AN ANATOMICAL EXPLORATION INTO THE VARIABLE PATTERNS OF THE VENOUS VASCULATURE OF THE HUMAN KIDNEY.

by

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To my wife Pratima,

daughter Vedika, son Pravir,

and my family.

ABSTRACT

In clinical anatomy, the renal venous system is relatively understudied compared to the arterial system. This investigation aims to clarify and update the variable patterns of the renal venous vasculature using cadaveric human (adult and foetal) and Chacma baboon (*Papio ursinus*) kidneys and to reflect on its clinical application, particularly in surgery and radiology. The study employed gross anatomical dissection and detailed morphometric and statistical analyses on resin cast and plastinated kidneys harvested from 211 adult, 20 foetal and 10 baboon cadavers. Radiological techniques were used to study intrarenal flow, renal veins and collateral pathways and renal vein valves.

The gross anatomical description of the renal veins and its relations were confirmed and updated. Additional renal veins were observed much more frequently on the right side (31%) than previously documented (15.4%). A practical classification system for the renal veins based on the number of primary tributaries, additional renal veins and anomalies is proposed. Detailed morphometric analyses of the various parameters of the renal veins corroborated and augmented previous anatomical studies. Contrary to standard anatomical textbooks, it was noted that the left renal vein is 2.5 times the length of its counterpart and that there are variable levels of entry of the renal veins into the IVC. Justification for the distal segment of the left renal vein to be termed the surgical trunk, and the proximal segment to be the homologue of the right renal vein is presented.

Radiological investigations demonstrated a non-segmental and non-lobar intrarenal venous architecture, an absence of renal vein valves and extensive venous collaterals centering on the left renal vein. These collateral channels, present in the foetus, and persisting in the adult, may be operative and of clinical significance in pathological states.

No sex differences and no race differences of note were recorded in this study.

The Chacma baboon displayed similar intra-renal venous anatomy.

The applied clinical anatomy of these findings with particular regard to renal surgery and uro-radiology is emphasised.

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PREFACE

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CHAPTER 1

INTRODUCTION

"The current description of veins is woven around that of arteries. This description is largely incorrect as the function of one is active and distributing and the other is passive and collecting. For different functions we find different designs in anatomy. So the design of the venous system should be, and is, different from the design of the arterial system. In other words, our conception of the design of the venous system (based on the arterial system) is, for the most part, incorrect."

Herlihy 1947

Contemporary anatomical descriptions reinforce Herlihy's perception of the renal vasculature. More recently, Hodson (1978) cautioned that "Most textbooks and many medical anatomical publications astonishingly misrepresent the internal anatomy of the kidney and this tends to perpetuate old misconceptions and to positively mislead in other respects" .

It is also well recognised that the current norms of renal vasculature hold true in only half the population (Merklin and Mitchels 1958 and Coen and Raferty 1992). Although the renal arterial system has been the topic of repeated anatomical investigation, statistical analyses and description, there is a deficiency of similar exhaustive study into the renal venous anatomy. Modern surgical and radiological techniques dictate a reappraisal and definition of the renal venous anatomy. In this regard, the role of the primary tributaries of the renal vein and their relationship to the branches of the renal artery and the hilum of the kidney is important. Furthermore, the confusion in nomenclature regarding renal veins makes it difficult to determine the number, exact kind, site of origin and mode of distribution. In addition "The variation among pairs of human kidneys in every aspect of their anatomy makes simple, direct description unrealistic. Nevertheless, without some

logical method of analysis, the task of deciding whether an unusual feature is abnormal or an acceptable normal variant becomes almost impossible" (Hodson 1978).

In view of these shortcomings this study attempts to :

1. Update both the intra- and extrarenal venous anatomy of the kidney.
2. Perform detailed morphometric analyses of the renal vein and its segments, including the inferior vena cava (under renal vein influence).
3. Formulate a practical classification of the patterns of drainage of the renal veins.
4. Investigate intrarenal flow patterns.
5. Elucidate the role of the renal veins in the collateral venous drainage in this anatomical region.
6. Examine the renal veins for the presence of valves.
7. Determine whether any sex or race differences exist with regard to renal venous anatomy.

An evaluation of these concepts will impact in a clinical context and particularly in the fields of renal surgery and uro-radiology. In renal transplantation, the morphology of the renal veins has a special significance, in that abnormalities may greatly influence the technical feasibility of the operation. The scarcity of this resource demands maximum conservation of renal parenchyma and maximum preservation of renal function. Of no lesser import, is this knowledge a vital prerequisite in planning the technical feasibility of "shunt" surgery involving the renal veins. Angiographic competence in renal and related venography renders an adequate knowledge of venous anatomy, variations and anomalies mandatory.

CHAPTER 2

REVIEW OF LITERATURE

"For out of olde feldes, as men seyth

cometh al this newe corn from yer to yere,

And out of olde bokes, in good feyth,

Cometh al this newe science that men lere".

Chaucer (1328-1400)
Assembly of Foules.

HISTORICAL INTRODUCTION

At the turn of the sixth century BC anatomical ideas regarding veins were somewhat crude, but it was nevertheless documented, in particular, by Alcmaeon of Croton who stated that "sleep was caused by the retreat of blood to the veins and awakening by its fourthpouring". Empedocles of Agrigentum (430 BC) was credited with the concept of the heart being the centre of the vascular system. Early reference to the venous system is made in the Mahabharatha (400 BC). Allusion to this system is also made by Hippocrates (460 - 377 BC) and Aristotle (384 - 322 BC), but it was Prascagoras of Cos (circa 335 BC) who is first credited with differentiating between arteries and veins. Galen of Perganum (130 - 200 AD) introduced the concept of capillaries and the slow transference of blood from the venous to the arterial system. Leonardo da Vinci (1452 - 1519) thereafter made extensive anatomical drawings and notes on the venous system, but it was Vesalius (1514 - 1564) who was the first to give a good description of the venous system of the human body. He divided the venous system into four main trunks and their branches. Two of these were abdominal and had the liver as their centre; these were the portal vein and, in the foetus, the umbilical vein. The other two were thoracic, namely the vena cava and the pulmonary aorta or "artery-like vein".

