To the Graduate Council:

I am submitting herewith a dissertation written by Mark Boberg Dignan entitled "Efficacy of Selected Diagnostic Procedures for the Detection of Hypertension." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Health Education.

Irshad Ahmad

Irshad Ahmad,
Major Professor

We have read this dissertation
and recommend its acceptance:

Warren J. Huffman

W. Alan Lassater

Robert W. Kirk

Accepted for the Council:

L. Evans Roth

Vice Chancellor
Graduate Studies and Research

EFFICACY OF SELECTED DIAGNOSTIC PROCEDURES FOR THE DETECTION OF HYPERTENSION

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Mark Boberg Dignan

August 1977

1312613

Copyright by Mark Boberg Dignan 1977
All Rights Reserved

ACKNOWLEDGMENTS

For their assistance in this undertaking, the author extends sincere appreciation to Dr. Irshad Ahmad and Dr. H. Alan Lasater. Their knowledge, understanding, and good humor provided a much needed dimension to this project. Appreciation is also expressed to Dr. Warren Huffman and Dr. Robert Kirk for their valuable input.

The author is especially grateful to Thomas Mackey and Dr. Jesse Walker for their essential contributions, both personal and professional, to this project.

For their counsel, ideas, and mainly for their friendship the author extends sincere thanks to fellow graduate students Mimi Hall, Dan Denson, Bob Hogsett, and Dave Foulk.

Last, but certainly not least, the author would like to acknowledge Caroline Dignan, without whose love and understanding this dissertation would not have been completed.

ABSTRACT

The purpose of this study was to determine, through investigation of procedures routinely used for diagnostic purposes in medical practice, a set of diagnostic procedures contributing most significantly to the detection of hypertension.

Data were gathered from summary sheets of medical records; 931 observations were included in the study population. Specific information recorded included systolic and diastolic blood pressures, body weight, results of urinalysis for protein, hematocrit, serum cholesterol, age, sex, and height. The data were analyzed initially by regressing systolic and diastolic blood pressures on the remaining variables using forward stepwise multiple linear regression. In addition, systolic and diastolic blood pressures were partitioned into categories operationally defining hypertension, borderline hypertension, and normotension; a multiple discriminant analysis procedure was used to determine variables contributing to discrimination among the three groups. A split sample analysis procedure was used to validate the discriminant analysis results.

A relationship was demonstrated, at the .01 significance level, between systolic blood pressure and age, body weight, height, serum cholesterol, proteinuria and hematocrit. The R^2 for this equation was .255. For diastolic blood pressure, body weight, height, hematocrit and age were found to

contribute to regression at the .01 significance level. R^2 for the diastolic blood pressure equation was .145.

The variables body weight, proteinuria, hematocrit. serum cholesterol and height contributed to discrimination among the groups hypertension, borderline hypertension and normotension at the .01 level of significance. The split sample analysis provided validation of discrimination.

Based on the analysis of the data, it was concluded that the variables that most significantly influence systolic blood pressure are age, body weight, and serum cholesterol. The variables that most significantly influence diastolic blood pressure are age, body weight, and hematocrit. The set of diagnostic procedures found to contribute most significantly to detection of hypertension includes measurement of systolic and diastolic blood pressures, hematocrit, serum cholesterol, and consideration of age and body weight.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
	Purpose	4
	The Problem	4
	Hypotheses	4
	Definitions	5
	Delimitations	5
	Limitations	6
II.	REVIEW OF RELATED LITERATURE	7
	Hypertension	7
	Diagnostic Procedures for Hypertension	13
	Evaluation of Diagnostic Tests	15
III.	METHODOLOGY	22
	Preliminary Methodology	22
	Review of the Literature	22
	Selection of the Diagnostic Procedures	23
	Operational Methodology	24
	Data Collection	24
	Treatment of the Data	25
IV.	RESULTS	28
	Introduction	28
	The Data	28
	Hypothesis Tests	28
	Discriminant Analysis	37
	Split Sample Analysis	42
	Summary	45
V.	SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS	46
	Summary	46
	The Problem	46
	Procedures	46
	Findings	47
	Hypothesis Tests	47
	Validation	48

CHAPTER PAGE

Conclusions 49
Recommendations 50

VI. FURTHER ANALYSIS AND IMPLICATIONS 51

Implications for Health Education 59

LIST OF REFERENCES 61

APPENDIXES 67

A. SAMPLE SUMMARY SHEET 68

B. CORRELATION MATRIX 70

C. CONVERSION OF Λ TO RAO'S R 72

VITA 74

LIST OF TABLES

TABLE		PAGE
1.	Mortality Ratios for Men According to Groups of Systolic and Diastolic (Fifth Phase) Blood Pressure Readings, Without Minor Impairments, All Ages	12
2.	A General Decision Matrix	18
3.	Selected Descriptive Statistics for 931 Observations (618 Female, 313 Male)	29
4.	Overall Test of Regression for Hypothesis 1, Dependent Variable Systolic Blood Pressure	32
5.	Relative Contribution of Independent Variables to Regression, Dependent Variable Systolic Blood Pressure	32
6.	Overall Test of Regression for Hypothesis 2, Dependent Variable Diastolic Blood Pressure	33
7.	Relative Contribution of Independent Variables to Regression, Dependent Variable Diastolic Blood Pressure	34
8.	Changes in Squared Multiple Correlation Coefficients (R^2) with Addition of Independent Variables for Systolic and Diastolic Blood Pressure Models	36
9.	Conditional Tests of Significance for Variables Included in the Discriminant Analysis	40
10.	Classification of Observations by the Discriminant Functions (N=931)	41
11.	Expected Frequencies Calculated Using A Priori Probabilities (N=465)	43
12.	Observed Frequencies Classified by the Discriminant Functions (N=466)	44

TABLE PAGE

13. Conditional Tests of Significance for Variables Included in the Discriminant Analysis 53

14. Classification of Observations by the Discriminant Functions (N=931) 54

15. Probabilities for Observing Elevated Values of Selected Diagnostic Procedures (N=931) 57

16. Correlation Matrix 71

CHAPTER I

INTRODUCTION

The problems currently facing the health care delivery system in the United States involve the provision of quality medical services to the American people, within the limits of increasing demand for specialized services, as well as a shrinking health dollar. In such a context, it seems a foregone conclusion that the diagnostic procedures used by primary care practitioners should be optimally precise, and yet within the confines of budgetary limitations. As stated by Frame and Carlson (16:29):

> One of the primary obligations of family doctors and other primary care physicians is the prevention of disease and early recognition of disease states in the hopes of preventing or minimizing subsequent complications. However, the question "What health examinations or tests should be done at what intervals, on which asymptomatic patients?" remains unanswered.

Recent changes in the pattern of morbidity and mortality of the population of the United States give impetus to renewed interest in the practicability of diagnostic procedures. The most notable change in the morbidity pattern of the United States has been the increase in prevalence of chronic conditions. Formerly, the diseases experienced most commonly were acute in nature, and as a result, preventive emphasis was concentrated in such areas as immunization and

case finding. Currently the diseases causing most concern in the United States are chronic, and preventive emphasis is slowly changing to this new direction (27, 30, 61).

Crucial to the prevention of illness, both catastrophic and minor, is the identification of those individuals at high risk of developing disease. In order to accomplish such a task, diagnostic procedures capable of distinguishing between low and high risk patients are essential. Diagnosis is the act of identifying a disease from its signs and symptoms. The process leading to diagnosis involves both science and art. The science component of the process of diagnosis grows more complex through the development of new technology; the art emanates from the human elements involved in medical practice. Engle and Davis pointed out (14:512):

> Diagnosis is such an established part of medical practice that few physicians consider whether there is general agreement about what is meant by the term diagnosis; whether diagnosis is an art, a science or both; whether diagnosis is an essential prerequisite to medical management; and even whether diagnoses are clearly defined disease entities.

Thus, diagnosis is an extremely important, pervasive part of the practice of medicine. From a working, or admitting, diagnosis a medical practitioner proceeds through a classification of disease possibilities. Classification narrows the selection of appropriate diagnostic tests for definitive diagnosis leading to progressively finer focus on the area of intended treatment.

Hypertension is a condition now known to be one of the most significant contributors to morbidity and mortality in the United states (31,57,58,59). For purposes of classification, hypertension is divided into primary and secondary types. Primary hypertension, referred to as "essential hypertension," has no known cause (63). Secondary hypertension, by contrast, has several known causes. "In most . . . it is secondary to various kidney or adrenal diseases, Cushing's Syndrome, primary aldosteronism and pheochromocytoma" (33:980). In addition, hypertension is known to be the most significant risk factor related to the development of stroke, congestive heart failure, and coronary heart disease (31,33,36) From National Health Surveys (30, 43,57) it has been estimated that 15 to 20 percent of adults in the United States have hypertension. These surveys based their findings on 140/90 mm Hg as blood pressure criteria dividing normotension and hypertension.

Health education, and particularly patient education as a specialty under the rubric of health education, has directed considerable attention to the education of hypertensive individuals (20,53,54,39). Indeed, the amount of effort directed toward educating the hypertensive appears to be increasing, largely under the direction of the federally sponsored National High Blood Pressure programs currently underway. A report of the Hypertension Information and

Education Advisory Committee of the National High Blood Pressure Education Program stated (42:17):

> Patient education should be an integral part of the medical care of hypertension, and health professionals in private office practice and every other patient care facility should use a planned approach to meet the patient's education and motivation needs.

Consequently, to facilitate early preventive treatment, the diagnostic techniques designed to detect hypertension should be under continuous scrutiny since the success of preventive measures are inherently dependent on the accuracy of early identification of populations at risk.

