EXPERIMENTS ON THE PATENCY OF THE BLOOD VESSELS OF NEPHRITIC KIDNEYS OBTAINED AT AUTOPSY

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One of the first questions which arise in the study of the physiology of the diseased kidney concerns the capacity of its vessels to permit a normal blood flow. If this capacity is normal, alterations in renal function must be attributed either to extrarenal factors, to functional rather than structural changes in renal vessels, or to changes in the renal parenchyma. If conditions in the kidney preclude a normal blood flow, completely normal function is impossible and the basis for interpreting certain types of urinary abnormality has been disclosed. The experiments described here were undertaken in the hope of distinguishing those types of kidney disease in which a mechanical, anatomic obstruction to blood flow exists from those in which the structural condition of the vessels may be believed to permit a normal blood flow.

Study of changes in the renal vessels in disease by other than histological methods is by no means new. Evidence of the capacity of the diseased kidney to transmit blood has been sought in measurements of blood flow after experimental renal injury, in roentgenograms of injected kidneys, and in perfusion of isolated organs. The design of the present experiments involved a combination of the last two methods, namely, measurement of the outflow from the renal vein during perfusion under constant conditions, and correlation of this flow with roentgenograms of the vessels after injection, and with histological sections.

Direct measurements of renal blood flow in experimental disease have been confined to acute injury. Tribe, Hopkins and Barcroft (1) found the renal blood flow, measured by Barcroft and Brodie's method, at least as great in a rabbit acutely poisoned by uranium acetate

as in a normal animal. In one poisoned by diphtheria toxin, Tribe, Harvey and Barcroft (2) found a decrease in flow, but believed it completely accounted for by the fall in blood pressure. Dunn, Dible, Jones and McSwiney (3) detected little change in renal blood flow in acute oxalate nephrosis. Schlayer (4) and his pupils showed that the renal vessels of the rabbit gave normal responses to vasoconstrictor and vasodilator substances after injection of chromium salts or corrosive sublimate, while after arsenic or cantharidin the vascular responses were minimal. Pearce, Hill and Eisenbrey (5) obtained similar results in dogs. The type of renal lesion produced in these experiments is, however, only rarely met in man. On the other hand, this type of experiment has the capacity of showing alterations in blood flow resulting from functional as well as structural changes in kidney vessels, which the other types, applicable to human material, have not.

Roentgenograms of injected kidneys have been used almost as long as the roentgen ray itself. Hauch (6) and Gross (7) showed differences in the vascular architecture of normal and arteriosclerotic kidneys by radiopaque injections which went as far as the interlobular arteries. Graham (8), using a suspension of bismuth, succeeded in making complete injections as far as the glomeruli, clusters of which gave an appearance stereoscopically of cone shaped columns around an interlobular artery. Acute nephritis, nephrosis, and passive congestion did not produce any detectable alteration from the normal picture. Severe arteriosclerosis yielded pictures showing uneven calibre of vessels, wide, club-like interlobar branches, and interlobular arteries which were fewer, shorter and more tortuous. The cortex was distinctly narrowed. In milder degrees of nephrosclerosis the first changes detectable in the roentgenograms were in the interlobular arteries, which appeared coarser and more tortuous. Graham believed he could detect differences in the arterial tree of nephrosclerosis and chronic glomerulonephritis. In the latter the cortex was wider, the sclerotic changes milder, the glomeruli few and greatly enlarged.

Baehr and Ritter (9), on the other hand, were unable to detect any difference in the vascular tree of primary and secondary contracted kidneys. The reproductions accompanying their paper, however, do not permit study of the smaller vessels. They believe that extreme

vascular changes develop in patients with chronic diffuse nephritis who survive the glomerulonephritis for a sufficient time, which are pathologically identical with those of primary arterial disease.

It has been assumed that in those types of disease giving a normal injection there was no mechanical obstruction to flow in the kidney itself, while in the contracted kidney such an obstruction was present. It seems, however, that an artery might offer abnormal resistance to the flow of fluid through it, and still appear normal when injected at high pressure.

Perfusion of nephritic kidneys has been practiced since the middle of the last century. Dickinson (10) in 1860 perfused human kidneys with warm water at a constant pressure of 8 feet 4 inches of water. The average flow in 13 normal kidneys was 11.9 ounces (352 cc.) per minute, while in 6 contracted granular kidneys the average flow was only 2.5 ounces (74 cc.) per minute. The perfusability of "large smooth kidneys" was within normal limits. The decreased flow he attributed to changes in the minute anatomy, since measurements of normal and nephritic renal arteries and veins failed to show any differences.

