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THE ST. VINCENT HOSPITAL of WORCESTER, MASSACHUSETTS 01610 - TELEPHONE 617-798-1234

June 1, 1977

V.R. McCall
Supervisor,
Educational Training
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Dear Mac:

It was a pleasure speaking with you on the phone today concerning the systolic time interval ambulatory monitoring system which we have recently developed. I have enclosed the entire manuscript which was submitted to the Journal of Clinical Engineering (to be published in July or October, 1977) for your reference. The edited version of the publication has some minor changes which should not effect any information you need.

As I mentioned on the phone we are already conducting several studies utilizing the technique presented in the manuscript and are proliferating these methods to our highest capability. Naturally, the Del Mar Avionics Co. can carry out the marketing, packaging, and distribution to an even greater extent and we hope that we can work together in this matter for a long time.

Our main interest is to become the primary laboratory and investigation site of the technique and to work with you and your marketing people on a consultation basis. Specifics and finances can be worked out in time and I am confident that with the highly respected and professional nature of both our organizations, nothing more need be said at this time.

The enclosed manuscript contains all the necessary information which I believe you will need to evaluate the potential application and feasibility of the methods.
An added note to the manuscript is that we have named the method
The SHK-STI monitoring system.
(Spodick - Haffty - Kotilainen.)
(Systolic Time Interval)

We are interested in retaining this name and have already referred to the system as such in local press articles and medical society presentations.

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 June 1, 1977

As I mentioned above our main interest is to proliferate the technique to its fullest capability and be recognized as the primary investigative site.

We feel that the enclosed manuscript establishes our sincerity in working with your organization solely and in full cooperation. To firmly establish our relationship we feel it would be appropriate to request a modest

"Consultation Retainer Fee"

for Drs. Spodick, Kotilainen and myself for our initial work in this matter.

I hope you will find all the information you need in the manuscript. If you have any questions at all please feel free to call me at (617) 798-6054.

Again it was a pleasure meeting you at the conference and hope to be getting together in the future. Please give Bruce Del Mar my regards.

Sincerely,

Bruce G. Haffty

Bruce G. Haffty
Supervisor,
Non-Invasive Cardiology

BGH/jlf

Enclosure

cc: Peter Kotilainen, Ph.D.
David H. Spodick, M.D.

DEVELOPMENT OF AN AMBULATORY SYSTOLIC TIME INTERVAL MONITORING SYSTEM

by

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ABSTRACT

A system for ambulatory monitoring of systolic time intervals has been developed. This was accomplished by adaptation of a standard two channel long-term electrocardiogram monitoring unit, (Holter Monitor), in which the second channel was modified to record a pulse tracing, while the first channel recorded a bipolar V_5 ECG. The pulse tracing used was a derived ear densitogram signal.

From the two channel printout, measurements of pre-ejection period and left ventricular ejection time could be computed as long as pulse transmission time was pre-recorded.

Systolic time interval measurements were recorded on four subjects for several hours. The values of systolic time intervals obtained and the changes in systolic time intervals on each subject were consistent with those reported in the literature.

KEY WORDS

Systolic Time Interval
Ambulatory Monitoring
Holter Monitoring
Ear Densitogram
Electrocardiogram
Left Ventricular Ejection Time
Pre Ejection Period

ACKNOWLEDGEMENTS

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INTRODUCTION

The use of long-term ambulatory electrocardiographic monitoring has risen sharply over the past five years. Application of this technique for arrhythmia monitoring, drug evaluation, and diagnostic electrocardiographic changes during routine activities has revolutionized these aspects of cardiology.

Since 1949, when Dr. Norman Holter first transmitted an ambulatory ECG with an 85 pound backpack, the technique has seen many changes. Today, 2 channels of ECG data can be recorded for up to 24 hours with a small 2 pound recorder. Highly trained technicians, with the aid of modern computerized scanning equipment, are able to accurately scan the 24 hours of data in less than an hour. It is apparent that long-term monitoring is a valuable diagnostic tool that will continue to develop and find increased applications.

One promising area of progress in long-term monitoring is to augment the ECG with other information during the twenty-four hour monitoring period. Respiratory rate monitoring has already found clinical application.[1]

The addition of systolic time intervals to the ECG data for long-term monitoring is of particular interest. These measurements (principally Pre-ejection Period and Left Ventricular Ejection Time) are simple to make and require only an ECG and pulse tracing as long as phonocardiographic data are pre-recorded.

The carotid sphygmogram is the standard pulse tracing used, as it has been shown to accurately reflect the true relationships of the central aortic pressure tracing.[2] The left ventricular ejection time is simply taken as the time from the carotid upstroke to the carotid incisura. The true pre-ejection period is calculated from the Q wave of the ECG to the upstroke of the aortic tracing. The carotid pulse can be used as a "delayed aortic pulse" if a simultaneous heart sound tracing is taken so that pulse transmission time can be accounted for.[9]

Therefore, a true pre-ejection period can be calculated from the carotid pulse, ECG, and phonocardiogram. These measurements are shown in Figure 1.

Several laboratories have documented the value of systolic time interval measurements for evaluating left ventricular function.[3,4,5] Lewis et.al. cite a plethora of clinical applications for systolic time interval measurements.[5] A system which would allow long-term ambulatory monitoring of systolic time intervals adds a new dimension and could contribute tremendously to our knowledge in this field.

As a first thought, it would appear that a commercially available 2 channel long-term electrocardiographic monitor could be easily modified to record systolic time intervals. Specifically, the first channel could be used as it normally is for the ECG, and the second channel could be modified to record a pulse tracing. The difficulty lies not in modifying the apparatus to record the pulse tracing, but in selecting a stable and suitable pulse tracing to record.

The carotid pulse tracing would be ideal, as this has been used as the standard technique in most laboratories for measuring systolic time intervals. This tracing, however, poses two problems. First, anyone who has tried to obtain a carotid tracing realizes the difficulty in stability due to movement or adverse anatomical factors, even at rest and particularly in uncomfortable patients. Stable carotid tracings during routine activity of a subject would be next to impossible. Secondly, one would need a sizeable amplifier for the carotid transducer which could be difficult to carry during ambulatory monitoring. The use of impedance carotid tracings and strain gage techniques have similar difficulties.

Photo-electric densitogram tracings show promise as a suitable pulse tracing for a long-term systolic time interval monitoring. The pulsatile flow through the arterioles and capillaries in the tissues produce cyclic volume and opacity

changes which can be detected by a photosensitive device. With a photosensitive device applied at the pinna of the ear, Chirife and Spodick developed the circuitry and demonstrated a remarkably stable pulse tracing.[6] They found a left ventricular ejection time correlation between the densitogram and carotid pulse tracing to be 0.97 and concluded that "densitograms are an excellent substitute for the carotid pulse tracing for measuring time intervals of the cardiac cycle, and they are the curve of choice to be obtained in non-invasive studies during exercise". This was further substituted by Quarry-Piggott, Chirife and Spodick[7] in extensive studies using a wide variety of body positions and cardiocirculatory challenges. The final step in making feasible the work we report here was the demonstration by Spodick and Quarry-Lance[8] that the phonocardiogram could be eliminated for most test conditions because the relationship of the second heart sound to the pulse incisura remained fixed. Indeed, the upstroke and incisura of the differentiated ear pulse signal accurately reflect their counterparts of the carotid pulse for measurement of systolic time intervals.

METHODS & MATERIALS

An Avionics Model 445 holter was selected as the recording apparatus for this study. This unit features two full data channels plus a time channel. Normally, modified V_1 and V_5 ECG leads are used in the data channels. The instrument has a frequency response of .04 to 100 Hz in each channel. One can record up to 26 hours of continuous data for each battery charging. A digital clock display with an event marker on the time channel provides a time-event correlation capability. The recorder is shown in Figure 2.

In order to record a pulse tracing the second channel of ECG data was eliminated. An NDM cable shown in Figure 3 was used to modify the recorder to accept the pulse tracing. Channel I retained its ECG function with the right leg still serving as ground. The ECG electrode leads were removed from Channel 2 and replaced by the positive and negative input of mini-phone plug. The ear densitogram signal, which is described below, was applied to this phone plug.

Photo-electric Transducer

The photo-electric densitograph used in this study is a Hewlett-Packard Model 780-16 Ear Plethysmograph. The U-shaped device is attached to the uppermost portion of the ear (pinna) (Figure 4). On one side of the pinna is a light bulb, and on the other side a photoconductive cell which receives the light transmitted through the skin and cartilage.

Variations in the amount of blood in the interposed tissues will produce proportional changes in the light reaching the photocell and a consequent variation in its conductivity.

The basic operation of the device is shown in Figure 5. When fully illuminated, the photocell is highly conductive, and the voltage read at point A is simply the turn-on voltage of the photocell ($\approx$.6V). If light is completely

blocked from the photocell, there is essentially no conduction, and the voltage at point A is approximately the full battery voltage.

The circuit configuration given above would not be useful for ambulatory monitoring of pulse tracings because the device would be sensitive to baseline shifts (DC changes) in light transmission. For example, a change in ambient temperature could result in a change in venous volume (and consequent change in opacity) of the ear, and the tracing would go off scale. Therefore, the first filtering device needed is a high pass filter that will block out DC drift.

Chirife and Spodick, in their original work, used a high pass filter with a time constant of 0.17 seconds (frequency cutoff =.9Hz)[6]. This response would probably be adequate; however, a more highly derived signal might be more stable in long-term monitoring and would still be accurate for measuring systolic time intervals because the waveform shape is not essential for the interval measurements. It is only necessary to clearly define the slope changes associated with the upstroke and the incisura. In fact, the derivative signal usually clarifies these points because of their high frequency characteristics.