Purpose

The purpose of this study was to clarify the diagnostic process for hypertension, through investigation of selected procedures commonly used in medical practice to diagnose hypertension.

The Problem

The problem was to determine from a preselected group, a set of diagnostic procedures that contributed most significantly to the detection of hypertension.

Hypotheses

The following null hypotheses were formulated and tested by appropriate procedures.

1. There were no significant relationships between systolic blood pressure and the following predictor variables: body weight, proteinuria, hematocrit, serum cholesterol, age, sex, and height.

2. There were no significant relationships between diastolic blood pressure and the following predictor variables: body weight, proteinuria, hematocrit, serum cholesterol, age, sex, and height.

Definitions

For clarification, the following terms were defined for use in the study.

1. Hypertension. Blood pressure elevated to a point resulting in an increased risk of death.

2. Essential Hypertension. Elevated blood pressure for which no cause can be found.

3. Secondary Hypertension. Elevated blood pressure caused by underlying disease.

Delimitations

This study was delimited to:

1. Data collected from the following sources:
    a. Indian Mountain Family Practice Group, Jellico, Tennessee;
    b. Clearfork Clinic, Clairfield, Tennessee;

c. Laurel Fork Clinic, Frakes, Kentucky;

d. Wynn-Habersham Clinic, Lafollette, Tennessee.

2. Data from summary sheets of medical records of individuals 15 years of age and older.

3. Data from summary sheets of medical records of individuals who had been treated between January 1, 1976 and September 1, 1976.

Limitations

This study may have been limited by:

1. The accuracy and reliability of sources of data.

2. The limitations imposed on the scope of the study by the availability of data.

CHAPTER II

REVIEW OF RELATED LITERATURE

The purpose of this chapter is to provide a review of selected literature as background for the problem under investigation. An extensive review of literature dealing with hypertension revealed little agreement on the relative value of specific diagnostic procedures. However, voluminous research was reviewed concerning hypertension detection in general, its treatment, and prevention. To facilitate the readers' perspective on the specific problem under study, this chapter has been divided into sections. The first introduces the problem of defining hypertension, the second section reviews literature concerning diagnostic tests for hypertension, and the third section discusses the methodology used for evaluation of diagnostic tests.

Hypertension

Hypertension is a condition now known to be among the most potent contributors to mortality in the United States (10). Commonly, hypertension is defined in terms of elevation of blood pressure above normal levels; however, the definition of "normal" levels of blood pressure has generated considerable debate. Pickering (50:570) wrote:

> It has been known for over a century that high arterial pressure lessens life expectancy, and for half that time in most patients the raised pressure and its consequences constitute the disease (essential hypertension). Thus the first question the physician asks is "What is hypertension?"

Among the first efforts directed toward definition of hypertension were those focused on describing the condition in terms of definite blood pressure values. Ayman (3) in a study of over 1500 individuals from 277 families, concluded that the dividing line between normotension and hypertension is 140 mm Hg systolic, with a diastolic blood pressure of 80 mm Hg. Robinson and Brucer (51) using data gathered from over 11,000 individuals decided that a systolic blood pressure of 120 mm Hg with a diastolic blood pressure of 80 mm Hg could effectively identify hypertensive patients. Brown (8) in a study of hypertension and pregnancy, concluded that hypertension could be diagnosed by a systolic blood pressure of 130 mm Hg with a diastolic blood pressure of 70 mm Hg. Bechgaard (6) in a follow-up investigation of 1000 individuals determined that the dividing line between normotension and hypertension is a systolic blood pressure of 160 mm Hg and a diastolic blood pressure of 100 mm Hg. Perera (48) concluded that a systolic blood pressure of 140 mm Hg with a diastolic blood pressure of 90 mm Hg are descriptive of hypertensive individuals. Burgess (9) investigating long term effects of high blood pressure, determined that a

systolic blood pressure of 180 mm Hg with a diastolic blood pressure of 100 mm Hg could describe hypertension. Thomas (56) concluded that hypertension could be diagnosed by a systolic blood pressure of 150 mm Hg and a diastolic blood pressure of 90 mm Hg. In a textbook, Evans (15) concluded that a systolic blood pressure of 180 mm Hg with a diastolic blood pressure of 110 mm Hg could be used as the diagnostic criterion for hypertension.

The determination of hypertension based on systolic and diastolic blood pressure measurements is a problem that has seen extensive research investment, but without achieving any apparent consensus. Suggested values for systolic blood pressure definitive of hypertension range from a low of 120 mm Hg to a high of 180 mm Hg. Suggested values for diagnostic criteria for diastolic blood pressure range from a low of 80 mm Hg to a high of 110 mm Hg. Clearly there is little agreement.

The variability of blood pressure values compounds the confusion over specific values of systolic and diastolic blood pressures definitive of hypertension (2). Ahmad (1) in a study of blood pressure levels among 322 subjects in Pakistan, reported standard deviations of 13.9 and 7.9 for systolic and diastolic blood pressure measurements, respectively. The National Center for Health Statistics of the United states (57), in a report of selected information

from "Blood Pressure Levels of Persons 6-74 Years: United States, 1971-1974," reported standard deviations of 17.9 for systolic blood pressure, and 11.54 for diastolic blood pressure. The relatively large standard deviations reported in both instances, add to the problem of determining critical values for diagnosing hypertension, by indicating the presence of additional variability, where interpretation is already uncertain. In addition, it was reported by the Hypertension Detection and Follow Up Program of the National Heart, Lung, and Blood Institute that 29 to 39 percent of the subjects initially found to be hypertensive did not exhibit elevated diastolic blood pressures at a second screening (26,39).

The insurance industry stakes its financial health on its ability to make accurate predictions. Where health status of insurees is concerned, those factors affecting longevity are of particular interest. In this vein, hypertension has been recognized as a condition affecting longevity (40). When considering risk of death according to groups of systolic and diastolic blood pressure values, a definite relationship emerges, associating high expected death rates with higher systolic and diastolic blood pressures. "The higher the arterial pressure when initially measured, the greater the mortality; this is true from the lowest to the highest pressures. The relationship is quantitative" (50:570).

When viewed in this context, the definition of hypertension becomes an abstraction, only derived actuarially. Based on this actuarial concept, hypertension has been defined operationally in terms of diastolic blood pressure. "A diastolic pressure of 90 mm Hg is associated with an increase in mortality rates of two to three times the normal. This diastolic level is selected arbitrarily as being 'hypertensive'" (7:20). This level for diastolic blood pressure, as definitive for the diagnosis of borderline hypertension has wide support (16,19,26,34,48,31).

Using the same acturial approach in a longitudinal study, Kannel, Wolf, Verter and McNamara (32) further refined diastolic blood pressure criteria to distinguish between borderline hypertension and hypertension. This investigation established a level of 95 mm Hg diastolic blood pressure as the criterion for the diagnosis of hypertension, with 90 mm Hg diastolic for borderline hypertension (see Table 1).

Using the same developmental process, systolic blood pressure criteria for borderline hypertension and hypertension have also been established. Kannel (31) in a report of the Framingham Study, demonstrated that a division between normotensive and borderline hypertensive individuals could be established at a systolic blood pressure of 140 mm Hg. Overt hypertension was similarly defined at a systolic blood

Table 1. Mortality Ratios* for Men According to Groups of Systolic and Diastolic (Fifth Phase) Blood Pressure Readings, Without Minor Impairments, All Ages

Systolic Reading (mm Hg)	Diastolic Reading (5th Phase) mm Hg				
	64-83	84-88	89-93	94-103	All
118-132	90**	91	99	97	92
133-142	99	107	118	134	110
143-152	133	137	141	173	148
153-167	186	178	189	237	210
All	95	100	116	151	106

*Actual to expected deaths (expected = 100)

**This included only systolic readings 128-132 mm Hg

Source: Adapted from Pickering (50).

pressure of 160 mm Hg. In addition, it has been demonstrated that systolic and diastolic blood pressures are both closely associated with hypertension (24,35).

Diagnostic Procedures for Hypertension

The measurement of blood pressure is but one of the diagnostic tools used in the detection of hypertension. An additional problem involved in the diagnosis of hypertension is to distinguish between hypertension of secondary causation and essential hypertension. A wide variety of recommendations have been made to assure the validity and reliability of diagnostic procedures for this problem. Perloff stated three objectives in examining a patient with reference to hypertension (49:77).

> (1) confirm the persistence of inappropriately elevated blood pressure, (2) assess and quantitate the severity of the hypertension and resulting cardiovascular complications, and (3) find or exclude the curable causes of secondary hypertension.

The diagnosis of hypertension involves careful evaluation of the patient by the clinician. Essential in all diagnostic processes is gathering of historical information from the patient or his/her family which may be of value in narrowing the spectrum of interest. Accurate history taking is essential to the determination of symptoms for secondary hypertension, such as kidney disorders. In addition, hypertension is a condition for which information about heredity is important. Macleod wrote (32:274):

> It has been estimated that if both parents have hypertension the incidence of the disease in the children is about 45 percent and if one parent has hypertension about 30 percent. If the patient is under 35 years and there is no family history of hypertension, an underlying cause is likely to be present.

The medical history of the patient may also reveal, in some cases, such necessary pieces of information about symptoms as headaches, fatigue, dizziness, etc., which may represent complications of hypertension.

