

REPORT NUMBER 1

DEVELOPMENT OF NON-INTRUSIVE AUTOMATED METHODS FOR EVALUATION  
OF PHYSIOLOGIC FUNCTIONS IN SEVERELY TRAUMATIZED PATIENTS

ANNUAL PROGRESS REPORT

by

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## SUMMARY

The objective of this program is to develop an automated, non-intrusive, predictive system for the evaluation of physiologic function in severely traumatized patients. While a number of patient monitoring systems have been developed by others, many of the methods which hold great predictive and diagnostic promise for on-line use in trauma patients have not been evaluated. These include non-state-of-the-art monitoring systems such as: nuclear magnetic resonance (NMR) blood flow measurements, on-line transcerebral impedance, on-line EEG period analysis, and on-line cerebral evoked potentials. To achieve the program goals, some of the more traditional techniques, such as measurement of transthoracic impedance, heart rate, respiration rate, temperature, etc., will be used as an adjunct to the physiologic evaluation. A suitably designed system should provide reductions in morbidity, mortality and manpower.

During the first year of the program, approximately 85% of the project monies were used for equipment purchase. Nevertheless, the LINC-8 computer system was installed, debugged, and interfaced with monitoring equipment. Software has been written and debugged for on-line monitoring of cerebral evoked potentials and EEG period analysis. The system for monitoring transcerebral impedance, transthoracic baseline impedance, heart rate, respiratory rate and temperature should be completed by July 1, 1972. This system will permit collection of integrated sets of clinical data. On-line statistical trend analysis for detection of early changes of clinical condition have been initiated.

Nuclear magnetic resonance blood flow measurements were made in an isolated perfused kidney and an NMR detector suitable for blood flow measurement in the upper extremities was designed and fabricated. An NMR system for regional blood flow, such as cerebral blood flow, is under development. Transcranial impedance measurements were made on a control population of over 300 human volunteers. Measurements made on 6 patients with closed head injuries showed a more than 50% transcranial impedance decrease from control levels. Nocturnal EEG was recorded during several successive nights of normal sleep from 7 control subjects and compared with the EEG recorded from 9 coma patients. A computerized evaluation of the records based on zero-crossing techniques suggests that the presence or absence of cyclic EEG patterns may be valuable in predicting clinical outcome.

## FORWARD

In conducting the research described in this report, the investigators adhered to the "Guide for Laboratory Animal Facilities and Care," as promulgated by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences-National Research Council.

**RESULTS: May 1, 1971 through April 30, 1972**

## **1. Monitoring System**

Installation of the computer was delayed by remodeling of the neuro-surgical ward at Milwaukee County General Hospital. The facility was made available and work began on the computer approximately 1 August. A real time clock, time of day clock, and plotter interface were designed and installed. The computer, including a 4K core memory extension, was operational in mid-October.

Conduit and cable installation from the computer to the patient area was completed in mid-January. At the end of February, interfacing of a constant-current stimulator and evoked potential amplifier was completed, thus providing on-line capabilities for evoked potentials. The interface provides for computer selection of stimulus and record sites and for automatic recognition of excessive amplifier offset due to faulty electrodes.

Additional monitoring equipment was procured on consignment from General Electric Company, Medical Systems Division, Milwaukee, Wisconsin. Included are an EEG amplifier, temperature monitor, impedance-type respiration rate monitor, and heart rate monitor using an optical finger plethysmograph. Installation and interfacing of this equipment was recently completed.

An impedance instrument used in a study of transcranial impedance is currently being modified for on-line use. Provisions are being made for measuring both transcranial and transthoracic baseline impedances.

The monitoring system is summarized in Figure 1. A CRT display at the nurses station will be added to the system.

Software development for on-line monitoring of evoked potentials and EEG has been completed. It is anticipated that software for transcerebral impedance, transthoracic baseline impedance, heart rate, respiratory rate, and temperature will be completed by July 1, 1972. All monitored parameters will be stored on magnetic tape for subsequent trend analyses and correlation with standard clinical data such as blood gases, radiologic findings, etc.

## 2. NMR Blood Flow Measurement

The latest model 9.5 mm I. D. NMR flowmeter developed by Badger Meter, Inc. was purchased and evaluated in vitro with blood, saline, and water. It was also used in flow measurements for arterial and venous flow in the isolated perfused kidney.

