A study of arterial blood noises (cervical bruits)
by Joel Morris Bowers

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Aerospace and Mechanical Engineering
Montana State University

Abstract:
The purpose of this investigation, a mathematical analysis of the acoustical properties of cervical bruits, was to differentiate the auscultatory signals of diseased neck arteries (stenotic bruits) from similar sounding healthy artery signals (innocent bruits).

By studying the variation and first moment of *the acoustical signal distribution curve, no significant difference was found between the stenotic and innocent bruit.

Significant difference between the innocent and stenotic bruit was evident from an examination of the zero crossing frequency of the signal. The bandwidth, mean frequency, and number of peaks in the energy spectrum of the signal also showed significant difference between the innocent and stenotic bruit.

The average stenotic bruit studied was found to have 90% of its energy contained in a frequency band width of 188 Hz. with a center frequency of 131 Hz. The frequency band containing 90% of the energy of the average innocent bruit was 123 Hz. wide and centered at 82 Hz. Counting the number of spectral peaks in the energy density spectrum proved to be the most reliable test for identifying the two types of bruits. Stenosis was diagnosed correctly in 77% to 85% of the patients studied using the spectral peak count.

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ABSTRACT

The purpose of this investigation, a mathematical analysis of the acoustical properties of cervical bruits, was to differentiate the auscultatory signals of diseased neck arteries (stenotic bruits) from similar sounding healthy artery signals (innocent bruits).

By studying the variation and first moment of the acoustical signal distribution curve, no significant difference was found between the stenotic and innocent bruit.

Significant difference between the innocent and stenotic bruit was evident from an examination of the zero crossing frequency of the signal. The bandwidth, mean frequency, and number of peaks in the energy spectrum of the signal also showed significant difference between the innocent and stenotic bruit. The average stenotic bruit studied was found to have 90% of its energy contained in a frequency band width of 188 Hz. with a center frequency of 131 Hz. The frequency band containing 90% of the energy of the average innocent bruit was 123 Hz. wide and centered at 82 Hz. Counting the number of spectral peaks in the energy density spectrum proved to be the most reliable test for identifying the two types of bruits. Stenosis was diagnosed correctly in 77% to 85% of the patients studied using the spectral peak count.

I. INTRODUCTION

Early Warning and Prevention of Stroke

Many strokes occuring in older people are the result of an obstruction or narrowing in the major neck (carotid) artery leading to the brain. Such an obstruction, an ailment labeled stenosis by physicians, can be diagnosed and repaired by surgery because of the accessibility of the artery. Diagnosis is made by auscultation (listening to the sound). An abnormal sound heard between the first and second heart sounds may be an indication of stenosis. The medical term applied to this abnormal sound is the cervical bruit.

The Existing Problem

Unfortunately, the cervical bruit, referred to in future references as the bruit, may also occur in normal, healthy people. This type of bruit is called an innocent bruit, and its existence can make the diagnosis of stenosis frustrating and uncertain. It is possible to increase the efficiency and reliability of diagnosis of stenosis by applying modern mathematical methods to the acoustical bruit signal. The purpose of this investigation is to find a method of analysis which will allow differentiation of the stenotic bruit from the innocent bruit. Also, any identifying characteristics which help to explain the mechanism of bruit are labeled.

The General Approach

An attempt is made to solve the problem by analyzing the recorded sound from the neck artery of 13 patients, seven of whom have healthy arteries and six of whom have diseased arteries. In all cases studied, a bruit exists. In this study an attempt is made to separate the innocent bruit from the stenotic bruit by three techniques -- statistical analysis, spectral analysis, and zero crossing analysis.

II. REVIEW OF THE LITERATURE

Bruit Research

A study of over 4,000 patients made by Braun, et al, (1966) revealed that bruit occurance varies with age. Table I summarizes the type of variation which was discovered in his study.

