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Changes of Cardiac Output Caused by Aging: An Impedance Cardiographic Study

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Abstract

The various parameters of cardiac output were studied in 132 healthy subjects from 20 to 89 years of age by impedance cardiography. This noninvasive method supplied data that were similar to those found by others by dye dilution methods.

All parameters of cardiac output decrease with age. However, we found a difference between the two sexes in the rate of decrease of the cardiac index: women had a more marked drop at an earlier age and then a steady course, while men had a progressive decrease from the youngest to the oldest group.

Introduction

Few authors[1,2] have reported data on cardiac output in older subjects. We thought that a new study using a noninvasive method would be appropriate because it would supply a practical basis for comparison whenever one studies old persons with cardiovascular disease, especially during treatment.

Materials and Method

Our study was made on 132 subjects. Fifty-five of them, between 20 and 59 years of age, were either hospital employees or outpatients with no clinical or laboratory evidence of cardiovascular diseases. These 55 were studied to establish average data with our equipment in the normal adult population. Thirty-one of them were men and 24 were women.

We then studied 25 men and 12 women in the 60 to 69-year group, 15 men and 5 women in the 70 to 79-year group, and 13 men and 7 women in the 80 to 89-year group. All these subjects were inpatients of our hospital, a geriatric institution, as well as a chronic diseases institution. They were selected after we

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excluded patients with (1) hypertension, (2), valvular lesions, (3) old infarcts, (4) any arrhythmia or block including grade 1 AV block, (5) any use of cardiovascular or diuretic medication, and (6) any severe chronic disease, including lung disease, cancer, and neurologic or blood diseases.

In all subjects a history was taken and a physical examination performed, including measurement of blood pressure. An electrocardiogram and a chest x-ray film were also recorded. Electrocardiographic abnormalities or cardiac enlargement were criteria for exclusion. In subjects with a grade 1 murmur, a phonocardiogram and a carotid pulse tracing were recorded and studied to exclude valvular lesions. Subjects with louder murmurs were excluded, even though they might have had an innocent aortic flow murmur.

The equipment was an impedance cardiograph (supplied by Instrumentation for Medicine Inc., 283 Greenwich Avenue, Greenwich, CT 06830) which was operated according to the original studies of Kubicek et al.[3-5] (Figure 1). By this method two aluminized strips are placed around the neck, and two others around the chest. The first and the fourth apply an alternating current of 4 ma RMS, 100 kHz to the subject. The second and third are used to record both the electical impedance (Z) and the electrocardiogram. The impedance tracing was recorded, together with the electrocardiogram and a phonocardiogram, from the amplifiers of a Hewlett Packard assembly. The microphone for phonocardiography was applied to the fourth left intercostal space (ICS), and the tracing was recorded with a 100 Hz, 24 db/octave high-pass filter.

Following the recording of the impedance tracing, the first time derivative of this cardiogram (dZ/dt) was recorded. This tracing was used to calculate cardiac output according to a formula that includes the measurement of the distance between the second and third electrodes.*

The measurement of the maximal deflection of the systolic wave is the base of the calculation of the stroke volume (ΔV). It is the current procedure to take the distance from the peak of this wave to the baseline of the calibration wave (Figure 2). However, our tracings revealed that there are slow cyclic shifts of the tracing caused by respiration. As the baseline of the calibration remains unchanged, this fact would cause an error because, in certain cycles, the point of intersection of the baseline with the impedance tracing occurs at the time of the first component of the first heart sound or even earlier.

Like Lababidi et al.,[6] we believe that the negative wave that precedes the main systolic wave is atrial in origin. This wave, plus occasional notchings, especially found in old subjects, may cause errors if we base the measurement on the fixed calibration baseline. Thus we prefer to draw a vertical line at the onset

*According to Kubicek et al.,[3] the stroke volume (ΔV) is calculated from the formula $V = p\,(L/Zo)^2 \cdot T \cdot (dz/dt)$, where p = resistivity of blood = 135 ohm-cm at 100 kHz; L = distance between the second and third electrodes; Zo = impedance between the second and third electrodes based on the height of the calibration deflection; and T = ejection time. The cardiac index was determined by dividing the body surface area (BSA) by the cardiac output. The latter figure was derived by miltiplying the stroke volume by the heart rate per minute and dividing by 1000.