A 10 cm lumen detector proposed for peripheral limb blood flow was constructed and evaluated using the electronics from the Badger Meter unit. Tests indicated the need to return to an earlier design employing a modulating field since the transmitter-to-receiver coil leakage could not be easily and stably minimized for the larger lumen.

A new detector was designed and constructed. The electronics from a Badger Meter, Inc., MRF-1 Magnetic Resonance Flowmeter was modified and supplemented to energize the coils of the detector section for processing the NMR signal induced in the receiver coil.

The phenomenon of "self-tagging" for pulsatile flow can be used for the measurement of arterial blood flow. A paper, titled, "Analysis of a NMR Blood Flowmeter for Pulsatile Flow" is to be published (in September 1972) in the IEEE Transactions on Bio-Medical Engineering. This paper describes a two-magnet system which utilizes the pulsatile nature of the flow to cause a pulsed magnetization of the fluid. The results of theoretical computation closely approximate in vitro data with respect to the shape of the NMR signal and to the proportionality of the NMR signal amplitude to flow rate. Waveshapes of in vivo data are similar.

Laboratory tests have been made using the tag-detect mode. NMR signals have been measured directly by a cathode-ray oscilloscope. With averaging flow rates of approximately 50 milliliters per minute, can be measured.

## 3. Electrical Impedance Measurements

Transcranial impedance measurements were made on 313 human volunteers. The frequency histogram of impedance at 1 KHz approximates a normal distribution with a mean of 87 ohms and a standard deviation of 11 ohms. Transcranial impedance was recorded from six patients with severe closed head injury. For these patients, the impedance was less than 40 ohms.

The transcranial impedance meter is being modified so that it may be interfaced with the computer for extended duration monitoring. Switching circuits are being supplied so that this instrument may be used for both transcranial and transthoracic baseline impedance. Completion of the modifications is anticipated in the next several weeks.

An impedance instrument for measuring tidal volume and cardiac output has been designed and is being fabricated. Following completion of the instrument, off-line studies on measuring tidal volume will be conducted. The feasibility of the approach is well documented. The intent of the study will be to determine what type of signal processing and artifact detection will be required for on-line monitoring.

#### 4. EEG

Magnetic tape recordings of the EEG were made on 7 normal subjects during nocturnal sleep and on 9 coma patients. The records were divided into contiguous one-minute epochs and analyzed off-line using period analysis. For normal subjects, the cyclic variation of EEG during sleep could be detected by plotting the occurrences of delta, total zero-crossings or the ratio of these parameters for each contiguous one minute epoch. The records of the coma subjects were analyzed with the same technique. Two patients with relatively normal cyclic patterns recovered. A third subject with post-traumatic coma was followed for five months. During the first two months, no organized cyclic activity was observed. After five months, cyclic patterns were detected. The patient remains alive but is decerebrate. The remaining six patients, all of whom expired did not exhibit cyclic patterns.

It was also noted that plots of delta activity versus the total number of zero-crossings per one minute epoch may be useful in monitoring and predicting coma outcome. In normal subjects during nocturnal sleep, an approximately linear relationship (correlation coefficients of approximately -0.9) with a negative slope was observed. Similar results were obtained in patients that recovered. In patients that expired, correlations were lower than for normal subjects and, in some cases, slopes were positive.

EEG was recorded from four monkeys (*Macaca speciosa*) during induced hypovolemic shock. Cyclic EEG patterns similar to those observed in the surviving coma patients were observed during the shock phase with return to normal at blood reinfusion.

The program used for off-line analysis was implemented for on-line monitoring. The time between zero-crossings is measured and a histogram of waves falling within the standard EEG frequency bands is generated (Fig. 2) for a one minute sampling epoch. The parameters are stored for detection of cyclic patterns. A measure of EEG amplitude (rms or average rectified value) will be added. In the next phase of the project, emphasis will be placed on correlation of EEG activity with evoked potentials, transcranial impedance, and related clinical data.

## 5. Evoked Potentials

More than 1500 evoked potential studies have been conducted in our laboratories. Based on these studies, a program for on-line evoked potentials was written. A 100 msec analysis interval is used. The number of sweeps and the stimulus and record sites are selectable. Both mean and standard deviation are computed and stored on magnetic tape. The mean value can be displayed on the computer oscilloscope or plotted (Fig. 3).

On-line evoked potentials were recorded at 30 minute intervals from two patients in post-traumatic coma. Both patients were in deep coma and expired approximately 24 hours after monitoring was begun. Evoked potentials were isoelectric throughout the monitoring period.