TABLE I

INCIDENCE OF BRUIT BY AGE

Age in Years	Bruit Occurance Percentage	Number Examined
0-9	20	30
10-19	14	605
20-29	6	1082
30-39	5	680
40-49	3	685
50-59	3	566
60-69	4	387
70-79	3	232
80-89	14	28

It is apparent from this table that bruits occur most commonly in the very young and the very old. Bruits occuring in the young can usually be assumed to be of an innocent nature because the incidence of arterial disease at this age is practically nil. Braun, et al, (1966) also found that the innocent bruit occuring in 20% of all young healthy people is of a shorter duration, appearing closer to the first heart sound than the stenotic bruit. This does not necessarily hold true for the innocent bruit in older people.

A study by Rennie, Ejrup and McDowell (1964) found that, especially in young adults, the innocent bruit originates lower in the neck on the right side, while the stenotic bruit is normally found near the middle of the neck over the carotid artery. An X-ray picture of an opaque solution injected locally into the blood stream, an arteriogram, is used to verify the existance of a stenosis in this type of study, but the discomfort and trouble of this procedure make it impractical for use on healthy people whose bruits may be innocent.

The bruit has been identified with stenosis since 1954, (Fisher, 1954) and little research has been done which would help to differentiate between the stenotic and innocent bruit. Neither Braun's nor Rennie's studies were conclusive in identifying the characteristics of the innocent or stenotic bruit. Some characteristics must be found to enable simpler methods of diagnosis.

Related Research

In order to determine and understand the origin of bruits and the diagnosis of stenosis it is necessary to search related topics for pertinent information. Especially important, because of their close relation to the bruit, are four such topics: 1) the structure of the arteries, 2) the flow of blood in arteries, 3) the mechanism of heart murmurs, and 4) the diagnosis of heart murmur.

Rodbard has been particularly active in blood vessel and blood flow research. He explains and has shown by experiment (1956,1957,1959) how hydraulic forces can act upon the vascular lining to form valves, cushions, and stenosis. It is known that blood vessels, besides growing during childhood, tend to elongate and become twisted (Rodbard, 1956) losing their elasticity (Simpson and Nakagawa, 1960) with old age. Blood is a very complex media and its flow is very difficult to describe exactly, in any but qualitative terms. Blood flow is pulsatile, "... the vessel diameter changes during each surge in pressure, filtration across the vessel wall disturbs the boundary layer, and the viscosity of the blood probably changes anomalously from moment to moment." (Rodbard and Johnson, 1962) The red blood cells have a tendency to group along the axis of a vessel giving rise to a radial viscosity gradient. (McDonald, 1960) It is apparent that there is a wide latitude of variation in both the blood flow and the vessel structure.

Bruns advances a general theory of the causes of murmur

(1959) which is also applicable to bruits since they are so closely related. Based on theoretical and experimental evidence, he discounts the importance of cavitation and turbulence as noise generators in arteries and asserts that vortex shedding or eddies are the more likely cause of the noise we hear as murmurs or bruits. Anemia or other causes of high cardiac output as well as stenosis are associated with bruits and murmurs; all these conditions can cause vortex shedding under the appropriate conditions. Bruns produced murmurs artificially by introducing obstructions in the form of paper clip wire and orifices into rubber tubing. He showed that the frequency of noise produced is related to the vessel geometry and the rate of flow, and the noise can be made similar to that of murmurs.

Bruns has shown that for large diameter orifices in tubes, the frequency of sound produced will be approximated by

$$\text{FREQUENCY} \simeq \frac{\text{velocity of fluid flow}}{6 \times \text{width of orifice shoulder}},$$

where the width of the orifice shoulder is equal to one-half the difference between the tube and orifice diameters. For very small diameter orifices, however, the frequency of the tone produced by vortex shedding is approximated by

$$\text{FREQUENCY} \simeq \frac{0.6 \times \text{velocity of flow}}{\text{orifice diameter}}.$$

"Thus, as a constriction or stenosis becomes greater (orifice diameter decreases) one should find that the basic frequency, at first high, will become lower and then increase once more." (Bruns, 1959)