Vesalius failed to note the anastomoses of the azygos vein with the renal and lumbar veins. Eustachius (1520 - 1574) and Fallopius (1523 - 1562) rectified this omission. The knowledge concerning the valves of veins is attributed to Giambattista Canano whose account of them appeared in 1555. A pupil of Fabricius ab Aquapendente, William Harvey (1628) well known for his observations on the circulation of blood, added essential points on the anatomy of veins. Early studies of renal vasculature patterns were made by John Hunter in 1793. He stated that the veins in the kidney are normally freely anastomotic but that the renal arteries were essentially end arteries with no intercommunication (cited by Franklin, 1937).

2.1 THE RENAL VEINS

The renal veins, and in particular the left renal vein, have been elevated to the status of prime importance to the clinician. It may be explored by catheterisation, phlebography, ultrasonography, scintigraphy, computerised tomography and magnetic resonance imaging. In addition, the left renal vein is the principal element around which various surgical techniques have been focused, including expanded nephrectomy for carcinoma of the kidney, retro-peritoneal lymphnodal resection, ligation of mesenteric lymphatic pedicles, the cure of an abdominal aortic ectasia, porta-caval shunting, kidney transplantation, removing obstructions from the renal vein and placement of a filter or a ligature on the inferior vena cava (IVC) for prevention of pulmonary embolism. Williams *et al* (1989) states "Renal veins, of large size, and anterior to the renal arteries, open into the inferior vena cava almost at right angles. The left is three times the right in length (7.5cm and 2.5cm); it crosses the posterior abdominal wall posterior to the splenic vein and body of pancreas and, near its end, is anterior to the aorta, just below the origin of the superior mesenteric artery. The left testicular or ovarian vein enters it from below and the left suprarenal vein, usually receiving one of the left phrenic veins, enters it above but nearer the midline. The left renal vein enters the inferior vena cava a little superior to the right. The right renal vein is behind the

descending duodenum and sometimes the lateral part of the head of the pancreas".

Pick and Anson (1940c) defined a renal vein "as one which, emerging from the hilum or either extremity, terminates separately in the inferior vena cava". The venous vessels of the kidney exit at the inferior part of the hilum, the terminal branches of the arteries and veins being intermingled for a variable distance from the kidney. In nearly all instances, the veins are ventral to the aorta and renal arteries (Merklin 1958).

Although most textbooks of gross anatomy and surgery still describe and picture the traditionally simple scheme of renal and associated blood vessels, several authors have contributed to revealing the great complexity of pattern and inter-relationship of the arteries and veins in the region of the kidney.

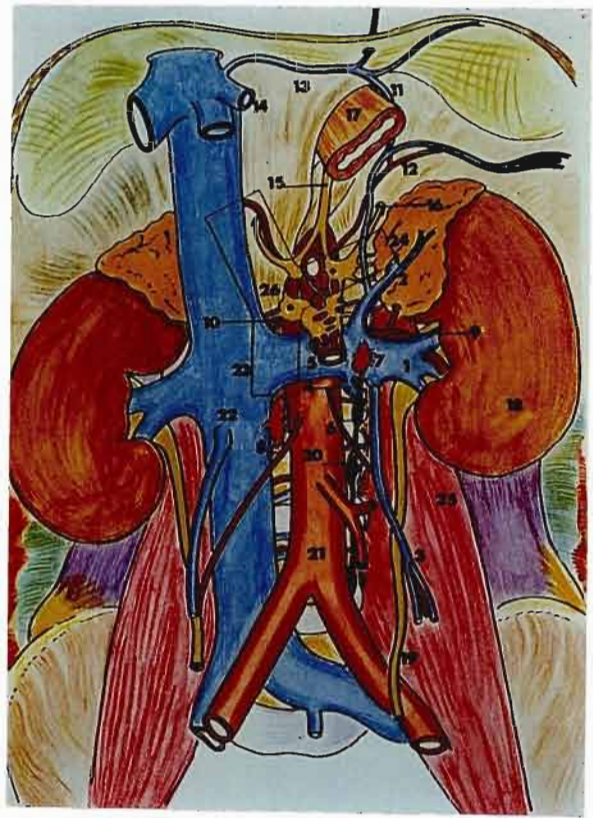
Kolster (1901), found that in 103 specimens, the right renal vein entered the IVC lower than the entry of the left renal vein in 53%, the left renal vein lower in 13% and bilateral equality in the level of entrance in 34%. In his series of 118 cadavers, Rupert (1915) observed that 61% of renal vessels showed either a unilateral or bilateral variation of artery or vein, or of both. After reviewing 215 renal specimens Pick and Anson (1940c) concluded that "compared with the left, the usual arrangement is a higher origin of the right renal artery, a lower termination of the right renal vein and a lower kidney". They also found an incidence of 14.4% (56 out of 388 specimens) of supernumerary renal veins. When these veins did occur on the right, they were usually close together; in the rare instances in which the veins of the left kidney are removed from each other by a considerable distance, they may communicate with each other through broad anastomotic channels or with larger iliac tributaries of the IVC. They maintained that these anastomoses and tributaries did not belong, strictly, in the category of an accessory renal vein.

The length of the renal veins were recorded from a series of 23 specimens by Anson *et al.* (1936) as being 9cm for the left renal vein and 3.5 cm for the right. Subsequently, the same author together with Daseler (1961), found, in a series of 30 that "the length of the right renal vein varied from 20 - 45 millimeters, with an average length of 32 millimeters.

Usually, there is a single right renal vein, but there may be doubling or in a rare instance, even trebling. In contrast to the right, the left renal vein ranged from 60 to 110 millimeters in length, with an average length of 84 millimeters, more than 2.5 times that of the right renal vein". In the same year, Ross *et al*, while analysing 34 specimens for suitability for renal transplantation noted significantly different lengths i.e. the right renal vein average length was 2.0 (0 - 3.8) cm and the left renal vein was 5.7 (2.5 -10.0) cm.