Measurement of blood pressure is perhaps the most basic diagnostic procedure for hypertension. According to Kirkendall, Burton, Epstein and Freis (33:980):

> Systemic arterial blood pressure represents a force which is the result of cardiac output and peripheral vascular resistance. It is readily measured indirectly by a standard sphygmomanometer. Compared with intraarterial measurements of blood pressure, the indirect measure is imprecise. Nevertheless, it is known that properly measured indirect blood pressure readings in the upper ranges and wide swings of blood pressure in the same individual are important signs of vascular disease.

As discussed earlier, the determination of blood pressure levels descriptive of hypertension is an issue with conflicting opinions. Nevertheless, the measurement of blood pressure is the least expensive, most readily accessible diagnostic technique for the detection of hypertension (39).

An additional diagnostic procedure which may be applied to the detection of hypertension, in addition to many other conditions, is retinoscopy to detect arterial wall thickening.

Freis commented on the usefulness of this procedure in diagnosing hypertension (17).

> A most important aspect of the physical examination is the observation of the optic fundi. Aside from the obvious hemorrhages, exudates and papilledema that are associated only with severe hypertension, the funduscopic changes seen in less severe forms of hypertension should be interpreted with some caution. There is a considerable overlapping of normal with hypertensive patients with respect to arteriolar narrowing, tortuosity, irregularity and other changes that are supposedly related specifically to hypertension. Even arteriovenous nicking can be seen in vessel crossings near the optic disc in some normal subjects. The presence of nicking at arteriovenous crossings that are more than two disc diameters away from the optic disc, however, does provide a reliable sign of arteriolar sclerosis.

To further assess the extent of hypertension, the patient should be given a resting electrocardiogram "to determine the presence and degree of left ventricular hypertrophy and associated coronary insufficiency" (49:80).

In addition to the above, it is recommended that the following procedures be included for diagnosing hypertension. A urinalysis to test for the presence of protein, a serum cholesterol determination, hematocrit, and a chest roentgenogram (28,34,39).

Evaluation of Diagnostic Tests

Diagnostic tests rarely, if ever, classify correctly all individuals tested as well or diseased. Most tests fall somewhat short of the theoretical optimum; classification of

diseased persons as diseased and nondiseased persons as nondiseased. This phenomenon does not necessarily invalidate a test, but necessitates the definition of acceptable levels of error. This raises the following problems as described by Greenhouse and Mantel (24:399).

> A diagnostic test for a disease is proposed and it is desired to test the hypothesis that it meets the specified requirements. A sample of known positives and known negatives is drawn: the diagnostic test is applied and the results are analyzed for consistency with the hypothesis. Then how large a sample of positives and negatives is required if it is desired to test this hypothesis when the probabilities of Type I and Type II errors are set at α and β respectively? Secondly, given two diagnostic tests, which one is more effective in detecting disease?

Given the situation where the test results can only be interpreted in one of two ways, positive or not positive, the selection of α and β will determine the necessary sample size. However, in most instances diagnostic test results are continuous variables, which are then in the case of blood pressure measurements used for the detection of hypertension, arbitrarily subdivided into regions designated as positive or negative. The selection of the dividing line between positive and negative will influence the measures of effectiveness of the diagnostic test, and in fact, can be manipulated to provide increasing precision of both sensitivity and specificity. Greenhouse and Mantel concluded (24:400):

> The choice of the point of demarcation of the positive-negative region cannot be independent of the two percents specified. One can always select a point of demarcation so that fewer than (percent diseased) of the diseased will be correctly classified or more than (percent well) of the well will be incorrectly classified. It would thus be possible to reject an acceptable test because of an improper selection of a critical point. In consequence, for any given set of experimental results designed to evaluate a diagnostic test there are at least two possible choices of a critical point for specified (percent diseased) and (percent well): that which yields exactly (percent diseased) percent of the well correctly classified, or that which yields exactly (percent well) percent of the well incorrectly classified.

Therefore, the problem to be dealt with is the determination of the inherent goodness of a procedure designed to detect disease.

To evaluate diagnostic procedures, a number of analytical methods are available. The ultimate goal of the diagnostic procedure is to detect individuals with disease, but at the same time exclude patients without disease.

A decision matrix logically classifies results of diagnostic tests into discrete categories, which are related to the clinical manifestations of the condition. In this format, the disease state is partitioned into either a positive or negative classification through use of an accepted measure. Results of the diagnostic procedure designed to detect the disease in question are also partitioned into discrete categories, positive and negative. When shown on a two-by-two table, four combinations are possible: disease

positive test positive, disease positive test negative, disease negative test positive, and disease negative test negative (see Table 2).

Table 2. A General Decision Matrix.

Test Results	Presence of Disease		
	Present	Absent	Totals
Positive	a	c	a + c
Negative	b	d	b + d
Totals	a + b	c + d	

Source: Adapted from McNeil (38).

Each of the four cells of the decision matrix gives information as to the value of the diagnostic procedure by comparing the results of the test with the actual pathological state. From this information, four ratios can be formed. The true positive, or test-positive, disease-positive, is the proportion of positive test results in the set of all diseased individuals, $\frac{a}{a + b}$. This true positive ratio expresses the sensitivity of the diagnostic test. The proportion of positive tests in the set of all nondiseased individuals, $\frac{c}{c + d}$, is the false positive ratio, and represents the probability of obtaining erroneous test results; that is, a positive test result but without disease.

The proportion of negative test results in all tested individuals is the true negative ratio, $\frac{d}{c + d}$. This ratio expresses the specificity of the diagnostic test. The proportion $\frac{b}{a + b}$ is the ratio of negative tests in all the individuals who actually had the disease, and represents the probability of obtaining erroneous test results, but in this instance the test would be negative while the true disease state was positive.

Ideally, a diagnostic test should have a high true positive ratio, and a low false positive ratio, however the consequences of falsely diagnosing a well individual as diseased is often preferred to the consequences of falsely diagnosing a diseased individual as well.

After a diagnostic test has been evaluated to determine its sensitivity and specificity, further refinement of the calculated probabilities may be pursued. Cornfield (12) pointed out that there are two basic questions to be answered by a diagnostic test. If a patient has a disease, what is the probability that a correct diagnosis will be made? If the patient has been diagnosed as having a disease, what is the probability that the disease is actually present?

Bayes' theorem (4) allows the calculation of a posteriori probabilities, which can be applied to the evaluation of a diagnostic test in question. The general form of Bayes' formula is the following:

$$P(D_1|S_1) = \frac{P(D_1)P(S_1|D_1)}{\Sigma P(Di)P(S_1|Di)}$$

where $P(D_1)$ is the a priori probability which is the relative frequency of the disease D_1, and $P(D_1|S_1)$ is the conditional probability of symptom S_1 among individuals with disease D_1.

The usefulness of Bayes' formula is that estimates of the efficacy of diagnostic tests, in this instance, can be derived using observable information. Barnoon and Wolf, in discussing Bayes' theorem, explained its utility in the following manner (4:16).

> For example, it is desired to identify the probability of a disease given the existence of certain signs and symptoms $(Pi|Sj)$. In actuality, it is possible to accumulate the frequency with which a given disease occurs $P(Di)$ and also the frequencies with which certain symptoms are observed when the disease is known to be present $P(Sj|Di)$

Warner, Toronto and Veasy (62) in dealing with computer applications of Bayesian analysis to the diagnosis of congenital heart disease, compared the computerized results to the results obtained by several different physicians all diagnosing the same patients. Although not dramatic, the results demonstrate the efficacy of the Bayesian approach to the evaluation of diagnostic procedures.

Overall and Williams (47) in an extensive investigation of diseases involving the thyroid gland, studied over 1500 individuals. Overall they demonstrated 98 percent correct diagnoses. In addition, computer systems were developed to

predict a posteriori probabilities for hypothyroidism, euthyroidism and hyperthyroidism.

Nugent, Warner, Dunn and Tyler (46) in an investigation of the diagnosis of Cushing's syndrome, found that there are geographic differences in the a priori probabilities established. It was concluded that analysis must rely on information on symptoms and diseases obtained in the vicinity of the experiment. In addition, the same authors noted that the primary limitation of Bayesian analyses is the choice of criteria for positive definition of disease states.

It has been shown that the concept underlying Bayes' theorem can be used as an effective format for the analysis of problems encountered with defining disease states, and technical difficulties involved with computerization of analytical algorithms. However, it must be noted that large sample sizes are required to achieve reliability of estimates.

CHAPTER III

METHODOLOGY

The purpose of this chapter was to provide a record of the methodology employed in the analysis of the research problem. Methods for this study were divided into phases, preliminary and operational.

Preliminary methods were those steps necessary prior to gathering of data. Included were the following:

1. A review of the literature pertinent to the problem
2. Selection of the diagnostic procedures to be included in the study
3. Determination of the best methods for data collection and analysis

Operational methods included those tasks involved with data collection and analysis, and included the following steps.

1. Data collection
2. Tabulation and analysis of the data

Preliminary Methodology

Review of the literature. An extensive review of literature relevant to hypertension and diagnostic procedures was conducted utilizing the libraries of the University of Utah at Salt Lake City, Utah, and the University of Tennessee

at Knoxville. This search provided a wide array of information, which was synthesized into a useful guide for analysis of the problem under investigation.

Selection of the diagnostic procedures. The procedures to be used for the diagnosis of hypertension, as recommended by numerous researchers were varied. As discussed in Chapter II, recommended diagnostic procedures for the detection of hypertension included, in addition to a thorough medical history, measurement of blood pressure (systolic and diastolic), examination of the retinal fundus, electrocardiogram, urinalysis, serum cholesterol, hematocrit, and a chest x-ray (17,28,33,34,36,39,49). This study, however, was concerned with an analysis of diagnostic procedures utilized by practitioners on a regular basis; procedures routinely carried out with a minimum of time and expense to the patient and the community.