Thoma (11) carried out similar experiments with solutions of gelatin and of sodium chloride which, together with measurements of the area of renal, interlobular and afferent glomerular arteries, led him to the conclusion that changes in or beyond the glomeruli were responsible for the increased resistance of the contracted kidney to perfusion.

Ghoreyeb (12) perfused rabbit kidneys from normal and nephropathic animals with Adler's fluid and with serum. He found a decrease in number of drops per minute from the renal vein of animals which had received uranium nitrate, potassium chromate, potassium arsenate, cantharidin, or diphtheria toxin. The decrease was proportional to the glomerular change and was maximal twenty-four hours after poisoning. He reported that kidneys from animals with spontaneous nephropathies also gave an abnormally low flow. He does not give sufficient data to calculate the volume of fluid perfused.

Rigo (13) and Doenecke and Rothschild (14) have recently performed similar experiments on human kidneys perfused at very low pressures.

All of these investigations have been concerned with the total volume of fluid flowing through the kidney in unit time, and its decrease in the contracted kidney. In none have variations in kidney weights been considered, nor comparisons made of the volume of perfusate per unit mass in normal and pathological kidneys, nor of the effects of increase of perfusion pressure on the volume of perfusate. Comparisons of the perfusability of a kidney and the appearance of its vessels after injection have not been made.

METHODS

Kidneys were removed at the autopsy table and perfused as soon as possible; a few two hours after death, the majority between five and fifteen hours, and a few successfully as late as twenty to twenty-four hours. Little difference was detected in the perfusability of kidneys between two and eighteen hours postmortem. After twenty-four hours perfusions were usually unsatisfactory; the kidneys were not uniformly blanched and became markedly edematous.

In removing the kidneys, renal artery and vein were left as long as possible and care taken not to rupture small vessels around the hilus. Kidney and adherent fat were then weighed to the nearest gram. At the end of the perfusion the fat was removed and kidney and fat weighed separately. There was an error in obtaining the true kidney weight, due to edema developing during perfusion. This varied considerably in different kidneys; it was always less, as expected, with acacia than with Ringer's solution. When the amount of adherent fat was small, and did not obviously become edematous, its weight was subtracted from the original weight. When the amount of adherent fat was larger, covering an appreciable part of the kidney, it also became edematous, due to perfusate leaving the kidney by way of capsular vessels. In such cases, after blotting the fat with a towel, fat and kidney were weighed, the assumption made that the degree of edema was the same in both, and the assumed kidney weight was calculated by proportion. After weighing, the kidney was put in a dish of water or Ringer's solution at 37°C. and cannulae tied in artery and vein.

The perfusion fluid, either aerated Ringer's solution or 6 per cent gum acacia in 0.9 per cent saline, was contained in a 4 liter bottle

placed in a water bath at 37°C. The outflow tube connected with the arterial cannula was provided with T-tubes for thermometer and manometer and passed under an electromagnet key by which the flow could be automatically interrupted once a second. Pressure in the perfusion bottle was maintained by compressed air, and kept constant by a mercury valve which permitted rapid adjustment to the desired pressure. The volume of fluid flowing through the kidney was estimated by the outflow from the renal vein. The kidney was supported

TABLE 1

Variation in venous outflow with duration of perfusion

Experiment number	Perfusion pressure	Venous outflow
	mm. Hg	*cc. per minute*
41	100	208
	150	332
	200	476
	Two liters Ringer's perfused 100 mm. Hg	
	100	196–230
	Two more liters Ringer's perfused 100 mm. Hg	
	100	250
	150	370
	200	540
31	100	60
	150	116
	200	184
	100	76
	150	120
	200	160
	100	60

in a metal pan which was arranged to permit collection of all "leak." This leak was made up of fluid escaping from small arterial twigs in the hilus which could not be tied, from the capsular vessels and from the ureter when this was not collected separately. The volume of "leak" varied considerably, in many instances only a few cc. per minute; in others, as great as the flow from venous cannula. The volume of "leak" depended chiefly on the number of vessels perforating the capsule. There was no consistent difference in the degree of leak from normal and nephritic kidneys. All experiments

were discarded in which the cortex was not uniformly and completely washed out. The pyramids were the last part of the kidney to be completely perfused. In most instances they retained a faint pink color. Only in the fresher kidneys did they become completely bloodless. The same is true of dog and rabbit kidneys perfused at similar intervals after death. Perfusion with 6 per cent acacia after saline frequently resulted in washing out additional blood.