Capacious hiatuses occurred in both renal veins and more commonly on the right than on the left. The hiatus usually transmitted the gonadal (testicular or ovarian) artery. The gonadal artery may also cross the renal pedicle, follow the renal artery in its transverse course before descending, to hook around the suprarenal tributary of the left renal vein.

Consequent to its applied surgical anatomy, researchers have refocussed on the renal veins to further define their anatomy. This dissertation therefore proposes to present an updated review of the anatomy of the renal veins based largely on Gillot's (1978) description.



1 *Left renal vein*
2 *Adrenal vein*
3 *Gonadal vein*
4 *Lateral root of the hemiazygos*
5 *Superior mesenteric artery*
6 *Gonadal artery (testicular artery)*
7 *Pre-venous lymph node*
8 *Sub-venous lymph node*
9 *Left renal artery*
10 *Right renal artery*
11 *Adreno-diaphragmatic venous arch*
12 *Left phrenic artery*
13 *Left phrenic vein*
14 *Left hepatic vein*
15 *Right vagus nerve*
16 *Greater splanchnic nerve*
17 *Esophagus*
18 *Left kidney*
19 *Ureter*
20 *Left lumbar sympathetic chain*
21 *Aorta*
22 *Inferior vena cava*
23 *Super mesenteric vein*
24 *Splenic vein (these two veins and the portal confluence are projected upon the posterior elements)*
25 *Psoas muscle*
26 *Diaphragm right crus*

Plate 1 *The renal veins and retro-peritoneal elements (from Gillot 1978).*

2.1.1 THE LEFT RENAL VEIN (THE FORMED TRUNK OR THE MAIN RENAL VEIN)

The primary tributaries of varying number converge towards the hilum and unite to form a trunk which is directed transversely and ascending from left to right, crossing over the aorta before crossing the median line to join the left side of the IVC at the level of the inter-vertebral disc of L1 - L2 (Kahn 1969, Lein and Kolbenstveldt 1977 and Beckmann and Abrams 1980)

The left flank of the aorta demarcates the left renal vein into two segments : a proximal (pre-aortic) and distal (aortic and post-aortic) segment (Gillot 1978) or a lateral (renal) and medial (caval) segment (Anson and Kurth 1955).

The average length of the left renal vein has been recorded in the literature as 9cm (Anson *et al.* 1934), 8.4 cm (Anson and Daseler 1961), 5.7 cm (Ross 1961), 4.64 cm (Gillot 1978), 6.8 cm (Beckmann and Abrams 1980), 7.5 cm (Williams *et al,* 1989) (Table I).

TABLE I LENGTH OF THE RENAL VEINS

REFERENCE	SAMPLE NUMBER	LENGTH (cm)	
		LEFT	RIGHT
Anson *et al. (1934)*	23	9	3.5
Anson & Daseler *(1961)*	30	8.4	3.2
Ross *(1961)*	34	5.7	2.0
Gillot *(1978)*	181	4.64	—
Beckmann and Abrams *(1980)*	56	6.8	2.6
Williams *et al (1989)*	—	7.5	2.5

2.1.1.1 THE PROXIMAL SEGMENT

The proximal segment, pre-aortic (before the crossing) averages 3cm in length (Gillot 1978) and a diameter of 1.3 (0.7–1.6) cm (Beckmann and Abrams 1980). However, Erlik (1964) observed that the tributaries of the left renal vein enter close to the hilum of the kidney leaving the proximal segment (5 to 7cm) of the vein free of branches. This segment constitutes the crossroads of the extrarenal tributaries of the left renal vein - the suprarenal vein from above, the gonadal vein from below and the azygolumbar group from behind. In

addition, the left renal vein may also receive the phrenic vein (separately or as a conjoined trunk with the suprarenal vein) and capsular tributaries directly or indirectly (by the suprarenal vein as an intermediary) (Anson *et al.* 1948).

These tributaries frequently communicate with channels which drain adjacent organs, general retroperitoneal tissue, skeleton and muscles (through lumbar connections) and adipose capsular tissue. Parietal communications may be so numerous and prominent as to render the pattern similar to that of the azygos scheme of drainage (Pick and Anson 1940b, c).

2.1.1.2 The Distal Segment

The distal segment, simultaneously aortic and post-aortic, is the common terminal collecting channel measuring an average of 1.64 (0.8 - 2.8)cm (Gillot 1978). This segment has a larger calibre 1.9 (1.1–2.5) cm (Beckmann and Abrams 1980) and is free of notable tributaries. Simeone and Hopkins (1967) however, describe the diameter of the left renal vein as between 2.0 to 2.5 cm in adults and 1.5 and 2.0 cm in children.

2.1.1.3 Relations

Since the left renal vein is flattened in the sagittal plane, it presents two surfaces, anterior and posterior, and two edges, superior and inferior (Gillot 1978).

a) POSTERIOR RELATIONS

From the renal pelvis, the vein rests upon the psoas muscle and the left crus of the diaphragm, the latter being perforated by the splanchnic nerves. It also sits upon the abdominal aorta, which itself covers the first ganglion of the lumbar sympathetic chain. Finally, it bridges the aorticocaval groove. The left renal artery and then the origin of the right renal artery are typically situated behind the left renal vein near its superior edge.

b) SUPERIOR RELATIONS

The left renal vein is near the inferior pole of the adrenal gland. The suprarenal vein runs obliquely to reach the superior edge of the renal vein and empties into it before the latter crosses the aorta. The next principal relation is the superior mesenteric artery which takes its origin from the aorta immediately above or several millimeters from the left renal vein and crosses in front of the latter during its descent.

c) INFERIOR RELATIONS

The left renal vein crosses over a sheath formed of three elements which are included in the groove which separates the aorta from the inferior pole of the kidney; the ureter, the left gonadal artery and vein. The gonadal vein empties into the inferior edge of the left renal vein.

