoff, and Ketchel, 1979; McClelland, 1979). A self-report instrument developed and validated with adults by Baer et al. (1979) was adapted for use with adolescents and included in the second part of the questionnaire. Terminology of some items was changed based on a pilot study with a small sample of teenagers in a larger town than the study communities, but full-scale validation was not carried out. To avoid parental influence in responses to the personality questions and those about smoking and beer consumption, they were administered at school prior to blood pressure screening. Questions to elicit information about the prior night's sleep and the length of time since the last meal were answered in the second questionnaire as well.

Blood Pressure

Blood pressure screening was done by four volunteer nurses. Their reliability in judging blood pressure readings in response to a training film was tested. A "Y" stethoscope was used to verify their findings on ten readings with those of the researcher prior to the beginning of the study. Every hour of screening included a recheck of each screener with the dual stethoscope on a random basis. Each screener was given a 10 minute break and returned to a different station every hour following the break.

Students remained sitting during completion of the questionnaire and sat for one full minute prior to initiation of each of three blood pressure readings taken at each station. The right arm was used for all readings. Subjects carried a number identified booklet which corresponded to the number of their questionnaire. Each blood pressure was recorded on a different page of the booklet to prevent screener bias from previous recordings. (See Appendix B).

Readings of blood pressure were obtained using mercury-gravity manometers which were calibrated to zero prior to both day's screening. Cuff width and length were measured for each subject at the first station. The bladder of the cuff encircled the arm without overlapping and the cuff width was at least two-thirds the length of the arm but not extending into the antecubital space or axilla. The radial pulse was palpated, the cuff rapidly inflated to a point 30 mm above the disappearance of the radial pulse, then slowly deflated during auscultation throughout notation of systolic and diastolic values (Weidman, 1979). Radial pulse rate and dressed height and weight were recorded. Quiet was maintained during pressure recordings by having waiting students contained in an adjoining room in which questionnaires were completed. The students were very quiet and orderly throughout the screening.

Precautions were taken to assure similarity of data collection between communities. In scheduling testing days, basketball tournaments and tests were avoided. Since Tuthill and Calabrese (1979) had found a significant effect from the length of time since the last meal, the same number of students was tested before lunch as after lunch in each town. Data collection was performed December 8, 1980 in the low sodium town and December 9, 1980 in the high sodium town.

Water Testing

Water samples were taken from the tap at each school on the days blood pressure screening was done in each community. Chemical analysis of the water performed by the State Chemistry Laboratory Bureau showed results listed in Table 4. On the day tested, the sodium value for both schools was lower than previous community water analysis reports indicated.

Table 4

Chemical Analysis of High School Water

Parameter:	Low Na	High Na
Sodium	2.1 mg/l	378 mg/l
Potassium	.5 mg/l	1.9 mg/l
Calcium	4.8 mg/l	5.2 mg/l
Magnesium	1.6 mg/l	3.6 mg/l

Some authors studying lower hypertension rates in communities with hard water have proposed that high potassium (Walker, Whelton, Saito, Russell, and Hermann, 1979) or calcium, magnesium, and cadmium

(Neri and Johansen, 1978) are protective elements for the development of hypertension. If that hypothesis is true, the high sodium community which has higher levels of those elements could have lower blood pressures because of that protective effect. The differences between communities in levels of those ions was not large, however, Cadmium levels in both towns were less than .001 when tested in 1977 (high sodium town) and 1978 (low sodium town). Thus, sodium level in drinking water was confirmed as the independent variable for this study at the time of data collection.

Methods of Analysis

The subjects for this study could not be randomly assigned to an experimental and a control group. Parametric statistics have random group assignment as a major assumption for the use of those statistics in generalization to a larger population from a sample. Because of the need to determine whether the observed differences between the groups was a chance happening, and the power provided by parametric statistical procedures, much of the data analysis used those statistics. The target population was composed of 14 through 16 year olds in the two towns and all students in that age group had an opportunity to participate in the study. Sample selection criteria were imposed following data collection.

