JCI The Journal of Clinical Investigation

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J Clin Invest. 1926;3(2):449-463. https://doi.org/10.1172/JCI100091.

THE EFFECT OF TACHYCARDIA ON THE BLOOD FLOW IN DOGS

II. The Effect of Rapid Regular Rhythm

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(Received for publication July 16, 1926)

In the first paper of this series (1) were reported observations on the effect of *irregular* tachycardia (auricular fibrillation) on the blood flow in dogs. It was found that the blood flow was decreased during this mechanism. Observations on the effect of *regular* tachycardia form the subject of this paper.

The operative procedure used in the preparation of the dogs and the method of investigation were described in the preceding paper. Briefly, wire electrodes were sutured to the right auricles. The operations were performed with sterile precautions. The dogs were anesthetized with ether given by the intratracheal method. After the dogs recovered from the preliminary operation the heart was stimulated through these electrodes and the effect of the induced rhythm on the blood flow was studied. The regular tachycardias were induced by means of single induced break shocks thrown into the auricle at a regular rapid rate, which could be varied as desired. We have used rates between 250 and 400 per minute. The apparatus (fig. 1) which we used to obtain these stimuli was essentially the same as that used by Cohn and Levy (2) in studying the effect of quinidine sulphate on the refractory period of the heart muscle in dogs. Only break shocks were used, the make shocks being short-circuited. The induced current was obtained from two dry cell batteries inserted in the primary circuit of a Du Bois-Reymond induction coil. The rate of the induced shocks was recorded by the shadow of the string of a second galvanometer on the same photographic film on which the electrocardiogram was photographed. An electromagnetic signal was placed in the primary circuit and indicated on the film when the

stimuli began to be thrown in and when they were discontinued. The rhythm was followed constantly by watching the shadow of the

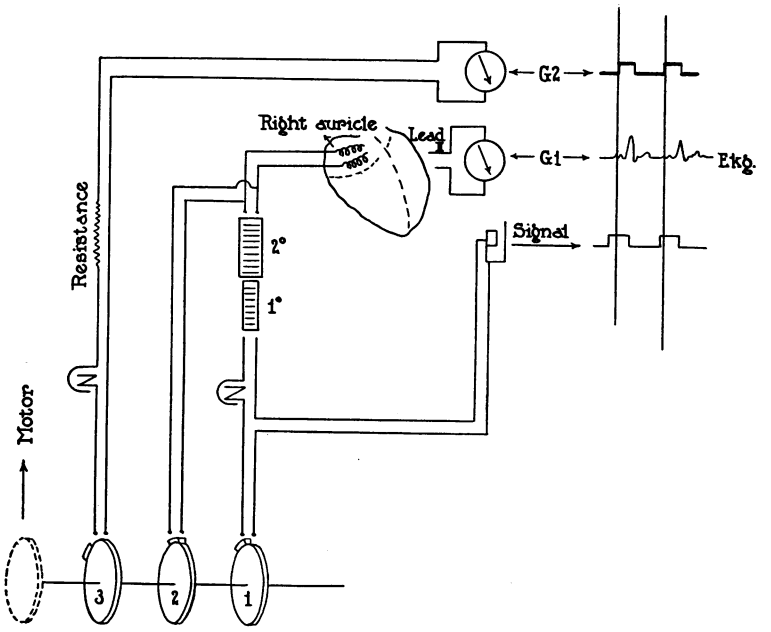

FIG. 1. A diagram is shown of the apparatus used to obtain regular rapid induced "break" stimuli. *1*, *2* and *3* are wheels arranged on a shaft which is driven by a motor, the speed of which can be varied. *1°* and *2°* are the primary and secondary coils respectively of the Du Bois-Raymond induction apparatus. *G1* and *G2* represent string galvanometers. The cog on wheel *2* is placed slightly ahead of the cog on wheel *1*. By this arrangement, when the wheels revolve the induced "make" shock resulting from the contact made by cog *1* is short-circuited by cog *2*. By the time the cogs have moved around so that the "break" shock occurs the cog on wheel *2* has also moved on and leaves the secondary circuit open, the induced "break" shock passing on to the heart. The cog on wheel *3* is placed so that it makes a contact affecting *G2* at the instant the "break" shock occurs. The electromagnetic signal is inserted in the primary circuit. In the apparatus we have used there are three cogs on each wheel; the speed of revolution of the shaft was regulated by gearing pulleys of various size; the speed of the motor could be varied by a resistance coil.