To determine which of the diagnostic procedures discussed in Chapter II were to be included in this investigation, a brief, informal feasability study of the data gathering procedures was conducted. With the consultation of Jesse M. Walker, M.D. and Thomas Mackey, R.N., P.A., practitioners recording information in the medical records, it was determined that the results of the retinoscopy and chest roentgenogram procedures were not systematically interpretable

from the primary data source. It was determined that the results of systolic and diastolic blood pressure measurement, body weight, height, sex, age, urinalysis for protein, and blood tests for hematocrit and serum cholesterol could be systematically interpreted and recorded. Based on the criterion of reliable interpretability of the primary data sources, and the procedures recommended for inclusion from Chapter II, it was decided that the following diagnostic procedures would be included in the study.

1. Systolic and Diastolic Blood Pressures, recorded as measured using a mercury sphygmomanometer (21).
2. Body Weight, recorded in pounds.
3. Height, recorded in inches.
4. Sex.
5. Age, recorded in years.
6. Proteinuria, recorded as results of the Reagent Strip Method of testing for protein in urine (63).
7. Hematocrit, determined by microtechnique.
8. Serum Cholesterol, determined by Autoanalyzer.

Operational Methodology

Data collection. The data were recorded directly from summary sheets of the medical records onto prepared data collection sheets. The summary sheets were a part of the medical record that included only vital data and results of

diagnostic tests displayed in tabular form (see Appendix A). No other portions of the medical records were inspected. To protect anonymity of the patients, no personal identifying information was recorded.

Treatment of the data. Statistical treatment of the data was designed to describe the data collected and test the stated hypotheses. To avoid possible errors occurring during the transference of data from the data collection sheets onto tabulation sheets for computerization, the collected information was keypunched directly onto computer cards and verified.

Specifically, the data were treated using the following procedures.

1. Initially, the data were tabulated and selected statistics were calculated to provide a meaningful summary of the characteristics of the variables. Selected statistics included the mean, mode, standard deviation and range.

2. To select the diagnostic procedures that best predicted hypertension, a stepwise multiple linear regression approach was used. The dependent variables systolic and diastolic blood pressures were regressed separately on the set of independent variables body weight, proteinuria, hematocrit, serum cholesterol, age, sex, and height to derive discrete equations for both systolic and diastolic blood

pressures. From the tests of statistical significance obtained, the best set of diagnostic procedures for estimating systolic and diastolic blood pressure were selected.

3. To quantify the potential for classification of the set of variables found to be statistically significant by the stepwise multiple regression procedure, multiple discriminant analysis was used. The observations were initially partitioned into three groups using the definitions for normotension, borderline hypertension, and hypertension derived from the review of literature discussed in Chapter II. Specifically the definitions were as follows.

1. Normotension. A systolic blood pressure of 140 mm Hg or less and a diastolic blood pressure of 90 mm Hg or less.

2. Borderline Hypertension. A systolic blood pressure greater than 140 mm Hg but less than 160 mm Hg and/or a diastolic blood pressure greater than 90 mm Hg but less than 95 mm Hg.

3. Hypertension. A systolic blood pressure greater than or equal to 160 mm Hg and/or a diastolic blood pressure greater than or equal to 95 mm Hg.

The independent variables found to be significant contributors to overall regression, for both systolic and diastolic blood pressures, were tested for contribution to discrimination among the groups normotension, borderline hypertension, and hypertension.

4. As a validation procedure for the discriminant analysis, a split sample analysis was used. The data set was divided into two halves, by an even-odd criterion for each observation, and the discriminant analysis procedure applied to one of the halves. The derived discriminant functions were then tested on their ability to classify the unanalyzed half of the data set.

CHAPTER IV

RESULTS

Introduction

The purpose of this chapter was to present the analysis of the data. The form of the chapter was dictated by the hypotheses stated in Chapter I, as well as by the procedures for data analysis outlined in Chapter III. Accordingly, the presentation of the data analysis was divided into three broad procedural categories; a description of the data, the tests of the hypotheses, and procedures used for validation of results.

The Data

The data are the information collected from the primary data sources as outlined in Chapter III. Of the 1023 summary sheets encountered and examined for inclusion into the study, 92 had necessary information missing, leaving 931 observations to be included in the study population. Pertinent information was recorded from each summary sheet individually. Selected descriptive statistics are presented in Table 3.

Hypothesis Tests

The null hypotheses to be tested were as follows:

1. There were no significant relationships between systolic blood pressure and the following predictor variables:

Table 3. Selected Descriptive Statistics for 931 Observations (618 Female, 313 Male)

Variable	Mean	Mode	Standard Deviation	Range
Systolic BP	127.7	120	24.1	76-200
Diastolic BP	81.1	80	13.2	50-120
Body Weight	158.7	160	36.5	76-275
Height	65.1	62	3.6	57-76
Proteinuria		1		0-3
Hematocrit	43.8	42	4.0	32-56
Serum Cholesterol	216.8	220	24.6	150-350
Age	50.5	56	16.6	15-85

body weight, proteinuria, hematocrit, serum cholesterol, age, sex, height.

2. There were no significant relationships between diastolic blood pressure and the following predictor variables: body weight, proteinuria, hematocrit, serum cholesterol, age, sex, height.

A correlation matrix including all independent and dependent variables is presented in Appendix B.

The hypotheses were tested initially using a stepwise (forward) multiple linear regression approach. The goal of using this procedure was to establish both the overall relationship of the dependent variables, systolic and diastolic blood pressures, with the predictor variables, and a specific ordering of the predictors as they influenced the dependent variables. Since the independent variable sex could assume only two values, male and female, a dummy variable was generated for the regression procedure for this variable. Computations for the hypotheses tested were done using the "stepwise" procedure of the SAS76 package of programs (5). All computations involving use of packaged programs were done using an IBM 360-65 computer.

The procedures for testing the hypotheses consisted of two components. First, a test of significance of regression of each dependent variable on the independent variables was obtained to determine the overall statistical significance

of each hypothesis. Second, where overall regression was demonstrated, the relative contribution of each independent variable was determined. Each independent variable was tested sequentially for its potential contribution to the overall model, expressed as a sequential F statistic. If the sequential F statistic was significant at the .50 level of significance, the variable was entered into the model. After a variable was entered into the model, a partial F statistic was recalculated for each variable in the model, adjusted for all other independent variables in the model, each time an additional variable was added. For a variable to be maintained in the model, the F statistic had to continue to be significant at the .10 level of significance. The model produced at the conclusion of the variable-addition process contained only those variables meeting both inclusion criteria. Significance tests of the variables included in the final model were then done using the partial sums of squares; each variable adjusted for all other variables in the model.

For hypothesis 1, the Analysis of Variance Table for the test of significance of the relationship between the dependent variable systolic blood pressure, and the independent variables, is presented in Table 4. The degrees of freedom in Table 4 reflect the fact that the independent variable sex did not meet the inclusion criteria and was not retained in the final model.

Table 4. Overall Test of Regression for Hypothesis 1, Dependent Variable Systolic Blood Pressure

Source	df	Sum of Squares	Mean Squares	F	P>F
Regression	6	132287.54	22047.92	52.72	.0001
Error	924	386439.90	418.22		
Total	930	518727.44			

There was a significant regression of systolic blood pressure on the independent variables body weight, proteinuria, hematocrit, serum cholesterol, age, and height at the.01 significance level. Therefore hypothesis 1 was rejected at the .01 level of significance. The independent variable sex did not meet the inclusion criteria and was eliminated from the model.

The relative contribution of each independent variable in hypothesis 1 to overall regression is indicated in Table 5. The partial sums of squares are sums of squares for each variable, adjusted for all other independent variables listed.

Table 5. Relative Contribution of Independent Variables to Regression, Dependent Variable Systolic Blood Pressure

Source	Partial Sums of Squares	F	P>F
Age	68070.74	162.76	.0001
Weight	25066.73	59.94	.0001
Height	6709.22	16.04	.0001
Serum Cholesterol	4418.64	10.57	.0012
Proteinuria	4041.67	9.66	.0019
Hematocrit	3772.55	9.02	.0027

Each of the variables retained by the inclusion criteria was significant at the .01 level of significance, and therefore contributed to the overall statistical significance of systolic blood pressure on the independent variables.

The second hypothesis was tested using the same format that was used for testing hypothesis 1. For hypothesis 2, the Analysis of Variance Table for the test of significance of the relationship between the dependent variable diastolic blood pressure and independent variables is indicated in Table 6. Again, the independent variable sex was not retained in the model as a consequence of the inclusion criteria.

Table 6. Overall Test of Regression for Hypothesis 2, Dependent Variable Diastolic Blood Pressure

Source	df	Sum of Squares	Mean Squares	F	P>F
Regression	6	23361.78	3893.63	26.11	.0001
Error	924	137787.04	149.12		
Total	930	161148.82			

There was a significant regression, at the .01 significance level, of the dependent variable diastolic blood pressure on the independent variables body weight, proteinuria, hematocrit, serum cholesterol, age, and height. Therefore hypothesis 2 was rejected at the .01 level of significance. The independent variable sex did not meet the inclusion criteria and was eliminated from the model.

The relative contribution of each independent variable except sex in hypothesis 2 to overall regression is indicated in Table 7.