In Stage 1 analysis, mean blood pressures were subjected to t-test to analyze differences between towns for systolic and diastolic values for the town samples and by gender. Average systolic was computed using all systolic readings as was average diastolic to arrive at means for each parameter. The samples were divided for gender because Tuthill and Calabrese's study (1979) had demonstrated differences in between town means when their samples were separated for males and females.

In Stage 2 analysis, intervening variables were analyzed to assess their effect on the main question of difference of mean blood pressures between groups. Intervening variables were studied by correlational methods, using Spearman's rho for ordinal data and Pearson r for interval data to determine those variables which showed significant correlation with blood pressure. From those studies, multifactorial analysis of variance studied the combined effects of several variables to determine which interactions or main effects were strongest in relationship to the blood pressure measures. A final grouping of strongly influential variables for each gender was tested by analysis of covariance which combines analysis of variance and regression techniques (ANCOVA). The dependent variable (systolic or diastolic blood pressure) was adjusted to eliminate the effects of factors and covariates other than water sodium level. The statistic used with ANCOVA was multiple classification analysis which produced a grand mean systolic and grand mean diastolic adjusted for factors and covariates for each gender. The amount of variation in that grand mean caused by the water sodium variable was then added to or subtracted from the grand mean to give an adjusted mean systolic and diastolic pressure, controlled for the effects of other variables for each sample group. The level of significance to be met for determining chance occurrence was less than .05 probability.

CHAPTER 4

DATA ANALYSIS

Sample Description

The sample for this study included subjects from the high schools of two rural communities in Montana. One group was from a town with low sodium in the drinking water (2.1 mg/l), the other from a town with high sodium in drinking water (378 mg/l). The subjects' ages were limited to those who had passed their fourteenth birthday but had not reached their seventeenth birthday by the time of questionnaire distribution. Students who reported a history of heart or kidney disease, medication use, use of bottled water or water from other than city sources were not included.

There were 34 subjects in the low sodium town who completed both parts of the questionnaire and blood pressure screening. Thirty-three subjects formed the high sodium town group. Breakdown of the two groups by gender is displayed in Table 5.

Table 5

Distribution of Subjects by Gender and Group

	Males	Females	Total
Low Sodium Group	19	14	34*
High Sodium Group	16	16	33*

* One missing case each town.

Although one subject in each town did not respond to the question about subject gender, those two cases were included in those analyses in which variables were correlated with blood pressure without sex breakdown. Tests of blood pressure differences by sex did not include the two missing cases. The age of subjects was similarly distributed between the two towns as shown in Table 6.

Table 6

Age Distribution by Town

	Age in Years			
	14-14.9	15-15.9	16-16.9	Total N
Low Sodium Group	11	10	12	33*
High Sodium Group	13	9	10	33

* One missing value

Stage 1 Analysis

To test the first hypothesis that there would be higher blood pressure values in the high sodium group, mean systolic and mean diastolic pressures were analyzed by *t*-test for significance of difference between the town means. Table 7 presents the results of that analysis.

There was no significant difference between the groups for either systolic or diastolic mean blood pressures when the groups consisted of males and females together. There was a slight upswing in the mean systolic value in the high sodium group and even less difference was found in the mean diastolic value.

For females, the systolic mean was 4.7 mm higher in the experimental group; the diastolic mean was 5.7 mm higher and was the only statistically significant difference demonstrated between the towns. Male blood pressures were elevated by 2.1 mm in the high sodium community over the control group but were 3.8 mm lower than the control group for diastolic mean.

