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A STEREOSCOPIC ANALYSIS OF THE ARTERIAL SUPPLY TO THE KIDNEY*

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During a comparative study of the arterial supply of kidneys of White and non-White South Africans, in conjunction with my colleague, Dr. I. W. Simson, of the Pathology Department, Pretoria General Hospital, a method of stereoscopic examination of kidneys after the injection of opaque medium into the arteries, was evolved. A review of the literature reveals no evidence of any previous study by this method.

HISTORICAL REVIEW

The Greeks traced the course of blood-vessels by inserting flexible sticks into them, but Galen[21] (130 - 210 A.D.) was probably the first to inject vessels by forcing air into them. In 1563 Eustachius,[19] an Italian anatomist, related in his work *De Renum Structura* that water, injected into the renal artery and vein, returned by way of the ureter, and drew the erroneous assumption of a direct connection between the blood-vessels and uriniferous tubules, until Bowman,[7] in 1842, disproved this theory. Bellini,[5] in 1665, injected the renal artery and vein through quills fastened to bladders of coloured liquid, and in 1666 Malpighi,[37] using ink in the same manner, saw glomeruli on the cut surfaces of the kidney. In 1668 Robert Boyle[8] used a fluid mass of plaster-of-paris and gelatin which later hardened and left a cast of the renal artery and its larger subdivisions. By means of a syringe Ruysch,[43] in 1727, filled both the renal artery and renal vein with molten wax. In 1882 Schiefferdecker[44] described an injection mass consisting of celloidin dissolved in ether and coloured by asphaltum. Huber,[29] in 1906, suggested the use of old X-ray films dissolved in acetone. More recently Graves[24-26] used coloured resin, Smithuis[45] used plastoid, Chatain[11] used plastic material (Rhodopas), and Chatterjee and Dutta[12] used neoprene latex.

Variations in Extrarenal Arterial Supply

In 1891 the Anatomical Society of Great Britain and Ireland sent a questionnaire to 13 medical schools throughout the British Isles asking for reports of all available data obtained by dissection relative to renal vascular anomalies. The final report by Thompson[50] (1891) listed the arterial blood supply of 419 kidneys. This was followed by results obtained by Brewer[9] (1897), Seldowitsch[46] (1909), Eisendrath and Strauss[17] (1910), Gerard[22] (1911), Ruppert[42] (1913), Eisendrath[15,16] (1920 and 1930), Anson, Richardson and Minear[2] (1936), Anson and Kurth[3] (1955), Merklin[38] (1956), Merklin and Michels[39] (1958), Anson and Daseler[4] (1961) and Czeck and Weiman[14] (1962).

The general consensus of opinion is that conformity to the pattern depicted in most of the texts of anatomy and surgery is encountered in approximately one-quarter of the cases studied, and this more frequently on the right than the left side.

Division of the Renal Artery

Investigators have for many years attempted to discover and describe general patterns of division of the renal artery. These investigators include Hyrtl (1882),[30] Kelly (1902),[31] Albarron and Papin (1908)[1] and Kuprinjanoff (1924).[32] A great variety of divisions was revealed and no general pattern appears to have emerged.

Intrarenal Arteries

Graves[24,25] made a detailed study of the intrarenal arteries of normal human kidneys, using plastic casts. He divided the kidney into upper, middle, lower, posterior and apical segments on a basis of the intrarenal arterial distribution.

In 1959 Ives Chatain[11] did similar work and his findings differed from those of Graves.

Other investigators include Ilhan Eralp,[18] Goldby and Harrison,[23] Ungvary and Faller,[51] Smith,[47] David Sykes,[49] and Chatterjee and Dutta.[12]

Employing a different approach Löfgren[33] and Boijsen[6] brought out a nomenclature based on a distribution to the renal pyramids.

PREPARATION AND INJECTION

The apparatus which was used is illustrated in Fig. 1.

The kidney, renal artery (or arteries, if multiple) and the aorta are exposed by means of dissecting around them.

