INVESTIGATION OF THE RELIABILITY OF INDIRECT METHODS OF DETERMINING THE STROKE VOLUME

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By a comparison of the direct Fick method with the thermodilution and integral rheographic methods and by mathematical analysis of the results of this comparison, the reliability, reproducibility, and justifiability of using sphygmographic methods of determining the stroke volume and Starr's method were studied in healthy subjects and in patients with mitral disease and with acute and chronic nonspecific diseases of the lungs under stable conditions and during rapid changes in the stroke volume. It is shown that the use of sphygmographic methods is justified in healthy subjects and in patients with combined mitral lesions and with chronic pneumonia in the initial stages provided that corrections are introduced. A correcting nomogram is suggested. The use of Starr's method is not justified in healthy subjects and in the patients of all these groups.

Sphygmographic methods and Starr's method are often used on healthy subjects and patients with diseases of the cardiovascular and respiratory systems [1, 4, 15]. The reliability of these methods is questionable, even on healthy subjects [2, 3, 5]. Their comparison with direct methods on patients always gave unsatisfactory results [10-13]. The error factor of these methods has frequently been studied, but since no generally accepted method of its assessment exists the results have often proved contradictory [14]. The use of the standard deviation and the error of the arithmetic mean and direct comparison of values (as percentages or as ratios) are evidently insufficient for sound conclusions regarding the reliability of the method to be drawn.

To begin with it is essential to have a control method, applicable equally to healthy subjects and patients, for whom direct methods (involving catheterization) are inadmissible. These requirements are satisfied by the method of integrative rheography of the human body (IRHB) suggested recently by Tishchenko [6-10]. We have studied this method with respect to its suitability as an intermediate control method.

In the case of simultaneous determination of the minute blood volume by the IRHB method and by the direct Fick method in patients with mitral heart disease, chronic pneumonia, and tumors of the lungs (28 determinations) a coefficient of correlation $r = 0.99 \pm 0.02$ was obtained, with probability of significance $P > 99.9\%$, $t_{st} = 39.68$; the coefficient of linear regression $R = 0.95$; the standard deviation of the results $\sigma = 6.6\%$.

The results obtained by simultaneous determination of the minute volume by the IRHB method and by the thermodilution method (25 comparisons) were as follows: $r = 0.96 \pm 0.06$; $P > 99.6\%$; $t_{st} = 14.63$; $\sigma = 12\%$. The linear regression equations deduced from the results fully confirm the goodness of fit. An advantage of the IRHB method is the low value of the relative random errors (reproducibility 5%), which gives it its good resolving power [7]. For all these reasons the IRHB method can be used as an intermediate control method for the investigation of healthy subjects and patients with various diseases. By means of the IRHB method it is possible to determine the stroke volume per contraction of the heart and to study the reliability, the reproducibility, and the limits of applicability of the sphygmographic methods and of Starr's method.

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TABLE 1. Statistical Indices for Comparing Sphygmographic Methods and Starr's Method with the Direct Fick Method, the Thermodilution Method, and the Integrative Rheography (IRHB) Method on Healthy Subjects and Patients

