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THE EFFECTS ON THE CARDIOVASCULAR SYSTEM OF FLUIDS ADMINISTERED INTRAVENOUSLY IN MAN. IV. THE LUNG VOLUME AND PULMONARY DYNAMICS

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Earlier studies from this laboratory (1, 2, 3) have shown that the intravenous administration of 500 to 1500 cc. of fluids, at rates ranging from 9 to 125 cc. per minute, results in appreciable increases in plasma and blood volumes. Significant changes in cardiovascular dynamics did not occur at rates of injection under 20 cc. per minute; administration of fluids intravenously at faster rates resulted in rises in venous pressure and cardiac output, slight increases in pulse rate and pulse pressure, and, in some experiments, acceleration of the velocity of blood flow. Acceleration of blood flow usually occurred (2) when 500 to 600 cc. of fluid were given intravenously, at rates of 20 to 30 cc. per minute; infusions given in larger volume or at more rapid rates caused unexpectedly small increases, or even transitory decreases, in the velocity of blood flow. It was therefore believed that transitory increase in the amount of blood in the lungs may have occurred under these circumstances. Studies of respiratory dynamics were made (2) in several patients who received 400 to 1000 cc. of fluid intravenously, at rates of between 11 and 36 cc. per minute; no changes were found in respiratory rate or minute volume, tidal air, or vital capacity. However, it was apparent that additional studies of respiratory dynamics should be made after larger infusions, given more rapidly; accordingly, measurements of respiratory dynamics and of the various subdivisions of the lung volume have been made in subjects receiving 1800 cc. of fluid intravenously, at rates of between 39 and 185 cc. per minute.

MATERIAL AND METHODS

Six subjects, ranging in age from 18 to 44 years, were used in this study; one (case 5) was female. None had evidence of any abnormality of the cardiovascular or respiratory systems. All received 1800 cc. of isotonic saline solution intravenously, at rates ranging between 39 and 185 cc. per minute. The subdivisions of the lung

volume were estimated by the method of Christie (4), slightly modified (5), the respiratory dynamics being measured at the same time. Duplicate studies of these pulmonary functions and estimations of the hematocrit and plasma protein were made before the infusion and again at the end of injection. The first of the measurements of lung volume, after infusion, was completed as the infusion ended or within three minutes thereafter. Immediately following this, the reserve and complemental airs were measured and then the second of the post-infusion estimations of the lung volume was made. The hematocrit and plasma protein concentration were measured as in previous studies (1, 2, 3). Calculations of the changes in blood volume were based on methods previously described (1).

OBSERVATIONS

The *functional residual* and *residual airs* before and after the injection of fluids showed no differences outside the limits of error of the method used (Table I).

The changes in the other components of the total lung volume and in the total lung volume itself were in most instances only slight and frequently well within the limits of error of the method. However, there was a consistency in the changes which demonstrated a tendency toward a decrease (Table I), as is evident from the following resumé. The *reserve air* was diminished in all instances after injection, the decreases ranging between 30 and 240 cc., or 2.5 and 26.8 per cent of the original volumes. The average decrease was 98 cc. or 10.9 per cent. The *complemental air* was diminished in all instances after injection, the decreases ranging between 40 and 360 cc., or 1.0 and 12.3 per cent of the original volumes. The average decrease was 198 cc. or 6.6 per cent. The *vital capacity* was diminished in all instances after injection, the decreases ranging between 105 and 600 cc., or 2.1 to 14.3 per cent of the original volumes. The average decrease was 296 cc. or 7.4 per cent. The *lung*

TABLE I
Effects of intravenous infusions on blood and lung volumes and respiratory dynamics