galvanometer string and records were made frequently. When regular tachycardias and auricular fibrillation were induced in the same animal, faradic current as before was used to induce the irregular

rhythm (auricular fibrillation). In some instances the regular tachycardia was induced first, while in other experiments the observations were made first during the period of fibrillation; after a rest the heart was driven at the same ventricular rate but with a regular rhythm. Oxygen contents of the arterial and of the mixed venous blood were estimated three times: during the normal rhythm, when the induced rhythm had been present for one hour, and a third time several hours after the stimulation had been discontinued. As before, the dogs lay quietly on the table without anesthesia and food was not given on the day of the experiment. Under these conditions we have interpreted changes in the oxygen consumed per liter of blood (that is to say, the difference between the oxygen content of the arterial and of the mixed venous blood) as representing changes in blood flow. The ratio of the oxygen consumed in the two periods gives then the relative blood flow during the two periods. This method of interpretation is discussed at greater length in the preceding paper.

In a few experiments we have more than one observation on the effect of regular tachycardia on the blood flow. In 5 animals we have been able to compare the effect of regular tachycardia with that of irregular tachycardia (auricular fibrillation) at the same absolute ventricular rate per minute or at comparable rates. A period of rest followed each period of tachycardia in order to allow the blood flow to return toward normal if there had occurred any change, and also in order that there should be no cumulative effect from prolonged stimulation.

OBSERVATIONS

We have 16 observations on 9 dogs showing the effect of regular tachycardia on the circulation.

The effect of regular tachycardia on the oxygen saturation of the arterial blood. In 11 observations in 7 dogs the oxygen saturation of the arterial blood was unchanged (tables 1, 2 and 3) while in 5 observations in 4 dogs (approximately one third of the observations) there was an unimportant decrease in saturation ranging from 4 to 7 per cent. There were no increases beyond 3 per cent. There was then no consistent change in the arterial oxygen saturation. Usually it was unchanged although occasionally a slight decrease occurred.

TABLE 1

The effect of regular tachycardia on the blood flow in dogs

Dog number	Weight	Time with reference to stimulation	O_2 content		O_2 consumed per liter of blood	Blood flow per cent of initial	Change in blood flow*	O_2 capacity	O_2 saturation ¶		Rhythm	Duration of stimulation	Heart rate per minute	Heart rate per cent of initial	Duration of rest
			Arterial	Mixed venous					Arterial	Mixed venous					
	kgm.		*mM*	*mM*	*mM*	*per cent*	*per cent*	*mM*	*per cent*	*per cent*		*minutes*		*per cent*	*hours*
189	8.8	Before	6.41	4.32	2.09	100		7.22	87.5	59.3	N. R.		160–170		
		During	6.62	4.12	2.50	84	−16	7.20	90.7	56.6	N. R.	42	250–280	175	
		Before	6.48	3.75	2.73	100		7.12	89.8	52.1	N. R.		210		3
		During	6.43	3.57	2.86	95	−5	7.16	88.6	49.3	Reg. tachy†	80	340	162	
	7.7	Before	5.91	2.89	3.02	100		6.45	90.2	44.2	N. R.		210		
		During	5.71	2.61	3.10	97	−3	6.33	88.8	40.6	N. R.	38	240–250‡	120	
190	14.6	Before	10.71	7.67	3.04	100		11.16	95.2	68.4	N. R.		160		
		During	10.07	6.72	3.35	91	−9	10.99	90.8	60.8	N. R.	33	300–320	200	
	14.4	Before	10.29	6.34	3.95	100		10.39	98.2	60.8	N. R.		190		
		During	9.54	5.51	4.03	98	−2	10.39	90.9	52.6	N. R.	73	300–310	163	
		After	8.86	5.06	3.80	104	+4	9.95	88.1	50.4	N. R.		180		22
191	14.9	Before	9.72	7.59	2.13	100		10.11	95.3	74.7	N. R.		170–180		
		During	9.50	7.00	2.35	91	−9	9.82	95.8	72.4	N. R.	70	300–320	188	
		After	9.39	7.00	2.39	89	−11	9.88	94.1	70.4	N. R.		250		2⅔
		Before	9.39	7.00	2.39	100		9.88	94.1	70.4	N. R.		250	80–128	
		During	9.22	6.74	2.48	96	−4	9.72	93.9	68.9	N. R.	50	200–310–320		
		Before	7.55	6.15	1.40	100		7.90	94.4	77.3	N. R.		160	100	
		During	7.56	6.12	1.44	97	−3	8.13	91.8	74.7	N. R.	60	310	193	