Table 7. Relative Contribution of Independent Variables to Regression, Dependent Variable Diastolic Blood Pressure

Source	Partial Sum of Squares	F	P>F
Body Weight	12889.44	86.44	.0001
Height	2377.57	15.94	.0001
Hematocrit	2221.44	14.90	.0001
Age	1506.92	10.11	.0015
Serum Cholesterol	743.89	4.99	.0258
Proteinuria	735.25	4.93	.0266

The variables body weight, height, hematocrit, and age, adjusted for all other independent variables, were significant at the .01 level, and therefore contributed to the overall statistical significance of regression of diastolic blood pressure on the independent variables. Serum cholesterol, proteinuria, and sex were not significant.

From the analysis presented, it is clear that both systolic and diastolic blood pressures are related to individual members of the predictor list. However, the squared multiple correlation coefficients (R^2), which quantify the amount of variability in the model explained by each set of statistically significant independent variables, are

relatively low; .255 and .145 for systolic and diastolic, respectively. There is a large amount of variation in the models unexplained by the regression procedures; 74.5 percent in the case of systolic blood pressure, and 84.5 percent for diastolic.

The change in R^2 expresses the additional variation explained with the addition of each new independent variable to the model. Changes in the squared multiple correlation coefficients, R^2, indicating the additional variation in the model explained with the addition of each independent variable are presented in Table 8. For systolic blood pressure, the change in R^2 became small—less than .01—after the third independent variable, serum cholesterol, was entered into the model. The addition of more than three independent variables to the multiple regression equation produced very little reduction in the variation explained by the model. For diastolic blood pressure, the change in R^2 became less than .01 after the second independent variable, age, was entered into the model, but the addition of hematocrit, the fourth independent variable, resulted in a change in R^2 greater than .01.

For the models investigated for systolic and diastolic blood pressures, virtually the same degree of predictability could be obtained by deleting proteinuria, height and hematocrit from the systolic blood pressure model; proteinuria,

Table 8. Changes in Squared Multiple Correlation Coefficients (R^2) with Addition of Independent Variables for Systolic and Diastolic Blood Pressure Models

Independent Variable	R^2	Change in R^2
Systolic Blood Pressure		
Age	.1650	.1650
Body Weight	.2212	.0562
Serum Cholesterol	.2314	.0102
Proteinuria	.2400	.0086
Height	.2477	.0077
Hematocrit	.2550	.0073
Diastolic Blood Pressure		
Body Weight	.1004	.1004
Age	.1127	.0123
Height	.1199	.0072
Hematocrit	.1357	.0158
Proteinuria	.1404	.0047
Serum Cholesterol	.1450	.0046

height and serum cholesterol from the diastolic blood pressure model. Although statistically significant, these independent variables contributed little to the overall predictability of the multiple regression models.

Discriminant Analysis

To provide another approach to analysis of the problem investigated by this study, a discriminant analysis procedure was implemented. Specifically, the discriminant analysis procedure was used to quantify the potential of the independent variables found to be statistically significant by the hypothesis testing procedure dealt with previously, for classifying observations into the categories normotensive, borderline hypertensive, and hypertensive. Discriminant functions, weighted linear combinations of the selected independent variables, were derived for each group to effect the maximum statistical distinction between the three groups (44). The discriminant functions were derived for each group using the 931 observations included in the study population. The observations were grouped into discrete categories according to predetermined criteria, as stated in the definitions for normotension, borderline hypertension and hypertension in Chapter III. Based on the numbers of observations in each of the three groups formed; 656

normotensive, 121 borderline hypertensive, and 154 hypertensive, a priori probabilities for group membership were determined: .70 normotensive, .13 borderline hypertensive, and .17 hypertensive.

For the discriminant analysis, each observation consisted of the values of the independent variables body weight, proteinuria, hematocrit, serum cholesterol, age, and height. Sex was not included, as it was not found to be a significant contributor to either of the multiple regression analyses reported earlier. The values of these variables, in addition to the probabilities attached to membership in each of the groups, were first used to calculate the discriminant functions for the three groups. Based on the discriminant functions, which were derived to maximize the separation of the three groups, the observations, ungrouped, were then classified into one of the three groups based on the unique set of independent variable values of each observation and the discriminant functions. In this way, the extent to which the independent (discriminating) variables were able to replicate the a priori classification of the observations was investigated. Computations for the discriminant analysis were carried out using the 07M routine of the BMD data analysis system (13).

Three separate sets of tests were obtained from the discriminant analysis (55). First, an overall test of significance of discrimination among the three groups by the independent variables body weight, proteinuria, hematocrit, serum cholesterol, age, and height was obtained. This overall test was used to determine if the discrimination among the groups, as established by the independent variables, was greater than would have been expected by chance. The F statistic obtained was 15.55, with 12 and 1846 degrees of freedom. The critical F value at the .01 level of significance is 2.18 in this case, which indicated that there was significant discrimination among the three groups.

The second set of tests were obtained to determine the statistical significance of each of the variables included in the discriminant functions. This set of tests, "conditional F tests," measured the contribution of each independent variable to discrimination, with all other independent variables held constant. For this procedure, each of the independent variables was tested initially for entry into the discriminant function. The test for entry was expressed as an F statistic. If the F statistic was significant at the .50 level of significance, the variable was entered into the equation. After each new independent variable was entered,

F statistics were calculated for all variables in the discriminant equation. To be maintained in the discriminant equation, the F statistic had to be significant at the .005 level of significance. The discriminant functions produced at the conclusion of the process contained only those independent variables that maintained sufficient F statistic values to remain significant at the designated levels throughout. Results of the conditional tests of significance of the variables used in the discriminant functions are presented in Table 9. The values obtained for each of the independent variables are presented using Rao's R, which is distributed approximately as an F statistic (55). The method used for the conversion from the BMD07M F statistic to Rao's R is presented in Appendix D.

Table 9. Conditional Tests of Significance for Variables Included in the Discriminant Analysis

Source	Rao's R	df	$F_{.01}$
Age	42.24	12,1846	2.18
Body Weight	30.04		
Proteinuria	20.57		
Serum Cholesterol	19.66		
Height	19.19		
Hematocrit	18.93		

The final operation performed by the discriminant analysis was to classify the observations in the study

population into groups using the derived discriminant functions. The observations were considered ungrouped, and based on the discriminant functions, were classified into one of the (predicted) groups normotensive, borderline hypertensive and hypertensive. From the knowledge of the numbers of observations in each of the original groups, designated as the "clinical diagnosis" groups for this part of the analysis, the number of misclassifications and the number of correct classifications into the "predicted diagnosis" groups were assessed, giving a comparison of the classification by the discriminant functions and by the established definitions. Therefore, indirectly the potential of the set of independent variables for classifying observations into the diagnostic categories was investigated. The classification results are presented in Table 10.

Table 10. Classification of Observations by the Discriminant Functions (N=931)

Clinical Diagnosis	Predicted Diagnosis		
	Hypertensive	Borderline	Normotensive
Hypertensive	31	0	123
Borderline	10	1	110
Normotensive	22	0	634
Percent Correctly Classified		71.54	
Percent Misclassified		28.46	

The discriminant analysis revealed that there was a significant discrimination between the three groups normotensive, borderline hypertensive, and hypertensive by the independent (discriminating) variables body weight, proteinuria, hematocrit, serum cholesterol, age and height, at the .01 level of significance. When each independent variable was considered separately, with all other variables held constant, each variable contributed to the overall significance of discrimination (see Table 9, page 40).

Split Sample Analysis

To validate the discriminant analysis results, an additional procedure was used (45). The question to be answered by this analysis was: is the classification of a new set of data by the discriminant functions as good, or better than classification using only the a priori probabilities for each of the three groups? The approach used was to split the data set into two halves, by even-odd criteria in this case, determine discriminant functions for each of the three groups for one of the halves, and then subsequently apply the derived functions to the other unanalyzed half of the data.

To test the results of the split sample discriminant analysis procedure, a Chi Square goodness-of-fit test was used (22). Expected frequencies for each cell of the Chi

Square table were calculated for half of the data set (N=465) from a priori probabilities for normotensive, borderline hypertensive, and hypertensive; .70, .13, and .17 respectively. Expected frequencies calculated from the a priori probabilities are presented in Table 11.

Table 11. Expected Frequencies Calculated Using A Priori Probabilities (N=465)

	Hypertensive	Borderline	Normotensive
Hypertensive	14	10.3	55.5
Borderline	10.3	7.9	42.4
Normotensive	55.5	42.4	228

To determine if the classification by the discriminant functions was as good as classification by a priori probabilities, the expected frequencies were tested against the frequencies observed from the classification by the discriminant functions. The observed frequencies and the results obtained from the Chi Square test for goodness-of-fit are presented in Table 12.

Table 12. Observed Frequencies Classified by the Discriminant Functions (N=466)

	Hypertensive	Borderline	Normotensive
Hypertensive	17	0	60
Borderline	10	2	49
Normotensive	22	2	304

Chi Square = 98.78

degrees of freedom = 4

$P < .001$

There was a significant difference between the expected and observed frequencies, at the .001 level of significance. The discriminant functions derived from the analysis of one half of the data set, applied to the classification of the other half of the data, classified the observations in a different way than would a chance classification. Specifically, by inspection of Table 12, the greatest differences between observed and expected are in the normotensive and borderline classifications. Normotensives, vertically, are consistently observed in greater numbers than expected from Table 11. Additionally, the borderline classification, vertically, is consistently observed in considerably smaller numbers than expected.