d) ANTERIOR RELATIONS

The left renal vein is covered by the pancreas. It separates the pancreas from the omental bursa and the stomach. The superior mesenteric artery is inserted longitudinally between the pancreas and the vein. This constitutes the "hinge" of pancreatic detachments : to the left, the body is joined to the retro-peritoneal plane by the retropancreatic fascia (of Toldt); to the right, the neck is placed upon the termination of the renal vein, joined like the head of the pancreas, by the fascia (Gillot 1978). Each segment possesses one of the major roots of the portal trunk so that the spleno-mesenteric portal plane, included in the pancreatic region, is placed against the renocaval systemic plane. The splenic vein which is oblique, hangs over the left renal vein by 1 to 3cm, becoming closer and closer during its descent. The vertical superior mesenteric vein crosses the terminal part of the left renal vein. Usually the portal confluence is situated 1 - 2cm above and slightly to the left of the renocaval junction. The left renal vein is situated near the inferior surface of the pancreas, at the location where the transverse mesocolon is attached and the vein crosses over the duodeno-jejunal flexure. The anatomical relationship of the left renal vein passing between the aorta and the superior mesenteric artery may in some instances cause compression of this vein and result in elevated pressure. De Schepper (1972) described this as the "nutcracker phenomenon".

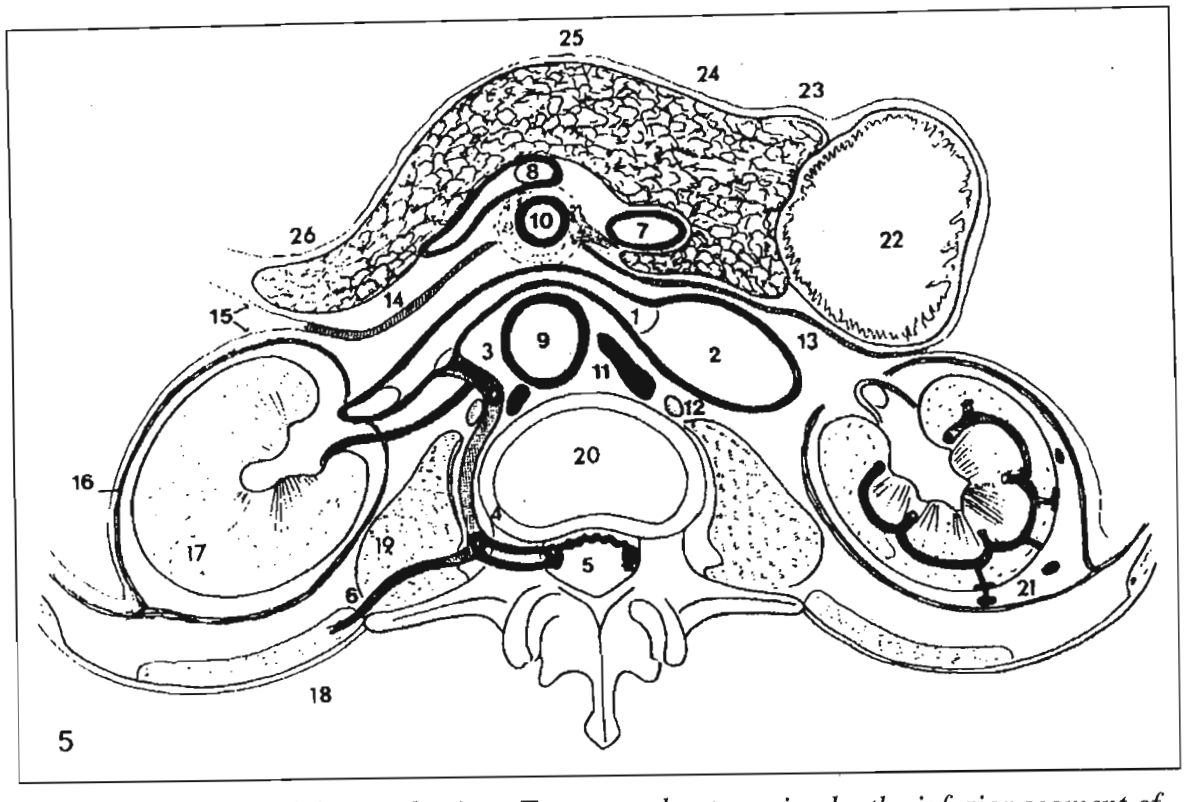


Fig. 1 *Relations of the renal veins : Transversal cut passing by the inferior segment of the second lumbar vertebra (the left side of the pancreas is projected on the slice). (from Gillot 1978)*

1	*Left renal vein*	*14*	*Retro-pancreatic fascia (of Toldt)*
2	*Inferior vena cava*	*15*	*Parietal and visceral peritoneum*
3	*The common trunk of the derivations*	*16*	*Perirenal fascia*
4	*The lateral root of the hemiazygos*	*17*	*Left kidney*
5	*Intra-vertebral (antero-lateral) venous plexus*	*18*	*Quadrate muscle*
6	*Lumbar wall vein*	*19*	*Psoas muscle*
7	*Superior mesenteric vein*	*20*	*Second lumbar vertebra*
8	*Splenic vein*	*21*	*Vein of the adipose capsule*
9	*Aorta*	*22*	*Descending (second part) duodenum*
10	*Superior mesenteric artery and its plexus*	*23*	*Head of the pancreas*
11	*Right crus of the diagram*	*24*	*Isthmus of the pancreas*
12	*Lumbar sympathetic chain*	*25*	*Body of the pancreas*
13	*Duodeno-pancreatic fascia (of Treitz)*	*26*	*Tail of the pancreas*

2.1.1.4 Additional Left Renal Vein

Additional renal veins occur rarely on the left side. An additional renal vein (Table II) was present in 1% in Rupert's series (1915) of 118 cadavers, while of 200 cadavers, Anson *et al.* (1936) noted a 3% incidence. In a later study, Pick and Anson (1940c), demonstrated an incidence of 1% of 194 specimens. In the same year, in a series of 203 specimens, Weinstein demonstrated a significantly higher incidence of 6% of one additional renal vein and a 2% occurrence of two additional veins. In their series of 500 specimens, Reis and Esenther (1959)

observed a 0.8% incidence while a higher incidence of 3% was recorded by Ross *et al.* (1961) and subsequently Merklin (1958) found 3.1% from 185 dissections. Of 56 renal venogram examinations, Beckmann and Abrams 1980 noted a 1% incidence of such an additional renal vein while Pollak *et al.* (1986) found 2% in a series of 400 cadaver organ donors.