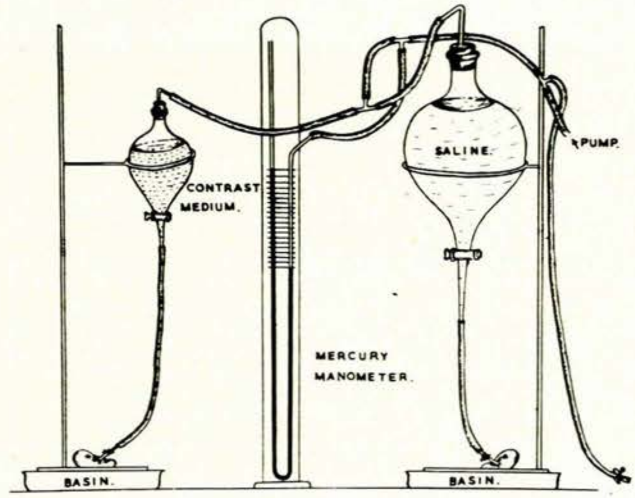

Fig. 1. Apparatus. See text for description.

The aorta is clamped above and below the origin of the renal artery (or arteries). All the vessels arising from the aorta, except one which is used as an inlet for the saline and contrast medium (and, of course, the renal artery/arteries), are carefully tied off.

The artery which has been preserved is connected to the flask containing the saline. The tap of this flask is now opened and saline is pumped into the aorta at a pressure of 100 mm.Hg. From the aorta the saline flows into the renal artery/arteries, through the kidney and out via the renal veins. Six litres of saline were found to be necessary to flush the kidney satisfactorily. The first 1 - 2 litres of saline to flow through are blood-stained, but the emerging saline gradually clears and litres 5 - 6 are quite clear. At the completion of this process the tap of the saline flask is closed. The kidney is connected to the flask containing the contrast medium, after first evacuating all the air in the tube serving as a connection between the flask and the

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kidney. The tap serving this latter flask is now opened and contrast medium is pumped into the kidney. The contrast medium is milky in appearance and can be seen in the vessels serving the kidney capsule. The minimum time taken to fill a kidney satisfactorily was found, in experiments preceding this series, to be 4 minutes. After 4 minutes the vessel used as an inlet to the aorta is tied off and the kidney is ready for X-ray examination.

Initial experiments with water-soluble contrast materials showed that this type of opaque medium was too watery and flowed through too rapidly. Various barium mixtures were also found to be unsatisfactory, and the material of choice turned out to be an oily suspension of contrast medium.

Radiographs employing tube-shift were taken and studied on a stereoscopic viewer.

Positive prints of the kidneys were then coloured in (Figs. 2 and 3). Branches arising from the anterior main division of the renal artery with an anterior course of distribution are coloured black; the vessels left untouched (i.e. not coloured) are intended to indicate a posterior distribution derived from a posterior main division; red was used to indicate anterior vessels of supply derived from branches of a posterior main division and blue for posterior vessels of supply derived from an anterior main division.

In addition to anteriorly and posteriorly situated arterial branches, I frequently observed vessels in the centre of the kidney substance, retaining their central position throughout their course and giving off alternate small anterior and posterior tributaries of supply. I have found no mention of these in the literature and have named them intermediate branches. Green was the colour used to depict these intermediate vessels.

A total of 84 kidneys were studied.

A. An Analysis of the Anterior and Posterior Distributions

1. In 43 cases (51·2%) out of 84 studied there were anterior vessels of supply within the renal substance from a basic posterior arterial branch.

In 27 (32·1%) cases this anterior-from-posterior supply was demonstrated in the upper pole; in 8 cases (9·5%) in the lower pole and in 15 cases (17·9%) in the portion of the kidney between the upper and lower poles. In 6 cases

Fig. 2. See text.