Summary

This chapter has been concerned with the presentation and analysis of the data. The stepwise multiple linear regression procedure revealed that the variables age, body weight, height, serum cholesterol, proteinuria and hematocrit, in that order, contributed to a significant regression on systolic blood pressure. However, serum cholesterol and proteinuria did not contribute to significant regression on diastolic blood pressure, although the remaining independent variables did. To further investigate the classifying power of the independent variables discriminant analysis was used and validated by a split sample analysis. These two procedures indicated that the set of independent variables classified observations into normotensive, borderline hypertensive, and hypertensive categories in a specific pattern that was different from the classification by chance alone.

Despite the statistical significance obtained, there remains a considerable amount of unexplained variation in the prediction models. The squared correlation values (R^2) for the stepwise multiple regression tests of hypotheses were .255 and .145 for systolic and diastolic (blood pressures) respectively, leaving 74.5 percent of the variation unexplained for systolic, and 84.5 percent for diastolic.

CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The problem. The problem was to determine from a preselected group, a set of diagnostic procedures that contributed most significantly to the detection of hypertension.

Procedures. The procedures used were divided into two broad categories, preliminary and operational. The preliminary procedures were those that preceded the collection and analysis of the data. Essentially, the preliminary procedures consisted of reviewing the literature and selecting the diagnostic procedures to be included in the analysis.

Operational procedures included those tasks involved directly with data collection and analysis. The data were collected from inspection of summary sheets of all medical records in the study population, with special attention paid to measures included to assure anonymity of the subjects. Analysis of the data included procedures directed toward testing of the stated hypotheses, and validation of the results obtained. Stepwise (forward) multiple regression,

discriminant analysis, and a split sample validation technique were employed in the analysis of the data.

Findings

Results of the data analysis were organized into two categories of findings, hypothesis tests and clarifying, validatory results.

Hypothesis tests. The tests of the stated hypotheses produced the following findings.

1. There was a relationship at the .01 level of significance between systolic blood pressure and body weight, proteinuria, hematocrit, serum cholesterol, age, and height. The specific order in which the predictor variables influenced systolic blood pressure, as determined by stepwise (forward) multiple linear regression, was age, body weight, height, serum cholesterol, proteinuria, and hematocrit. The squared multiple correlation coefficient for this equation was .255.

2. There was a relationship at the .01 level of significance between diastolic blood pressure and body weight, hematocrit, age, and height. The specific order in which the predictor variables influenced diastolic blood pressure, as determined by stepwise (forward) multiple linear regression, was body weight, height, hematocrit, and age. The squared multiple correlation coefficient for this equation was .145.

3. The greatest reduction in variation in the stepwise multiple regression models for systolic and diastolic blood pressures occurred with the independent variables age, body weight, serum cholesterol and hematocrit.

Validation. Analyses designed to clarify and validate the results of the hypothesis testing procedures produced the following findings.

1. The variables body weight, proteinuria, hematocrit, serum cholesterol, and height all contributed, at the .01 level of significance, to discrimination of observations into hypertensive, borderline hypertensive, and normotensive groups, without reference to systolic or diastolic blood pressure.

2. The variables body weight, proteinuria, hematocrit, serum cholesterol, age and height, without systolic or diastolic blood pressure measurements, were found to classify new observations into hypertensive, borderline hypertensive and normotensive groups differently than classification by chance, at the .01 level of significance.

Despite statistical significance demonstrated, the squared multiple correlation coefficients (R^2) indicate that only a small amount of variability was explained by the multiple regression models. The R^2 for the systolic blood pressure equation was .255, leaving 74.5 percent of the

variation in the model unexplained. For the diastolic blood pressure equation the R^2 was .145, leaving 85.5 percent of the variation in the model unexplained. The relatively large amounts of variability unexplained by each of the two models limits the practical applicability of the results of the study, regardless of the significance level used in rejecting the two hypotheses tested.

A parallel explanation, and partial interpretation of the findings may be found from examining the nature of systolic and diastolic blood pressures. Whereas systolic blood pressure is relatively labile and responsive to changes in physiological needs of the body, diastolic blood pressure is, by comparison, stable. The standard deviations for systolic and diastolic blood pressure reported in Table 3, page 29, Chapter IV, are 24.1 and 13.2, respectively. As the values of physiological parameters measured increase, systolic blood pressure would also tend to increase—more than would diastolic blood pressure. Therefore the difference between amounts of variability explained by systolic and diastolic blood pressures may be due to the difference in the nature of the quantities being measured, and may not necessarily reflect any real difference in predictability.

Conclusions

Significant relationships have been demonstrated between systolic and diastolic blood pressure and specific members of

the set of predictor variables body weight, proteinuria, serum cholesterol, hematocrit, age, height, and sex. Accordingly, the following conclusions were drawn.

1. The variables that most significantly influence systolic blood pressure are age, body weight, and serum cholesterol.

2. The variables that most significantly influence diastolic blood pressure are age, body weight, and hematocrit.

3. The set of diagnostic procedures contributing most significantly to the detection of hypertension, as defined by systolic and diastolic blood pressure values, includes age, body weight, hematocrit and serum cholesterol.

Recommendations

Based on experience gained from conducting this study, the following recommendations for future research were made.

1. A study should be conducted incorporating a valid method of estimating reliability of measurements into the evaluation of results of diagnostic procedures used for the detection of hypertension.

2. A study should be conducted using a repeated measures design to quantify the effect of random variability in measurements.

3. A study should be conducted to determine the possibility of predicting factors indicating a change from borderline hypertension to hypertension.

CHAPTER VI

FURTHER ANALYSIS AND IMPLICATIONS

The purpose of this chapter was to examine the data further, beyond the limits imposed by the study design. To more completely explain the results obtained from the study, it was decided to continue exploring the diagnostic process used for the detection of hypertension using the following procedures. First, the categories borderline hypertension and hypertension were combined to produce a two classification system, hypertension and normotension. Second, a discriminant analysis, as in Chapter IV, was done using the two category format instead of three. From the results of the discriminant procedure the sensitivity and specificity of the set of results of diagnostic procedures body weight, proteinuria, hematocrit, serum cholesterol, age, height, in classifying hypertension using discriminant functions was determined. Finally, a Bayesian approach was used to further explain the diagnostic process. Specifically, Bayes' theorem was applied to quantify the probability of classifying an observation correctly, when given only abnormal results of the diagnostic procedures. (The discriminant analysis and regression procedures do not address the issue of considering the contribution of abnormal values specifically, but use all observations.)

The data were recombined into the categories hypertensive and normotensive according to the following definitions, as concluded from review of literature.

1. Hypertension. Systolic blood pressure greater than 140 mm Hg or a diastolic blood pressure greater than 90 mm Hg.

2. Normotension. Systolic blood pressure of 140 mm Hg or less, with a diastolic blood pressure of 90 mm Hg or less. Collapsing the categories from three to two resulted in 275 observations in the "new" hypertensive group, and 656 normotensives.

The discriminant analysis for the two groups was conducted using the same procedures as in Chapter IV. Based on the number of observations in each of the two groups, a priori probabilities of .2954 for hypertensive and .7046 for normotensive groups were determined. Each observation included the values for body weight, proteinuria, hematocrit, serum cholesterol, age, and height. The discriminant functions derived using the independent variables listed above, and the prior probabilities resulted in three separate sets of tests; an overall test of significance of discrimination, conditional tests of the contribution of each independent variable to overall discrimination, and a classification giving the results obtained when each observation was classified using the derived discriminant functions.

For the overall test of discrimination, the F statistic obtained was 28.56 with 6 and 924 degrees of freedom. The critical F value at the .01 level of significance is 2.80 in this case, which indicated that there was a significant discrimination between the two groups by the set of independent variables.

Tests for the contribution of each of the independent variables to overall discrimination were conducted by considering each variable separately, with the effect of all other variables held constant. The significance of contribution of each independent variable was tested using Rao's R, which is distributed approximately as an F statistic. Table 13 summarizes the results of the conditional tests.

Table 13. Conditional Tests of Significance for Variables Included in the Discriminant Analysis

Source	Rao's R	$F_{.01(6,924)}$
Age	10.83	2.80
Body Weight	5.58	
Height	2.33	
Hematocrit	2.29	
Serum Cholesterol	2.06	
Proteinuria	0.96	

From Table 13, it is shown that of the independent variables age, body weight, height, hematocrit, serum cholesterol, and

proteinuria, body weight and age contribute to overall significance of discrimination between the hypertensive and normotensive groups.

The results of the classification of the ungrouped observations into categories, hypertensive and normotensive, from the discriminant functions are presented in Table 14. In the table, "clinical diagnosis" represents the judgment of hypertension or normotension based on the definitions presented earlier in this chapter. Classification from "predicted diagnosis" represents the classification derived using the discriminant functions.

Table 14. Classification of Observations by the Discriminant Functions (N=931)

Predicted Diagnosis	Clinical Diagnosis	
	Hypertensive	Normotensive
Hypertensive	69	61
Normotensive	206	595

From the results shown in Table 14, sensitivity and specificity of the independent variables, considered as a set, were calculated using the format for computations described in Chapter II. The true positive ratio was .251, indicating that the set of procedures were 25 percent sensitive. The

true negative ratio was .907, which indicated that the set of procedures were over 90 percent specific in determining the normotensives. Sensitivity is interpreted to mean the probability of diagnosing an individual as diseased by the diagnostic procedures, given the presence of the disease. Specificity, on the other hand, is interpreted to mean the chance of diagnosing an individual as not diseased, given the absence of the disease. Therefore, in this case the set of diagnostic procedures were able to detect hypertension 25 percent of the time, while normotension was detected 90.7 percent of the time. The false negative and false positive ratios are complementary to the sensitivity and specificity, respectively. The false positive ratio was .093, the false negative .749. Therefore the independent variables judged an individual as normotensive 74.9 percent of the time, when in fact according to the definitions, the individual was actually hypertensive as determined by blood pressure. The error of falsely diagnosing a hypertensive individual as normotensive is generally agreed to present a greater risk to the future health of the individual than diagnosing a normotensive individual as hypertensive. In this context, the false negative ratio obtained casts serious doubts on the value of the set of independent variables as predictors of hypertension using discriminant analysis. A limitation of the analysis detailed above is that using discriminant

analysis, the determination of hypertension or normotension was based on weights assigned to the various procedures. The weights were derived specifically to maximize the distance between the groups. In using this format, no interpretation of the individual diagnostic procedures as to normality or abnormality of values was made.