On this basis, we designed a passive high pass filter (derivative circuit) at the output of the earpiece. In order to reduce high frequency noise and artifact, a low pass filter with a theoretical frequency cutoff of 30 Hz was also designed and constructed into the circuit. The cutoff of 30 Hz in no way distorts the pulse waveform as this is a relatively low frequency signal. It has been reported that a frequency response of up to 20 Hz is adequate for pulse wave reproduction.[9] The schematic of the final circuit is shown in Figure 6.

The high pass filter (derivative circuit) is governed by components C_2 and R_2. The theoretical corner frequency of the high pass circuit is therefore given by:

$$F = \frac{1}{2\pi R_2 C_2}$$

$$= \frac{1}{2\pi (10^5)(10^{-7})}$$

$$= 16 \text{ Hz}$$

The low pass filter is governed by R_1 and C_1, in which the theoretical corner frequency is given by:

$$F = \frac{1}{2\pi R_1 C_1}$$

$$= \frac{1}{2\pi (1.2 \times 10^4)(.33 \times 10^{-6})}$$

$$= 40 \text{ Hz}$$

It was found that a single 4.2 Volt Mercury Battery was an adequate power supply for the entire unit and dissipated less heat on the ear than a 6 volt unit.

Pulse Signal Amplitude

As noted previously a full-scale deflection of the photo-cell (total illumination to total blockage) was approximately equal to the battery voltage minus the turn-on voltage of the photocell ($\simeq$ 4.0 volts in this case). The small changes in opacity due to pulsatile blood flow in the ear, however, result in only a 50-100 millivolt signal. This signal is further reduced by the passive filter net-

work applied at the output of the earpiece. Therefore, if one is to obtain a reasonable size signal, careful impedance matching of the filter network in combination with the photocell and recording apparatus must be considered.

In a prototype model which we developed, the pulse signal at the recorder was extremely small (1-5 mV). Too large a signal, on the other hand, can cause saturation of the recording apparatus. After careful impedance matching we were able to record a signal with a peak amplitude which is comparable in size to an ECG (10-30 mV). One must, therefore, be sure in selecting battery voltages and resistances to obtain a signal which is the same order to magnitude as an ECG.

Procedure

The subject's skin was prepared for electrode application in three locations on the chest as shown in Figure 7 (modified Lead V). The reference electrode, exploring electrode, and ground electrode were attached to the patient and run into Channel I of the patient cable.

The Hewlett-Packard earpiece was then applied to the patient and plugged into the power supply filter box. A piece of clear acetate material (David Clark Co., Worcester, MA) was placed between the light source and the surface of the ear to prevent burning, as the device would be on for a period of up to 24 hours. The output of the filtered earpiece signal was plugged into Channel II of the recording apparatus cable. The recorder filter box, and cabling was then securely fastened to the subject as shown in Figure 8.

A signal test run was made to assure all signals are clear to artifact and on scale. This is done using a test cable connecting the recording apparatus output to an external recorder. The signals displayed indicate what is being taped on Channels I and II of the recorder.

In addition to the ECG and pulse tracing from the Holter recorder, a heart sound signal and carotid pulse directly from the patient to the external recorder were recorded for the signal test run.

These additional recorded signals allowed for calculation of pulse transmission time so that a true value of pre-ejection period could be computed for the final data analysis. Also, initial values of PEP and LVET by densitogram could be compared to the same measurements by carotid pulse.

Signal test runs were made on the external recorder with the subject in the standing, sitting, and supine positions. Figure 9 shows a typical test run recording.

The subject was then disconnected from the test cable and external recorder and went about routine activities for up to 24 hours. The subject was instructed to keep an accurate activity log. The event marker on the time channel of the recorder was pushed by the subject if any unusual physiological sensations occurred.

When the subject returned to the laboratory, the recording apparatus was removed; and the taped data was scanned on a Del Mar Avionics 660A electrocardioscanner (Figure 10). The scanning operation was done at 120X real time by trained technicians.

Strips were printed: every half hour; whenever heart rate increased significantly; when ectopic beats occurred; and whenever the subject wrote significant activities in the diary.

Data Analysis

All data analysis was taken from the printout of recorded data, and the original signal test-run strip (ear densitogram, carotid pulse, heart sound, and ECG).

From the original test-run strip the pulse transmission time (PTT) was calculated as the time interval from the aortic component of the second heart sound to the incisura of the densitogram. The PTT of the carotid pulse tracing on the original test strip was also calculated so that values of PEP obtained by the ear densitrogram could be compared to the carotid.

Table I gives the control data obtained on two subjects. After the control strips were analyzed, the printout of recorded data was analyzed. The following measurements were taken from the printout and are shown in Figure 11.

RR:	Time interval, in milliseconds of the RR interval on the ECG
Q-dDen U:	Time interval, in milliseconds, from the Q wave of the ECG to the upstroke of ear densitogram derivative.
Q-dDen In:	Time interval, in milliseconds, from the Q wave of the ECG to the incisura of the densitogram derivative.

From these measurements, the following parameters are calculated.

Heart Rate (HR) $= \frac{60{,}000}{RR}$

Left Ventricular Ejection Time (LVET) = Q-dDen In minus Q-dDen U

Pre Ejection Period (PEP) = Q-dDenU minus PTT (from control tracing)

Ejection Period Ratio = PEP/LVET

Corrected Ejection Time $= LVET/\sqrt{RR}$.

All measurements were averaged over five cardiac cycles. The quality of tracing on a scale from 1-5 (5 is optimum) was also noted for each measurement.

RESULTS

Long-term monitoring of systolic time intervals using the methods described above was performed on four subjects. On the first two subjects, prototype models were used which had slightly different filter networks than the final schematic shown in Figure 6.

The first subject experienced some burning of the skin of the ear due to the constant heat of the light. This problem was resolved for the remaining subjects by applying the thin, clear piece of acetate material between the light source and the skin. Lowering the battery voltage also helped reduce the heat produced by the incandescent bulb.

The second subject's output signal amplitude was lowered significantly due to the lower battery voltage along with the plastic material reducing the intensity of light across the ear. The low signal amplitude caused difficulty in reading the systolic time intervals from the printout, even at the maximum gain of the scanner.

For the above reasons we redesigned the filter network so that an optimum impedance matching between the recorder and ear densitogram signal could be achieved. This resulted in the final model presented in Figure 6.

The final model was tested on two subjects. The two subjects experienced no unusual pain or discomfort; and clear, readible tracings of simultaneous ECG and ear densitogram were obtained.

The systolic time intervals measured on three of the four subjects were realistic when compared to normal values reported in the literature. On one subject there were unusually short pre-ejection period values. It is not known whether these are the true values or errors in paper speed calibration.

Table 2 gives the complete data taken from subject K.K. (final model). This subject was instructed to wear the device as long as possible, as we were

interested in determining the battery life (approximately 15 hours).

Figures 12 and 13 show the tracings from 3:09 p.m. and 8:39 p.m. on the subject K.K. Note that the subject is in the upright and supine position respectively at these two times. The change in the PEP/LVET ratio in these two positions is in the expected direction for positional changes as reported in the literature.[10] This change also closely tracks the positional change in PEP/LVET ratio as measured by the carotid in the control tracings.

Figures 14 and 15 show typical tracings, with the associated activities, on another subject.

DISCUSSION

The techniques and methods originated by Spodick and colleagues[6,7,8] and further developed here present a reliable and predictable system for ambulatory monitoring of systolic time intervals. The potential application of these methods as both research and clinical tools is very great.

The methods developed here will allow the subject to perform daily activities while being evaluated. Information generated from this type of study could be valuable not only in drug studies but also to our understanding of physiology and hemodynamics.

We have already begun a research study in which normal subjects are monitored while doing prescribed activities at specified times. The systolic time intervals are being documented for each activity. This includes comparisons of coronary patients and age-matched normals during their daily routine and while performing identical tasks at specified times.

Another exciting area of application of this technique is in the simultaneous evaluation of the effects of cardiac drugs on arrhythmias and ST segment deviations (ECG channel) and systolic time intervals, (both channels). Previous studies evaluating the effects of drugs on systolic time intervals have been confined to the laboratory usually with the subject at rest or post-exercise.

The techniques presented here, however, are by no means optimal. Modifications and improvements in the methods should develop with experience. We still have much to learn about the scanning process. Currently, the technicians are trained to scan the tape electrocardiogram only. The pulse is looked at secondarily as a result of changes in ECG or rate. We would like to develop a technique of scanning the pulse curve itself for changes.

The scanning apparatus used in this study has digital readout and analog trend printout of both heart rate and ST-level. For routine evaluation of sys-

tolic time intervals, similar displays of left ventricular ejection time and pre-ejection period would be desirable.

Circuitry which will give a digital readout of LVET and PEP is currently under development in this laboratory. If possible, we would like to wire this unit into the scanning apparatus so that a constant digital readout of LVET can be monitored while scanning.

Another aspect of the technique presented here which could be improved is in the earpiece itself. The burning problem on the ear was resolved in a crude fashion by simply dissipating the heat with insulating material. A more sophisticated approach would be to limit the energy loss of the light by selecting a single frequency light source and a matched frequency-sensitive photocell. This would not only prevent burning of the ear but would also significantly expand battery life.

It is evident that these and many other changes could improve the techniqie for ambulatory systolic time interval evaluation. Yet, as it stands, a reliable and predictable method has been presented.

We will continue to apply, improve, and develop this technique in this laboratory. We hope that others will find the methods presented to be useful as both research and clinical tools.