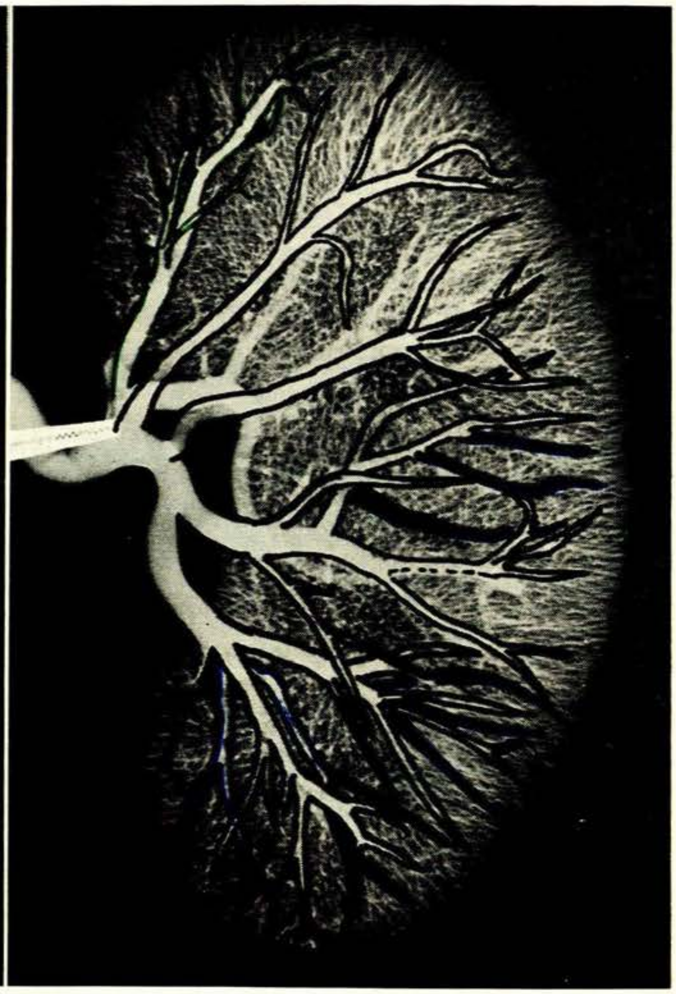

Fig. 3. See text.

(7·1%) this anterior-from-posterior supply was found in more than one quadrant (Table I).

TABLE I. ANTERIOR-FROM-POSTERIOR SUPPLY

Studies	*Cases in which present*	*Upper pole*	*Lower pole*	*Central*	*Multiple*
84	43	27	8	15	6
Percent	51·2	32·1	9·5	17·9	7·1

2. A posterior-from-anterior distribution was found in 60 cases (71·4%); this was located in the upper pole in 15 (17·9%), in the lower pole in 44 (52·4%) and in the area between the upper and lower poles in 25 cases (29·8%). In 25 instances (29·8%) this distribution was seen in more than one quadrant (Table II).

TABLE II. POSTERIOR-FROM-ANTERIOR SUPPLY

Studies	*Cases in which present*	*Upper pole*	*Lower pole*	*Central*	*Multiple*
84	60	15	44	25	25
Percent	71·4	17·9	52·4	29·8	29·8

3. Intermediate vessels: in 59 cases (70%) intermediate vessels were found. This type of arterial supply was only found in the upper and lower poles and in not one instance was it seen in the central portions of the kidney. The distribution was upper polar in 37 (44%) and lower polar in 41 (48·8%) instances. In 19 cases (22·6%) both the upper and lower poles showed this distribution, either as a whole or in part (Table III).

TABLE III. INTERMEDIATE SUPPLY

Studies	*Cases in which present*	*Upper pole*	*Lower pole*	*Upper and lower poles*
84	59	37	41	19
Percent	70	44	48·8	22·6

4. The upper pole supply showed 13 variations of origin. It was supplied by the anterior and posterior divisions in 37 (45%) cases; by the posterior division in 16 (19·5%); by the anterior division in 8 (9·8%); by the renal artery in 6 (7·3%); by an accessory artery from the aorta plus anterior division in 1 (1·2%); by the renal artery plus the posterior division in 2 (2·4%); by the renal artery plus the anterior division plus the posterior division in 2 (2·4%); by an accessory artery from the aorta in 2 (2·4%); by an accessory artery from the aorta plus the anterior division plus the posterior division in 2 (2·4%); by superior plus inferior renal artery branches in 2 (2·4%); by the superior branch of the renal artery in 2 (2·4%); by a branch from the renal artery at the bifurcation into anterior and posterior divisions in 1 (1·2%), and in 1 (1·2%) case, where there was no division of the renal artery and the upper pole, it was supplied by branches from the second and third anterior branches given off by the renal artery plus its posterior continuation after giving off 3 anterior branches.

