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Cardiac Output Determinations with Ear piece Densitometry

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ABSTRACT

The results of cardiac output determinations by a dye dilution technique were compared using (*a*) a dichromatic earpiece which was calibrated as a flow-through cuvette, but also permitted automatic computing by virtue of a pressure capsule, and (*b*) an ordinary flow-through densitometer. Eleven subjects, some with cardio-pulmonary disease, were investigated. Cardiac outputs were systematically overestimated when automatically computed. The results obtained by manual calculation with the earpiece corresponded more nearly with those derived from the flow-through cuvette, but still with a deviation from the identity line and with a residual standard deviation of 0.8 l/min. Double determinations had a residual standard deviation of 0.7 l/min. Despite its ease of handling, an earpiece densitometer seems to be too unreliable to be suitable for routine use.

INTRODUCTION

The technique of determining cardiac output by indicator dilution was introduced by Stewart (7). This technique was further developed for use in humans by Hamilton et al. (2). Wood & Gerasi (8) presented the method of continuous monitoring of dye concentration by photoelectric cells. Obviation of arterial catheterization was made possible by earpiece densitometry (4). However, the results of earpiece densitometry have not been uniformly encouraging. Difficulty in calibrating the device has been given as an explanation and the reliability of the ear as a recording site has been questioned (8). The development of dichromatic densitometry seems to have reduced the variability of the results (5). A simple calibration device has further facilitated ear-piece densitometry by converting the densitometer to a flow-through cuvette (1).

The present study was performed to elucidate the reliability of ear densitometry using the innovations described above (i.e. dichromatic densitometer and flow-through calibration). Hence, comparisons were made between an earpiece densitometer and a conventional direct sampling cuvette.

MATERIAL AND METHODS

Altogether 11 subjects were investigated (Table I). Nos. 1–4 had no cardio-pulmonary disease. Nos. 1–3 were studied during anaesthesia prior to surgery. No. 4 was a healthy volunteer. Subjects 5–11 demonstrated ventilatory and/or circulatory impairment. Subjects 8–10 were ventilated with a respirator. No one was in shock or showed peripheral cyanosis.

The earpiece densitometer consisted of a dichromatic photocell (Waters XE-302) with amplifier (Waters MD 41) and cardiac output computer (Waters MC-4A). The estimation of cardiac output by continuous sampling of arterial blood was performed with a Beckman cardio-densitometer.

The pinna of the ear was cleansed with alcohol and rubbed briskly to promote flushing of the ear tissue before the earpiece was fastened on the pinna. The earpiece was switched on at least 10 min before measurement to allow for thermal equilibration. A black cloth was placed over the earpiece and pinna to eliminate extraneous light.

A short teflon catheter was percutaneously introduced into a brachial or femoral artery and was connected to the flow-through cuvette. A withdrawal pump (Sage 351) drew blood continuously through the cuvette at a rate of 20 ml/min. The aspirated blood was handled under sterile conditions and was reinfused after each determination.

Another catheter was introduced, via a medial cubital vein to the superior vena cava or right atrium, the position of the tip being anticipated from the length of the catheter being moved in.

When measuring cardiac output 5 mg indocyanin green (Cardiogreen®) was injected as a bolus dose in the venous catheter followed by rapid flushing with 10 ml saline. A second determination was performed as soon as the previous blood sample was reinfused and a stable zero-line was achieved, i.e. 3–4 min after the first determination.