Group tested	Statistical Index	Broemser–Ranke method			Wezler–Böger method			Starr's method		
		Fick's method	thermodilution method	IRHB method	Fick's method	thermodilution method	IRHB method	Fick's method	thermodilution method	IRHB method
Healthy	r			0,86±0,07			0,63±0,15			0,06±0,19
	P (in %)			>99,9			>99,9			<50
	R			0,63			0,91			—0,09
	σ			0,23			0,16			0,27
Patients:										
with combined mitral defects	r			0,64±0,23			0,46±0,27			0,30±0,29
	P (in %)			>98			<90			<50
	R			0,32			0,35			0,44
	σ			0,58			0,29			0,47
with chronic pneumonia, stage II	r	0,40±0,19		0,47±0,24	0,46±0,19		0,64±0,21	0,37±0,20		0,30±0,27
	P (in %)	>95		>90	>95		>99	>90		<50
	R	0,66		0,51	1,25		1,01	0,67		0,77
	σ	0,27		0,50	0,15		0,31	0,42		0,62
with acute lung abscesses	r		0,45±0,25	0,42±0,27		0,45±0,25	0,38±0,28		—0,12±0,37	0,22±0,29
	P (in %)		>90	<90		>90	<68		<68	<50
	R		1,90	0,43	0,17	0,17	0,88		—0,11	0,43
	σ		0,78	0,39		0,47	0,23		0,57	0,28
with acute pneumonia	r			0,30±0,29			0,32±0,28			0,06±0,30
	P (in %)			<68			<68			<50
	R			0,29			0,39			0,12
	σ			0,44			0,28			0,34
with chronic pneumonia, stage III	r			—0,21±0,26			—0,28±0,26			—0,37±0,25
	P (in %)			<68			<68			<50
	R			—0,23			—0,46			—0,83
	σ			0,35			0,23			0,21

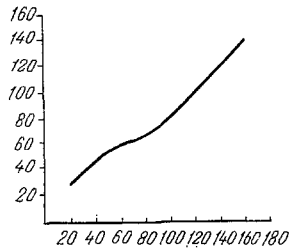

Fig. 1. Correction nomogram for approximating values of the stroke volume calculated by the Broemser–Ranke method (abscissa) to actual values (ordinate) in the range from 25 to 165 ml.

EXPERIMENTAL METHOD

Tests were carried out on healthy persons (56 observations) and patients with combined mitral defects of the heart (13 observations), acute pneumonia (15 observations), chronic pneumonia (30 observations), and lung abscesses (15 observations). The stroke volume as reflected by the IRHB was determined by Tishchenko's method [7, 8]. The stroke volume was calculated in the sphygmographic methods and Starr's method in various ways. The IRHB and the central and peripheral sphygmograms (using an Infratone converter) were recorded simultaneously on a Mingograph polycardiograph. The arterial pressure was measured by Korotkov's method. The patients lay down for 15-20 min before the investigation. To assess the results the values of $r \pm m$, P, t_{st}, R, and σ were determined, and the linear regression equations were deduced. When possible the results obtained by the sphygmographic methods and by Starr's method were checked not only by the IRHB method, but also by the direct Fick method or the thermodilution method.

EXPERIMENTAL RESULTS

Comparison of the Broemser–Ranke and IRHB methods showed that correlation between the data for healthy subjects was high and direct (Table 1). For low values of the stroke volume (under 55 ml) the Broemser–Ranke method gave results which were too low, for average values (55-90 ml) the results were a little too high, and for high values (over 90 ml) they were definitely too high. Corrections for each of these ranges (1.2, 0.8, and 0.9, respectively) to bring the calculated values close to the actual values could be determined by the use of linear regression equations. With these corrections values of $r = 0.9 \pm 0.06$ and $P > 99.9\%$ for $t_{st} = 15.25$ were obtained. The relationship between the values calculated by this method and the actual values is nonlinear in character. The nomogram (Fig. 1) enables the calculated data to be corrected more accurately.

In patients with combined mitral defects the results were less reliable but still significant. In patients with acute lung abscesses and with stage II of chronic pneumonia the results can still be regarded as relatively applicable (Table 1). In patients with acute pneumonia and stage III of chronic pneumonia, even with the introduction of corrections the method does not allow reliable determination of the stroke volume.

In healthy subjects the Wezler–Böger method gives slightly worse results than the Broemser–Ranke method but they are still usable (Table 1). The values of the stroke volume were considerably and consistently too low throughout the whole range. They can be brought close to the actual values by the introduction of a correction factor of 1.3. In patients with combined mitral defects this method gives results which are still usable but are less reliable than those obtained by the Broemser–Ranke method. In stage II of chronic pneumonia, on the other hand, the results are rather better than those obtained by the Broemser–Ranke method. The results for the other groups are not comparable.

Starr's method did not yield a statistically significant correlation between the calculated values and the data obtained by the control methods in either the healthy subjects or the patients (Table 1).