There were 5 (6·1%) cases that had accessory vessels from the aorta supplying the upper pole, either as the sole supply or in combination with anterior and/or posterior divisions (Table IV).

5. The lower pole supply showed 9 variations of origin. The supply to the lower pole originated from the renal artery in 12 (14·3%) cases; from the anterior division of the renal artery in 35 (41·7%); from the posterior division of the renal artery in 2 (2·4%); from both the posterior and the anterior divisions in 21 (25%); from the renal artery and the posterior division in 1 (1·2%); from a branch from the aorta plus the anterior division plus the posterior division in 1 (1·2%); from accessory aortic branches alone in 5 (6%); from the aorta plus the anterior division in 3 (3·6%) and from an inferior branch of the renal artery in 4 (4·8%) cases.

Altogether there were 9 (10·7%) cases that had accessory vessels from the aorta supplying the lower pole, either as the sole supply or in conjunction with anterior and/or posterior divisions (Table V).

B. Renal Artery Division

Of the 84 cases that were studied, there was division into anterior and posterior divisions in 74 (88·1%). This division occurred in the proximal third in 10 cases (13·5%), in the

TABLE IV. UPPER POLE SUPPLY

	Both divisions	*Posterior division*	*Anterior division*	*Renal artery*	*Accessory from aorta and anterior division*	*Renal artery and posterior division*	*Renal artery, anterior and posterior divisions*	*Accessory from aorta*	*Accessory from aorta and anterior division and posterior division*	*Superior and inferior*	*Superior*	*Renal artery at bifurcation into anterior and posterior*	*No division 2nd and 3rd anterior branches and posterior continuation after giving off three anterior branches*	*Total cases*
Cases	37	16	8	6	1	2	2	2	2	2	2	1	1	82
Percent	45·0	19·5	9·8	7·3	1·2	2·4	2·4	2·4	2·4	2·4	2·4	1·2	1·2	

There are 5 accessory vessels from the aorta to the upper pole = 6·1%

TABLE V. LOWER POLE SUPPLY

	From renal artery	*Anterior division renal artery*	*Posterior division renal artery*	*Posterior and anterior division*	*Renal artery and posterior division*	*Aorta and anterior and posterior divisions*	*Aorta*	*Aorta and anterior division*	*Inferior branch of renal artery*	*Total cases*
Cases	12	35	2	21	1	1	5	3	4	84
Percent	14·3	41·7	2·4	25·0	1·2	1·2	6·0	3·6	4·8	

There are 9 accessory vessels from the aorta to the lower pole = 10·7%

TABLE VI. RENAL ARTERY DIVISION

Total cases 84	*Division into anterior and posterior branches, total 74*			*No division into anterior and posterior*	*Posterior lies superior to anterior*	*Anterior lies superior to posterior*	*Anterior and posterior directly over one another*	*Posterior larger than anterior*	*Anterior larger than posterior*	*Of equal size*
	Near aorta	*Middle third*	*At or near hilum*							
Cases	10	14	50	10	40	20	14	16	27	31
Percent	13·5	19	67·6	11·9	54·1	27·0	18·9	21·6	36·5	41·9

Division into anterior and posterior 88·1%

middle third in 14 cases (19%) and in the distal third in 50 cases (67·6%).

There was no division into anterior and posterior divisions in 10 cases (11·9%).

In 40 cases (54·1%) of the 74 that showed anterior and posterior divisions of the renal artery, the posterior division was found to be superior to the anterior division; in 20 cases (27%) the anterior division was the superior one and in 14 cases (18·9%) the two vessels were superimposed.

In 16 cases (21·6%) the posterior division was found to be the larger; in 27 cases (36·5%) the anterior was the larger and in 31 cases (41·9%) the two divisions were of equal size (Table VI).

DISCUSSION ON THE PATTERNS OBSERVED AND THE SIGNIFICANCE OF SUCH PATTERNS

In my study the only findings that occur in a large enough percentage to be regarded as reasonably constant are that there is division of the renal artery into anterior and posterior divisions (88·1%) and that this division usually occurs at or near the hilum of the kidney (67·6%). Hyrtl[30] in 1882, stated that there are anterior and posterior divisions of the renal artery separated by the kidney pelvis. Smithuis,[45] in 1956, found an anterior and posterior division in 99%; while Boijsen[6] has confirmed this in 51·3% and Sykes[49] in 83·1% of cases.