TABLE II *ADDITIONAL RENAL VEIN - LEFT KIDNEY*

REFERENCE	SAMPLE NUMBER	ADDITIONAL RENAL VEIN (%)
Rupert *(1915)*	118	1.0
Anson *et al. (1936)*	200	3.0
Pick and Anson *(1940)*	194	1.0
Weinstein *(1940)*	203	6.0
Merklin and Michels *(1958)*	185	3.1
Reis and Esenther*(1959)*	500	0.8
Ross *et al. (1961)*	34	3.0
Beckmann and Abrams *(1980)*	56	1.0
Pollak *et al. (1986)*	*400*	*2.0*

Additional renal veins, which occur less frequently than supernumerary arteries, often communicate, on the left side, with other visceral veins, (suprarenal and spermatic or ovarian) with a retroaortic venous plexus and with the left lumbar and hemiazygos veins, as well as vertebral, meningeal and adjacent parietal vessels. In 1888 Lejars, demonstrated left renal vein connections with the lumbar, ascending lumbar or hemiazygos communications in 88% of cases, while Fagarasanu (1938) noted a slightly higher incidence of these connections (91.5%) and Pick and Anson (1940c), a lower incidence of 68.8%. Not infrequently, the regular veins pass in front of the aorta, the supernumerary vein behind, forming (between left kidney and vena cava) a circumaortic venous ring. This aspect on the various channels of communication of the left renal vein will be discussed in greater detail later.

In an exceptionally rare instance, Gillot (1978) described the drainage of a short left renal vein into a voluminous plexiform retroaortic trunk of a left azygos vein at the level of L3-L4. There was consequently no renal opening into the left side of the IVC.

2.1.2 RIGHT RENAL VEIN

The primary tributaries of varying number converge towards the hilum and unite to form a single short vessel which in its slight ascent crosses transversely from right to left to join the right side of the IVC at the level of the lower third of the body of the first lumbar vertebra (Kahn 1969 and Beckmann and Abrams 1980). The average length of the right renal vein has been recorded as 3.5cm (Anson *et al.* 1934), 3.2cm (Anson and Daseler 1961), 2.0cm (Ross *et al.* 1961) 2.6 cm (Beckmann and Abrams 1980) and 2.5cm (Williams *et al* 1989) (Table I). The diameter was observed to range between 1.4 to 1.5 cm (Abrams *et al.* 1964, Kahn 1969 and Beckmann and Abrams 1980). As if matching in simplicity the venous drainage of the right suprarenal gland, the right kidney usually possesses one vein, which is typically independent of vascular channels from neighbouring structures. Since the IVC lies to the right of the midline of the body, and hence in close proximity to the suprarenal gland and the embryonic gonad, it usually receives the right suprarenal vein and the right internal spermatic or ovarian vein (Pick and Anson 1940c). Hence visceral, diaphragmatic and parietal veins in the renal territory on the right side drain into the IVC.

2.1.2.1 RELATIONS

The short pedicle of the right renal vein is behind the descending part of the duodenum and occasionally the head of the pancreas. Emerging from the renal pelvis, the right renal vein rests upon the right psoas muscle and the right crus of the diaphragm, the latter structure being perforated by the splanchnic nerves.

Typically the right renal vein receives no tributaries. Sometimes the right gonadal vein empties into the right renal vein (15%) or dividing, communicates, by Y-shaped tributaries with both the right renal vein and the IVC (Anson *et al.* 1936). Reis, in 1959, noted a 3% incidence (from a series of 500 cadavers) of entry of the right gonadal vein into the right renal vein. Rarely, when single it receives the right phrenic or capsular vein near the junction with the IVC (Anson 1932). Typically, it receives no other visceral tributaries,

and never parietal vessels. However, in an extremely rare instance, Wozniak (1965), reported a case in which the ileocolic vein terminated in the additional right renal vein.

2.1.2.2 Additional Right Renal Veins

Additional right renal veins occur much more frequently than on the left side. (Table III)

TABLE III ADDITIONAL RENAL VEINS - RIGHT SIDE

REFERENCE	SAMPLE NUMBER	ADDITIONAL RENAL VEIN (%)		
		1	2	3
Rupert *(1915)*	118	27.0	—	—
Anson and Caudwell *(1932)*	425	22.0	3.0	—
Anson *et al. (1936)*	200	10.0	1.0	—
Pick and Anson *(1940)*	194	27.8	—	—
Weinstein *(1940)*	203	12.0	4.0	—
Merklin and Michels *(1958)*	185	16.3	3.3	1.1
Reis and Esenther *(1959)*	500	10.2	1.0	—
Ross *et al. (1961)*	34	21.0	—	—
Beckmann and Abrams *(1980)*	56	23.0	5.0	—
Pollak*et al. (1986)*	*400*	*8.0*	—	—

In 1915, Rupert noted that of 118 cadavers, 27% of kidneys showed additional right renal veins, whilst Anson and Caudwell in 1932 described from a cadaver series of 425 that 22% of specimens had a second right renal vein of approximately equal size and in 3% of cases two supernumerary renal veins were present.