Case	Rate of injection	Venous pressure	Hematocrit	Serum protein	Plasma volume	Blood volume	Functional residual air	Residual air	Reserve air	Complemental air	Vital capacity	Total capacity	Tidal air	Respirations	Respiratory volume	Oxygen consumption	Remarks
	cc. per minute	cm.	per cent	grams per cent	cc.	cc.	cc.	cc.	cc.	cc.	cc.	cc.	cc.	per minute	liters per minute	cc. per minute	
1	39	7.6	43.6	6.76	3270	5800	3660	2550	1110	3925	5035	7585	675	11	7.43	305	Before
		11.6	38.0	5.69	3890	6280	3630	2680	990	3885	4875	7515	655	11.5	7.53	279	After
2	54.6	5.0	42.0	6.38	2580	4450	2185	1430	755	2775	3530	4960	785	9	7.07	204	Before
		10.1	37.6	5.21	3160	5070	2230	1555	675	2580	3255	4810	615	14	8.61	182	After
3	68	7.2	46.2	7.46	3150	5850	3940	2760	1180	3925	5105	7805	475	15	7.10	286	Before
		13.2	42.0	6.59	3560	6140	3800	2650	1150	3850	5000	7650	435	16	6.98	310	After
4	92	3.0	44.6	7.55	2630	4750	2360	1465	895	3295	4190	5635	435	16	6.96	245	Before
		10.0		6.42	3090		2140	1485	655	2935	3590	5095	395	19.5	7.70	242	After
5	180	9.0	41.2	6.11	2470	4200	1710	1195	515	1945	2460	3675	515	14.5	7.47	239	Before
		13.5	33.8	4.56	3310	5000	1815	1340	475	1705	2180	3520	480	15	7.14	224	After
6	185	7.2	44.2	6.86	3570	6400	2595	1445	1150	4160	5310	6755	435	18	7.83	319	Before
		12.3	40.0	5.83	4200	7000	2495	1425	1070	3885	4955	6380	485	17.5	8.49	337	After

volume was diminished in all instances, the decreases ranging between 70 and 540 cc., or 0.9 and 9.6 per cent of the original volumes. The average decrease was 241 cc. or 4.2 per cent.

The respiratory minute volume increased significantly after the infusion in three of the six experiments, being essentially unchanged in the other three. The increases in respiratory minute volume were due in two instances to increases in respiratory rate and in one, to augmented tidal air volume. In five of the six experiments, the volume of the tidal air was somewhat diminished.

The above described changes in the pulmonary dynamics and subdivisions of the total lung volume were still detectable 40 minutes after the end of infusion.

DISCUSSION

Earlier studies (2) have shown that intravenous infusions of 400 to 1000 cc. of fluid, at rates between 11 and 36 cc. per minute, resulted in no change in vital capacity, respiratory rate, or minute volume. Richards *et al.* (6) observed slight decreases in vital capacity in normal subjects after infusions of 1500 cc. of isotonic sodium chloride solution at 50 cc. per minute; these decreases were never greater than 8 per cent of the initial vital capacity. In the present study, the three subjects

who received 1800 cc. of fluid, at rates of 39 to 55 cc. per minute, showed changes within this limit; two of the three receiving the fluid at 90 to 185 cc. per minute showed only slightly greater decreases in vital capacity (Table I). The two components of the vital capacity, *i.e.*, the reserve and complemental airs, showed approximately the same degree of change following infusion. Since the residual air did not change, it is clear that the slight decreases observed in total lung volume were due to diminution of the vital capacity. In general, the changes in the total lung volume and its various subdivisions were too small to be considered physiologically significant.

Congestive failure results in a relative increase in residual and functional residual air volumes as compared to total lung volume (7). In the present study changes in the ratios between functional residual and residual air volumes and the total lung volume were small and not consistently in the same direction (Table II). It is clear, therefore, that large intravenous infusions, given at rapid rates in normal subjects, do not produce the typical pulmonary signs of congestive failure. None of the subjects developed dyspnea, orthopnea, cough or other symptoms, nor were râles audible over the chest. Studies in animals corroborate this conclusion. Warthen (8) gave dogs

