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FINAL PROGRESS REPORT

WEARABLE, WIRELESS OXIMETER

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WEARABLE, WIRELESS OXIMETER

Introduction

This is the final report for a Wearable, Wireless Oximeter, with blood pressure measurement capability, which was developed for Ames Research Center, under Contract NAS2-1362.

Purpose

The purpose of this report is to summarize the salient points of the development program.

Abstract

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The oximeter development program was proposed because it was thought that certain improvements, such as the use of interference filters and improved dilation, would overcome many of the difficulties experienced with past ear oximeters. The development was based on the premise that the narrow band optical filters, together with good dilation, would provide accurate results that would be repeatable between individuals. The narrow band optical interference filters would minimize the errors, due to spectral changes in lamp, differences in skin pigments or changes in the absorption characteristics of the blood. Improved dilation would result in a field of view which consisted primarily of arterial blood. This is very important, as the presence of venous blood would cause errors in the output; especially if the relative amounts of venous and arterial blood varied from time to time, or from person to person.

The possibility that the device could also be used to make blood pressure measurements was based on the idea that the blood volume in the ear lobe would be a function of the blood pressure. The IR channel of the oximeter would be used for this measurement since this channel responds to blood volume only and, unlike the red channel, does not respond to changes in blood oxygen.

author

Summary of Results

An ear oximeter was constructed, using the optical interference filters and a very thorough study of dilation was done. An additional feature of solving the equation of oximetry automatically in the instrument electronics, to further enhance the accuracy of the unit, was also included.

Ear Piece

The earpiece, which utilized the interference filters, was constructed. A unique design feature was incorporated, which consisted of a small light prism, allowing both red and IR channels to share the same field of view. The results met expectations with respect to its desired optical characteristics. The filters worked satisfactorily and the light prism was effective in providing a field of view shared by both red and IR channels. The ear piece was somewhat larger than anticipated. This was due to size of the interference filters. They were cut from larger pieces and there was a size limitation on what could be cut satisfactorily in this way.

Electronics

The electronics was designed to solve the equation of oximetry which involves converting the output of the photocells to a log function for both red and IR channels. The bloodless values must be subtracted and the results must be divided. This was all accomplished in a small package (cigarette package) with an overall accuracy of 5%. The computer was designed to operate over a range of 4 to 1 in energy level. This should be sufficient to account for the variations in the transmissions of the ear lobes for most individuals.

The electronics was designed to operate from batteries or from 115 volts, 60 cps power. The batteries were chosen to last at least 8 hours and the size of the battery pack is about twice that of the computer. The computer was designed to operate directly into a recorder or telemetry system when operated on batteries. If 115 volt, 60 cps power is used, the output may be observed on a panel meter.

Dilation

A very thorough study of dilation techniques was made. Six medical doctors were consulted and several techniques and drugs were tried. The results of this study were very disappointing. The drugs used were either ineffective or they resulted in undesirable side effects. In no case did the use of drugs result in dilation that was an improvement over that which resulted from the ear piece energy source.

Telemetry

During the course of the development, the requirement for telemetry was deleted. This came before any significant work on this portion of the program was done.

Calibration

The most difficult part of the whole program was the calibration of the instrument. The ideal way is to place the instrument on a subject, monitoring his arterial oxygen content, by means of an arterial tap and a Van Slyke analysis, then varying his oxygen content, by having him breath various oxygen mixtures. This method, however, was beyond the scope of the contract. Therefore, calibration was accomplished by the above method with the exception of the arterial tap.

Oxygen Content

Several attempts were made to calibrate the instrument on different subjects. It was found that the 100% point was considerably different for different subjects. The difference in extreme cases was as much as the total span of the instrument -- that is, 100% to 60%. This was disappointing because it should not have occurred if our theories had been correct. The instrument span, or change, with changes in oxygen content, was reasonably equal between subjects.

Blood Pressure

Several attempts were made to determine the ability of the instrument to measure blood pressure. A definite correlation between blood pressure and blood volume was revealed. The modulation of the IR channel was about 10% with a 30 mm Hg change in blood pressure. This change was masked by changes in blood volume caused by heat dilation. Therefore, the blood pressure measurement would be a relative one instead of an absolute measurement.

Discussion

The following is a detailed discussion which expands on the items mentioned in the summary of results.

Ear Piece

The ear piece consists of a light source, an optical filter and photocell for the IR and Red channels, and a method for occluding the ear so that a bloodless reading could be obtained.

Optical Filters

Interference filters were selected because of the narrow bandwidth that can be achieved. The filters chosen were 660 mμ for the red and 826 mμ for the IR. These are somewhat higher

than the theoretical values of 640 mμ and 800 mμ . The higher values were chosen because the incident light is not collimated because of the scattering due to the ear. When the interference filters are used with incident energy not perpendicular to the plane of the filter, the characteristics are changed. The following table shows the transmission and center frequency change with incident light angle. A 617 mμ filter was used for this test.

Incident Light Angle	Center Wavelength mμ	Transmission %
90°	617	33
60°	592	16
45°	575	4

The result of scattered light is, therefore, a net shift of the center wavelength to a shorter wavelength, and an increase in the bandwidth. The bandwidth of the filters with collimated light is 15 mμ . The filters for the earpiece were cut from a 2" square. The filter was first cut in half with a diamond saw. The edges were then coated with an epoxy. Then one of the halves was cut and coated - and so on - until the desired size was achieved. The cut filter was inspected visually. Any separation is easily seen and manifests itself as a discoloration. One cut filter was checked on a spectrophotometer and no ill effect was observed.