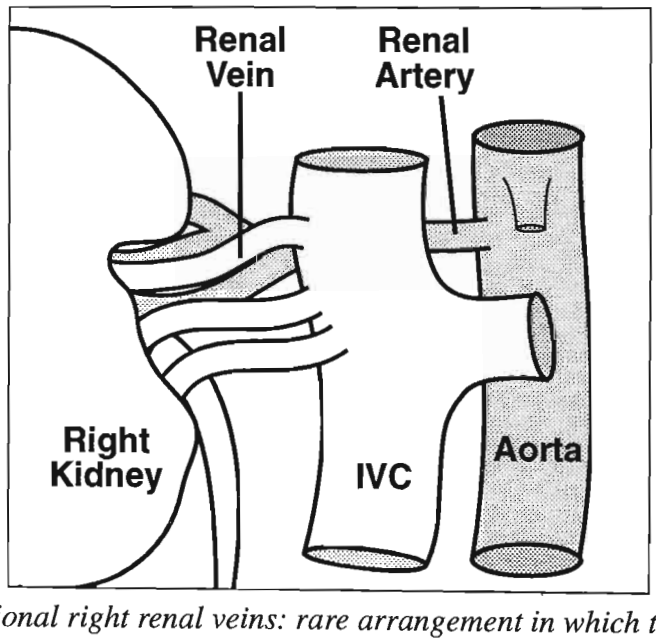


Fig. 2 *Additional right renal veins: rare arrangement in which the renal veins occur in triplicate (adapted from Anson 1947)*

In a subsequent study in 1936, Anson demonstrated from 200 kidneys, a 10% incidence of one additional renal vein and a 1% incidence of two additional veins. Pick in 1940 recorded a similar incidence as Rupert, of an additional renal vein, of 27,8% from a series of 194 specimens. In the same year, Weinstein (1940) reported a much lower incidence of additional veins than Pick and Anson (1940c) but the value compared favourably to the previous statistics of Anson *et al.* (1936). From 203 specimens, he recorded 12%, 4% and 1% incidence of one, two and three additional renal veins respectively. Merklin (1958) subsequently determined from a series of 185 kidneys a 16.3%, 3.3% and a 1.1% incidence of two, three and four renal veins respectively. A year later Reis noted, from a series of 500 specimens, a much lower incidence of 10.2%, and a 1% incidence of a second and third renal vein, whilst Ross in 1961, in analysing 34 specimens to assess the kidney's suitability for transplantation, found a 21% incidence of an additional renal vein. Beckmann and Abrams (1980) observed an additional right renal vein in 23%, and a second additional right renal vein in 5% of 56 venograms studied. In reviewing 400 cadaver organ donors, Pollak *et al.* (1986) noted 92% of right kidneys that had a single renal vein.

In those instances in which the vein is double, the cranial one of the pair may receive the right inferior phrenic or a capsular vein, the caudal member being joined by the gonadal vein. Such a venous scheme would be expected since the superior one of the parallel vessels is then located near the diaphragm, while the inferior member is placed at the embryonic site of the testis or the ovary.

2.1.3 SUPRARENAL VEINS

The venous patterns for the suprarenal glands of the same specimen are profoundly dissimilar. While there are numerous suprarenal arteries, there is usually a single vein for each gland. There is therefore no similarity in pattern between the suprarenal veins and the arteries. So dissimilar were these patterns that Anson *et al.* (1947) claimed that "nowhere in the human body are vessels of the two categories of blood as discrepant in scheme as they are in supply to this endocrine gland".

2.1.3.1 Left Suprarenal Vein

A varying number of tributaries issue from the hilum of the left suprarenal gland to emerge as a trunk from the middle of the anterior surface of the gland. It is of large calibre, being approximately 0.4 (0.3-0.7)cm, very oblique inferiorly and medially, and contains an ostial valve which is usually incompetent (Gillot 1978). It lies in front of, or just lateral to the left coeliac ganglion, and passes behind the body of the pancreas to enter the horizontally coursing left renal vein cranially at a point slightly medial to that at which the gonadal vein enters the caudal aspect. Gillot (1978), in a series of 129 specimens, described the entry of the suprarenal trunk into the left renal vein as being pre-vertebral in 9%, juxta-vertebral in 65% and extra-vertebral in 26%

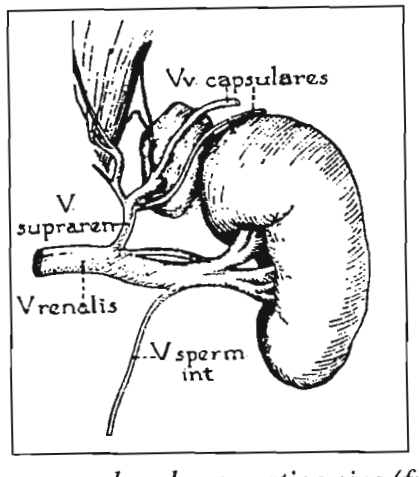


Fig. 3 *Renal, suprarenal and spermatic veins (from Anson 1948)*

In 76% of 33 specimens examined by Anson and Kurth (1955), the suprarenal and left inferior phrenic veins were confluent, the common stem being a tributary of the renal vein.(Fig. 3). Infrequently, separate stems of the suprarenal and inferior phrenic veins entered directly into the left renal vein. Either of these tributaries may occasionally double. Rarely the suprarenal vein splits proximal to the point of union with the renal, thus appearing as a bifid vessel. In association with the latter variation or as an independent feature, the inferior phrenic vein traverses the suprarenal gland in approximately the middle third of its course. They noted further that the suprarenal veins separate throughout their course and empty independently into the renal vein in 8% of cases. The suprarenal vein may infrequently receive one or more capsular veins. Rarely the suprarenal vein may form a common channel with the left gonadal vein to enter the left renal vein.

2.1.3.2. RIGHT SUPRARENAL VEIN

From the hilum of the suprarenal gland, a varying number of primary tributaries join to form a short trunk which courses transversely to empty invariably into the IVC on the dorso-lateral aspect of the latter channel. The suprarenal vein itself is very short, owing to the proximity of the gland to the caval vein. In his account of a singular left sided IVC , Becker (1962) demonstrated a case where both the right suprarenal vein and the right ovarian vein entered the right renal vein before its juncture with the cava. An accessory suprarenal vein connected to the right renal vein in 31% of the cases examined by Clarke in 1959.