More and Duff,[40] Smithuis[45] and Boijsen[6] all state that the anterior division is larger than the posterior division. In my series the most common finding was that the two divisions are of equal size (41·9%). The anterior division is larger than the posterior one more often than vice versa, viz. 36·5% as compared with 21·6% of cases where the posterior division is larger than the anterior.

In my series there was division into anterior and posterior main branches in the proximal third of the renal artery in 13·5%; in the middle third in 19% and in the distal third in 67·6% of cases. This compares with the findings of Schmerber[45] who found a proximal-third division in 35%; with Gerard[22] and Hou-Jensen[25] who found a proximal-third division in 18%, middle-third in 14%, distal-third in 68%; and with Palumbo[41] who found a proximal-third division in 6%, middle-third in 12% and distal-third division in 82% of cases.

More and Duff[40] found that the interlobar arteries varied between 8 and 12. I found the variation to be from 4 to 11.

As far back as 1924 Kuprinjanoff[32] found a great variety of divisions, and he states that it is a futile and fruitless task to attempt to describe any general pattern or patterns and that the repeated dichotomous branching made his study, in detail, so difficult, that it was abandoned. Graves[24-27] states that the arrangement of renal arterial segments is such that only resection of the upper or lower pole is

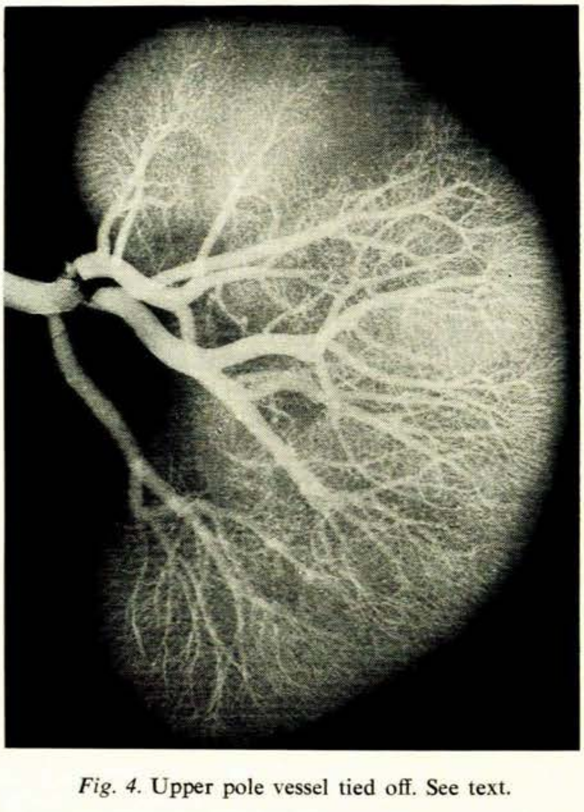

Fig. 4. Upper pole vessel tied off. See text.

of practical value, and Smithuis[45] states that there is no renal segmentation which would have a useful practical application. My findings confirm these views.

As for the division of the kidney into exact and constant segments, opinions are many and varied. Kuprinjanoff[32] found this to be a futile and fruitless task; Löfgren[33] described 3 parts of the kidney, namely, superior, intermediate and inferior; Graves[24,25] found a constant pattern; Chaiudano[13] states that he could not recognize any upper and lower polar regions as entities and, therefore, cannot accept the term 'polar'; Boijsen[6] confirms Löfgren's[33] findings; Chatain[11] states that he cannot accept Grave's classification; Ungvary and Faller[51] found a front lobe with 4 segments and a back lobe with 3 segments; Sykes[49] describes 3 types of pattern, namely, the one found by Graves, a venous pattern and a dual pattern; and Chatterjee and Dutta[12] described 5 segments.

My findings do not support the theory of any constant pattern of the intrarenal arterial supply. The patterns are many and varied as can be seen from a glance at Tables I - VII.