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13. ABSTRACT This project is devoted to the development of automated non-invasive methods for monitoring patients with combat-type injuries. The techniques under study include nuclear magnetic resonance (NMR) blood flow measurement, on-line analysis of EEG and evoked potentials, and impedance measurements. For evaluation of the techniques, a LINC-8 computer-based monitoring system was installed. The system is capable of on-line analysis of EEG and cerebral evoked potentials. Capability of monitoring transcerebral impedance, transthoracic baseline impedance, heart rate, respiration rate and temperature is anticipated within the next month. An impedance instrument for monitoring tidal volume and cardiac output was designed and fabrication begun. All monitored parameters will be stored on magnetic tape for trend analysis and correlation with standard clinical data such as blood gases, radiographic findings, etc. Off-line research was conducted concurrent with installation of the computer system. Successful NMR flow measurements were made in an isolated perfused kidney and in vitro using blood, saline, and water. A NMR detector suitable for flow measurements in the upper extremities was designed and tests initiated. Analyses of EEG recordings from 7 normal subjects and 9 coma patients indicate that the presence or absence of cyclic patterns may be useful in predicting coma outcome. Transcerebral impedance measurements were made in over 300 normal volunteers. In 6 patients with severe closed head injury, transcerebral impedance was approximately 50% lower than control values. In the next phase of the project, emphasis will be placed on collection and analysis of integrated sets of clinical data.



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## KEY WORDS

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## ROLE

18. T

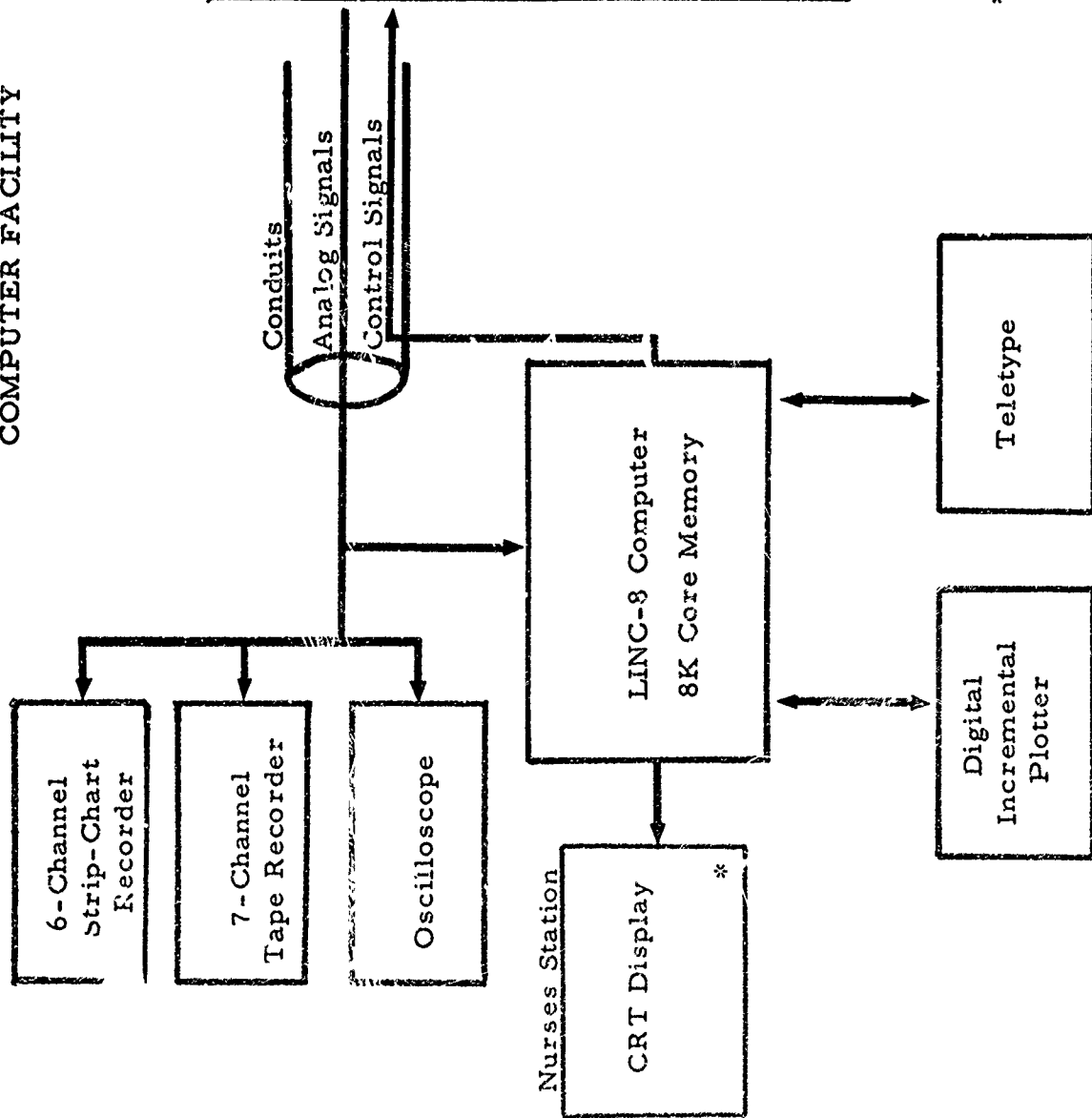
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- EEG analysis
- Evoked potentials
- Non-invasive monitoring
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- Patient monitoring
- Transcerebral impedance
- Transthoracic impedance