2.1.4 INFERIOR PHRENIC VEINS

The right and left phrenic veins follow the course of their corresponding arteries on the inferior surface of the diaphragm. The left phrenic vein is often represented by two branches, one of which ends in the left renal or suprarenal vein, while the other passes in front of the oesophageal opening in the diaphragm and joins the IVC (Williams *et al* 1989). The inferior phrenic vein together with the corresponding suprarenal vein commonly (in the proportion of 5 to 1) drain into the left renal vein through a common trunk. The right phrenic vein enters the IVC.

2.1.5 GONADAL VEINS (TESTICULAR OR OVARIAN)

The gonadal vein, spermatic or ovarian, is the inferior affluent of the left renal vein, which has an average diameter of 0.35cm (Gillot 1978). It drains slightly lateral to the point of entry of the suprarenal vein into the left renal vein.

2.1.5.1 TESTICULAR VEIN

The testicular veins emerge from the posterior aspect of the testes and after receiving

tributaries from the epididymis unite to form the pampiniform plexus, which ascends in the spermatic cord. At about the level of the superficial inguinal ring, the plexus forms itself into three or four veins, which ascend the inguinal canal to unite into two veins at the deep ring. These ascend on either side of the testicular artery in front of psoas major to unite into a single vessel. On the right side, the testicular vein usually enters the IVC at an acute angle, caudal to the termination of the right renal vein. On the left side, the testicular vein usually drains at a right angle into the left renal vein. The testicular vein usually has a tight ostial or preterminal valve (Gillot 1978). Kuypers *et al.* (1992) in a series of 46 cadaver dissections found a valved pathway from the testicle to the IVC of 83% on the right and 46% on the left. The left vein passes behind the lower part of the descending colon and the lower margin of the pancreas and is crossed by the left colic vessels; the right passes behind the terminal part of the ileum and the horizontal part of the duodenum and is crossed by the root of the mesentry, the ileocolic and right colic vessels.

2.1.5.2 Ovarian Vein

These veins correspond with the testicular veins; each forms a plexus in the broad ligament near the ovary and the uterine tube, and communicates with the uterine plexus. The veins issue from this plexus and ascend across the external iliac artery, on each side of the ovarian artery. Their further course and mode of termination are like those of the testicular veins. Valves are occasionally found in the ovarian veins.

Various authors have reported from large series different statistics regarding the drainage of the gonadal vein on both sides. In 1873, Rivington observed in a short series of 10 specimens, that 20% of right gonadal vessels drained into the right renal vein. Subsequently, Anson and Cauldwell (1932), noted that the right gonadal vein drained into the right renal vein in 15% and the left gonadal vein into the left renal vein in 99%. Almost identical statistics were obtained by Pick in 1940. Anson *et al.* (1948) found a higher incidence of 21.7% drainage of the right gonadal vein into the right renal vein. Reis and Esenther (1959), however, in an extensive series of 500, noted a much lower incidence of 3%.

TABLE IV GONADAL VEIN DRAINAGE INTO RENAL VEINS

REFERENCE	SAMPLE NUMBER	Drainage of Right Gonadal into Right Renal Vein(%)	Drainage of Left Gonadal into Left Renal Vein(%)
Rivington *(1873)*	10	20.0	—
Anson & Caudwell *(1932)*	425	15.0	99.0
Pick and Anson *(1940)*	180	15.0	98.8
Anson *et al. (1948)*	450	21.7	100
Reis and Esenther *(1959)*	500	3.0	99.6
Anson & Daseler *(1961)*	125	20.0	99.0
Ahlberg *et al.(1966)*	84	8.3	100
Beckmann and Abrams *(1980)*	56	7.0	—
Kuypers *(1992)*	46	10.0	99.0

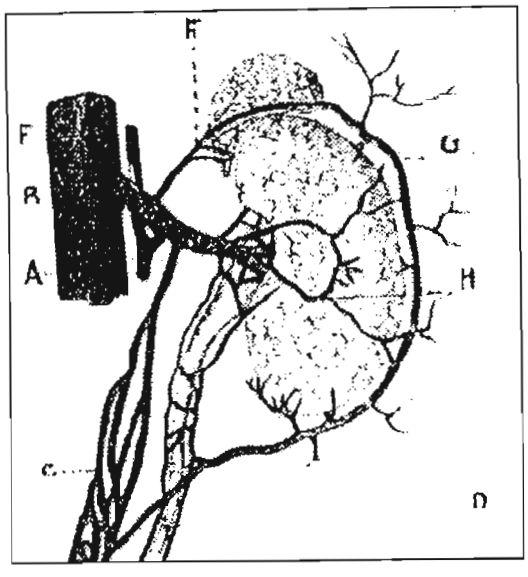
Anson and Daseler (1961) re-examined this area and noted a 20% incidence of right gonadal drainage into the right renal vein whilst Kuypers (1992) observed a 10% occurrence (Table IV). Alberg *et al.* (1966) noted that valves were absent in the gonadal vein about twice as often on the left as on the right side and that men more often have valves than women. Women more often than men have incompetent valves on both sides, and the diameter of the gonadal vein on both sides is greater in women than in men. (Diameter : females - right 0.32cm and left 0.33cm and males - right 0.26cm and left 0.28cm). A highly significant difference in the mean diameter of the left ovarian vein was found when nulliparae (0.24cm) were compared with multiparae (0.36cm). The valves are more often incompetent in women with multiparity than in others. Very rarely the right gonadal vein may drain as a double vessel into the right renal vein. However, its termination may be doubled, i.e.. into both the IVC and right renal vein, infrequently. In complete situs inversus viscerum, the drainage of the tributaries is consistent with the inverse arrangements of the major vessels : the right internal spermatic contributes directly to the IVC; likewise the second lumbar vein joins the dorsal aspect of the right renal vein. Pick and Anson (1940a) reported a single instance of the right gonadal vein draining into the left renal vein.