196	9.8	Before	9.81	6.87	2.94	100		10.18	95.5	67.1	N. R.		220		
		During	9.17	3.93	5.24	56	−44	9.57	94.8	40.6	N. R.§	60	380	173	
		After	8.95	5.70	3.25	90	−10	9.14	96.9	61.9	N. R.		240		1½
		Before	8.95	5.70	3.25	100		9.14	96.9	61.9	N. R.		240		
		During	8.68	3.26	5.42	60	−40	8.95	95.9	35.9	N. R.	60	350	150	
				1.10	7.58	43	−57			11.9	Vent. tachy.	2	360		
		After	7.96	2.61	5.35	61	−39	8.56	91.9	30.0	N. R.		240		1½

* In this table and in table 2, + in this column indicates increase and − decrease.

† Faradic stimulation.

‡ No response to stimuli.

§ Paroxysm of ventricular tachycardia at end of record.

¶ Before calculating the oxygen saturations in this table and in table 2, 0.09 *mM.* and 0.04 *mM* O_2 (the amounts of oxygen in physical solution) were subtracted from the arterial and mixed venous oxygen contents respectively.

TABLE 2

A comparison of the effect of regular and irregular tachycardia (auricular fibrillation) on the blood flow in dogs

Dog number	Weight	Time with reference to stimulation	O_2 content		O_2 consumed per liter of blood	Blood flow per cent of initial	Change in blood flow	O_2 capacity	O_2 saturation		Rhythm	Duration of stimulation	Heart rate per minute	Heart rate per cent of initial	Duration of rest
			Arterial	Mixed venous					Arterial	Mixed venous					
	kgm.		*mM*	*mM*	*mM*	*per cent*	*per cent*	*mM*	*per cent*	*per cent*		*minutes*		*per cent*	*hours*
198	16.0	Before	9.19	7.15	2.04	100		9.77	93.2	72.8	N. R.		140		
		During	9.72	5.05	4.67	45	−55	10.35	93.0	48.4	A. F.	60	280–300–320	214	
		After	9.47	6.57	2.90	70	−30	9.78	95.7	66.7	N. R.		170		$2\frac{1}{2}$
		Before	9.47	6.57	2.90	100		9.78	95.7	66.7	N. R.		170		
		During	9.13	6.22	2.91	100	0	10.08	89.7	61.3	N. R.	80	320–330	194	
193	18.2	Before	9.35	5.98	3.37	100		9.66	95.8	61.4	N. R.		120		
		During	9.08	5.44	3.64	92	−8	9.88	90.9	54.6	N. R.	60	270–280–290	229	
		After	9.25	5.61	3.64	92	−8	9.82	93.3	56.7	N. R.		150		2
		Before	9.25	5.61	3.64	100		9.82	93.3	56.7	N. R.		150		
		During	9.25	4.19	5.06	72	−28	9.98	91.8	41.6	A. F.	80	260–370	210	
		After	9.00	5.06	3.94	92	−8	8.91	91.9	51.8	N. R.		190		$1\frac{1}{3}$
197	25.8	Before	9.97	7.12	2.85	100		10.84	91.1	65.3	N. R.		180		
		During	9.75	3.42	6.33	60	−40	10.47	92.3	32.3	N. R.	60	370–380	208	
		During	9.54	5.16	4.38	66	−36	10.41	90.8	49.2	A. F.*	+60	280	186	
		After	9.12	6.21	2.91	100		9.56	94.4	64.5	N. R.		150		4
		Before	9.12	6.21	2.91	100		9.56	94.4	64.5	N. R.		150		
		During	9.02	4.35	4.67	62	−38	9.84	90.7	43.9	N. R.	60	280–290	190	