Calibration was performed with the two densitometers

Table I. *The clinical material*

No.	Age	Sex	Diagnosis and experimental conditions	Blood pressure (mmHg)	Heart rate [a] (beats/min)	Cardiac output [b] (range l/min)
1	37	F	Cholelithiasis; Anaesthesia, artificial ventilation, varying minute ventilations	95/70	58	3.6–4.5
2	69	F	Cancer of the breast; Anaesthesia, artificial ventilation, varying minute ventilations	85/60	55	2.8–3.3
3	45	M	Cholelithiasis; Anaesthesia, artificial ventilation, varying minute ventilations	90/65	68	3.8–4.6
4	25	M	Healthy volunteer; Conscious, spontaneous breathing, rest	120/75	76	5.8–7.1
5	54	F	Pulm. fibrosis; Conscious, spontaneous breathing, rest and light work	135/80	72	6.8–10.7
6	56	F	Myocardial infarction; Conscious spontaneous breathing, rest	125/70	114	3.6–3.8
7	52	M	Myocardial infarction; Conscious, spontaneous breathing, rest	140/90	100	7.6–8.0
8	57	M	Intestinal resection, left heart failure; Conscious, artificial ventilation, varying minute ventilations	140/90	83	4.2–7.3
9	78	M	Chronic bronchitis, left heart failure; Conscious, artificial ventilation, varying minute ventilations	110/65	70	4.3–5.2
10	68	M	Chronic bronchitis; Conscious, artificial ventilation, varying minute ventilations	120/80	106	4.9–6.4
11	57	M	Chronic bronchitis; Conscious, spontaneous breathing, rest	165/95	84	4.6–4.8

[a] Values obtained at rest and the smallest minute ventilation. [b] Values obtained with the flow-through cuvette.

connected in series, the earpiece mounted on a calibration device transforming the densitometer to a flow-through cuvette (1). Whole blood samples with dye concentrations of 0, 2, 4 and 6 mg/l were prepared with a Hamilton syringe and the blood drawn through the cuvettes at the same flow rate as during the cardiac output determinations. The cuvettes were flushed with saline between the calibrations with different dye concentrations.

Another stage of calibration was performed with the earpiece when fitted to the pinna of the ear. A pressure capsule was inflated making the transilluminated portion of the pinna bloodless. The difference in transmittance in this situation as compared with the normal blood-containing state is an expression of the absorption characteristics of that particular blood, factors which influence the calibration factor of the dye. Hence, this absorbance may be adequately corrected for by electrical adjustment of the amplifier (MD 41). Once this has been done an electrical calibration signal in the cardiac output computer (MC-4A) can be used for automatic derivation of the cardiac output. The built-in calibration signal was checked against known dye concentrations during the calibration procedure with the earpiece mounted as a flow-through cuvette, i.e. during each study.

In most subjects cardiac output was determined in different experimental conditions (see Table I), usually at different levels of minute ventilation. These variations affect intrathoracic pressure and arterial carbon dioxide tension, both being factors that may influence cardiac output. 2–8 determinations were made on each patient.

Comparisons were made between the earpiece densitometer and the direct sampling cuvette. Since the earpiece device includes an automatic integrator of dye area, comparisons were also made between cardiac outputs calculated automatically and manually with the earpiece densitometer and the corresponding values obtained by the direct sampling cuvette. Finally, the reproducibility of cardiac output measurement with earpiece densitometry was calculated from the double determinations.

Regression analyses were made according to the least squares method and paired analyses according to Student's *t*-test.

RESULTS

In Fig. 1 are plotted the simultaneous determinations of cardiac output with earpiece (including integrator) and flow-through cuvette densitometer. As can be seen there was a considerable deviation from the line of identity, the regression line also demonstrating a different slope from the identity line. Hence, cardiac output as measured with the earpiece ranged between 2.5 and 9.0 l/min whereas the

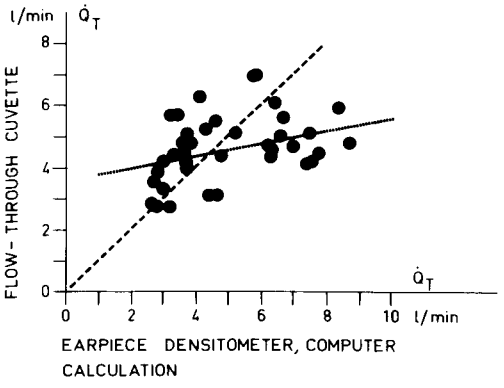

Fig. 1. Comparison between simultaneous cardiac output determinations with the earpiece (automatically integrated) and flow-through cuvette. - - -: line of identity. —: regression line. *r*: 0.32. Residual S. D.: 0.97 l/min. *n*: 37. Mean difference: 0.41 l/min. $p>0.05$.

corresponding values for the flow-through cuvette were 2.5–7.0 l/min.