TABLE I

CONTROL VALUES

SUBJECT KK

Position	Method	HR (beat/min)	Q-Upstroke (msec)	LVET (msec)	PTT (msec)	PEP (msec)	Ratio
Sit	Carotid	77	132	238	26	104	0.49
	Ear	77	179	240	61	118	0.44
Stand	Carotid	86	124	214	27	97	0.45
	Ear	86	164	218	58	106	0.49
Supine	Carotid	72	116	272	26	90	0.33
	Ear	72	162	274	66	96	0.35

SUBJECT BH

Sit	Carotid	85	146	48	98	242	0.40
	Ear	85	182	90	92	249	0.37
Stand	Carotid	96	132	38	94	216	0.44
	Ear	96	179	93	86	223	0.39
Supine	Carotid	78	127	41	86	266	0.32
	Ear	78	164	82	82	274	0.30

TABLE II

AMBULATORY MONITORING OF THE SYSTOLIC TIME INTERVAL

SUBJECT: K.K. - ACTIVITY LOG

TIME	ACTIVITY	HR	Q-EAR msec	PEP msec.	LVET msec.	RATIO msec.	QUALITY OF TRACING	CORRECTED ET
ontrol	Sitting Non-Inv.	88	168	106	220	0.49	+3	268
:09pm	) Lab. Standing	90	176	114	208	0.55	+4	257
:37pm	in Non-Inv. Lab.	96	-	-	-	-	+1	-
:45pm	Walked to the Bathroom	98	158	96	212	0.45	+3	272
:47pm		109	160	98	220	0.45	+4	297
S	Bathroom B.M.	60	140	78	268	0.29	+4	268
:55pm	(sinus arrhythmic)	91	154	92	232	0.40	+4	286
:56pm	Came out from Bathroom	97	176	114	234	0.49	+4	300
:01pm	Standing in the Room	93	186	124	224	0:55	+3	280
:30pm	Walked to the Cath Lab.	109	120	58	204	0.28	+2	276
:06pm	Walked to the Parking Lot	110	158	96	214	0.45	+2	289
:14pm	Went back to home.	88	-	-	-	-	+1	-
:51pm	Supper	105	-	-	-	-	+1	-
:01pm	Right after Eating	97	154	92	218	0.42	+2	279
:11pm	Sitting in chair	86	148	86	236	0.36	+2	284
:13pm	Reading Newspaper	117	150	88	190	0.46	+2	268

TIME	ACTIVITY	HR	Q-EAR msec.	PEP msec.	LVET msec.	RATIO msec.	QUALITY OF TRACING	CORRECTE ET
:34pm.	Sitting on Sofa	84	160	98	240	0.41	+2	285
:40pm	Watching TV	95	168	106	232	0.46	+2	294
:00pm.	"	88	150	88	226	0.39	+2~+3	276
:03pm.	Sitting, slight palpitation	118	150	88	178	0.49	+1~+2	251
:13 pm	Walking, carrying 25lb. daughter	104	170	108	202	0.53	+2~+3	265
:39pm.	Lying on Sofa	92	156	94	240	0.39	+3	300
:12 pm	Writing letters	90	160	98	232	0.42	+3	286
:49pm.	"	97	156	94	232	0.41	+3	297
0:46pm	"	84	168	106	216	0.49	+2~+3	257
0:51pm	"	96	162	100	226	0.44	+3	286
1:17pm	Watching T.V. News	89	160	98	244	0.40	+2~+3	301
1:34pm	A large cup of tea	117	154	92	188	0.49	+2~+3	265
	"	72	126	64	228	0.28	+2~+3	250
1:55pm	Writing letter	78	146	84	266	0.32	+3~+4	306
2:28am	"	88	178	116	246	0.47	+4	300
:16am	Sleep temporarily	68	160	98	284	0.35	+4	305
:15am	Woke up	118	154	92	204	0.45	+2	287
:51 am	Sleeping	63	160	98	300	0.33	+5	309

TIME	ACTIVITY	HR	Q-EAR msec.	PEP msec.	LVET msec.	RATIO msec.	QUALITY OF TRACING	CORRECT ET
3:10am	Woke up Walked to Bathroom	112	126	64	204	0.31	+4	279
3:31am.	Sleeping	63	158	96	282	0.34	+5	291
4:06am	Sleeping	68	154	92	280	0.33	+5	301
4:58am	Sleeping	66	152	90	288	0.31	+5	303
5:42am	Sleeping	66	150	88	284	0.31	+5	299
6:12 am.	Woke up Lying	78	152	90	266	0.34	+5	306
6:16am.	Washing teeth, Shaving	132	142	80	182	0.44	+4	272
6:40am.	Sitting on chair	94	172	110	232	0.47	+2~+3	290
7:08am.	Breakfast	123	150	88	170	0.52	+2	243
7:13am.	"	130	-	-	-	-	+1	
7:32am.	Went to the parking lot.	115	weak battery source -	-	-	- -	+1	
8:02am	Watching T.V.	90	-	-	-	-	+1	
8:06am.	Driving	77 122	-	-	-	-	+1	
8:12am	Came to the hospital.	100	-	-	-	-	+1	

Basic Tracing	HR	Q-upstroke	LVET	PTT	PEP	RATIO		
Sitting								
Ear Densitogram	77	179	240	61	118	0.49	273	379
Carotid pulse	77	132	238	28	104	0.44	270	377
Standing								
Ear Densitogram	86	164	218	58	106	0.49	263	373
Carotid pulse	86	124	214	27	97	0.45	258	369
Lying								
Ear Densitofram	72	162	274	66	96	0.35	301	360
Carotid pulse	72	116	272	26	90	0.33	299	358

PTT Central PTT 27msec.

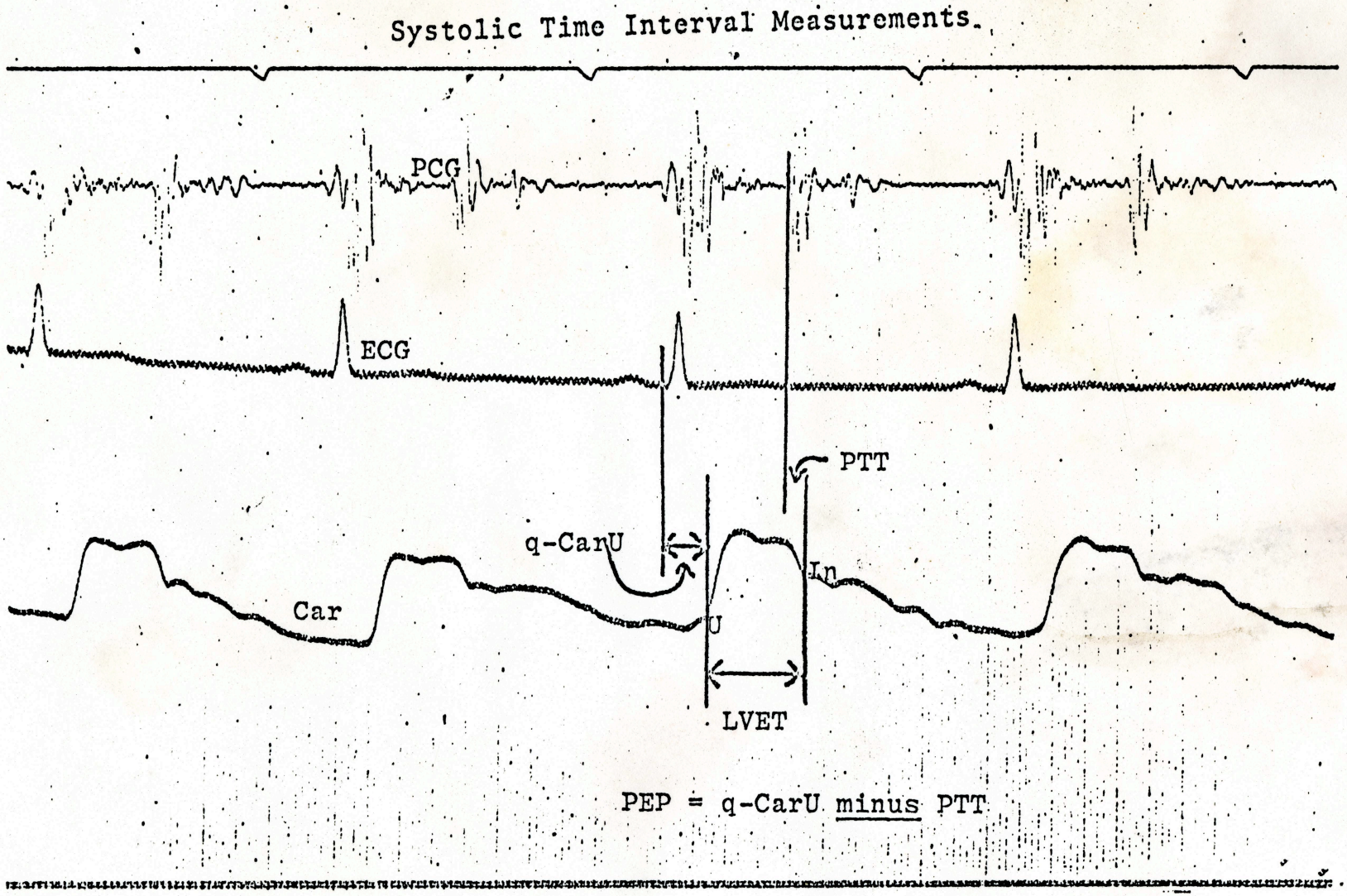

Systolic Time Interval Measurements.
PCG
ECG
PTT
q-CarU
In
Car
U
LVET
PEP = q-CarU minus PTT