194	14.2	Before	10.25	7.53	2.52	100		11.06	90.1	67.7	N. R.		120		
		During	10.22	7.61	2.61	96	−4	10.87	93.2	69.6	N. R.	60	300–110 Av. 240	200	
		After	9.91	7.26	2.65	95	−5	10.82	90.8	66.7	N. R.		200		1⅔
		Before	9.91	7.26	2.65	100		10 82	90.8	66.7	N. R.		200		
		During	9.84	5.92	3.90	68	−32	10.83	90.0	54.3	A. F.	90	340–350	173	
		After	9.11	5.25	3.86	69	−31	10.24	88.1	50.8	N. R.		220		1
		After	8.67	5.22	3.45	77	−23	9.25	92.8	56.0	N. R.		200		17
195	12.4	Before	12.21	5.90	6.31	100		12.97	93.4	45.2	N. R.		170		
		During	11.62	4.73	6.89	92	−8	12.45	92.6	37.6	N. R.	60	370–380–390	220	
		Before	10.92	6.89	4.03	100		12.01	90.2	57.0	N. R.		180		
		During	10.85	5.85	5.00	80	−20	11.94	90.1	48.6	A. F.	60	300–320	174	
		After	10.60	7.01	3.59	112.	+12	11.21	93.8	62.2	N. R.		180		1⅔

* Spontaneous auricular fibrillation was present when this series of observations was taken and its duration was not known. Auricular fibrillation was then continued for one hour and the circulation rate compared with the rate after a period of rest.

The effect of regular tachycardia on the blood flow. There are 16 observations made on 9 animals. The ventricular rates during the tachycardia varied between 250 and 390 per minute (table 4), the absolute increase in heart rate varying between 30 and 220 per minute and the percentage increase in heart rate varying between 120 and 229 per cent of what they were during the control periods (table 5). In 11 observations in 7 dogs (two thirds of the observations) the blood flow was not altered on changing from the normal rhythm to regular tachycardia (tables 1, 2 and 3) (only changes greater than 10 per cent are considered significant). In 5 observations in 4 dogs (one third of the observations) the blood flow was decreased during the period of tachycardia. Dog 189 falls in both these groups.

TABLE 3

Summary of experiments

Rhythm	Effect on blood flow		Effect on oxygen saturation of arterial blood	
	Decrease	No change	No change	Decrease (4 to 7 per cent)
Auricular fibrillation.....	10 observations in 10 dogs	0	10 observations in 10 dogs	0
Regular tachycardia.....	5 observations in 3 dogs	11 observations in 7 dogs	11 observations in 5 dogs	5 observations in 4 dogs

A comparison of the effect on blood flow of regular tachycardia and auricular fibrillation in the same dog. In 5 dogs we have been able to compare the blood flow during regular tachycardia and during auricular fibrillation of the same ventricular rate (dogs 198 and 197) or at comparable rates (dogs 193, 194 and 195) (table 2). The blood flow in dog 198 was decreased 55 per cent during the period of fibrillation and returned toward normal during the subsequent rest period (fig. 2). The blood flow remained unchanged when the heart was driven at the same regular rate. The arterial saturation was unchanged during fibrillation, but was slightly decreased during the period of regular tachycardia. The rhythms which obtained at the time that the blood samples were taken in this dog were recorded electrocardio-