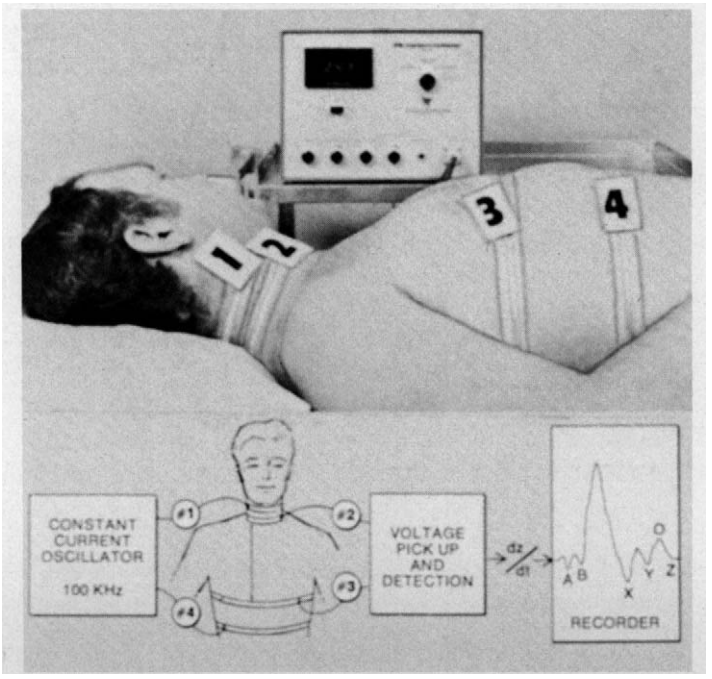

FIG. 1. Equipment used for impedance cardiography and attachment of the four aluminized, disposable electrodes (modified from Kubicek et al.[10]).

of the second component (b component) of the first sound (Figure 2), which, according to our studies[7,8] coincides with the onset of left ventricular ejection; we prolong this line until it intersects the impedance tracing. The point of intersection will mark the actual baseline on which the measurement should be based for that cycle.

The measurements were made in 5 to 6 subsequent cycles so that the final figure represented the average for each subject. The accuracy of this system has been demonstrated by numerous publications.[10] It was further confirmed by us in two young patients (one with atrial septal defect, the other with ventricular septal defect) who did not belong to the present study and were subsequently catheterized in other hospitals. The difference in output between the impedance and the dye dilution methods was less than 5%.

Results

Table 1 and Figure 2 present results of our study. They are listed, first, separately for men and women, and then in a combined column, where the average is given for both sexes in each decade, followed by the standard deviation from the mean.

As shown in that table, there were only moderate differences between the various groups in heart rates. Stroke volume, cardiac output and cardiac index decreased from the younger to the older subjects.

There is a minimal drop between the younger (20 to 39) and the middle-aged (40 to 59) groups. There is a more marked drop between the middle-aged

TABLE 1

Cardiac Output Through Chest Impedance in Normal Healthy Subjects of Various Ages

	No. = 33 20–39 years			No. = 22 40–59 years			No. = 37 60–69 years			No. = 20 70–79 years			No. = 20 80–89 years		
	M	F	M + F	M	F	M + F	M	F	M + F	M	F	M + F	M	F	M + F
No. by sex	22	11	—	9	13	—	25	12	—	15	5	—	13	7	—
Weight	149	134	—	171	136	—	160	142	—	165	142	—	148	121	—
Heart rate	75	72	73.5	68	72	70	78.6	75.7	77.1	69	88	78.7	78	76	77.2
Stroke	86	70	78	95	77	86	70.1	54.2	62.1	69.7	54.6	62.1	54.3	54.7	54.5
volume	±16.55	±20.63	±18.59	±20.74	±18.61	±19.67	±18.90	±16.19	±17.54	±14.0	±12.0	±13.0	±11.12	±11	±11
Cardiac	6.35	5.26	5.80	6.20	4.64	5.42	5.43	4.12	4.77	5.25	4.58	4.91	4.06	3.93	3.99
output	±1.52	±1.27	±1.39	±1.25	±1.27	±1.26	±1.41	±1.08	±1.24	±0.87	±0.56	±0.71	±0.87	±0.12	±0.49
Cardiac	3.58	3.03	3.31	3.36	2.74	3.05	2.83	2.59	2.71	2.86	2.56	2.71	2.39	2.60	2.49
index	±0.69	±0.56	±0.62	±0.44	±0.60	±0.52	±0.71	±0.61	±0.66	±0.40	±0.31	±0.35	±0.26	±0.23	±0.24