FIGURE 1

Avionics Model 445 Mini-Holter

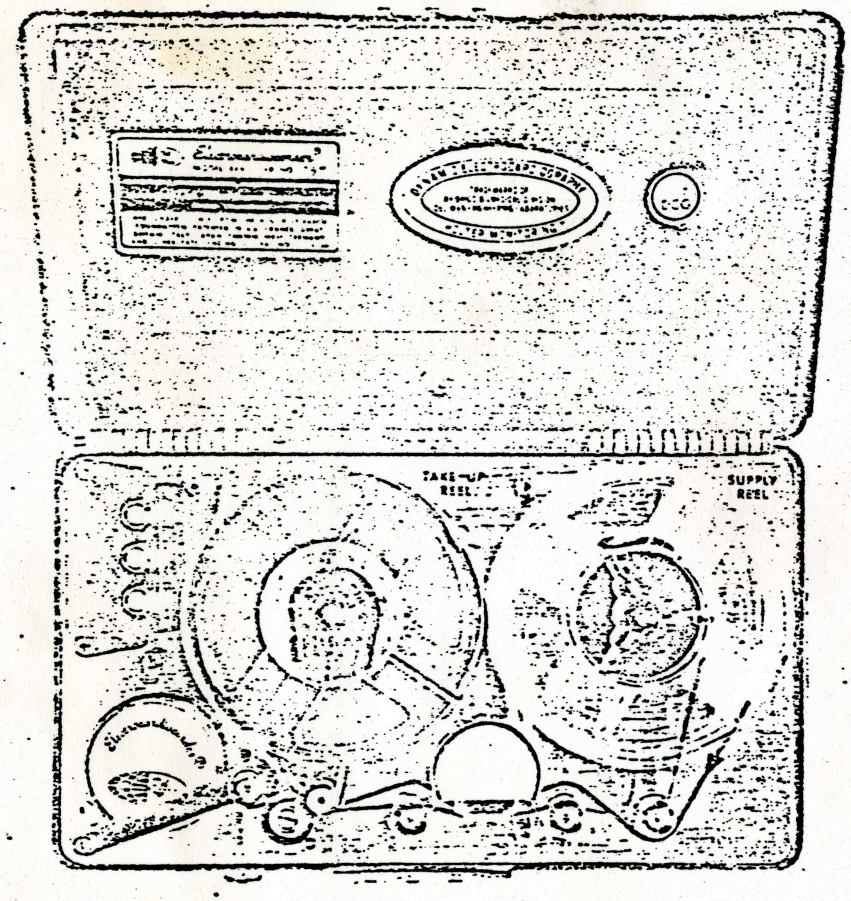


FIGURE 2

NDM Holter Cable

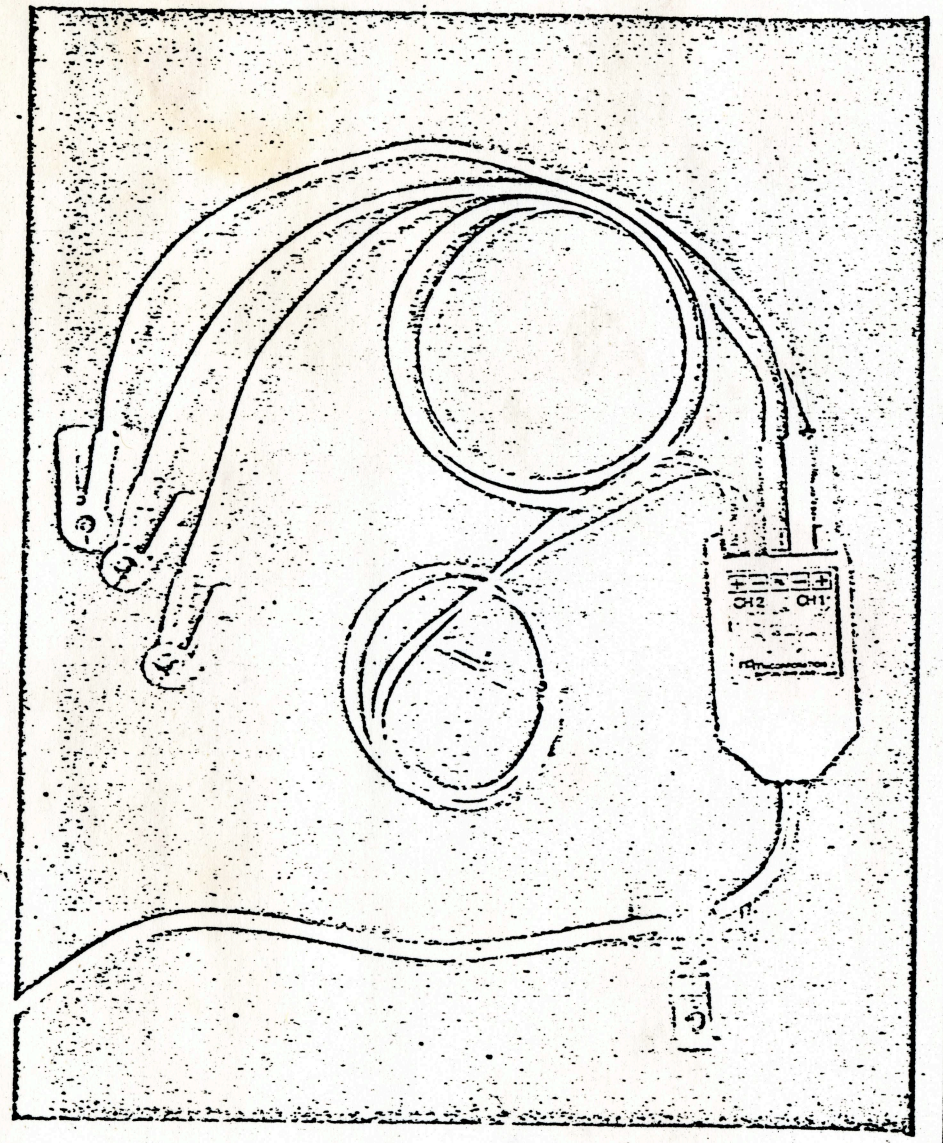


FIGURE 3