Kidneys were usually perfused at 100, 150 and 200 mm. Hg pressure. The flow from the venous cannula was collected for minute, or, when volume was large, one-half or one-quarter minute periods, timed with a stop watch. After the blood was washed out the venous outflow at a given pressure was reasonably constant (table 1). Injection of adrenalin, nitroglycerin, or barium chloride did not change the volume of perfusate.

Perfusion with a pulsating stream gave consistently lower values, but did not prevent the development of edema. This is in agreement with Ghoreyeb's experience, but contrary to Sollmann's (15). Interruption of the flow was therefore abandoned; all data discussed are based on perfusion at constant pressure.

After perfusion many, but not all, kidneys were injected with 25 per cent bismuth oxychloride in 12 per cent acacia, according to Graham's modification of Hill's (16) technique. Histological sections showed that the injection mass reached the glomeruli. Usually only single plates were made; stereoscopic exposures were obtained whenever possible. Paraffin sections were cut in all experiments, either from the perfused kidney or from its fellow. Because of the changes in tubule cells produced by perfusion, sections from the unperfused kidney were generally more satisfactory for pathological classification.

The kidneys have been grouped, according to Volhard and Fahr's classification, as normal, nephrotic, acute and subacute glomerular nephritis, chronic glomerular nephritis and arteriolarsclerosis. Kidneys showing any appreciable degree of focal arteriolarsclerosis or infarcts have been regarded as unsuitable for inclusion in the discussion. Forty-two kidneys have been satisfactorily perfused with Ringer's solution; twenty-five of these were also perfused with acacia.

RESULTS

Normal kidneys

The volume of Ringer's solution recovered from the venous cannula in eighteen experiments on normal kidneys varied from 56 cc. for a one year old child to from 141 to 262 cc. per minute for adult kidneys, perfused at 100 mm. Hg pressure. At a pressure of 150 mm. Hg the flow through adult kidneys ranged from 242 to 620 cc. per minute, at 200 mm. pressure from 348 to 824 cc. There was a marked increase in perfusate with age and kidney weight up to 13 years and a kidney weight of approximately 100 grams. From Arataki's (17) study of the growth of the rat's kidney this is probably due to an increase in size rather than in number of vessels perfused. Calculating flow per gram of kidney per minute, the small kidneys of children allow as great a flow as do adult kidneys. Because of the variation in kidney weight with body size, calculations of volumes of perfusate per gram of kidney per minute seemed the best way of establishing the normal range and of comparing pathological material. This, of course, introduces a disturbing factor in kidneys edematous from disease. It was hoped that calculation per square meter of body surface might give an apparent greater consistency and avoid the error of changes in kidney weight due to edema, since MacKay and MacKay (18) have shown that in normal animals kidney weight is more closely associated with surface area than body length or weight. This calculation, however, proved of no advantage, due, at least in part, to the inaccuracies of body length and weight data available.

Under the conditions of these experiments the volume of Ringer's solution collected from the renal vein of normal kidneys during perfusion at 100 mm. Hg pressure ranged from 1.2 to 2.5 cc. per gram per minute, the average being 1.7 cc. per gram per minute. When the perfusion pressure was increased to 150 mm. Hg, the venous outflow rose to from 2.1 to 4.3 cc. per gram per minute, average 2.6 cc., while at 200 mm. Hg perfusion pressure it ranged from 2.5 to 5.5 cc. per gram per minute, average 3.7 cc. These data are shown in table 3 and figure 1, *1* and *5a*. The volume of acacia perfused at any pressure was less than that of Ringer's solution, and the increase, both relative and absolute, with increase of perfusion pressure was less.

Dogs' kidneys perfused with Ringer's solution by the same technique gave flows which were of the same order of magnitude as the blood flow found in the living eviscerated animal by Barcroft and Brodie's method, and showed the same order of increase in flow with increase in perfusion pressure. It seems probable that in human kidneys the volume of perfusion fluid is of the same order of magnitude,