To check the accuracy of the integrator (MC-4A) included in the earpiece densitometer equipment cardiac output values obtained by the integrator were compared with those manually calculated according to Jorfeldt and Wahren (3). A systematic over-estimation of the flow values was produced by the integrator with a mean difference between the methods of 2.0 l/min ($p<0.001$).

In Fig. 2 manually calculated cardiac outputs are plotted against corresponding values with the flow-through cuvette. The regression line agreed better with the line of identity than the line for automatically integrated curves (Fig. 1). The standard deviation was slightly smaller for the manually calculated cardiac output.

27 double determinations were performed with the earpiece using the automatic integrator (MC-4A). There was no systematic difference between the first and the second determination. The standard deviation was 0.7 l/min and the mean difference 0.1 l/min ($p>0.05$).

DISCUSSION

The present study was undertaken in view of the considerable advantage an earpiece densitometer theoretically may offer in an intensive care unit. Thus, the rapid and easy handling of this device as compared with conventional equipment, obviating the need for arterial cannulation and even calibration after each investigation (cf. 5) is an essential factor in emergency cases. However, the present results were disappointing. But it should be kept in mind that the densitometers were handled not by engineers but by clinicians who made a considerable effort to induce the equipment to function. The study should therefore be regarded as a clinical test in the atmosphere of an intensive care unit.

As a reference for the earpiece densitometry we used the Beckman cardiodensitometer. Comparative studies between this densitometer and the Fick principle have been performed on this laboratory demonstrating a close correlation (*r*: 0.99) with a mean difference of 0.1 l/min in a material of 10 human subjects (6). We therefore consider the measurements made by the flow-through cuvette to be accurate.

Why did we not obtain reliable results with the earpiece densitometer? The most probable reason for the unreliable cardiac output determinations obtained with the earpiece is difficulties with the calibration. Thus, the flow curves were similar in shape to those obtained by the flow-through cuvette. But the calibration procedure, disconnecting the earpiece from the pinna and sliding it over the calibration device, means a change in the geometrical proportions of the earpiece which, together with the difference between the absorbance of the catheter within the calibration device and that of the pinna, results in a change in the illuminance of the photocells. An adequate correction for the altered transilluminance does not seem easy to arrange.

Another factor that influences calibration is the

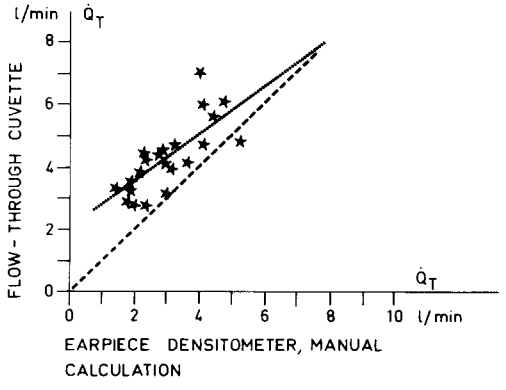

Fig. 2. Comparison between simultaneous cardiac output determinations with the earpiece (manually calculated areas) and the flow-through cuvette. - - : line of identity. —: regression line. *r*: 0.77. Residual S.D.: 0.76 l/min. *n*: 22, Mean difference: 1.23 l/min, $P<0.001$.

flow rate of blood through the calibration device. The absolute magnitude of absorbance increased with blood flow. However, the difference in amplitude between concentrations was unchanged.

The overestimation of the integrator of the earpiece densitometer may be due to a technical error within the instrument. But the device was checked several times by the agents during the study and was considered to function properly. It is possible that the use of the pressure capsule as a calibration step not only results in a bloodless pinna but also distorts the pinna itself resulting in an erroneous calibration factor. This points to a sensitive part of the calibration, the use of capsule pressure high enough to push away blood completely and low enough to keep the topography of the tissue unchanged.

Disregarding the error inherent in the calibration procedures, a variation in the flow values still exists as judged from the double determinations. This variation must be attributed to changes in the transilluminance of the pinna or blood. In addition, it may be questioned whether the vessels in the pinna obtain representative concentrations of dye as compared with the central arteries, especially in hypotensive patients.

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