Hewlett-Packard Model 780-16 Ear Densitogram

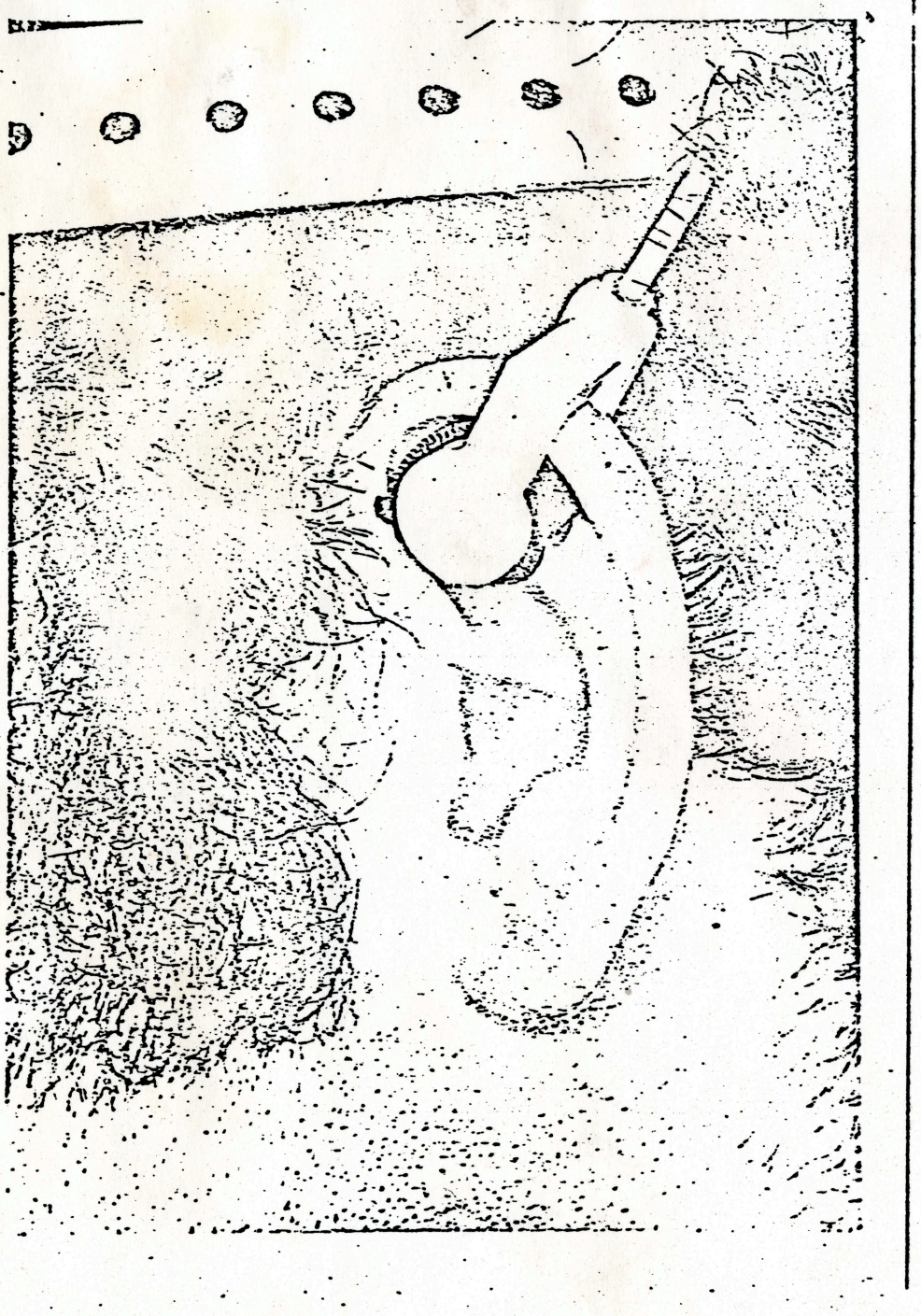
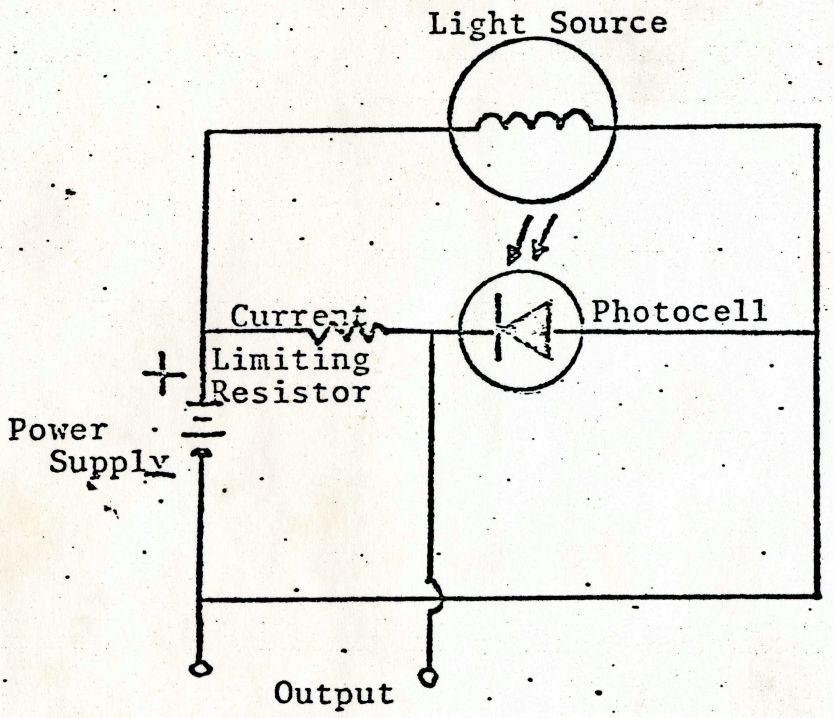
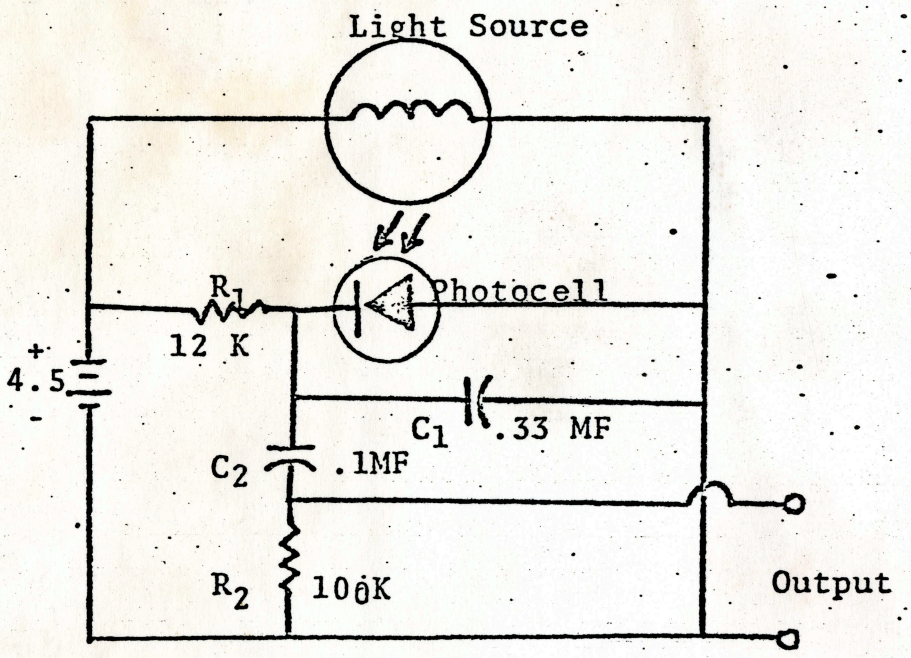