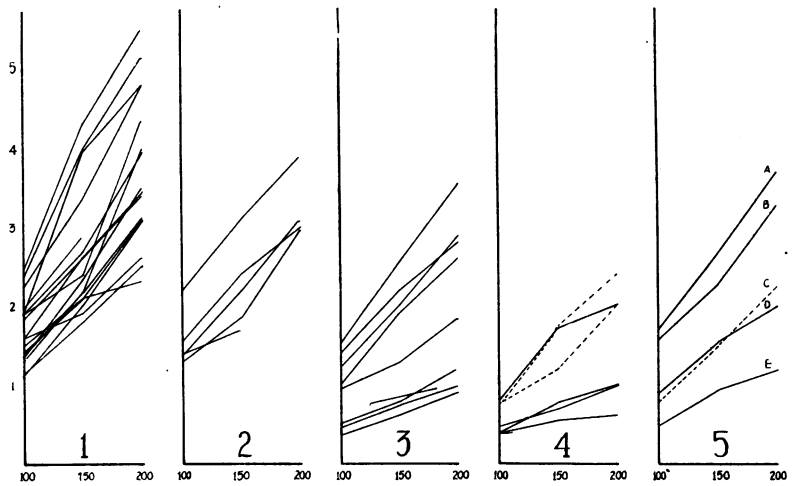

FIG. 1. PERFUSION FLOW THROUGH HUMAN KIDNEYS AT DIFFERENT PRESSURES

Abscissae, perfusion pressure in mm. Hg; ordinates flow in cc. per gram of kidney per minute. *1*, normal kidneys; *2*. nephroses; *3*, benign arteriolarsclerosis; *4*, acute (---------) and chronic (———) glomerular nephritis; *5*, average rates of perfusion flow; (*a*) normal, (*b*) nephroses, (*c*) acute glomerular nephritis, (*d*) arteriolarsclerosis, (*e*) chronic glomerular nephritis.

but probably less than the blood flow during life. The volumes of acacia perfused were distinctly less than that of Ringer's solution.

There was no detectable relation between the volume of perfusate per gram of kidney and age; the vessels of an elderly person which show only the normal amount of change for the age offer no mechanical resistance to the passage of either Ringer's solution or 6 per cent gum acacia solution.

Roentgenograms of these kidneys conformed to previous descriptions of the normal arterial tree. The primary divisions of the renal artery appeared on the film either just within the kidney shadow or

just outside it. The vessels were slender, gradually decreasing in calibre. The branching of interlobar and interlobular arteries were at acute angles. The interlobular arteries were slender, parallel and surrounded by columns of glomeruli giving the cortex a delicate, uniformly striated appearance (fig. 2).

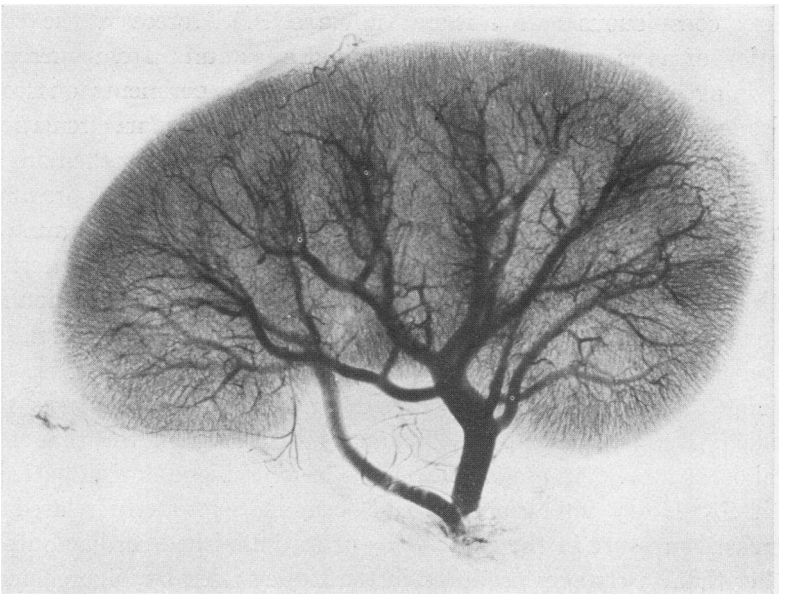

FIG. 2. ROENTGENOGRAM OF A NORMAL ARTERIAL TREE (EXPERIMENT 29)

