CHOICE OF AN OPTIMAL SYSTEM FOR BLOOD PRESSURE MEASUREMENT

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To record blood pressure it is essential to use a measuring system whose characteristics not only are linear over the whole range of signal amplitudes, but also correspond to the whole frequency spectrum of pressure fluctuations. Prevention of distortions of rapid fluctuations of pressure is particularly necessary when many parameters of time and velocity are to be determined, such as dp/dt, DP-time, etc. [2-5].

The aim of this investigation was to create an optimal measuring system to record blood pressure in cats.

The measuring system consisted of an 1187 oscilloscope ("O.T.E. Biomedica"), an EMT-34 (0-30 mm Hg), manometric transducer, and various catheters – PVC, polyethylene, and Teflon tubes or catheters of "Cournand" type (7F and 12F). The "pop test" [2, 3] was used to test 25 different versions of measuring systems. The dynamic characteristics of these systems were calculated by programs written in BASIC language, on the basis of a "Korvet" PC 8020 computer. The most important data are summarized in Tables 1 and 2.

The frequency properties of the measuring system are determined by its basic dynamic parameters [1, 2]: the natural frequency of the measuring system f_0 and the attention factor D:

$$f_0 = \frac{d}{4}\sqrt{\frac{\Delta p/\Delta V}{\pi l}}; \tag{1}$$

$$D = \frac{32\eta}{d^3}\sqrt{\frac{l}{\pi\rho\,(\Delta p/\Delta V)}}, \tag{2}$$

where d denotes the diameter of the catheter, ℓ its length, $\Delta p/\Delta V$ the modulus of bulk elasticity, η the viscosity of the liquid in the system, and ρ the density of the liquid in the system.

The values of these parameters for a particular measuring system can be determined by the transfer characteristic method, which consists essentially of applying the stepwise change of pressure to the input of the electromanometer [1, 2]. In the "pop test" method (a variant of that just discussed), which we used, the pressure step appeared during puncture of an inflated latex balloon, connected to the free end of the catheter. The parameters of the oscillations thus developing (Fig.1) were used to calculate f_0 and D by the following equations:

$$f_0 = \frac{f_d}{\sqrt{1-D^2}}, \tag{3}$$

$$D = \frac{1}{\sqrt{\frac{\pi}{\left(\ln\frac{a}{b}\right)}+1}}, \tag{4}$$

where f_d is the natural frequency of the decaying oscillations and $\ln(a/b)$ is the decrement of decay.

With the aid of equations 5 and 6 the amplitude-frequency and phase characteristics of the pressure measuring system were determined:

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TABLE 1. Basic Frequency Parameters of Measuring System Depending on Composition and Geometry of Catheter and also on Choice of Pressure Transducer

Variant	Catheter						Transducer	Frequency parameter		
	composition	length, cm	external diameter, mm	internal diameter, mm	side openings	cock		D	f_0, Hz	$\frac{A_{50}\text{ Hz}}{A_0}$, %
A	PVC	100	5	3,5	—	Metal	EMT-34	0,513	21	19
B	«Cournand 7F»	125	2,3	1,2	—	The same	EMT-34	0,458	25	28
C	PVC Polyethylene cannula	25 1,5	5 3	3,5 2,0	—	» »	EMT-34	0,406	68	133
D	«Cournand 7F»	25	2,3	1,2	—	» »	EMT-34	0,256	109	121
E	«Cournand 7F» «Cournand 12F»	13 13	2,3 4,0	1,2 2,8	—	» »	EMT-34	0,132	155	111
F	«Cournand 7F» «Cournand 12F»	13 13	2,3 4,0	1,2 2,8	+	» »	EMT-34	0,134	168	109
G	The same	13	4,0	2,8	+	Plastic	EMT-34	0,315	75	143
H	» »	13	4,0	2,8	+	Metal	EMT-33	0,260	16	11

TABLE 2. Detailed Amplitude and Phase-Frequency Characteristics of Individual Variants of Measuring System

Frequency f, Hz	Dynamic characteristics of variants of measuring system					
	C (PVC, 25 cm + polyethylene cannula)		D ("Cournand 7F," 25 cm)		F ("Cournand 7F," 13 cm + "Cournand 12F," 13 cm)	
	A_f/A_0, %	$\varphi/f\cdot 10^{-3}$	A_f/A_0, %	$\varphi/f\cdot 10^{-3}$	A_f/A_0, %	$\varphi/f\cdot 10^{-3}$
10	101	0,01	101	4,74	100	1,60
20	105	0,01	103	4,85	101	1,61
30	113	0,01	107	5,05	103	1,64
40	123	0,01	113	5,36	105	1,69
50	132	0,01	121	5,79	109	1,74
60	133	0,02	133	6,42	113	1,82
70	120	—0,02	148	7,31	119	1,92
80	98	—0,01	168	8,57	127	2,04
90	77	—0,01	189	10,31	137	2,20
100	60	—0,01	201	12,49	150	2,42