Bayes' theorem can be used to quantify probabilities of finding disease given symptoms, and finding symptoms given disease. In applying the concept underlying Bayes' theorem to the problem investigated by this study, the question was raised: if a practitioner were presented with an individual having a specific blood pressure—classified as normal or hypertensive by an a priori criterion—what would the probability be that other tests would confirm, or not confirm the initial diagnosis?

For this question, diagnostic test results were reexamined and classified as being either within a normal range, or not within a normal range (26,63). Included in this procedure were proteinuria, hematocrit, and serum cholesterol. Height, weight and age were approximated in combined form using a standardized table, and the determination of overweight or not overweight was made on this basis (60). Based on the numbers of normal and nonnormal observations, probabilities for observing nonnormal values of diagnostic procedures were calculated. Using the

probabilities calculated, Bayes' theorem was applied to determine the probability of disease (hypertension), given abnormally high results of tests for proteinuria, hematocrit, serum cholesterol, and overweight. The probabilities calculated for disease state and diagnostic test results are presented in Table 15.

Table 15. Probabilities for Observing Elevated Values of Selected Diagnostic Procedures (N=931)

P(D1) = .2954		P(D2) = .7046	
P(S11) = .1891		P(S13) = .0473	
P(S21) = .1219		P(S23) = .0169	
P(S12) = .0982		P(S14) = .6073	
P(S22) = .0427		P(S24) = .4497	

D1 = Hypertension
D2 = Normotension

S = Symptom (Diagnostic Procedure)
SX = Symptom: 1 = Hypertension
2 = Normotension
S.Y = Symptom: 1 = Proteinuria
2 = Hematocrit
3 = Serum Cholesterol
4 = Overweight

Bayes' theorem, as applied here, included the basic assumption that results from the diagnostic procedures were independent statistically. That is, each of the procedures was considered an independent contributor to the overall probability obtained. Using the probabilities calculated (see Table 15), the probability of finding a blood pressure

in the hypertensive range was calculated by Bayes' theorem, modified in the following way. If each diagnostic procedure is assumed to be independent, the results of each procedure may be combined (multiplied) to obtain an overall probability of symptoms (abnormally high results of diagnostic procedures) given a disease. Using this approach, Bayes' theorem is modified (4,27),

$$P(D1|S_j) = \frac{P(D1) \prod_j P(S_j|D1)}{\Sigma P(D_i) \prod_j P(S_j|D_i)}$$

where j indexes diagnostic test results, and i indexes disease status.

Using the above format, the probability of an individual being hypertensive if all the diagnostic indices considered here (proteinuria, hematocrit, serum cholesterol, overweight) were abnormally high is .8513. Or, stated alternatively, there is approximately an 85 percent chance of finding blood pressure in the hypertensive range if the results on tests for protein in urine, hematocrit, serum cholesterol and overweight are elevated. The probability would decrease if any of the test results were not elevated.

Evidence has been presented here to suggest that a physician may use the diagnostic procedures incorporated into this analysis as guides for diagnosis of hypertension. Their use is particularly indicated when hypertension,

secondary to other pathology is suspected. It must be noted, that methods used here are statistical, and are only as reliable as the measurements upon which they are based. Since the squared multiple correlations (R^2) were so low, it can be postulated that the variables included in this study did not include those critical to determining blood pressure. Additional research into the biochemical bases of blood pressure regulatory mechanisms is needed to further refine the measurement process.

Implications for Health Education

Health educators, particularly those engaged in community health education, are commonly involved with screening programs and education programs for hypertension. In most situations, the screening programs must rely on detecting hypertension through use of blood pressure measurement exclusively. From an initial screening, those with high blood pressure are referred for further evaluation by a physician (27,37). As one of the health professionals routinely involved with screening activities, it is important that health educators understand the mechanisms of screening operations, especially their limitations. As mentioned previously, the error of falsely diagnosing a hypertensive individual as normotensive is potentially more serious than incorrectly diagnosing a normotensive as hypertensive.

Evidence presented by the Hypertension Detection and Follow Up Program (25) demonstrates that an individual initially screened as hypertensive is likely to present blood pressure within normal limits at follow-up. To maintain the confidence of the patient in the value of the screening procedure, it is important to communicate fully possible shortcomings of screening tests. Because populations served by screening programs are varied in composition, problems may be encountered in communication due to differences in intelligence levels, and backgrounds of the individual patients (11). In addition, the perception of benefit to be derived from participation in the screening procedure, a crucial variable influencing participation, is difficult to generalize with large, diverse groups (52).

Consequently, the health educator has a potentially vital role to play in the screening process. As an individual specially trained to understand areas of miscommunication between patients and clinicians, the health educator is in a position to clarify and reinforce the results of screening tests. It is essential that the individual identified by a screening procedure as hypertensive understand the implications of the results of the screening. Without subsequent action on the part of the patient needing further evaluation, screening tests have little value.

LIST OF REFERENCES

LIST OF REFERENCES

1. Ahmad, I. "Hypertension Among Shopkeepers and Clerks," Journal of the Pakistan Medical Association, 26(9):180, 1976.

2. Armitage, P., and G. A. Rose. "The Variability of Measurement of Casual Blood Pressure: I, A Laboratory Study," Clinical Science, 30:325, 1966.

3. Ayman, D. "Heredity in Arteriolar (Essential) Hypertension: A Clinical Study of the Blood Pressure of 1524 Members of 277 Families," Archives of Internal Medicine, 53:792, 1934.

4. Barnoon, S., and H. Wolfe. Measuring the Effectiveness of Medical Decisions. Springfield: Charles C. Thomas, 1972.

5. Barr, A. J., J. H. Goodnight, J. P. Sall, and J. T. Helwig. A User's Guide to SAS76. Raleigh: SAS Institute, Inc., 1976.

6. Bechgaard, P. "Arterial Hypertension: A Follow-Up Study of 1000 Hypertonics," Acta Medica Scandinavica Supplement, 172, 1946.

7. Bolt, W. A Study of Mortality in Moderate and Severe Hypertension. New York: New York Life Insurance Co., Association of Medical Directors of America, 1957.

8. Browne, F. J. "Chronic Hypertension and Pregnancy," British Medical Journal, 2:283, 1947.

9. Burgess, A. M. "Excessive Hypertension of Long Duration," New England Journal of Medicine, 239:75, 1948.

10. Caldwell, J. R. "Perspectives in Hypertension—1976," Geriatrics, 31(1):46:1976.

11. Caron, H. S., and H. P. Roth. "An Evaluation of a Program for Teaching Clinic Patients the Rationale of Their Peptic Ulcer Regimen," Health Education Monographs, 5(1):25, 1977.

12. Cornfield, J. "Bayes' Theorem," Review of the International Statistics Institute, 35:34, 1976.

13. Dixon, W. J. ed. BMD Biomedical Computer Programs. Los Angeles: University of California Press, 1973.

14. Engle, R. L., and B. J. Davis. "Medical Diagnosis: Present, Past and Future," Archives of Internal Medicine, 112:512, 1963.

15. Evans, W. Cardiology. 2d ed. London: Butterworth & Co., 1968.

16. Frame, P. S., and S. J. Carlson. "A Critical Review of Periodic Health Screening Using Specific Screening Criteria, Part I," The Journal of Family Practice, 2:29, 1975.

17. Freis, E. D. "Age, Race, Sex and Other Indices of Risk in Hypertension," in Hypertension Manual, ed. J. H. Laragh (New York: Dun-Donelly, 1974).

18. Freis, E. D. "Effects of Treatment on Morbidity in Hypertension," JAMA, 213:1143, 1970.

19. Galen, R. S., and S. R. Gambino. Beyond Normality: The Predictive Value and Efficiency of Medical Diagnoses. New York: John Wiley & Sons, 1975.

20. Garbus, S. "Guidelines for Blood Pressure Mass Screening Projects," Southern Medical Journal, 68:279, 1975.

21. Geddes, L. A. The Direct and Indirect Measurement of Blood Pressure. Chicago:Year Book Medical Publishers, 1970.

22. Gibbons, J. D. Nonparametric Methods for Quantitative Analysis. New York: Holt, Rinehart and Winston, 1976.

23. Green, L. W., and M. H. Becker. "A Family Approach to Compliance with Medical Treatment," International Journal of Health Education, 18(3):173, 1975.

24. Greenhouse, S. W., and N. Mantel. "The Evaluation of Diagnostic Tests," Biometrics, 6:399, 1950.

25. The Hypertension Detection and Follow Up Program Cooperative Group. "Blood Pressure in 14 Communities: A Two-State Screen for Hypertension," JAMA, 237(22):2385, 1977.

26. _____. "Hypertension Detection and Follow Up Program Cooperative Program," Preventive Medicine, 5:207, 1976.

27. Hypertension Study Group. "Guidelines for the Detection, Diagnosis, and Management of Hypertensive Populations," Circulation, 44:A263, 1971.

28. _____. "Primary Prevention of Hypertension," Circulation, 42:A39, 1970.