Nephroses

Kidneys showing purely degenerative changes allowed as great perfusion flows as did normal kidneys. This group includes a kidney of pregnancy and one of bichloride poisoning. The latter is of particular interest. The woman had been anuric for four days, had a blood urea nitrogen of 73 mgm. per 100 cc., plasma CO_2 content 10 volumes per cent. During the 24 hours before death 60 cc. of urine had been obtained by catheter which contained 120 mgm. urea nitrogen per 100 cc., or less than twice the blood concentration. Grossly the kidney was soft, pale, and the cut edge everted. Sections showed morphologically normal glomeruli and extensive necrosis of

the convoluted tubules. There was apparently no mechanical interference with the free passage of fluid through the renal vessels. It is of course obvious that other factors, especially vascular spasm, may have led to a diminished blood flow during life. Experimental evidence, however, has not established the presence of such a contraction of renal vessels and diminished blood flow produced by poisons whose conspicuous action is on tubule cells. Moreover, the conception of a normal blood flow during an anuria from mercury poisoning is in accord with Richards' (19) experiments on frogs poisoned by mercury. He found a normal glomerular circulation, and that the glomerular filtrate was completely reabsorbed in its passage down the tubule. What part blocking of the proximal convoluted tubule with cellular detritus may play in causing anuria in man is unknown. Since the edema of the kidney does not interfere with perfusion, it throws doubt on the usefulness of decapsulation for mercurial nephrosis with the idea of relieving tension and so increasing blood flow.[1] Passive congestion of the kidney did not decrease the volume of perfusate: the effect of high venous pressures was not studied, Ludwig (20) and Sollmann (15) having shown that this diminishes flow. An assumed decrease in renal blood flow in patients with circulatory impairment would seem more properly related to increased pressure in the great veins or to diminished cardiac output rather than to changes produced in the kidney itself by engorgement.

No difference in roentgenograms of nephrotic and normal kidneys could be detected.

Arteriolarsclerosis

Kidneys from nine cases of benign arteriolarsclerosis have been perfused. Two of these (nos. 45 and 48) showed only slight thickening of interlobular and afferent arteries in histological section; no. 45 appeared entirely normal grossly, while no. 48 showed a few depressed arteriosclerotic scars, but no general narrowing of the cortex. Both kidneys were from patients who had had hypertension and had died of cerebral hemorrhage. Both these kidneys allowed a normal volume of perfusion flow, and did not show any definite abnormality in the

[1] Fischer, however, believes decapsulation effective because of removing a capsular-vasoconstrictor reflex. Deutsch. Med. Wchnschr., 1926, lii, 992.

roentgenograms (fig. 3). Four kidneys (nos. 1, 18, 25 and 28) presented some narrowing of the cortex and granularity of the surface grossly, and showed histological changes of moderate severity. Two of the patients had died from cardiac failure, one of lobar pneumonia, and one of a pulmonary embolus from a thrombosed pelvic vein. Only in this patient was any hypertension present during the period of observation. No estimations of blood urea nitrogen were available. All four had had albuminuria. One kidney allowed a perfusion flow per gram within the lower range of the normal group; the other

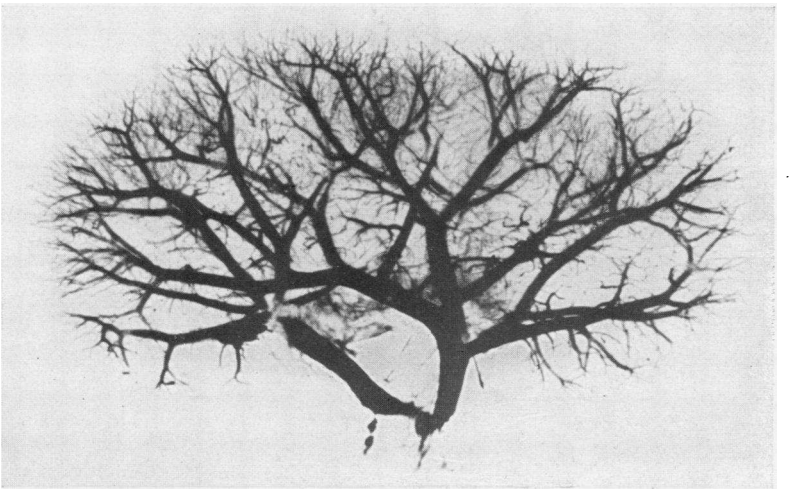

FIG. 3. ROENTGENOGRAM OF THE ARTERIAL TREE OF A KIDNEY SHOWING MILD ARTERIOLARSCLEROSIS HISTOLOGICALLY AND A NORMAL PERFUSION FLOW (EXPERIMENT 45)