Brödel[10] described an avascular zone. Kuprinjanoff,[32] Hou-Jensen,[28] Fuchs,[20] Löfgren,[33] Boijsen,[6] and Sykes[49] all state that there is no such avascular zone. My findings of overlapping of terminal ventral and dorsal arterial branches in every case certainly does not support the avascular zone theory of Brödel.

Further, where a single intrarenal branch has been blocked or tied off, one finds an area of non-filling of a segment that extends through the entire antero-posterior depth of the kidney substance and *not* a non-filling localized to either the anterior half or posterior half depending on whether it is an anterior or posterior vessel that is affected (Fig. 4).

Ludwig[34] found that certain intrarenal vessels traversed the renal substance to supply capsular and perinephric-fat arteries of supply. Huber,[29] MacCallum,[36] and More and Duff[40] maintained that 'Ludwig arterioles' were not encountered and that all vessels first traverse a glomerular capillary tuft. Fig. 5 shows a Ludwig arteriole. This type of vessel was not seen in any of my cases where the kidney had been dissected from its surroundings, but where the perinephric fat, etc. is left *in situ* they can be demonstrated.

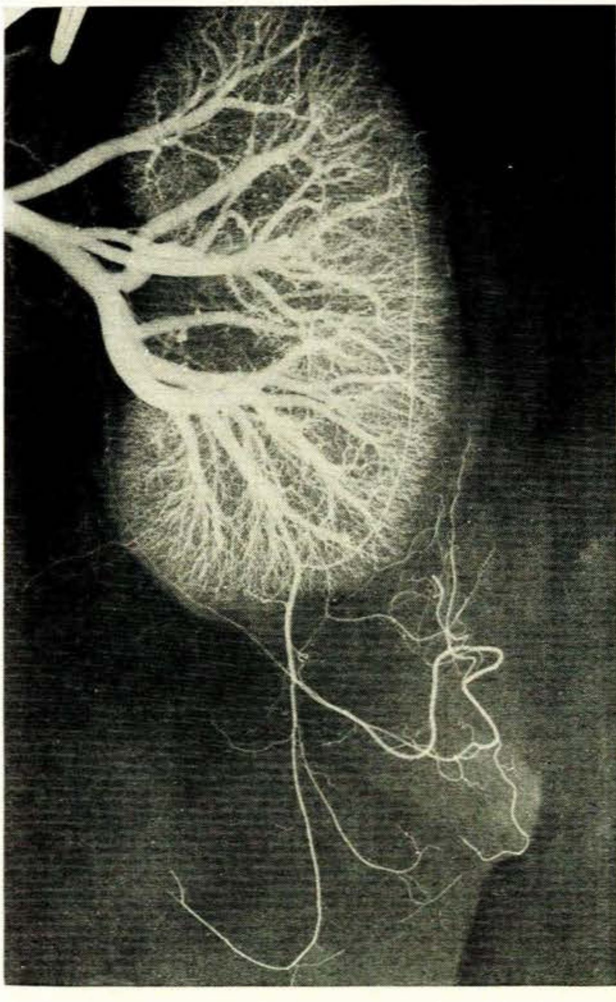

Fig. 5. Ludwig arteriole.