FIGURE 4



Basic Ear Densitogram Operation
Figure 5



Final Model Schematic

Figure 6

Electrode Configuration

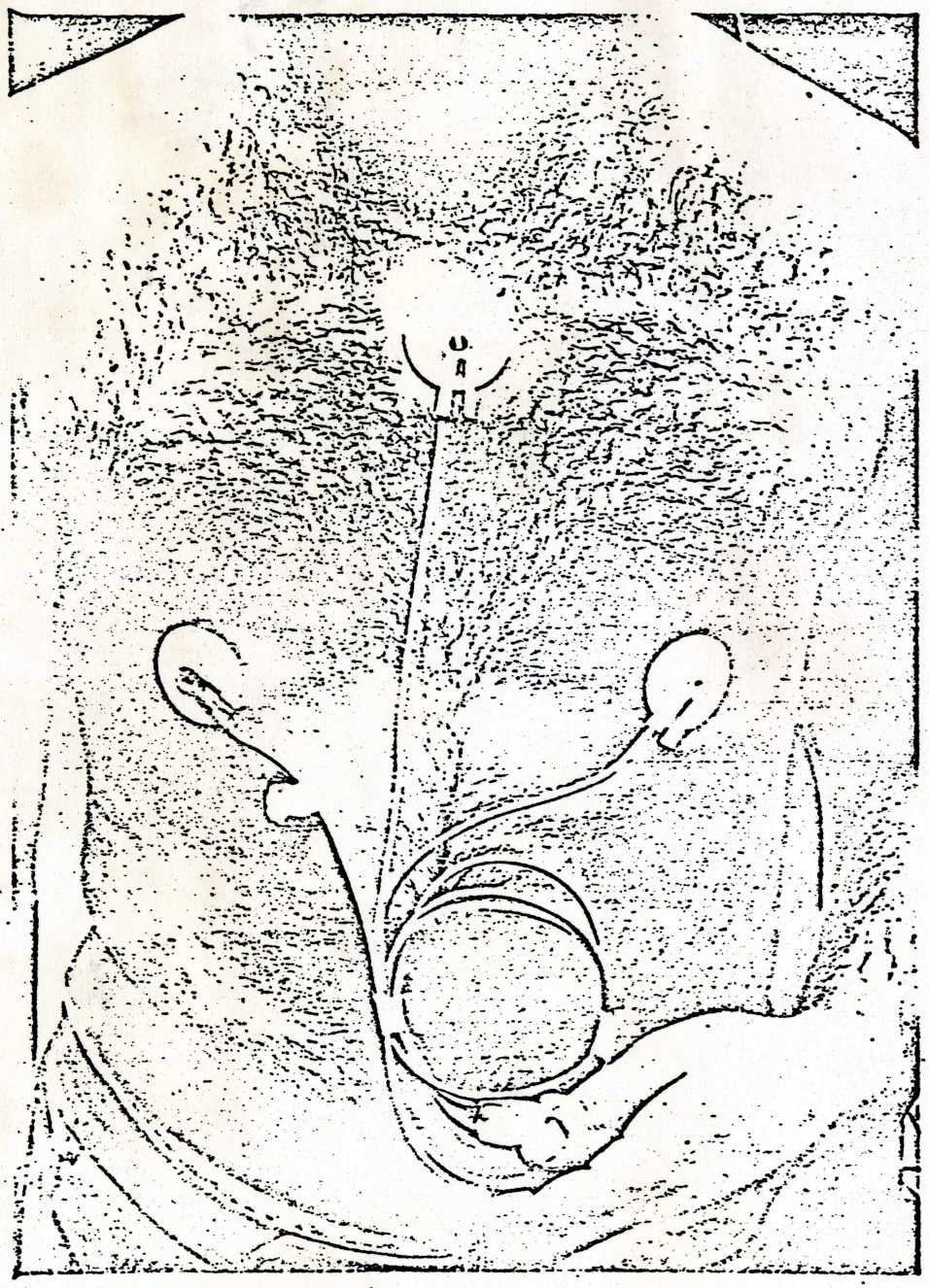


FIGURE 7

Complete Apparatus

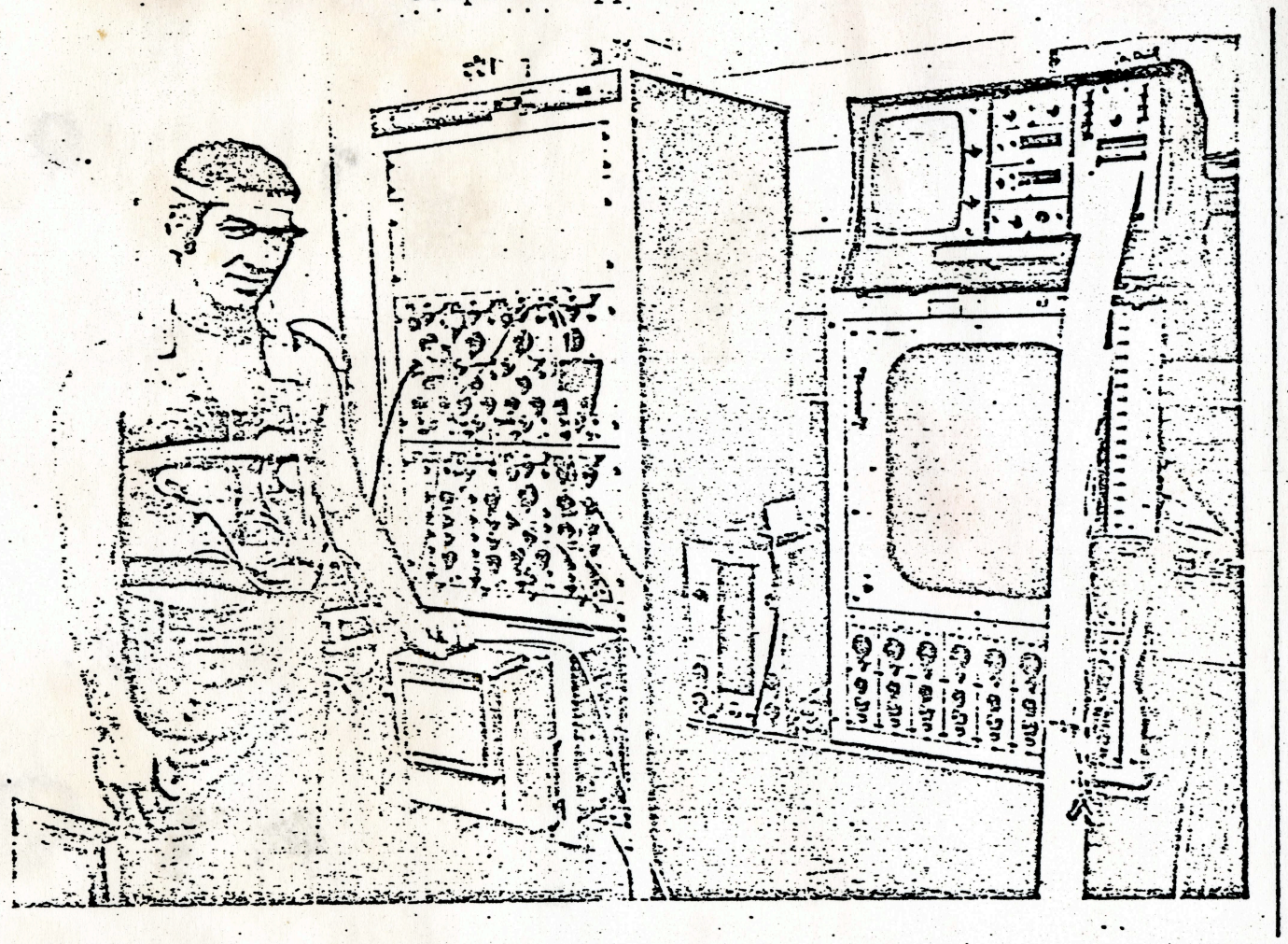


FIGURE 8

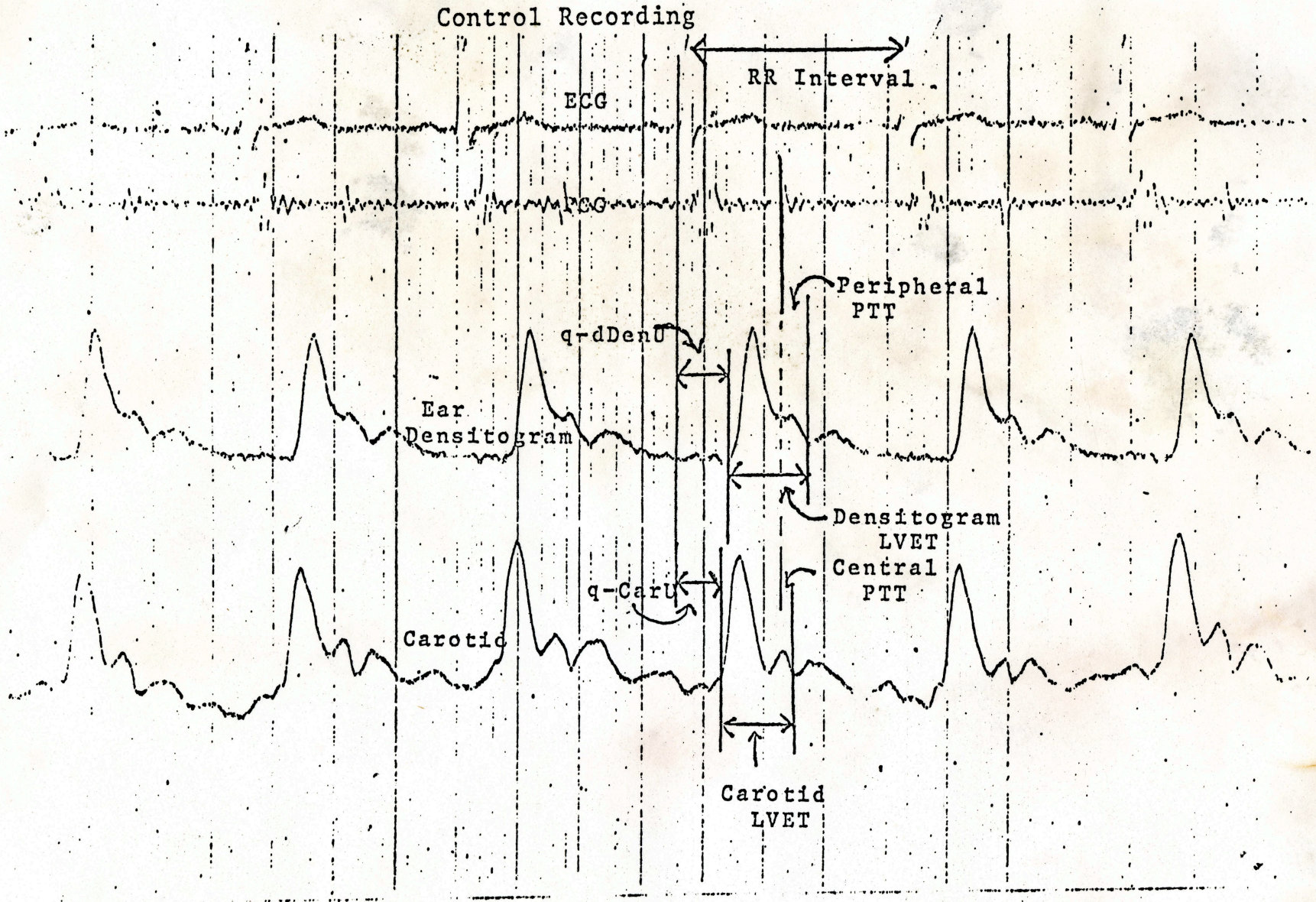

Control Recording
RR Interval
ECG
PCG
Peripheral
PTT
q-dDenU
Ear
Densitogram
Densitogram
LVET
Central
PTT
q-CarU
Carotid
Carotid
LVET