Murmurs have been the subject of active study in recent years. Jacobs, Horokoshi and Petrovick (1968) have devised an instrument which uses the phonocardiogram signal plus the electrocardiogram signal to separate normal hearts from grossly abnormal ones with approximately 94% certainty. This instrument uses a filter amplifier system to boost the low-level high frequency components of the phonocardiogram signal and a zero crossing detector to identify the abnormals based on the number of times per heart beat that the filter amplified phonocardiogram amplitude crosses the zero axis. The counting is started and stopped by triggering from the electrocardiogram signal. These men also ran tests on experimentally stenosed aortic valves from sheep. They found that stenosed aortic valves have characteristic frequency spectra. They also found, for a given heart and valve, that the noise intensity increases with flow rate, but a definite correlation could not be found. A concrete model of the sheep heart with a triangular brass orifice produced a similar stenosed spectrum characteristic, while the model with no obstruction produced a normal characteristic spectrum. Jacobs, et al, deduced from their studies that the changes which occured in the spectral analysis of valve noise were related to the degree of stenosis induced in the valve. While unable to ascertain the parameters responsible for the frequency changes, they did conclude that the noise is not determined uniquely by the stenosis but by the conditions of the system (heart and arterial conditions) as a whole. The zero crossing analysis of this study, while effective in separating grossly different signals, may not be sensitive enough to detect differences between two similar signals -- the innocent and stenotic bruit.

The Humetrics Division of the Thiokol Chemical Corporation developed a more sophisticated detector called the PhonoCardioScan (Durin, et al, 1965) for use in school heart test projects. Specialized analog digital circuitry which not only detects the presence of congenital heart defects, but also helps to identify the particular type of defect, was developed. The instrument used spectral analysis data acquired from known diseased hearts as a basis for comparison and diagnosis. The rather elaborate data acquisition system recorded simultaneously the sounds from four chest microphones, the electrocardiogram signal, the respiratory phase signal, and a voice commentary. The instrument itself only requires two inputs; an electrocardiogram and a chest microphone input. The microphone is moved to each of the four regions and 10 to 30 heart cycles are examined for each microphone placement. The whole testing process only takes three minutes per patient. A similar approach could be taken toward identifying stenotic bruits since bruit sounds are very similar to those sounds originating in heart defects. It is hoped that spectral analysis of the bruit will reveal a significant difference between the stenotic and innocent bruit which could be detected by such an instrument.

III. NATURE OF THE BRUIT WAVEFORM

Ausculation has been employed for many years by doctors to tell the condition of the heart, but variation in hearing ability and limitations imposed by the hearing threshold have led to recording the heart sounds on strip charts and magnetic tapes. This record of the heart sound is referred to as a phonocardiogram. One cycle of the normal phonocardiogram appears as in Fig. 1a. As shown, the first and second sounds are quite distinct. The remainder of the signal is fairly silent. These two sounds are transmitted through the major arteries and a similar waveform can be obtained by listening over an artery such as over the carotid artery during examination for cervical bruits.

> The first heart sound occurs with the onset of ventricular contraction. Before the ventricles contract, the mitral and tricuspid valves close by atrial contraction. The closure of these valves is the principle source of sound, although an additional component may come from vibrations of the chamber walls ... The second heart sound is generated by closure of the aortic and pulmonary valves ... The intensity of the sound is dependent on the rapidity with which the value closes and the condition of the valve. (Jacobs, et al, 1968)

It is instructive to examine simultaneous signals obtained from an electrocardiograph and from a pressure sensing device on the carotid artery such as shown in Figs. 1b. and 1c. The two heart sounds in Fig. 1a. mark the beginning and ending of systole (contraction) as seen from the carotid pulse, Fig. 1b.

> The first sound starts after the QRS wave of the electrocardiograph and before the onset of the anacrotic limb of the carotid pulse. The second sound begins just after the end of the T-wave of the electrocardiogram and just before the diacrotic notch of the carotid pulsation. (Green, 1957)