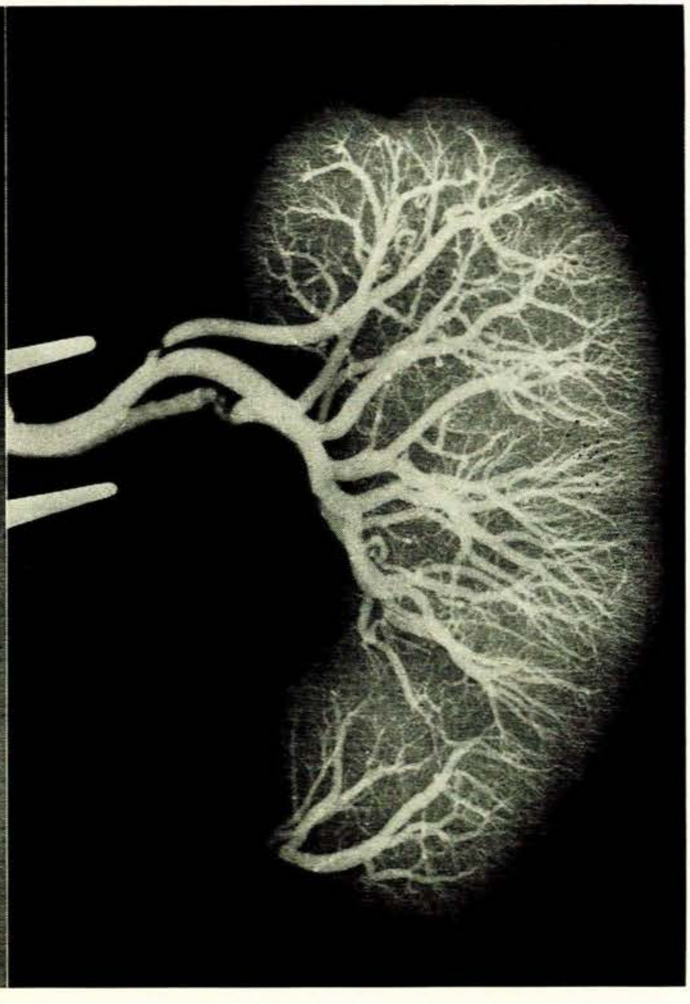

Fig. 6. Additional vessel to lower pole with unusual distribution.

My series of cases proves conclusively that 'aberrant renal artery' is a misnomer. All additional arteries to the kidney are accessory to the main artery and supply an in:egral part of the kidney. Severance of such vessels would therefore lead to necrosis. Fig. 6 shows an unusual distribution from one such vessel to the lower pole of a kidney.

CONCLUSIONS

At the outset the intention of my investigation was to report on a series of cases of kidneys examined stereoscopically after the introduction of intra-arterial contrast medium and to determine whether there is a constant arterial pattern as regards distribution in a lobar sense and whether there are also, in fact, separate anterior and posterior branches of supply dividing the kidney into anterior and posterior components.

A. Division of the Kidney into Lobes

No pattern emerged in a high enough percentage to warrant such a division on a basis of arterial distribution. The mere fact that in most instances previous investigators have differed widely in their conclusions, points to a non-existence of a constant pattern. Where both kidneys have been studied in the same case there are material differences on the two sides. I would go so far as to say that identical intrarenal arterial patterns must be very few and far between and can be compared to human beings where absolutely identical twins are exceptionally rare.

B. Anterior and Posterior Supply

The only finding that emerged from my study frequently enough to be regarded as a fairly constant appearance was the fact that, where there is a single renal artery, this vessel divides into anterior and posterior components in 88·1% of cases. As regards the intrarenal distribution, crossing over from anterior-to-posterior and vice versa was so common that a separate anterior and posterior supply has to my mind been disproved.

INCIDENTAL FINDINGS WHICH EMERGED FROM MY STUDY

Briefly these findings are as follows:

1. A study of the cases in which the renal pelvis and calyces were filled, showed that quite often intrarenal arteries run obliquely across the necks of calyces (Fig. 7). Should these vessels happen to change course from anterior-to-posterior or vice versa, they could cause a localized obstruction at the neck of a calyx just as an 'aberrant' renal artery could obstruct a ureter—a 'cyst' in