three were distinctly below it. Roentgenograms showed irregularities and tortuosity of the smaller arteries with a less dense injection of the cortex. The remaining three kidneys in this group (nos. 31, 33 and 46) showed a very granular surface, marked narrowing of the cortex and advanced arteriolarsclerosis histologically. One was from a diabetic, who had had a blood urea nitrogen of 36 mgm. per 100 cc.; no blood pressure estimation was recorded; one from a person dying from cerebral hemorrhage who had a blood urea nitrogen of 50 mgm. per 100 cc.; blood pressure 180/130; and one from a senile dement who had 10

mgm. blood urea nitrogen per 100 cc., and blood pressure 165/100. All showed a marked reduction in volume of perfusate per gram of kidney at all pressures. Roentgenograms showed the changes described by Hauch, Gross, and Graham. The cortex was narrow, the lumina of the larger vessels uneven in calibre. The interlobular arteries were fewer, branched at less acute angles, and ended abruptly

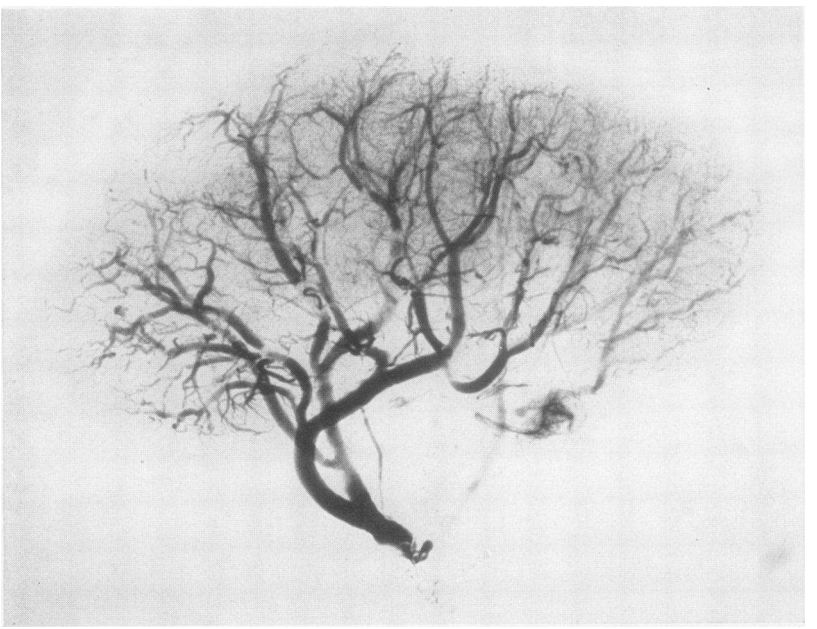

FIG. 4. ROENTGENOGRAM OF THE ARTERIAL TREE IN A SEVERELY CONTRACTED KIDNEY (ADVANCED ARTERIOLARSCLEROSIS) WHICH GAVE A GREATLY REDUCED PERFUSION FLOW (EXPERIMENT 46)

instead of tapering gradually. The cortex lacked the striated appearance produced by the rows of glomeruli (fig. 4).

Table 2 shows a comparison of the average volumes of perfusate per gram of kidney per minute in the normal and arteriolarsclerotic kidneys. In the moderately sclerotic group the flow at each pressure is less than in the normal, but at a pressure of 150 mm. Hg the volume is as great as in the normal at 100 mm. In the advanced group the flow at 200 mm. Hg pressure does not equal the normal at half that

pressure. That the volume of perfusate through a contracted kidney is less than through a normal one under similar conditions was shown years ago. The same relations hold when the flow is expressed per gram of kidney. Unfortunately suitable methods are not available for estimating quantitatively the decrease in number of patent glomeruli, so that it is uncertain what parts decrease in number of perfused units and increased resistance in existing vessels play in the diminished volume of perfusate. Since the relative increase in volume of perfusate with increase in pressure is of the same order in normal and arteriolarsclerotic kidneys, it seems probable that decrease in the number of patent glomeruli is the more important factor.

TABLE 2

Average volume of Ringer's solution per gram of kidney per minute in normal and arteriolarsclerotic kidneys

Perfusion pressure	Normal	Moderate arteriolarsclerosis	Advanced arteriolarsclerosis
mm. Hg			
100	1.7	1.0	0.5
150	2.6	1.8	0.7
200	3.7	2.1	1.0

Nephritis

One example of acute focal glomerulonephritis gave a normal volume of perfusate. Two kidneys showing mild acute diffuse nephritis gave perfusion flows below the normal range. If this be accepted as evidence of obstruction to blood flow present during life, it lends support to the conception that the mechanism of the oliguria of acute glomerulonephritis and that of mercury poisoning or eclampsia may be essentially different.