The second hypothesis predicted proportionately higher between town difference in this study than in Tuthill and Calabrese's 1979 study to show a dose-response relationship with higher levels of sodium in the drinking water. In that study, male systolic was 3.57 mm higher,

Table 7

Differences in Blood Pressure Means

	Low Sodium Group Mean	n	High Sodium Group Mean	n	Difference of Means	t value	df	p Value*
Sample systolic	108.726	34	111.434	33	+2.708	1.24	65	.110
Sample diastolic	67.716	34	68.667	33	+ .951	0.48	65	.315
Female systolic	104.762	14	109.5	16	+4.738	1.48	28	.075
Female diastolic	64.952	14	70.667	16	+5.715	2.30	28	.014*
Male systolic	111.747	19	113.583	16	+2.109	0.71	33	.242
Male diastolic	70.474	19	66.667	16	-3.807	-1.33	33	.097

* p = < .05 for one-tailed t-test

diastolic was 2.69 mm higher in the high sodium city which were significant differences for the large sample size of their study. In order to show a directly proportional dose-response relationship, male systolic in this study would have been 12.85 mm higher in the high sodium town, which did not occur. For male diastolic, the dose proportionate level would be 9.68 mm higher, but this study produced a finding of lower diastolic in males in the experimental group. Female systolic would have been 18.4 mm higher if the second hypothesis held true; diastolic also would have been that high. This study used three grades of student; Tuthill and Calabrese used only sophomores. Sophomore males in this study showed no difference between towns in systolic pressures and a 5 mm lower diastolic mean in the high sodium group. For female sophomores, the results came closer to showing a dose-response relationship. Female systolic for sophomores was 8.587 mm higher in the high sodium town. Diastolic showed a more dramatic increase, 14.221 mm. The numbers of sophomores was too few, however, for meaningful analysis by gender.

The definition of adolescent hypertension was individuals with higher than 140 mm systolic or 90 mm diastolic blood pressures over three repetitions. Only one subject even came close to presenting a blood pressure that high, and her high reading was only in the first of the three recordings. That subject was eliminated from the sample because of diabetes and was from the high sodium community. Thus, there was no incidence of adolescent hypertension in either community.

Stage 2 Analysis

Because of the large number of variables and small number of cases, analysis of the intervening variables was done by studying each variable for effect on blood pressure means and/or differences in responses between towns. On the basis of those studies, a list of 45 variables was reduced to nine for further analysis by analysis of covariance and computation of an adjusted mean for each group.

Family history of hypertension was expected to be an important intervening variable with the potential of confounding study results. If sodium had an effect in elevating blood pressures, the high sodium town could be expected to have more adults with diagnosed hypertension. Subjects in that town could have been expected to list more family members with hypertension. There was little difference between the two towns in response to those questions. More subjects in the high sodium group had larger numbers of family members with hypertension, but there was little difference in numbers of subjects with some family history versus those with no family history of hypertension. Table 8 displays the frequency of number of family members with hypertension. Ten students in each group did not know or did not answer the questions on family history even with parental help in completing the questionnaire.

Table 8

Family History of Hypertension

Number of Family With Hypertension	Low Sodium Group Responses		High Sodium Group Responses	
	N	Freq.	N	Freq.
0	5	20.8%	5	21.7%
1	12	50.0%	10	43.5%
2	6	25.0%	3	13.0%
3	0		4	17.4%
4	0		1	4.3%
5	1	4.2%	0	
Missing Values =	10		10	

Adjusted frequency calculated without missing cases

Pearson correlation coefficients were computed to determine the association between subject's blood pressure values and the number in the family with hypertension. Positive correlation was present in each town sample but none reached the level of significance. The low sodium town systolic values ($\underline{r}$ = .2847, $\underline{p}$ = .089) were more correlated than the high sodium group's systolic (r = .2813, p = .097). A slight opposite trend occurred in diastolic pressures. The control group (r = .1211, p = .286) had less correlation than the high sodium group (r = .1294, p = .278).

Whether subjects in either town drank softened water was of importance to the study since water softening adds about 100 mg of sodium to each liter of water. Only one subject in the sample consumed softened water at home. That student was in the low sodium group. The presence of that one case may have had some influence in elevation of the mean pressure in the low sodium group but the influence would be slight.