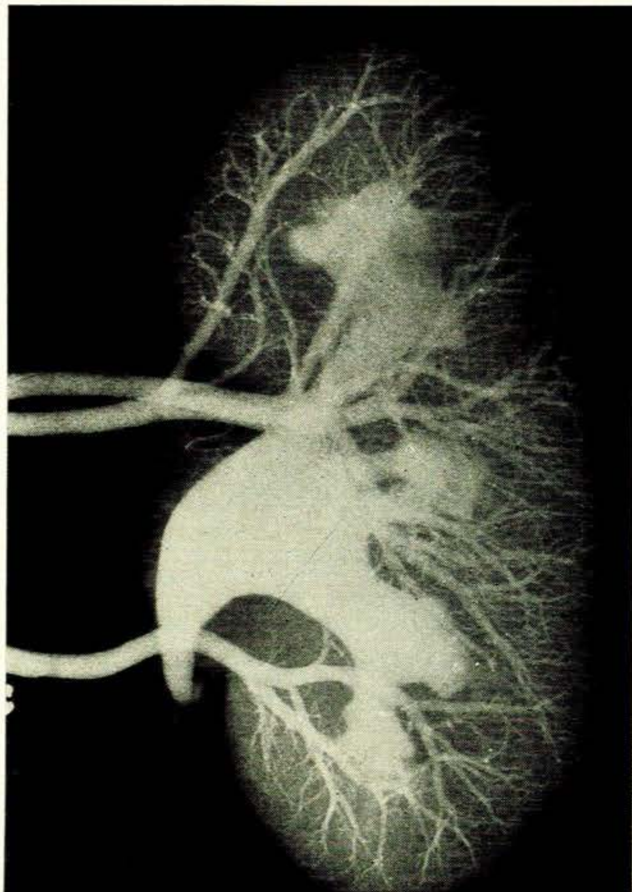

Fig. 7. Comparison of right and left kidneys in same patient.

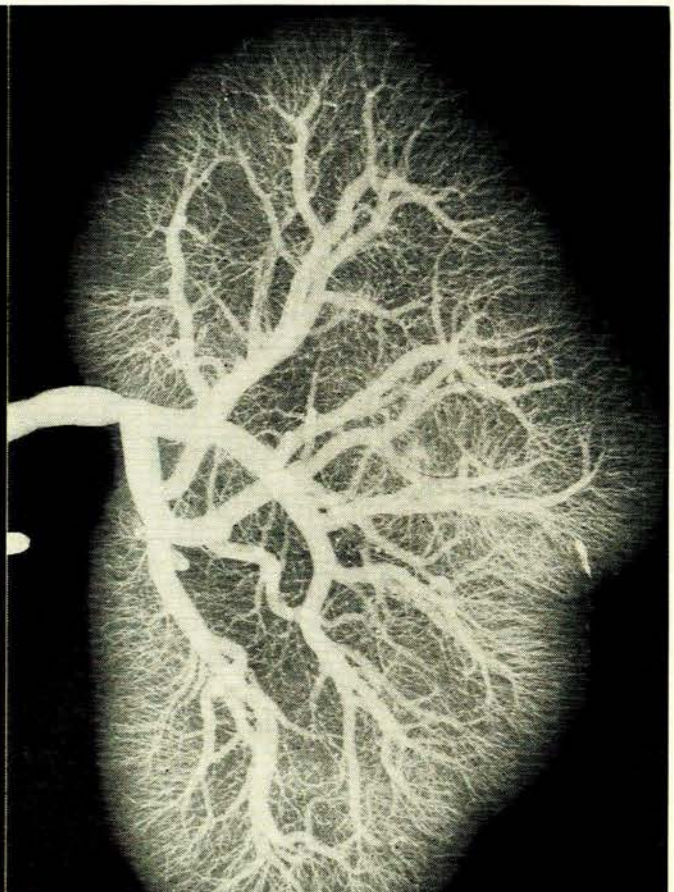

Fig. 8. Relationship of arteries to calyces.

the kidney could in fact sometimes be due to such obstruction. I approached Dr. P. Maas,[35] Senior Urologist at the Pretoria General Hospital and Pretoria University, and in a verbal communication he confirmed that he had, in fact, come across such cases at operation.

2. In 26 (31·7%) of the 82 cases there was foetal lobulation of the kidney (Fig. 8). One should therefore not be too hasty to diagnose pyelonephritis merely on the finding of an irregular renal outline on a plain radiograph or a nephrogram, as so many clinicians are inclined to do.

3. A type of vessel within the kidney substance to which no reference could be found in the literature, is the one which lies neither anteriorly nor posteriorly and which I have named *intermediate*. This type of vessel was found in 70% of cases.

4. When transplantation of kidneys becomes a practical procedure, as surely it must at some future date, it will be very important to make a thorough contrast-medium study of the kidney of the donor to eliminate the possibility of severed accessory vessels, since transplantation of such kidneys will inevitably lead to necrosis of the segments of the kidney originally supplied by accessory arteries, leading to renewed complications.

I wish to thank the University of Pretoria for permission to publish these extracts from my M.D. thesis submitted to them.

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