$$A_f = \frac{A_0}{\sqrt{4D^2\frac{f^2}{f_0^2} + \left(\frac{f^2}{f_0^2} - 1\right)^2}}, \tag{5}$$

$$\mathrm{tg}\,\varphi = \frac{2D\frac{f}{f_0}}{1 - \left(\frac{f}{f_0}\right)^2}, \tag{6}$$

where A_f denotes the amplitude of the pressure signal, reproduced by the system at frequency f, A_0 denotes the amplitude at zero frequency, and φ the angle of phase shift.

For the most adequate measurement of the signal conditions of linearity of the amplitude-frequency and phase characteristics must be observed within the range of the frequency spectrum of the process under study. These conditions are as follows: A_f/A_0 = 100% and φ/f = const. It has been shown that linearity increases with an increase in f_0 as D approaches the value of 0.707 [1, 2].

According to Eq. (1), for an increase in f_0 it is necessary to use a short, thick, and rigid catheter. For convenience in conducting the experiment, however, on the contrary a long, thin, and easily flexible tube is better. During the assembly of an optimal measuring system, a sensible compromise has to be made with the aim of correct reproduction of the

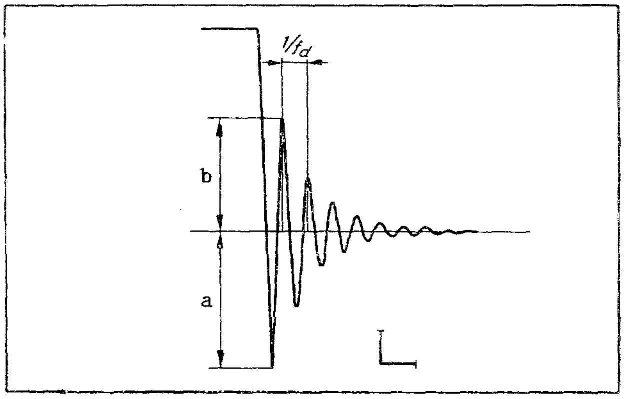

Fig.1. Fluctuations of pressure recorded by "pop test" method. Variant E of measuring system: "Cournand 7F" catheter, 13 cm MT-34 transdücer, 1187 oscilloscope, test on June 28, 1988. a, b) Two successive amplitudes of decaying oscillations; f_d) natural frequency of decaying oscillations. Calibration: 10 msec, 50 mm Hg.

"useful" frequency spectrum of oscillations of pressure in the cardiovascular system, i.e., from 0 to 50 Hz [1].

Thin-walled tubes made from various materials are flexible but unreliable because of possible kinking and, consequently, instability of their characteristics. Thick-walled polyethylene and Teflon catheters are not flexible enough. Thick-walled PVC tubes give good characteristics only if their diameter is large. A cardiovascular catheter of the "Cournand 7F" type, which was found to have best parameters, also was tested.

The initial length of the "Cournand" catheter can be substantially reduced and its diameter increased by replacing that part of it which is not directly used for insertion into the blood stream by the segment of a catheter of the same length and quantitative composition, but of larger diameter. This substantially improves the frequency characteristics of the system. Making side openings near the tip of the catheter does not affect the frequency possibilities of the system. Joints present in the catheter must not deform its lumen, and they must be as small as possible. A strict approach must also be made to the cocks included in the measuring system, for example, some plastic cocks manufactured by industry do not have suitable frequency characteristics for use in blood pressure recording.

An attempt to change the attenuation factor D (Eq. 2) by varying the material and the geometry of the catheter did not lead to improvement in the dynamic characteristics as a whole because of a fall in f_0. On replacement of the physiological saline by a more viscous fluid the system did not fill so satisfactorily and became unstable.

Inclusion of the EMT-33 pressure transducer instead of the EMT-34 into the measuring system led not only to an increase in the sensitivity of the system to the amplitude of the oscillations, but also to marked worsening of its frequency characteristics.

The presence of amplifiers in the electrical measuring instrument with a frequency transmission band 5-10 times greater than the frequency of the process measured enabled transducers of lower amplitude sensitivity to be used provided that the linearity of the characteristics was monitored. The use of electronic frequency filters makes it possible to achieve optimal dynamic characteristics.

By using the "pop test" method and varying the qualitative composition and geometry of the catheter, and also by choosing different variants of pressure tranducer, it was thus possible to create an optimal measuring system whereby slow and particularly fast fluctuations of blood pressure can be recorded with high accuracy.

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