The following variables were found to be of no significance in one-way analysis of variance with either systolic or diastolic subject's pressures: With whom subject lives, prior night's sleep, occupation of the head of the household, and amount of added food salt. Ten of the personality factors also had nonsignificant main effect in relationship to systolic or diastolic pressure. These were: friends get angrier than subject in similar situations; subject is tense and nervous; subject is seen as good looking; subject gets even rather than forgiving; subject is not restless; others overlook dangers the subject is concerned about; the subject is under pressure; the subject is critical of others; the subject is more anxious; and the subject is comfortable with sex role (no students answered "no" to that question). The F values for those variables studied by analysis of variance which were not significantly associated with blood pressure ranged from .007 for the variable about good looks to 2.390 for diastolic pressure with adequacy of the prior night's sleep.

Three other variables were eliminated early in the analysis. The subject's pulse rate showed only a weak nonsignificant correlation with blood pressures and little difference in mean pulse rate between towns was present. Mean pulse in the control group was 67.485. In the high sodium group, the mean pulse rate was 68.875. The difference between the two group pulse means parallels the difference in blood pressure and is affected by many of the same variables. Data on grade in school was collected for the purpose of comparing sophomores with Tuthill and Calabrese's study but was shown to be nonsignificant in association with blood pressure. The variable, length of time lived in the town, did not bear any relationship to blood pressure in either sex or within the high sodium town by gender. Many subjects in both towns lived there all their lives.

The relationships of other variables to subject's systolic and diastolic pressures was analyzed by Pearson Correlation Coefficient. The following variables had nonsignificant correlation with systolic or diastolic pressures in either town: Subject's age had weak, positive correlation in the control group, weak negative correlation with the high sodium group. The variable, number of soft drinks per week had the same between group difference in direction of correlation. No subjects in the high sodium town ate black licorice but that variable was positively correlated with pressures in the low sodium town. The number of water-based drinks such as tea, coffee, frozen juice and water correlated in a negative direction in both groups. The number of beers per week also had negative correlation with blood pressure. None of the above variables' correlation with blood pressure was statistically significant. The *r* values ranged from +.2464 to -.2043.

Ordinal level variables were analyzed with Spearman's rho for correlation with systolic and diastolic pressures. The variables, subject's general health self rating, and physicial activity self rating were not significantly correlated with blood pressure (*r* values ranged from +.1269 to -.2541). General health of the subject was rated from excellent to poor and varied in negative correlation with blood pressure in both groups. Physical activity was rated from much less active to much more active than friends. As the physical activity rating indicated more activity, the blood pressure was higher (positive correlation).

Significant Variables

Variables with significant correlation with blood pressure were further analyzed for male-female differences.

Height and weight were both significant in correlation with blood pressure. Since weight is to some extent a function of height, a height/weight ratio was computed for further analysis between towns and sexes by dividing height in inches by weight in pounds. A *t*-test of height/weight difference in means between groups showed no difference in between town height/weight. The control group mean height/weight ratio was .5216; the high sodium group mean was .5270 (p = .737). The mean height/weight indicates subjects in the experimental group were slightly thinner than the control group. Pearson correlation was run for each sex in each town. Results are displayed in Table 9.

Table 9

Height/Weight Ratio Correlation With Blood Pressures

	Males		Females	
	Low Sodium Group n = 19	High Sodium Group n = 17	Low Sodium Group n = 14	High Sodium Group n = 17
Syst	r -.2992	r -.4324	r -.3906	r -.4656
	p = .107	p = .042*	p = .084	p = .030*
Dias	r -.3315	r -.4901	r -.1461	r -.5361
	p = .083	p = .023*	p = .309	p = .013*

* p = .05

Subject's weight for height was significant only in the high sodium group, and significantly so in both sexes in that group. Negative correlations meant that the thinner the subjects, the lower their blood pressure and conversely, the heavier the subjects, the higher their blood pressure. The same correlation direction was present in the control group but not to a significant extent.