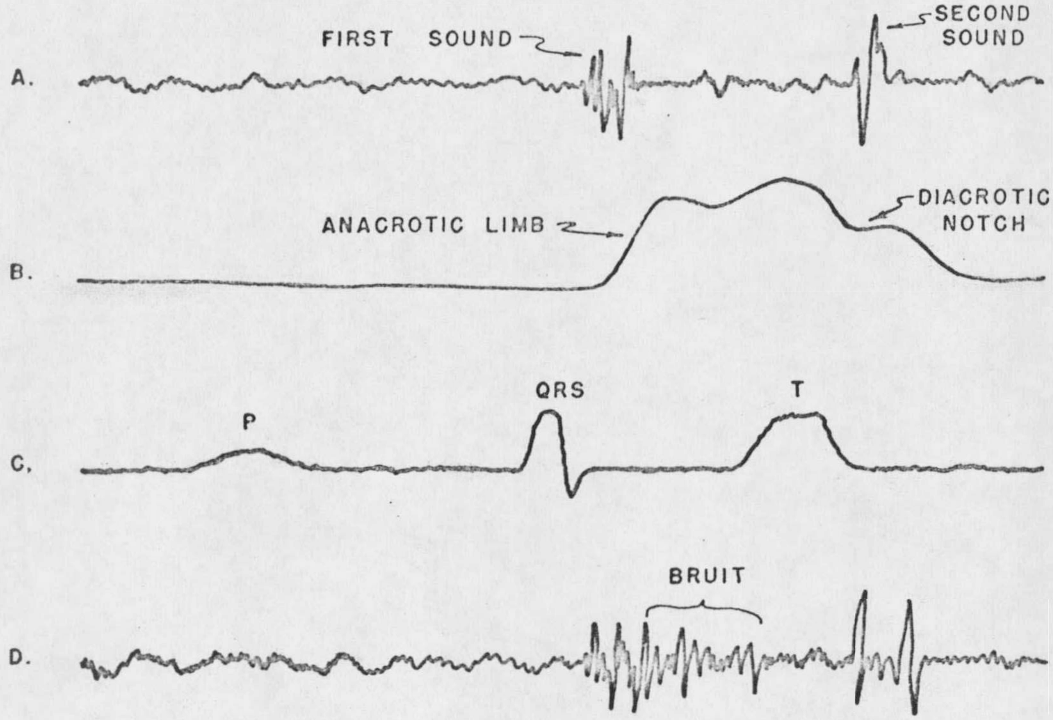

Figure 1. a) Normal phonocardiogram
b) Carotid pressure pulse
c) Normal electrocardiogram
d) Phonocardiogram with bruit.

Note: These sketches are taken from Green (1957).

The same relationships between the physiological signals shown in Fig. 1 should hold true in all persons. The diagram of the sound over the carotid artery in a normal person will appear as sketched in Fig. 1a., but where bruit is present the waveform will be that sketched in Fig. 1d., an additional noise being observed between the first and second sound.

Murmurs or other sounds may be transmitted through the artery and in some cases the sound observed at the neck could appear similar to that of Fig. 1d. but be caused by a murmur. But unlike murmur sounds the bruit appears loudest at a particular position on the artery with a diminishing intensity both up and down stream from the location of the bruit.

IV. APPROACH

Hypothesizing that the innocent bruit and the stenotic bruit belong to two different families of waveforms, this study has as its objective the identification of the characteristics which may be used to differentiate between the two waveforms. When the differences are known a reliable, more practical method of diagnosing stenosis can be devised.

Since only the characteristics of the bruit are being examined it is natural to exclude the other components of the phonocardiogram signal, such as the opening and closing sounds, from the analysis. The most useable type of record of the waveform is a digital record because it allows the utilization of the great speed and flexibility of the digital computer. A computer can be programmed to nearly duplicate any type of analysis which can be formulated, provided the sampling rate is fast enough to completely describe the signal.

Working with the sound recordings taken from a large group of stenotic and innocent bruits, the objective is to find criteria which will enable the separation of the bruits by family. Previous investigations of the waveform analysis type have been successful using one of three types of signal analysis: 1) statistical analysis, used most successfully on the random noise type signal; 2) zero crossing analysis, which has proved to be a simple, highly accurate method of speech analysis (Scarr, 1968) and murmur analysis (Jacobs, et al, 1968); 3) spectral analysis using Fourier transform methods as used in the development of the PhonoCardioScan. This investigation includes all three of these methods of analysis.