Photocells

Photoconductive cells were chosen, since these yield much higher signals than photovoltaic cells. The individual cells were chosen for maximum sensitivity at their respective wavelengths. The red cell is a Clairex CL-607, and the IR cell is a CL-604.

Energy Source

The criterion for the choice of an energy source was maximum energy for minimum power input in the ½-watt range. This resulted in the use of a tungsten lamp, No. 60, manufactured by the Los Angeles Miniature Products Company. The lamp consumes approximately 0.6 to 0.7 watts.

Light Prism

The light prism transmits the light from the ear to each of the photocell/filter combinations. It is essentially a three-sided device. One side fits against the ear, and the other two sides fit against each of the two photocell/filter combinations. The purpose of the light prism is to provide each of the two photocells with the same view.

Occluding Device

A mechanical clamp was provided to occlude the ear instead of the conventional inflatable rubber dam. The rubber dam was tried, but it did not occlude the ear sufficiently to provide a true bloodless reading. The mechanical clamp consists of a moveable plastic lens which clamps the ear between it and the light prism. The plastic lens is moved by means of a socket head screw located in the earpiece. The relative positions of the source and the light prism remain unchanged during the clamping operation.

Electronics

The electronics, or computer, consists of a network that converts the signal from the photocells to a log function; a circuit that subtracts the bloodless values and a circuit that divides the difference netween the bloodless and the blooded Red by the difference between the bloodless and the blooded IR. The range over which the computer was designed to work is 8 to 1, for the IR, and 16 to 1, for the Red. This gives a usable range of 4 to 1 in ear transmission. The change of energy due to the bloodless versus the blooded is about a factor of 2 for both the Red and the IR. There is an additional change in the Red of a factor of 2, due to changes of oxygen corresponding to the instrument fall span of about 40%.

The network for producing a log function for the IR photocell was merely a series and shunt resistor. This was not possible for the Red photocell, and a diode function generator had to be included to produce the required result.

The subtraction of the bloodless values was accomplished by biasing the output of the log circuit such that the bloodless readings are zero. This is accomplished by potentiometers for each of the two channels. When the ear piece is unclamped to provide the blooded readings, the voltage output from the log

circuits is the difference between the bloodless and blooded values.

The output of the Red log circuit is divided by the output of the IR log circuit by controlling the amplitude of a 100 cps square wave with the Red output and the width of the square wave with the IR output. This is accomplished as follows: The Red output is connected to the output amplifier through a gate. The IR output is passed through an integrator and an amplitude detector. The Red channel gate is turned on when the integration is started, and turned off when the integrator output reaches a predetermined value. The time during which the gate is on is inversely proportional to the IR output. After the gate is turned off, the integrator is reset and the cycle repeated. The result is a 100 cps square, the area of which is a function of oxygen content.

The instruction manual for this instrument, TM 188, indicates that the bloodless readings are adjusted to yield meter readings other than zero. This is because the log output circuits are single ended, and do not quite go down to zero. Therefore, the bloodless values that correspond to zero in the log output are used for adjustment. These values will vary from one instrument to another because of differences in the offsets of the amplifier. The log output circuits become operative well before the blooded values are reached.

Telemetry

It was originally intended to transmit the output of the instrument with miniature telemetry system. This requirement was waived in August 1964. This led to the addition of a meter box so that the bloodless readings could be set and the output monitored without auxiliary equipment. A power supply to operate from 117 volt 60 c.p.s. power was also included for convenience.

Dilation

Several schemes to achieve dilation were attempted with little success. A summary of the methods tried is given below.

1. Histamine applied by electrophoresis.
2. Nitroglycerin ointment.
3. Nicotinic acid ointment.
4. Methyl Salicylate.
5. Heat.

Histamine

Histamine dilation appeared to be the most promising, especially with the results shown by Elam in his paper on the "Source of Error in Oximetry", Annals of Surgery, October, 1949. The method of application of the histamine was similar to that used by Elam. A one cc aqueous solution containing 2.75 mgm of histamine acid phosphate was placed on a positive electrode clamped to the ear lobe. The negative was clipped to the pinna of the ear. Electrode paste was applied to the negative electrode to provide better contact. Current was applied at the rate of 1 ma for 10 minutes, 3 ma for 3 minutes and finally, 5 ma for ½ minute. This method was determined to be unsatisfactory because of severe edema that resulted in some individuals. The edema actually caused a reduction in blood volume.

Nitroglycerin Ointment

A nitroglycerin ointment was tried on three subjects. This method was considered unsatisfactory because it caused very severe headaches on all three subjects.

Nicotinic Acid Ointment

Mixtures of 2% and 5% nicotinic acid ointment were tried. This method did not produce any significant dilation. No other ill effects were noticed.

Methyl Salicylate

This method produced no significant dilations.

Heat

Heat dilation was also tried. Heat, in addition to that generated by the light source, was applied with a small heating pad. This causes an increase in blood volume but does not appear to arterialize the blood, since the instrument does not show an increase in oxygen tension when heat is applied.

Another method, not mentioned in the summary, was tried. This method would be unsatisfactory for practical usage. It involves heating the subject to about 1^{o} F above body temperature with a suitable heating blanket. Tests have shown that the circulation close to the skin is increased markedly,

as much as 50 to 100 times in the finger tips. It was thought that the ear lobes would behave in the same fashion. This method was tried on two subjects without success. The heating of the body had essentially no effect on the readings.