weighing 6.7 to 26.5 kgm., 900 to 2600 cc. of fluids intravenously at rates of 29 to 169 cc. per minute without producing pulmonary edema. One animal, weighing 9.4 kgm., developed pulmonary edema after receiving 3700 cc. in 35 minutes. Cohnheim and Lichtheim (9) found that rabbits might develop edema of the lungs after receiving intravenous infusions equivalent to approximately half their body weight; in dogs, pulmonary edema only rarely developed after the intravenous administration of fluids equivalent to as much as 90 per cent of their body weight. The slowing of blood flow previously noted (2) and the slight decreases in vital capacity observed in the present study and by Richards *et al.* (6) after large, rapidly administered intravenous infusions are to be ascribed to a minor degree of pulmonary vasodilatation, associated with increased total blood volume resulting from the infusions.

Evidences of speed shock (10) were not observed in these or previous studies in which fluid was given intravenously at rapid rates. It is not to be concluded, however, that the rapid administration of large intravenous infusions is likewise without deleterious effect in individuals who are not normal. Richards *et al.* (6) reported a marked decrease in vital capacity, dyspnea, and the appearance of râles in the lungs, after such infusions in cardiac patients; patients with various forms of pulmonary disease also exhibited marked diminution in the vital capacity (6, 11). In our own clinical experience, patients with severe uremic acidosis develop signs and symptoms of pulmonary congestion and edema consistently with intravenous infusions of relatively small amounts of fluid given at rates as low as 10 cc. per minute or slower. Experiments in animals

afford similar data. Kraus (12), Brunn (13) and Farber (14) have described increased susceptibility to pulmonary edema in animals following bilateral vagotomy. Farber found that whereas intact rabbits showed no pulmonary edema after intravenous infusions of 250 to 400 cc. of isotonic sodium chloride solution at rates of 30 to 40 cc. per minute, bilaterally vagotomized animals developed severe edema of the lungs after receiving smaller volumes at slower rates. The fact that changes in pulmonary dynamics and lung volume following rapid intravenous injections of large volumes of fluid in normal subjects were at most only slight, in no way alters the clinical concept that when it is necessary to administer fluids intravenously in patients with a tendency toward pulmonary congestion and edema because of cardiac, pulmonary, central nervous system, or renal disease, these infusions should be given at slower rates and with caution.

SUMMARY AND CONCLUSIONS

1. Studies of the effect of the injection of fluids intravenously on the subdivisions of the lung volume and on the respiratory dynamics have been made in six normal subjects.

2. Injection intravenously of 1800 cc. of isotonic sodium chloride solution, at rates of 39 to 185 cc. per minute, in these normal subjects caused no change in residual air, and only slight decreases in the vital capacity, its components, the reserve and complemental airs, and in the total lung volume. The respiratory minute volume showed no consistent change, although the tidal air was usually decreased. All the changes in pulmonary function found after intravenous infusions in these normal subjects were insignificant.

3. The slight decreases in vital capacity, its components, and the total lung volume, after these massive intravenous infusions at rapid rates in these normal subjects, are interpreted as due to slight pulmonary vasodilatation associated with temporarily increased blood volume.

4. The fact that changes in pulmonary dynamics and lung volume, following rapid intravenous injections of large volumes of fluid in normal subjects, were at most only slight, in no way alters the clinical concept that when it is necessary to administer fluids intravenously in patients with a

TABLE II

Effect of intravenous infusions on ratio of functional residual and residual air volumes to total lung volume

Case	Functional residual air Total lung volume $\times 100$		Residual air Total lung volume $\times 100$	
	Before	After	Before	After
1	48.3	48.3	33.6	35.7
2	44.0	46.4	28.8	32.3
3	50.4	49.7	35.4	34.6
4	42.6	42.0	26.0	29.2
5	46.5	51.6	32.5	38.1
6	48.4	49.1	21.4	22.3

tendency toward pulmonary congestion and edema, because of cardiac, pulmonary, central nervous system, or renal disease, these infusions should be given at slower rates and with caution.

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