FIGURE 9

AVIONICS SCANNER

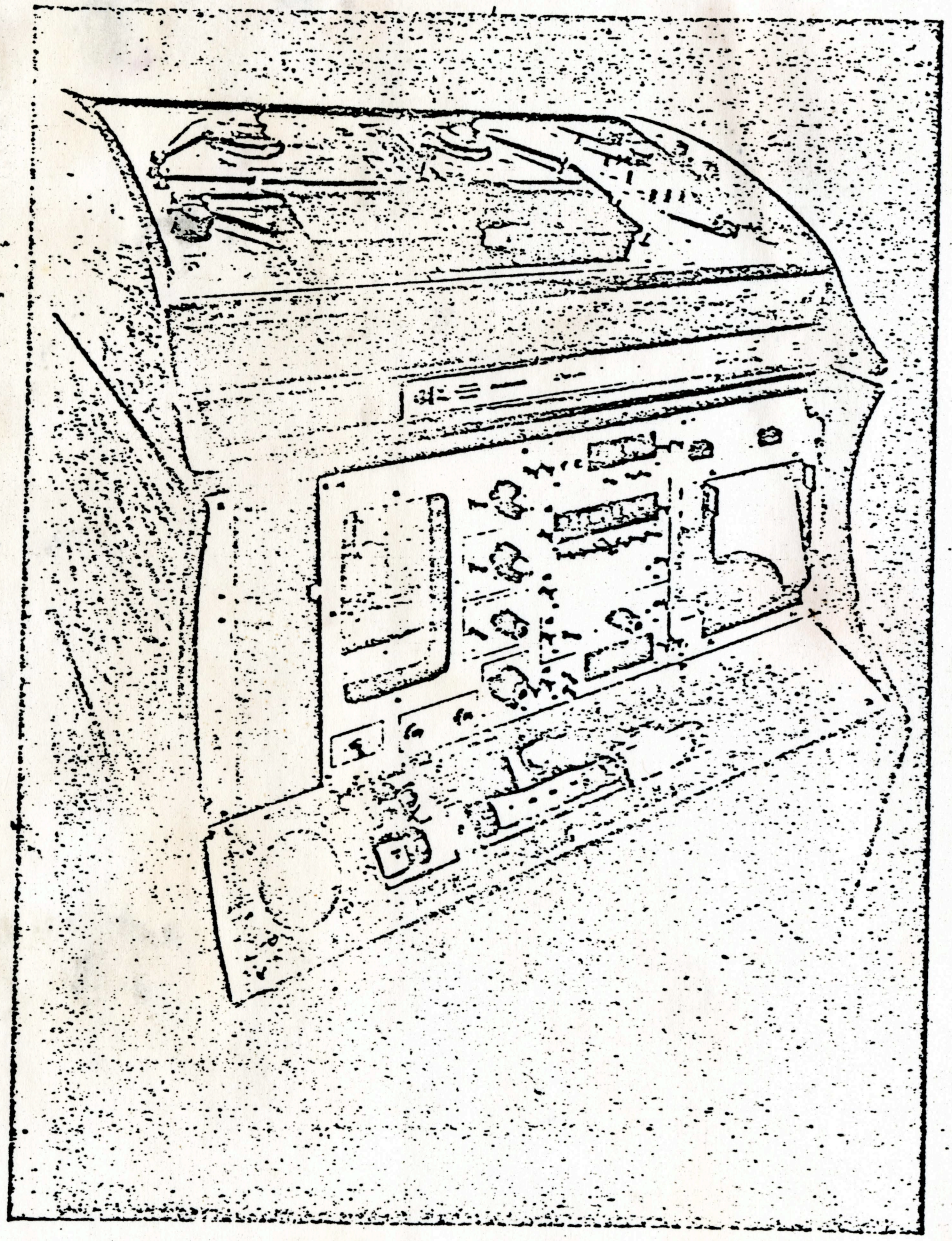


FIGURE 10

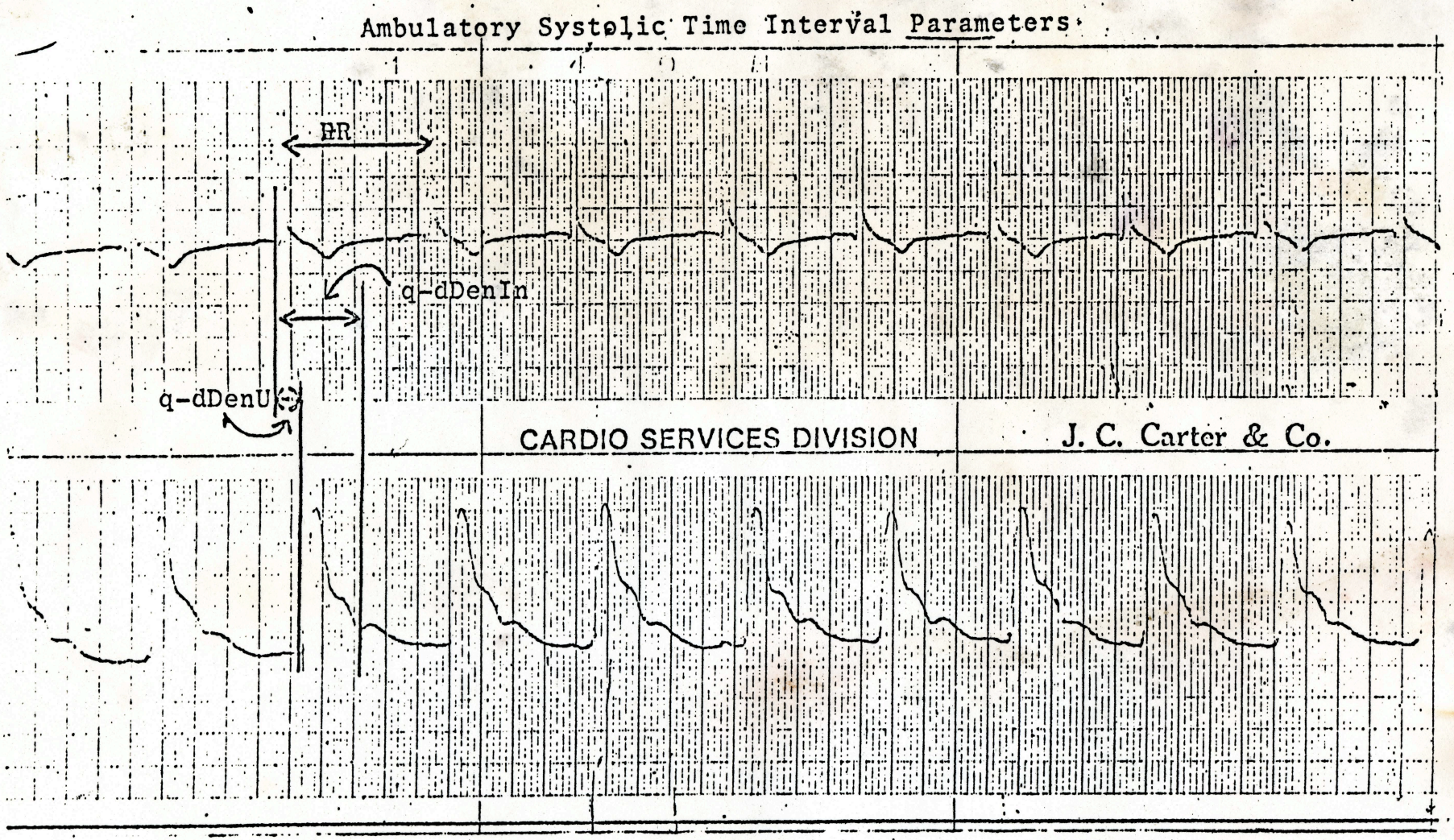
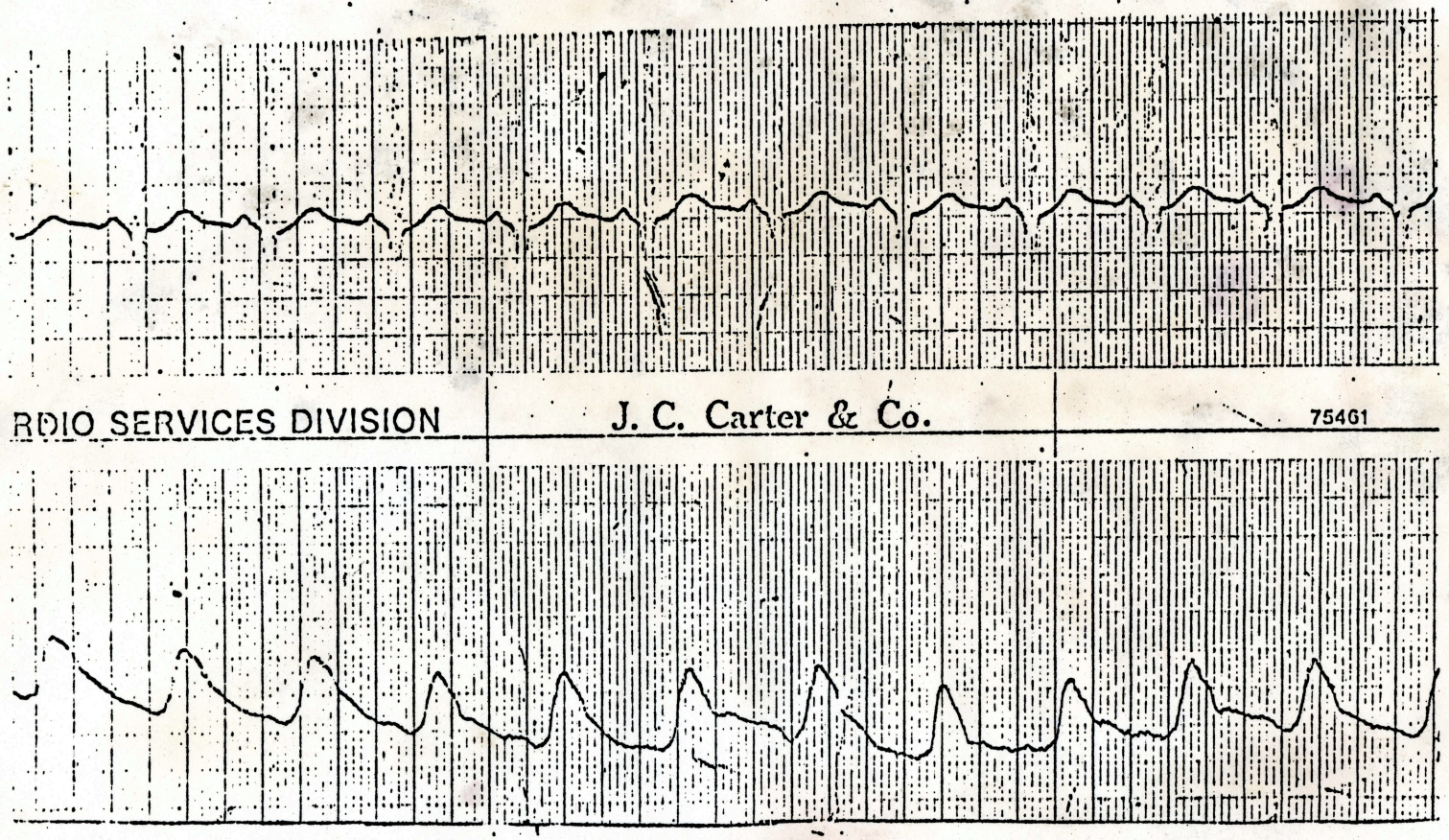

Ambulatory Systolic Time Interval Parameters
HR
q-dDenIn
q-dDenUp
CARDIO SERVICES DIVISION
J. C. Carter & Co.