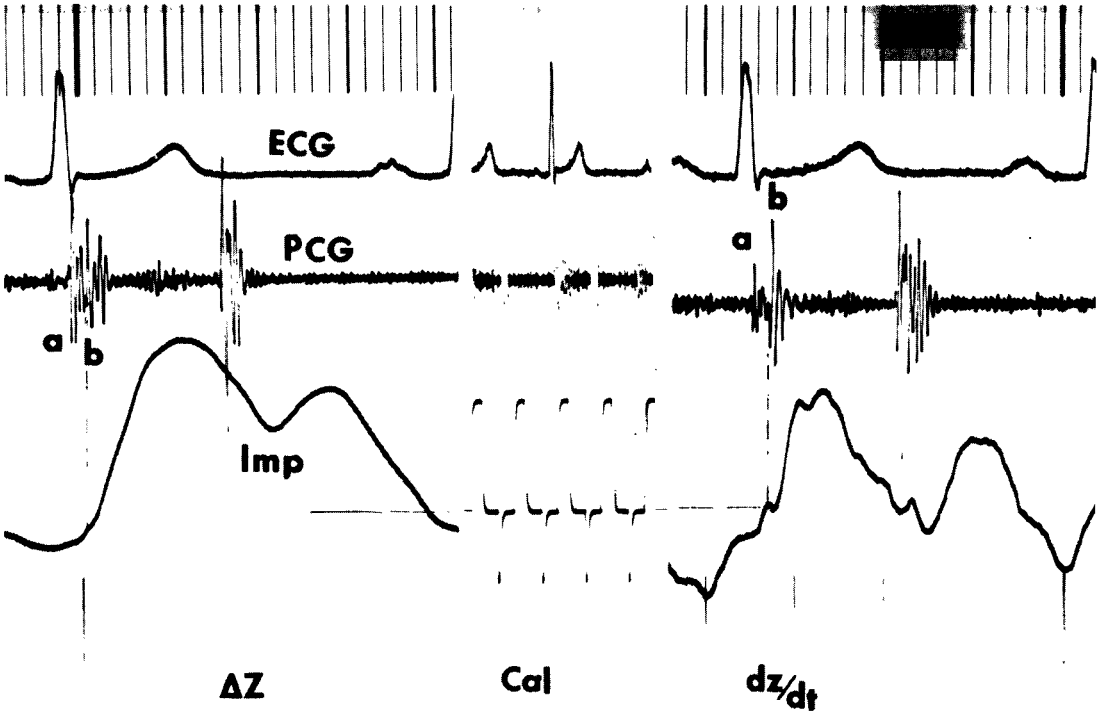

FIG.2. Impedance cardiogram in a 23-year-old normal subject. **Above:** electrocardiogram (ECG). **Center:** phonocardiogram (PCG) recorded with a 100 Hz high-pass filter. **Below:** impedance cardiogram (Z). **At left:** normal tracing. **In center:** calibration (Cal). **At right:** first derivative of impedance tracing (dZ/dt). **a, b:** first and second components of the first heart sound. Before the recording of the first derivative, the PCG tracing was lowered while the others were left at the same levels as at left. Because of the inertia of the blood mass ejected, the correct point for measuring the onset of the systolic wave is probably slightly to the right of the vertical line, that is, in the small trough that precedes the main wave.

(40 to 59) and the early senility (60 to 69) groups; then the data do not change until the end of the next decade, and show another drop between the 70 to 79 and the 80 to 89 groups.

If the two sexes are separately studied (Figure 3), one can observe that women have a sharp drop from the 20 to 39-year group to the 40 to 59-year group; then they have a slow decrease and, after the 60 to 69-year group, practically an unchanged output. In contrast, males have a much slower change so that the output gradually decreases until the oldest age.

The means of the various age groups were compared by the Kramer modification of the Duncan multiple range test, and the various changes were found significant.

The differences between female groups had a $P < 0.01$; the differences between male groups also had a $P < 0.01$, except between the 40 to 49-year group and the 70 to 79-year group, and between the 60 to 69 and 80 to 89-year groups, where the P was < 0.05.

As for the separate values for the two sexes, men had higher values than women up to the age of 80. But after 80 the cardiac index shows a reversal of the trend, and the women have a slightly higher index.