29. Inter-Society Commission for Heart Disease Resources. "Guidelines for the Detection, Diagnosis, and Management of Hypertensive Populations," Circulation, 44:A263, 1971.

30. Inter-Society Commission for Heart Disease Resources (Atherosclerosis Study Group and Epidemiology Study Group). "Primary Prevention of the Atherosclerotic Diseases," Circulation, 42:A55, 1970.

31. Kannel, W. B., and T. Gordon. "The Framingham Study, Section 26," Washington, D.C.: Government Printing Office, 1970.

32. Kannel, W. B., P. A. Wolf, J. Verter, and P. M. McNamara. "Epidemiologic Assessment of the Role of Blood Pressure in Stroke: The Framingham Study," JAMA, 214:301, 1970.

33. Kirkendall, W. M., A. C. Burton, F. M. Epstein, and E. D. Freis. "Recommendations for Human Blood Pressure Determination by Sphygmomanometers," Circulation, 36:980, 1967.

34. Laragh, J. H. "Evaluation and Care of the Hypertensive Patient," The American Journal of Medicine, 52:565, 1972.

35. Lundberg, G. D. "The Hypertensive Patient: An Algorithm for Diagnostic Work-Up," JAMA, 233:997, 1975.

36. MacLeod, John, ed. Davidson's Principles and Practice of Medicine. New York: Churchill Livingstone, 1975.

37. Maxwell, H. M. "Hypertension: A Functional Approach to Screening," in The Hypertension Handbook, ed. Merck, Sharp & Dohme, Inc. West Point, Pa.: Merc, Sharp & Dohme, Inc., 1974.

38. McNeil, B. J., E. Keeler, and S. J. Adelstein. "Primer on Certain Elements of Medical Decision Making," The New England Journal of Medicine, 293:211, 1975.

39. Merck, Sharp & Dohme, Inc. The Hypertension Handbook. West Point, Pa.: Merck, Sharp & Dohme, Inc., 1974.

40. Metropolitan Life Insurance Company. Blood Pressure: Insurance Experience and Its Implications. New York: Metropolitan Life Insurance Company, 1961.

41. Mroczek, W. J., M. Martin, and J. F. Finnerty. "Detection of Hypertension," JAMA, 231:1264, 1975.

42. National High Blood Pressure Education Program. Guidelines for the Evaluation and Management of the Hypertensive Patient. Bethesda, Md.: DHEW Publication Number (NIH) 76-744, 1973.

43. _____. Report to the Hypertension Information and Education Advisory Committee, Task Force II, Progressional Education. Bethesda, Md.: DHEW Publication Number (NIH) 74-594, 1973.

44. Nie, N. H., C. H. Hull, J. G. Jenkins, K. Steinbrenner, and D. H. Bent. Statistical Package for the Social Sciences. 2d ed. New York: McGraw-Hill, 1975.

45. Nissen-Meyer, S. "Evaluation of Screening Tests in Medical Diagnosis," Biometrics, 20:730, 1964.

46. Nugent, C. A. "Probability Theory in Diagnosis of Cushing's Syndrome," Journal of Clinical Endocrinology. 24:261, 1964

47. Overall, J. E., and C. M. Williams. "Conditional Probability Program for Diagnosis of Thyroid Function," JAMA, 183:307, 1963.

48. Perera, G. A. "Diagnosis and Natural History of Hypertensive Vascular Disease," American Journal of Medicine, 4:416, 1948.

49. Perloff, D. "Diagnostic Assessment of the Patient with Hypertension," Geriatrics, 31(1):77, 1976.

50. Pickering, G. "Hypertension: Definitions, Natural Histories and Consequences," American Journal of Medicine, 53:570, 1972.

51. Robinson, S. C. "Range of Normal Blood Pressure: A Statistical and Clinical Study of 11,383 Persons," Archives of Internal Medicine, 64:409, 1939.

52. Rosenstock, I. M. "The Health Belief Model and Preventive Health Behavior," in The Health Belief Model and Personal Health Behavior, ed. M. H. Becker (New Jersey: Charles B. Slack, Inc., Thorofare, 1974).

53. Sackett, D. C. "Randomized Clinical Trial of Strategies for Improving Medication Compliance in Primary Hypertension," Lancet, 79:1205, 1975.

54. Tagliacozzo, D. M. and I. Kenji. "Knowledge of Illness as a Predictor of Patient Behavior," Journal of Chronic Disease, 22:765, 1970.

55. Tatsuoka, M. M. Multivariate Analysis: Techniques for Educational and Psychological Research. New York: John Wiley & Sons, Inc., 1971.

56. Thomas, C. B. "The Heritage of Hypertension," American Journal of Medical Science, 224:367, 1952.

57. U. S. Department of HEW, "Advancedata," Vital and Health Statistics, National Center for Health Statistics, Number 1, October 18, 1976.

58. U. S. Department of HEW, Blood Pressure of Adults by Race and Area, United States, 1960-1962, National Health Survey, National Center for Health Statistics Series Number 5, 1964.

59. U. S. Department of HEW, Hypertension and Hypertensive Heart Disease in Adults, U. S. 1960-1962, National Health Survey, National Center for Health Statistics, Series 11, Number 13, 1966.

60. U. S. Department of HEW, Obesity and Public Health, PHS Publication Number 1485, National Center for Chronic Disease Control, Public Health Service, 1966.

61. U. S. Department of HEW, Proceedings: Workshop on Patient Education Programming, Bethesda, Md.: DHEW Publication Number (HRA) 74-4002, 1973.

62. Warner, H. R., A. F. Toronto, and L. G. Veasy. "Experience with Bayes' Theorem for Computer Diagnosis of Congenital Heart Disease," Annals of the New York Academy of Science, 115:558, 1964.

63. Widmann, F. K. Goodale's Clinical Interpretation of Laboratory Tests. Philadelphia: F. A. Davis Co., 1973.

APPENDIXES

APPENDIX A

SAMPLE SUMMARY SHEET

	HEIGHT_____ DATE								
VITALS	TEMPERATURE								
	BP (sitting)								
	PULSE PER MINUTE								
	WEIGHT (average)								
URINE	SPECIFIC GRAVITY								
	PROTEIN								
	SUGAR								
	BLOOD								
	COLOR								
	CHARACTER								
	PH								
	MICROSCOPIC								
	CULTURE								
	HBG/HCT								

	DATE								
VITALS	TEMPERATURE								
	BP (sitting)								
	PULSE PER MINUTE								
	WEIGHT (average)								
URINE	SPECIFIC GRAVITY								
	PROTEIN								
	SUGAR								
	BLOOD								
	COLOR								
	CHARACTER								
	PH								
	MICROSCOPIC								
	CULTURE								
	HBG/HCT								

PATIENT ENCOUNTER FLOW SHEET

APPENDIX B

CORRELATION MATRIX

Table 16. Correlation Matrix

Correlation Matrix	Systolic Blood Pressure	Diastolic Blood Pressure	Body Weight	Proteinuria	Hematocrit	Serum Cholesterol	Age	Sex	Height
Systolic Blood Pressure	1.0								
Diastolic Blood Pressure	.6661	1.0							
Body Weight	.2742	.3168	1.0						
Proteinuria	.1353	.1126	.1114	1.0					
Hematocrit	.1331	.1592	.2272	.0799	1.0				
Serum Cholesterol	.1745	.1185	.0882	.0192	.0675	1.0			
Age	.4062	.1402	.0937	.0420	.0662	.1438	1.0		
Sex	-.0974	-.0826	-.2131	-.0543	-.4570	-.0459	-.1354	1.0	
Height	-.0094	-.0024	.2421	.0037	.4119	-.0062	.0542	-.6769	1.0

APPENDIX C

CONVERSION OF Λ TO RAO'S R

Conversion of Λ to Rao's R (55:88)

$$R = \frac{1 - \Lambda^{1/s}}{\Lambda^{1/s}} \cdot \frac{ms - p(K-1)/2 + 1}{p(k-1)},$$

$$df_1 = p(K-1)$$

$$df_2 = ms - p(K-1)/2 + 1$$

where

$$m = N-1-(p+K)/2$$

$$s = \sqrt{\frac{p^2(K-1)^2 - 4}{p^2 + (K-1)^2 - 5}}, \text{ and } \quad \Lambda = \frac{N - K}{J-K + K-1(F)}$$

N = total number of observations

p = number of independent (discriminating) variables

K = number of groups

F = approximate F from BMD07M

Λ = Wilk's likelihood-ratio criterion

VITA

Mark Boberg Dignan was born in Salt Lake City, Utah on December 22, 1948. He is the son of D. Edward Dignan and LaRue Boberg Dignan. He attended schools in Seattle, Washington, Billings, Montana, and graduated from Sandia High School of Albuquerque, New Mexico in June of 1967. Following graduation from high school, he entered the University of New Mexico, where he earned a Bachelor of University Studies degree in December of 1971. The following September he entered the University of Utah where he earned a Bachelor of Science degree in Health Education in June 1973, and a Master of Science degree in June 1974.

Following graduation from the University of Utah in 1974, he was employed as a Lecturer in Health Education at Dalhousie University in Halifax, Nova Scotia.

In September of 1975 he entered the Graduate School of the University of Tennessee at Knoxville, where he was employed as a Graduate Teaching Assistant for two years. He received a Doctor of Philosophy degree with a major in Health Education in August of 1977.

The author is a member of the American Public Health Association, the Alliance for the Advancement of Health Education, and the Society of Public Health Educators.

The author is married to the former Caroline Susan Barich of Denver, Colorado.