FIGURE 11

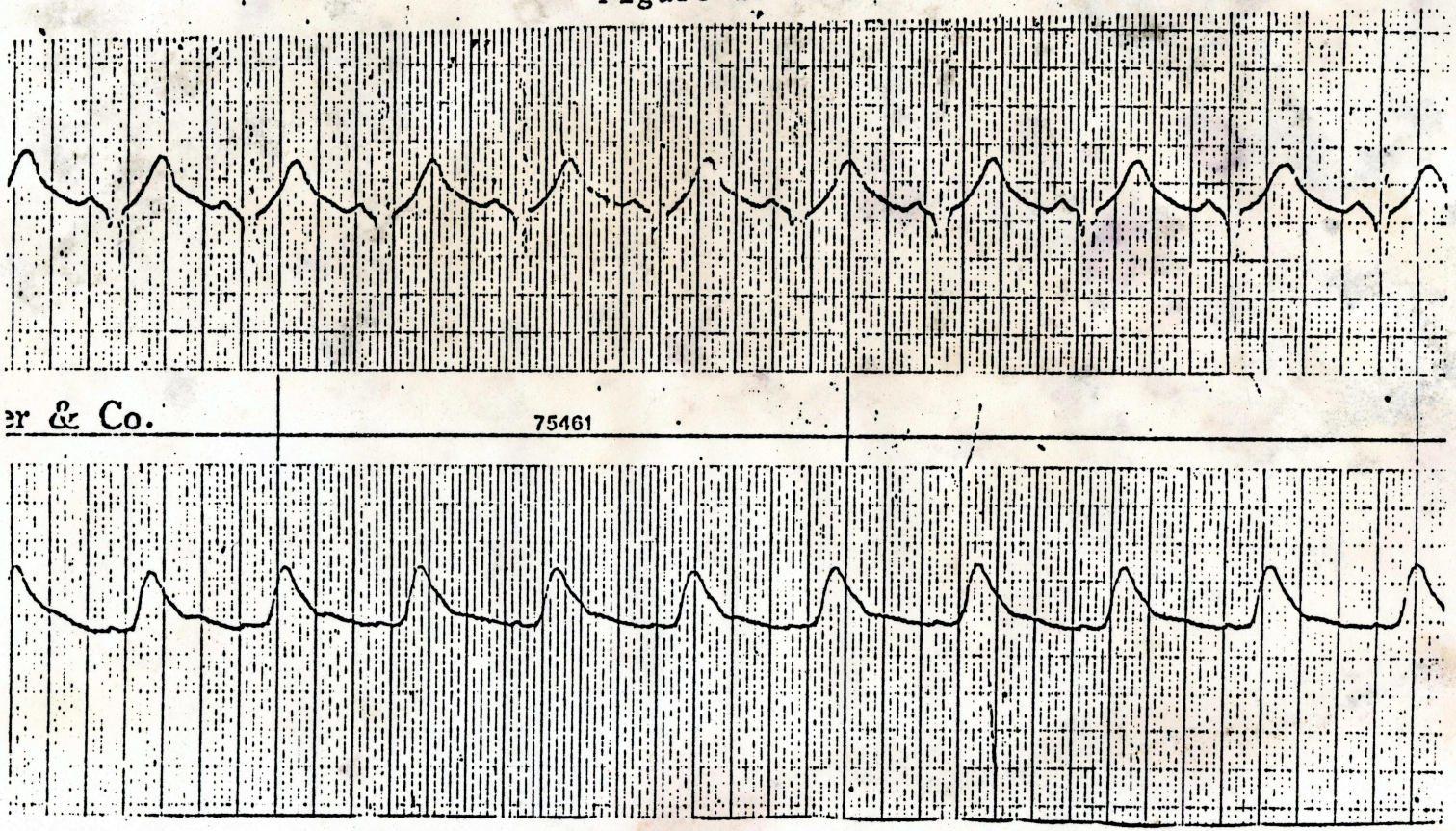
Figure 12



Subject KK 3:10 P.M. Standing

PEP = 114 msec LVET = 208 msec PEP/LVET = .55

Figure 13



Subject KK

PEP = 90 msec

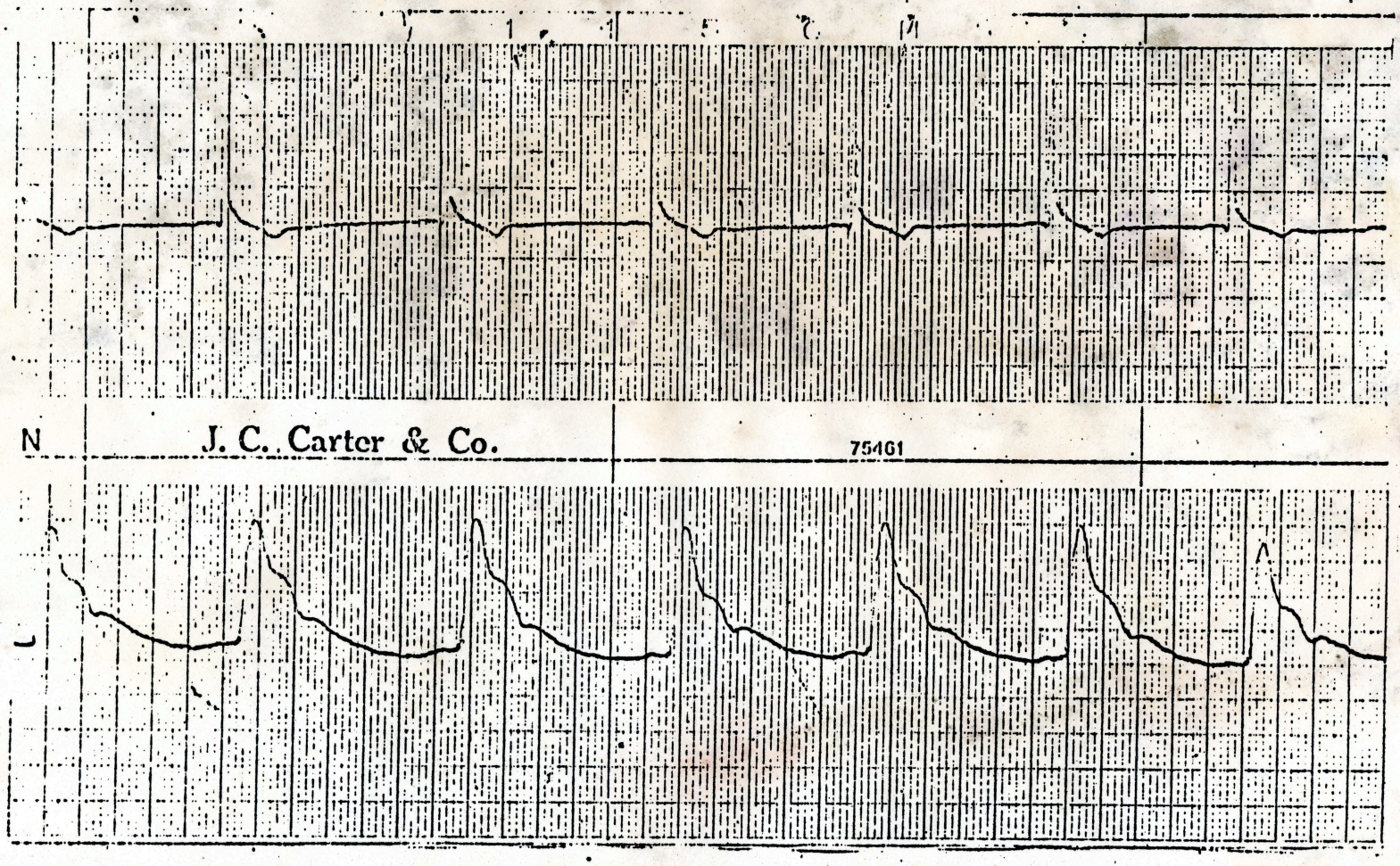
6:12 A.M.

LVET = 266 msec

Supine

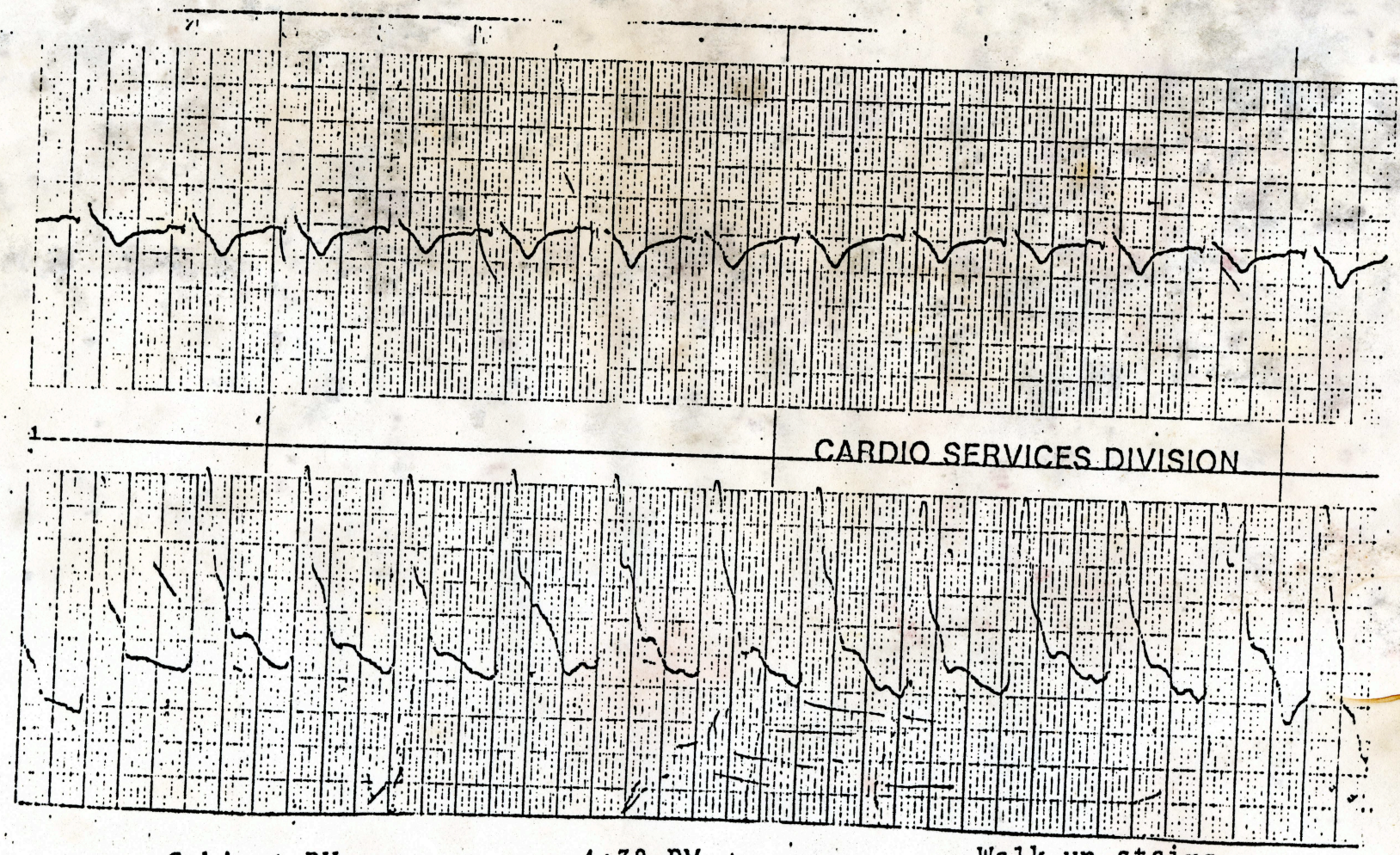
PEP/LVET = .34

Figure 14



Subject BH 11:56 P.M. Sleeping

Figure 15



Subject BH 4:38 PM Walk up stairs

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