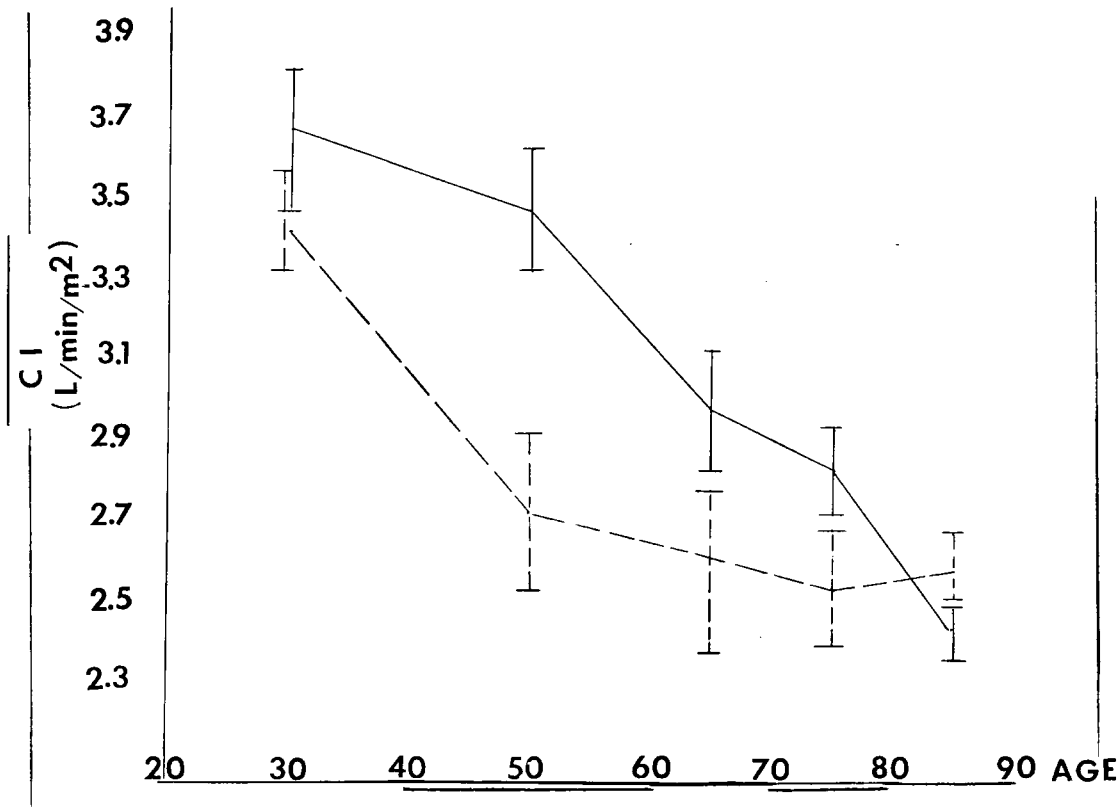

FIG.3. Changes of the mean cardiac index in men (continuous line) and women (broken line) for the various age groups and extremes in each group.

Discussion

This study was undertaken to test the general impression that cardiac output decreases in old age. Several studies performed with noninvasive methods show a decrease of various parameters of cardiac function when data of younger people are compared with those of old subjects. Of course the selection of "normal" subjects is very important and becomes more and more difficult with increasing age. The systolic time intervals in normal subjects of various ages were recently studied by us[11] and basically confirm the trend noted in the present series of measurements. Echocardiographic studies of the heart in old age were initiated by Derman[12] and continued by Quinones et al.,[13] Layton et al.,[14] and us[15]. They were further perfected by Gerstenblith et al.[16] and Gardin et al.,[17] who studied the ejection fraction and the left ventricular dimensions.

A few researchers have studied the cardiac output of old subjects. Using an indicator dilution technique, Smith et al.[9] found a cardiac index of 2.67 in 10 control subjects between 62 and 77 years of age (average 71). Their younger controls had an index of 3.5. Brandfonbrener et al.[2] studied 10 subjects with a mean age of 65.4, and 9 subjects with a mean age of 82. Their measurements were made with an indicator dilution method and showed a decrease of the

mean cardiac index, the cardiac output, and the stroke volume with a progression proportional to the increase in age. Cardiac output decreased from 6.69 L/min at the mean age of 34, to 3.87 L/min at the mean age of 82. The cardiac index decreased from 3.54 to 2.36 in the same groups.

Our study had the advantage of using a noninvasive method. Our findings are similar to those of Brandfonbrener et al.[2] because we noticed a drop of cardiac output from 5.80 in the 20 to 39-year group to 3.99 in the 80 to 89-year group for the cardiac output, and a drop of the cardiac index from 3.31 in the 20 to 39-year group to 2.49 for the 80 to 89-year group, the oldest group.

It is interesting that there seems to be a fairly stable cardiac index in women after 60 in spite of the age progression, whereas in men the drop is steady and progressive from young age to the 70 to 80-year group.

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