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# COMPUTER FACILITY



\* To be added to the system in the next month

\*\* Requires further off-line research before adding to system

FIGURE 1 Monitoring System

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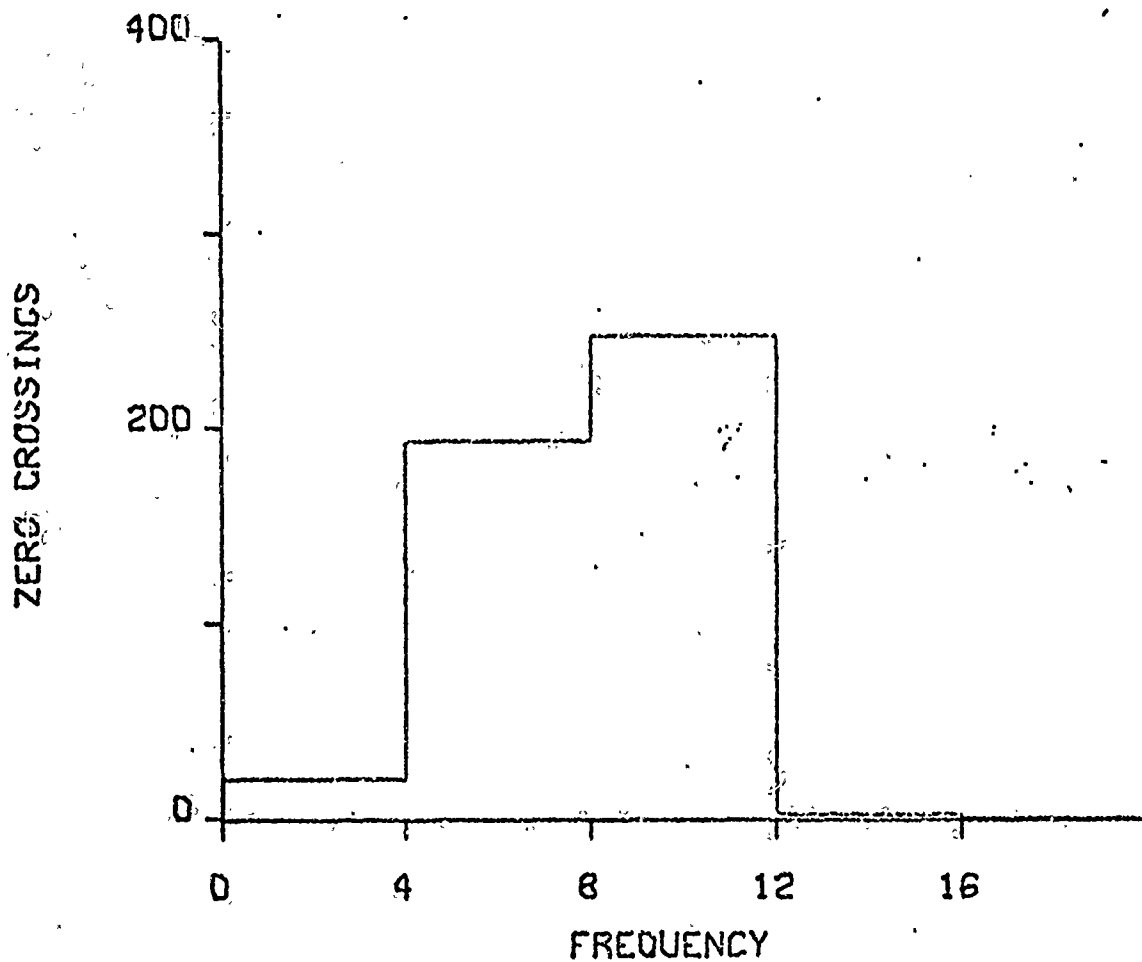


FIGURE 2 Histogram of simulated EEG for one minute epoch. Frequency of each wave is determined by measuring time interval between zero crossings.