Three personality variables demonstrated significant differences between group pressure means when analysis of variance was carried out for each of the personality variables. Displayed in Table 10 are the results of that analysis. There was no two-way interaction between water sodium group and any of the personality variables.

Table 10

Significant Personality Variables With Blood Pressure, Total Sample

	Systolic		Diastolic	
ANOVA	*F*	Sig. of *F*	*F*	Sig. of *F*
Dislike Center of Attention	9.953	.002*	2.116	.151
Calms Fast	6.150	.016*	1.966	.166
Low Surroundings Awareness	4.073	.048*	2.416	.125

* $p = .05$

Five of the personality variables which had shown a significant or near significant main effect within each sodium group with blood pressures were further analyzed for effects by gender. That analysis identified the variables scapegoating and hides anger as demonstrating a significant main effect for females. Those two variables were used in analysis of covariance to determine adjusted between town pressure differences for females. Analysis of variance for males singled out the variables "dislike center of attention" and "calms fast" for consideration in the final analysis of covariance to determine pressures for each town adjusted for significant intervening variables.

Other variables varied significantly with blood pressure by group and by sex within group. The educational level of the head of the household, subject's general health and time since the last meal variables had demonstrated significant correlation with blood pressure when run for each group separately. Those variables were further analyzed using one way analysis of covariance by sodium level groups with the three variables for each sex. For mean systolic pressure in males, the length of time since the last meal was the most powerful covariate with an $\underline{F}$ value of 4.569 ($\underline{p}$ = .043). With that combination of variables, the main effect of the water sodium groups was also significant in males ($\underline{F}$ = 5.296, $\underline{p}$ = .031). The other two covariates were nonsignificant. For male diastolic, none of the three covariates reached the level of significance and the main effect of the water sodium groups was significant ($p = .729$).

For females, neither the covariates nor water sodium groups were significant for mean systolic. Female diastolic also was nonsignificant for each of the covariates but the grouping by water sodium level was significant ($p = .013$) with an F value of 7.440.

Six more variables had shown significant variation in either systolic or diastolic pressures for each group. They were further analyzed by two-way analysis of covariance using salty snacks recoded as 1 = 0-10 per week, 2 = 11-25 per week and water sodium group as factors with the covariates weight gain, weight loss, height/weight ratio, smoking and Vitamin C pill use.

For male systolic, none of the covariates was significant, nor were the effects of salty snack intake or water sodium. There was no two-way interaction between the factors. Male diastolic was affected by the covariates to a large extent. The variables weight gain ($F = 9.268$, $p = .006$), smoking ($F = 4.701$, $p = .041$), and Vitamin C pill ($F = 5.465$, $p = .029$) were significant in male diastolic variation. Vitamin C pill use was negatively correlated with mean diastolic in the control group but did not reach the level of significance in the high sodium town. More subjects in the low sodium town took no Vitamin C pills. Water sodium group and salty snacks were nonsignificant but more of the variation from the mean was produced by the salty snacks variable.

A good portion of the between town difference in females' systolic and diastolic pressures was explained by the covariates, weight loss, height/weight ratio and smoking.

From the list of variables which had shown gender differences in effects on blood pressure, variables were chosen to be combined for each sex in a final three-way analysis of covariance.

Mean male systolic and diastolic pressures were controlled for the interaction of three factors: water sodium group, calms fast and center of attention, with time since last meal, weight gain, smoking, height/weight ratio and Vitamin C pill as covariates in three-way analysis of covariance.

For females, the factors, water sodium groups, scapegoating and hides anger were analyzed with the covariates, time since last meal, smoking, weight loss, height/weight ratio and Vitamin C pill.

Because the number of degrees of freedom was reduced to one by the combination of such a large number of variables, the amount of variation required to produce significance was higher than for the original _t_-test of means. The purpose of this portion of the analysis was to compute a mean for each of the water sodium groups after the influence of the significant intervening variables had been controlled. The multiple classification analysis statistic chosen produced a grand mean systolic and diastolic value after adjustment by independent variables and covariates. The amount of variation produced by the