TABLE 4

*The effect of changes in heart rate on the blood flow in dogs**

Rhythm	Dog number	Blood flow unchanged		Blood flow decreased	
		Ventricular rate		Ventricular rate	
		During control period	During induced rhythm	During control period	During induced rhythm
Regular tachycardia	189	210	340	160–170	250–280
		210	240–250		
	190	160	300–320		
		190	300–310		
	191	170–180	300–320		
		250	200–310–320		
		160	310		
	196			220	380
				240	350
	198	170	320–330		
	197			180	370–380
				150	280–290
	195	170	370–380–390		
	194	120	110–300		
	193	120	270–280–290		
Irregular tachycardia	151			150–160	48–50†
	157			160–170	330–340
	167			180	270
	169			200–210	350
	193			150	260–370
	194			200	340–350
	195			180	300–320
	197			150	280
	198			140	280–300–320
	199			140	330

* Some of the data on irregular tachycardia are taken from the first paper of this series.

† Femoral rate.

graphically (fig. 3). In 4 of the 5 dogs there was no change in the blood flow during the period of regular tachycardia, while the blood

TABLE 5

The effect of changes in the heart rate on the blood flow

	Per cent change in heart rate						
	100–109*	110–129	130–149	150–169	170–189	190–209	210–229
Dogs in which the effect of R and I are compared.....					197 I –	198 R 0 197 R – 197 R –	198 I – 193 I – 193 R 0
					195 I –		195 R 0
					194 I –	194 R 0	
Dogs R.....		189 R 0 191 R 0		189 R 0 190 R 0 196 R –	189 R – 191 R 0 196 R –	190 R 0 191 R 0	
Dogs I.....					167 I – 169 I –	157 I – 151 I –†	199 I –
Total.....		0 – / 2 R		0 – / 2 R 1 R	0 – / 1 R 2 R 5 I	0 – / 4 R 2 R 2 I	0 – / 2 R 3 I

In this table the dogs are arranged according to percentage changes in heart rate during the induced rhythm. The corresponding changes in blood flow are indicated by symbols. Some of the data are taken from the first paper of this series.

* 100 per cent = initial natural rate; R = regular rapid rate; I = irregular rapid rate (i.e., auricular fibrillation); 0 = no change in blood flow; – = decreased blood flow.

† Femoral rate; this dog may not be placed in the right column but this has no effect on the conclusions drawn from this table.

flow showed the usual decrease during the period of auricular fibrillation. In the fifth dog (dog 197) there was as great a decrease in blood flow during regular tachycardia as there was during the period of

auricular fibrillation, the ventricular rates during the two periods being the same. In dogs 193, 194 and 195, although the absolute