The statistical methods used here include the determination of the first moment and the variation of the bruit histogram.

A zero crossing analysis, which is actually a form of spectral analysis, usually includes a series of broad band filters whose outputs are all analyzed for zero crossings. But for this study, the zero crossings of the unfiltered bruit signal were counted.

A spectral analysis was made of the energy density spectrum obtained from a Fourier transform of the signal record. Recent advances in computing science have made this transform on a digital record feasible using the fast Fourier transform code, a very efficient method of obtaining the transform coefficients.

V. DATA COLLECTION

The recordings of arterial noise used in this research were made at the Western Montana Clinic in Missoula by Dr. Harold Braun using a Crown Model SS800-S tape recorder and a Sanborn surface contact microphone, Model 572-M, placed over the bruit in the neck artery of the patients. Scotch 202 silicon lubricated, one-fourth inch magnetic tape with a 1.5 millimeter polyester backing was used for the recordings. During the recording process, patients were instructed to take a breath, let it out, and remain still without breathing for a few seconds. One channel of the two-track recording was used for voice commentary; the other was used to record the arterial noise.

From the recordings, digital samples were taken using a digital controller, a Model EECO 765 multiplexer, a Model EECO 761 analog-to-digital converter, and a voltage limiter built specifically (See Appendix C) to protect the analog-to-digital circuitry from overload. The first sample records were made digitizing at a rate of 4,000 samples per second with the analog-to-digital equipment coupled directly to the IBM 1620 computer and card punch. The sampling was done at a fairly "clean" spot on the tape, where the signal wasn't obviously obliterated by skin noise made by microphone slippage or by voice or breathing interference. Fairly long sample records of two-second or three-second duration were taken and punched directly on cards. The bruit record was then hand selected by removing the unwanted first and second heart sounds. Only the portion of the signal labeled bruit in Fig. 1d. remains in the record.

The remainder of the sampling was done on the Hewlett-Packard 2116A computer utilizing an improved record selection process and a faster digitizing rate -- 10,000 samples per second. A trigger and delay system which eliminated the hand selection of records was established using a type 549 Tektronix storage oscilloscope with a four-channel type 1A4 plug-in unit. A trigger signal from the scope calibration output -- a one-kilohertz square wave -- was recorded on the voice channel near a clean portion of the tape. Triggering the oscilloscope from this signal and looking at the waveform of the arterial sound on the display screen, time delays were calculated to the beginning and end of the bruit part of the signal. The proper time delays were then set on the digital controller, the tape was positioned at the correct trigger signal, and the tape recorder was started for each sample; thus initiating the digitizing process. The Hewlett-Packard program accepted two lines of description from the teletype after each sample and punched the description and digital record on paper tape. A high-speed interface between the Hewlett-Packard and the IBM computers allowed the data to be punched on cards for later analysis on the Scientific Data Systems, Sigma 7 computer.

The removal of the IBM 1620 and its card punch cut short the data collection phase of this project. At that time 133 samples had been gathered from a total of 13 different individuals; seven of whom had innocent bruits, and six of whom had stenotic bruits. Of the total samples, about 55% are from innocent bruits. The remainder are from stenotic bruits.

VI. DATA ANALYSIS

Data Plot

Partly as a check on the analog to digital sampling process and partly as a visual check for outstanding similarities or differences between the families, a plot was made of each sampled waveform. Using the IBM 1620 computer and associated digital plotter, the magnitude of each data point in a sample was plotted against time. The time was scaled so that the time axis of the plots was of constant length. The amplitude was normalized so that the maximum amplitude in each record was 1,000 millivolts. (See Figs. 5, 6, 10 and 11 for examples of these plots.)

Statistical Analysis

If the waveforms of the innocent bruit family have a characteristic shape that is different from the waveforms of the stenotic bruit family, the difference may be more evident in the histograms than in the waveforms themselves. An histogram frequency distribution curve, was developed from the digital waveform which had any direct current bias removed and which was amplitude normalized. It was made by sorting the signal by amplitude brackets, counting the number of times that the signal falls within each bracket and plotting the frequency of occurrence versus the amplitude. For example,