Kidneys from five cases dying of chronic glomerulonephritis and uremia have been perfused (nos. 8, 9, 13, 26 and 34). All the patients had shown low fixed specific gravity of urine, elevation of blood pressure and blood urea nitrogens from 70 to 210 mgm. per 100 cc. All showed a marked reduction of perfusate at all pressures, both in total volume and in volume per gram of kidney. Even at the highest pressure used (200 mm.) the flow per gram was less than from the

TABLE 3

Perfusion flows through normal and pathological human kidneys obtained at autopsy

Experiment number	Postmortem	Age	Kidney weight	Perfusion flow, cc. per minute												Histological diagnosis
				Ringer's solution						Acacia						
				Total			Per gram kidney			Total			Per gram kidney			
				Perfusion pressure, mm. Hg												
				100	150	200	100	150	200	100	150	200	100	150	200	
	hrs.	*yrs.*	*gm.*													
50	17	1	27	56	65	118	2.1	2.4	4.4							Normal
17	24	4	47	64	110	164	1.4	2.3	3.5	62	84	122	1.3	1.8	2.6	
22	7	13	98	240	422	540	2.5	4.3	5.5	192	236	280	1.9	2.4	2.8	
32	19	14	130	200	270	400	1.5	2.1	3.1							
24	14	19	150	208	324	348	1.4	2.2	2.3	116	164	196	0.8	1.1	1.3	
27	23	19	152	200	333	604	1.3	2.2	4.0	124	200	528	0.8	1.3	3.5	
16	6	24	147	240	280	390	1.6	1.9	2.6	206	260	380	1.4	1.8	2.6	
40	9	31	100	224	336	480	2.2	3.4	4.8	220	284	360	2.2	2.8	3.6	
11	22	37	134	262	388		2.0	2.9								
41	9	38	152	208	332	476	1.4	2.2	3.1	120	128	144	0.8	0.8	1.0	
29	18	40	153	178	280	372	1.2	1.8	2.4							
42	9	45	156	260	404	540	1.7	2.6	3.5							
35	12	52	122	141	246	378	1.2	2.0	3.1	92	128	200	0.8	1.1	1.6	
47	7	53	165	246	320	472	1.5	1.9	2.9	280	344	440	1.7	2.1	2.7	
49	17	63	160	380	620	824	2.4	3.9	5.2							
21	17	66	128	243	506	618	1.9	4.0	4.8	240	310	470	1.9	2.4	3.7	
43	11	68	101	192	270	400	1.9	2.7	4.0	68	80	100	0.7	0.8	1.0	
36	11	69	129	224	336	444	1.7	2.6	3.4	144	164	216	1.1	1.3	1.7	
5	10	19	150	210	260		1.4	1.7								Simple nephrosis
7	15	25	101							118			1.2			Simple nephrosis
14	5	44	137	306	424	540	2.2	3.1	3.9							Cholemic nephrosis
15	8	26	171	265	412	520	1.6	2.4	3.0							$HgCl_2$ nephrosis
37	6	34	175	240	400	544	1.4	2.3	3.1							Pregnancy nephrosis
39	19	45	172	224	320	510	1.3	1.9	3.0	200	248	312	1.2	1.4	1.8	Simple nephrosis
45	5	39	137	208	352	488	1.5	2.6	3.6	134	200	268	1.0	1.5	2.0	Mild arteriolarsclerosis
48	6	72	140	172	280	408	1.2	2.0	2.9	158	180	336	1.1	1.3	2.4	
1	2	48	170	124		160	0.7		0.9							Moderate arteriolar-
18	20	67	100	143	229	284	1.4	2.3	2.8	124	198	248	1.2	2.0	2.5	sclerosis
25	22	60	136	142	260	356	1.0	1.9	2.6	180	224	300	1.3	1.6	2.2	
28	11	47	171	162	220	316	0.9	1.3	1.9	124	156	288	0.7	0.9	1.7	
31	8	77	153	76	120	184	0.5	0.8	1.2	50	80	116	0.3	0.5	0.7	Advanced arteriolar-
33	7	47	101	36	62	90	0.4	0.6	0.9							sclerosis
46	20	72	75	33	54	74	0.4	0.7	1.0							