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H: 10 MSEC/DIV, V: 1.25  $\mu$ V/DIV

L/R

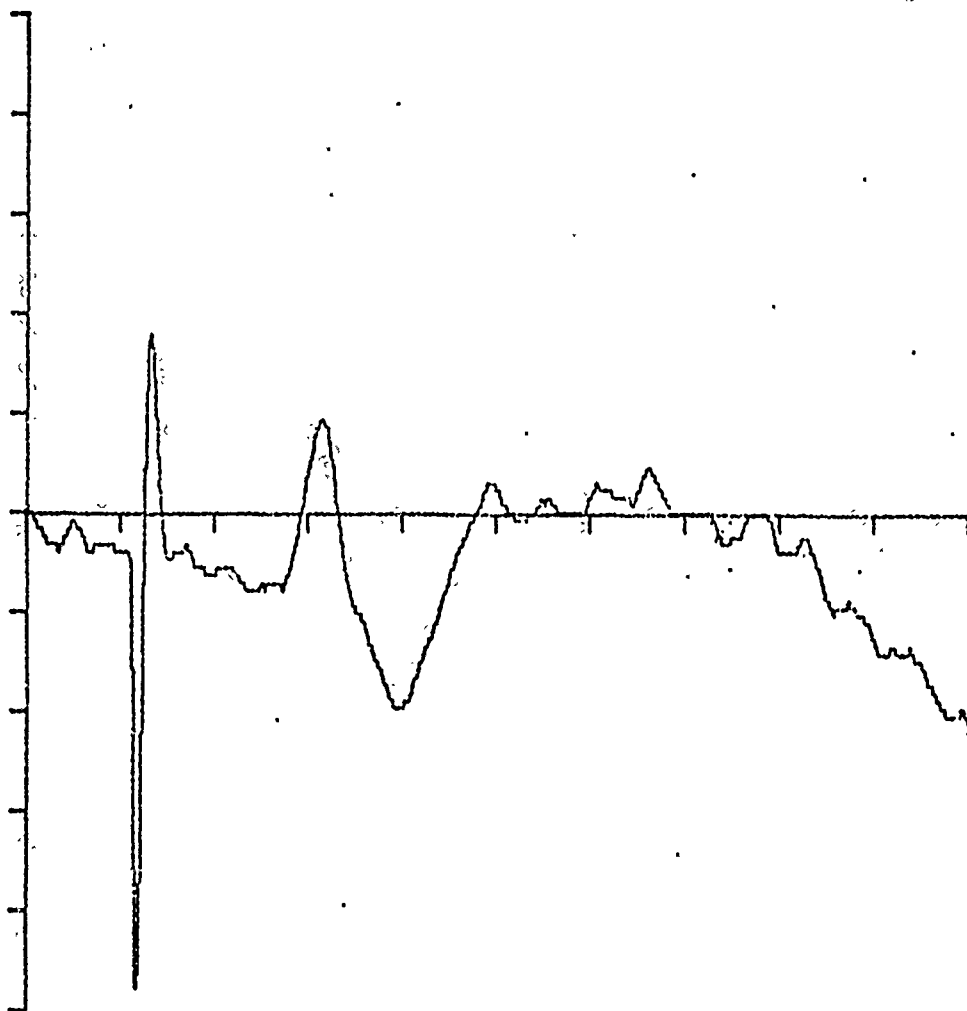


FIGURE 3 Evoked potential recorded from pre-operative patient using LINC 8 monitoring computer. Horizontal sensitivity is 10 milliseconds per division, vertical sensitivity is 1.25 microvolts per division. L/R indicates stimulate left wrist, record right scalp. The primary response occurs approximately 20 msec after the shock artifact and is 2.5 microvolts in amplitude. The 10 msec delay between start of sweep and stimulus is set by the stimulator.

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