With the aid of the chosen series of indices the degree of goodness of fit of the results of comparison of the data could be assessed objectively. In healthy persons under stable conditions the Broemser–Ranke method can give the actual values of the stroke volume if correction factors are introduced or, more exactly, by the use of a nomogram. Moreover, this method can be used with patients with combined mitral lesions, acute lung abscesses, and chronic pneumonia in the initial stages. With patients with acute pneumonia or with the late stages of chronic pneumonia the method does not yield reliable data.

The Wezler–Böger method is suitable for a rough preliminary estimation of the stroke volume under stable conditions in healthy subjects and in patients with combined mitral lesions and with chronic pneumonia in the initial stages. It could not be used with the rest of the patients who were studied.

Starr's method is unsuitable, even as a very rough means of obtaining a preliminary, relative estimate of the stroke volume in healthy subjects and in the patients who were studied.

The use of sphygmographic methods and of Starr's method was studied under conditions when rapid measurements of the stroke volume were required during hypoxic and hyperoxic tests (30 observations). In the hypoxic test a clear and significant increase in the mean stroke volume from 72 ±4 to 109±6 ml was obtained. During inhalation of oxygen a considerable and significant decrease in the mean stroke volume (53 ± 3 ml) relative to the initial level (76 ±4 ml) was recorded only by the IRHB method. The sphygmographic methods and Starr's method failed to detect any such changes in the hypoxic and hyperoxic tests: either no changes in stroke volume were determined at all or their dynamics was actually opposite in direction.

The reason for the discrepancy between the data during rapid changes in the stroke volume is the unacceptably large magnitude of the relative random errors of these methods. For instance, the reproducibility of the Broemser–Ranke method is 15.2% and that of the Wezler–Böger method is 13.8%. This mainly accounts for the low sensitivity of the sphygmographic methods when recording rapid changes in stroke volume, when the differences between the two measurements at times do not exceed ±10%.

LITERATURE CITED

1. V. I. Bezzubikova and B. B. Zelikson, Trudy Leningrad. Nauchno-Issled. Inst. Ekspertizy Trudosposobnosti i Organizatisii Truda Invalidov (Leningrad), 22, 119 (1967).
2. G. A. Glezer, Kardiologiya, No. 2, 88 (1962).
3. V. L. Karpman, in: Modern Methods of Investigation of Functions of the Cardiovascular System [in Russian], Moscow (1963), p. 125.
4. L. L. Luzin, Krovoobrashchenie, No. 6, 83 (1969).
5. N. N. Savitskii, Biophysical Bases of the Circulation and Clinical Methods of Studying the Hemodynamics [in Russian], Leningrad (1963).
6. M. I. Tishchenko, in: Methods of Collection and Analysis of Information in Physiology and Medicine [in Russian], Moscow (1971), p. 221.
7. M. I. Tishchenko, Biophysical and Metrological Bases of Integral Methods of Determination of the Stroke Volume of Human Blood [in Russian], Author's Abstract of Doctoral Dissertation, Moscow (1971).
8. M. I. Tishchenko, M. A. Seppen, and V. V. Sudakova, Fiziol. Zh. SSSR, 59, No. 3, 459 (1973).
9. M. I. Tishchenko and G. P. Zvonarev, Trudy Inst. Normal'n. i Patol. Fiziol. (Moscow), 17, 72 (1969).
10. H. J. Hauch and K. T. Donnel, Klin. Wschr., 32, 687 (1954).
11. K. Klein, A. Mostleck, and H. Siedek, Wien. klin. Wschr., 74, 922 (1962).
12. A. Schmid and F. Reubi, Cardiologia, 19, 42 (1951).
13. A. Schmid, F. Reubi, and V. Stettler, Cardiologia, 23, 90 (1953).
14. I. Starr and A. Schild, J. Appl. Physiol., 11, 169 (1957).
15. E. Völkner, Z. ges. inner. Med., 27, 8 (1972).