TABLE 3—*Concluded*

Experiment number	Postmortem	Age	Kidney weight	Perfusion flow, cc. per minute												Histological diagnosis
				Ringer's solution						Acacia						
				Total			Per gram kidney			Total			Per gram kidney			
				Perfusion pressure, mm. Hg												
				100	150	200	100	150	200	100	150	200	100	150	200	
	hrs.	*yrs.*	*gm.*													
19	8	23	198	150	241	412	0.8	1.2	2.1							Acute glomerulonephritis
20	10	60	160	128	277	384	0.8	1.7	2.4							
8	12	52	215	86			0.4				20			0.1		Chronic glomerulonephritis
9	10	36	74	30	41	47	0.4	0.6	0.6	9	20	20	0.1	0.3	0.3	
13	24	25	80	65	137	163	0.8	1.7	2.0							
26	9	24	95	38	74	98	0.4	0.8	1.0	9	17	23	0.1	0.2	0.2	
34	8	35	155	75	100	160	0.5	0.6	1.0	24	44	44	0.2	0.3	0.3	
23	5	38	218	278	484	711	1.3	2.2	3.3	190	248	307	0.9	1.1	1.4	Acute focal glomerulonephritis

normal group at 100 mm. The average flow per minute was 0.5 cc. at 100 mm. perfusion pressure, 0.9 cc. at 150 mm., and 1.2 at 200 mm. These averages are very close to those found in advanced arteriolarsclerosis.

Whether the ultimate pathological process is the same in the two groups, as maintained by Baehr and Ritter (9), or whether there are subtle differences, these data do not indicate. There was no significant difference in kidney weights in the two groups. The patients in the sclerotic group had shown only moderate evidence of renal insufficiency and did not die in uremia, while the patients in the nephritic group had all shown severe renal insufficiency and had died in uremia. The roentgenograms of the nephritic kidneys resembled the arteriolarsclerotic in general appearance, but showed some points of difference. The irregularity and tortuosity of the arteries was less marked; the cortex was not narrowed to the same degree, but the cortical injection was even more scanty than in the arteriolarsclerotic group (fig. 5). If the actual number of patent glomeruli were known, the analysis might be carried further.

Hypertrophy of remaining glomeruli is more evident in nephritic than in arteriolarsclerotic kidneys. A given volume of fluid may, in the nephritic kidney, traverse a greatly reduced number of glomeruli, many of which are enlarged, while in the arteriolarsclerotic kidney the same volume passes through a greater number of glomeruli of more nearly normal size. The filtering surface in the latter would be greater, and the volume of filtrate per unit volume of blood greater at the same pressure. Kidneys from patients dying in uremia and showing purely arteriolarsclerotic changes have not been obtained.

FIG. 5. ROENTGENOGRAM OF THE ARTERIAL TREE OF A CHRONIC GLOMERULAR NEPHRITIC KIDNEY WHICH GAVE THE SAME VOLUMES OF PERFUSATE PER GRAM AS THE KIDNEY IN FIGURE 4 (EXPERIMENT 34)

SUMMARY

Forty-two normal and nephritic human kidneys have been perfused with Ringer's solution or acacia at different pressures to distinguish in which structural interference to flow existed. The results have been compared with roentgenograms of the vascular tree after injection of bismuth and with histological sections.

1. There was no decrease in volume of perfusate per gram of kidney with advancing years.

2. Kidneys showing only degenerative changes showed no evidence of mechanical obstruction in the blood vessels. They permitted as great a perfusion flow as did normal kidneys. No abnormality was detected in roentgenograms of the vascular tree after injection.

3. Kidneys presenting benign arteriolarsclerosis showed a definite decrease in volume of perfusate per gram at a given pressure, proportional to the degree of histological change. When the degree of sclerosis was moderate, the volume of perfusate per gram at 150 mm. Hg perfusion pressure equalled the normal at 100 mm. pressure. In kidneys showing advanced lesions the volume flow per gram at 200 mm. pressure was less than the normal at 100 mm. Roentgenograms showed irregular, tortuous arteries, and a narrow cortex with fewer interlobular arteries.

4. Acute diffuse glomerulonephritis showed a diminished volume of perfusate at each pressure.

5. Chronic diffuse glomerulonephritis showed a marked reduction of perfusion flow per gram of the same magnitude as advanced arteriolarsclerosis. Roentgenograms resembled the picture of arteriolarsclerosis, but the cortex was less narrowed while the number of injected interlobular arteries and glomeruli were less.

The histological diagnosis of many of these sections has been confirmed by Dr. Baldwin Lucke, to whom I express my thanks. I am also indebted to Dr. Eugene Pendergrass and to Dr. I. S. Ravdin for making the roentgenograms.

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