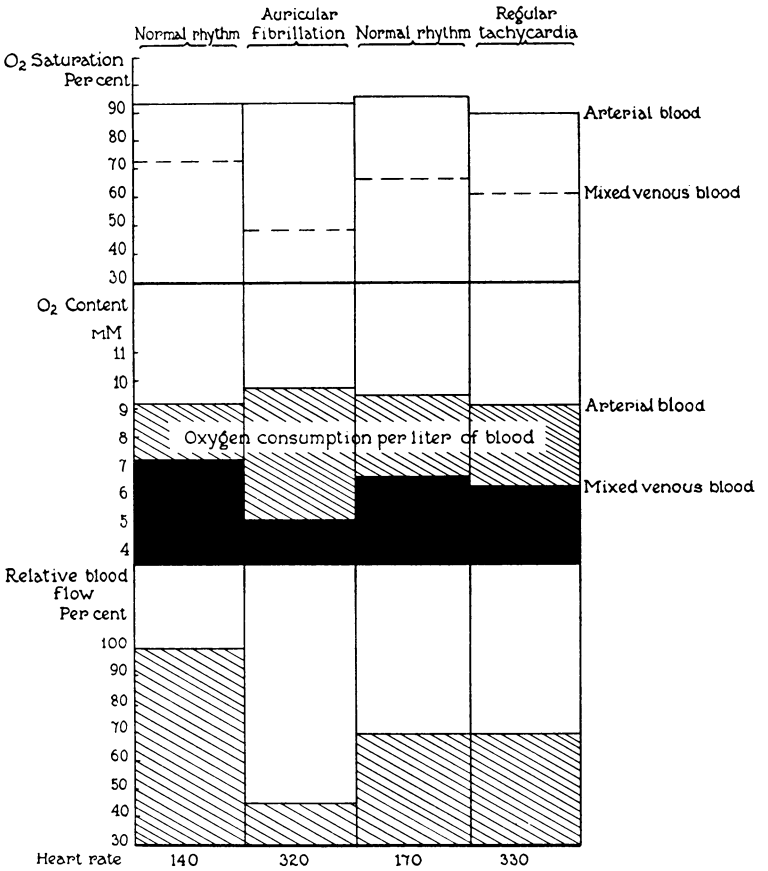

FIG. 2. In this figure is compared the effect of tachycardia both regular and irregular (auricular fibrillation) on the blood flow in dog 198. In estimating the relative blood flows shown in the last three columns, the ratio of the oxygen consumed per liter of blood in each of these periods to the oxygen consumed in the *initial* normal control period was calculated.

heart rate was slower during the fibrillatory period than during the regular tachycardia (though the percentage increase in heart rate over the control periods were approximately the same (table 5))

there was nevertheless no change in the blood flow during regular tachycardia as against a decrease in the irregular rhythm, emphasizing perhaps more strikingly the difference in effect produced by the two rhythms.

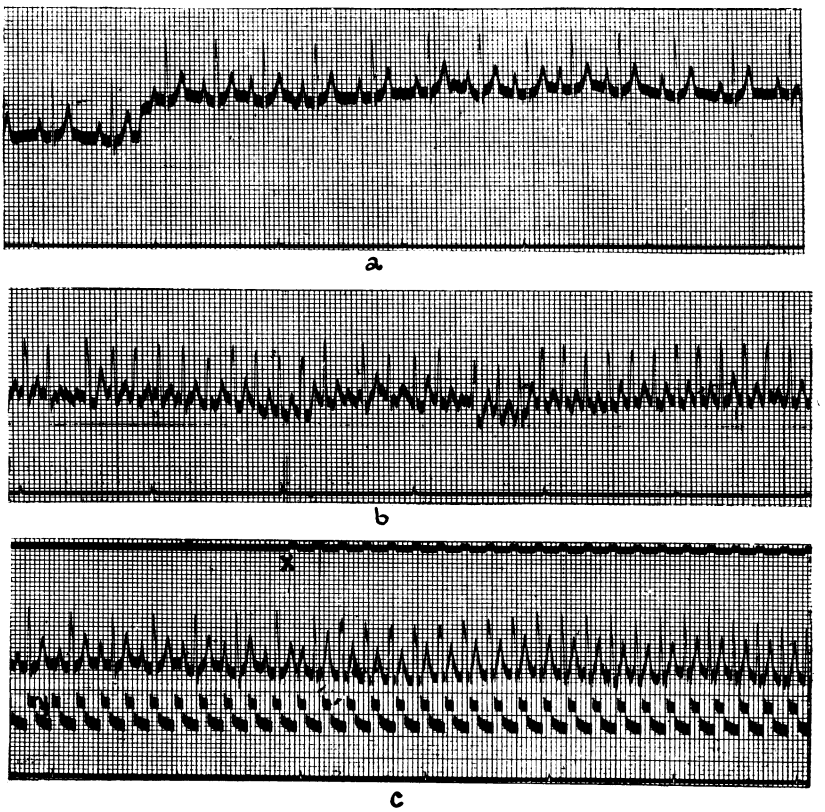

FIG. 3. Electrocardiograms (Lead II) are shown obtained from dog 198. *3a* was taken during the normal rhythm, *3b* during auricular fibrillation and *3c* during regular tachycardia. At *x* the electromagnetic signal shows when the induced break shocks began to operate. *y* is the shadow of the second galvanometer string and indicates at what instant the induced shocks were thrown into the auricle. A short time interval is seen between the electrical stimulus and the auricular P wave which results. Divisions of the ordinates equal 10^{-4} volts. Divisions of the abscissae equal 0.04 of a second. The original curves are sharply contrasted black and white; no half tones are lost by the method of reproduction here used. The curves are reduced to two-thirds of their natural size.

The blood flow was uniformly decreased in auricular fibrillation. In regular tachycardia the blood flow was unchanged in two thirds of the observations and decreased in the other one third.

DISCUSSION

Why the blood flow is unchanged in some dogs during regular tachycardia and decreased in others is not clear from the data which we have. It is not due to the absolute increase in heart rate because in dog 189 the blood flow was decreased during a ventricular rate of 250 to 280 per minute, while in dog 195 the heart was driven at a ventricular rate of 390 per minute without a decrease in blood flow occurring (table 4). Neither does it seem to be due to the percentile increase in heart rate. In dog 196 the heart rate during tachycardia was 150 per cent of what it was during the control period and the blood flow was decreased; on the other hand in dog 193 the heart rate was 229 per cent of the rate during the control period without any change in the blood flow (table 5). We have found without exception that the blood flow is decreased in dogs during auricular fibrillation (1) and in this rhythm we know that a pulse deficit occurs in patients. We have raised the question whether a pulse deficit may not occur during experimental auricular fibrillation and also in some animals during regular tachycardia of 250 to 400 per minute. These may be the animals in which a decrease in blood flow has been found. Experiments are now in progress in which we are recording the pulse deficits during these rhythms.

The results of these experiments in dogs parallel the results which Blumgart and Weiss (3) have found in human subjects. They have estimated the circulation time between two points by a new method and have found that it is increased in patients with auricular fibrillation not only when compared to the circulation time in normal subjects, but also when compared to the circulation time in the same patient after the normal rhythm has been restored following the administration of quinidine sulphate.

In two thirds of the observations the arterial oxygen saturation was not affected during regular tachycardia, but in the other one third of the observations the saturation was decreased 4 to 7 per cent (table

3). In auricular fibrillation the arterial oxygen saturation was uniformly unchanged. In none of the observations was the decrease as great as Carter and Stewart (4) and Dieuaide (5) found in their cases of paroxysmal auricular tachycardia and paroxysmal ventricular tachycardia respectively. In these two patients there was disease of the heart muscle as well as of the valves; in these circumstances the reaction to an abnormal rhythm might of course be different from that in presumably normal dogs. That the paroxysm of auricular tachycardia reported by Barcroft, Bock and Roughton (6) occurred in a healthy young student may account for the failure of this patient to show decreased saturation of the arterial blood. Stewart (7) has shown in patients with valvular disease as well as in patients with myocardial disease that the oxygen saturation of the arterial blood is unchanged following the increase in heart rate that occurred after the injection of atropine.

SUMMARY

The blood flow has been studied during artificially induced regular tachycardia in normal unanesthetized dogs. It was found that:

1. During regular tachycardia the blood flow was usually unchanged, but in one third of the observations it was decreased.

2. During regular tachycardia the oxygen saturation of the arterial blood was usually unchanged, but a small decrease of 4 to 7 per cent occurred in one third of the observations.

3. In 5 experiments the effect of regular tachycardia and auricular fibrillation of the same or comparable ventricular rates was compared in the same dogs. The blood flow was decreased as usual during auricular fibrillation, while in regular tachycardia the blood flow was unchanged except in one observation.

CONCLUSIONS

1. The heart is less effective in the propulsion of blood during irregular tachycardia (auricular fibrillation) than during regular tachycardia or the normal slower rhythm.

2. It is possible for the heart to be as efficient in the propulsion of blood during regular tachycardia as during the normal slower rhythm.

3. Tachycardia *per se* does not produce anoxemia of the arterial blood. Irregular tachycardia does not affect the oxygen saturation of the arterial blood. Regular tachycardia may occasionally be followed by a slight decrease in arterial oxygen saturation.

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