The left gonadal vein may be double (14.4% - Pick 1940) or rarely triple or quadruple. Equally rarely, it may end in the second lumbar vein, or the left suprarenal vein. Capsular

veins sometimes reach the renal through the gonadal as an intermediary. Rarely the gonadal vein receives a polar tributary from the inferior extremity of the kidney (Anson and Cauldwell, 1932). In the event of a singular left sided IVC, Becker 1962 recorded the left ovarian vein emptying into the IVC and both the right ovarian and suprarenal veins entered the right renal vein before its juncture with the IVC. At its point of termination in the inferior border of the left renal vein, Anson and Kurth (1955) noted that the gonadal vein was most frequently situated lateral to the common trunk of the phrenic and suprarenal veins, infrequently opposite, and in only a single instance medial to the stem of the confluent phrenic and suprarenal veins. However, Gillot observed that the left gonadal vein terminated in the distal segment of the left renal vein in 26% of cases, at the junction of the distal and proximal segment in 46% and in the proximal segment in 26%.

2.1.6 CAPSULAR VEINS

Subcapsular venules are located on the surface of the renal cortex immediately beneath the fibrous capsule of the kidney (Williams *et al* 1989). They drain most of the superficial parts of the renal cortex. These veins drain to the intrarenal venous system via the interlobular veins by the convergence of a number of venules which are referred to as stellate veins because of their appearance on surface view. The stellate veins also drain through the capsule to the perirenal venous plexus. These veins in the perirenal fat, empty into the renal or into one or more of its immediate tributaries (Morison 1926; Black 1963; Beres *et al* 1964, Hippona and Crummy 1965 and Brindle 1972). Placed circumferentially in relation to the kidney, they approach the renal pedicle from above and below. The capsular veins are prone to terminate in the nearest venous channels of axial course. Such vessels are the gonadal (caudally) and the suprarenal (cranially); through these visceral veins, blood from the special perinephric tissue and from the general retroperitoneal connective tissue of the left side of the abdominal wall is received by the renal vein. Either of the two capsular veins may divide en route to the renal pedicle and may communicate with the intercostal veins (Anson *et al.* 1947, Duskes 1927).



A vena cava inferior
B vena renalis
C plexus venous ovaricus (spermaticus)
D plexus venous uretericus
E vena phrenica inferior (anastomose reno-azygo-lumbar)
F vena suprarenalis
G arcus venosus perirenalis
H vena capsularis anterior

***Fig. 4** The normal collateral venous circulation. (from Poirier and Charpy, after Tuffier and Lejars: Duskes 1947)*

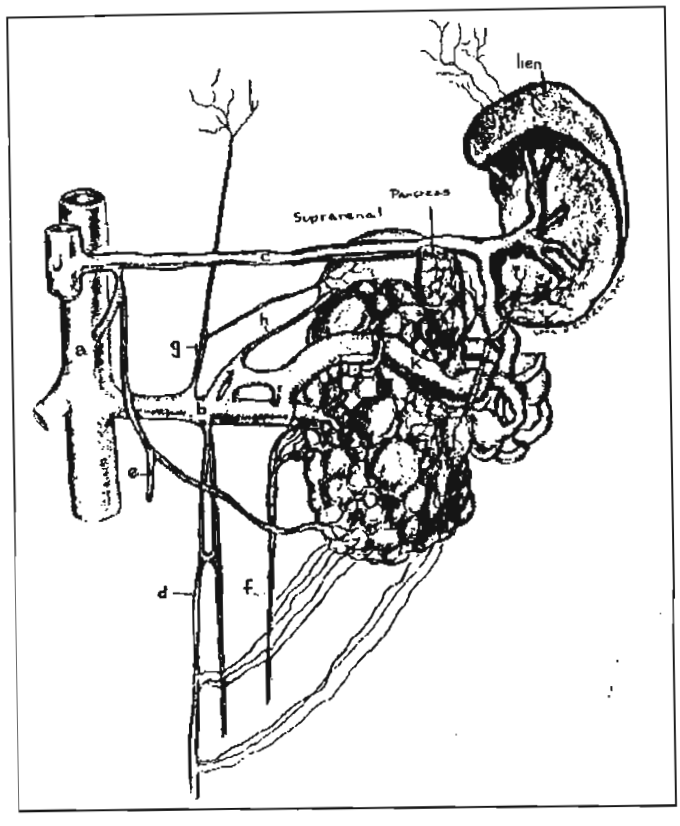
In addition, on the left side, the cranial set of veins often receive muscular tributaries (from the diaphragm, psoas major and quadratus lumborum) as well as lower suprarenal and phrenic tributaries, before emptying by multiple veins into the renal vein; the inferior set may receive one or more lumbar veins, usually indirectly; a caudal portion of the capsular system frequently joins the gonadal vein before entering the renal vein (Anson *et al.* 1948).

Gillot (1978) however succinctly divides these veins of the adipose capsule of the kidney into two varieties: the principal and accessory types. Those of the principal type are few in number and from 0.2 to 0.3 cm in diameter and have a relatively fixed arrangement. One vein penetrates between the superior pole of the kidney and the suprarenal gland and eventually joins the suprarenal vein. Another vein, infrarenal, empties into the gonadal vein. The pre- or retrorenal veins lead to one of the branches of origin of the renal vein or into the renal trunk itself. These principal constituents form vertical anastomoses, the most common one running along the external border of the kidney (the exo-renal circle). Non-systematizable porta-caval anastomoses can join this large meshed network. The accessory veins, many in number, anastomose among themselves and with the above-mentioned veins. The circumrenal venous pattern of this capsular network of veins was appreciated by earlier anatomists among whom, were Kolliker (1867) who termed

branches perforating the renal cortex and anastomosing with capsular vessels the, "rami capsularis". Hyrtl (1870) simply designated them "perforating branches". Tuffier and Lejars (1891) in a study of the capsular veins of the kidneys, classified the capsular venous anastomoses into five main groups : renal, mesenteric, suprarenal, spermatic (or ovarian) and lumbar. This was amplified by Poirier and Charpy (1920) who described the "veines emergentes" of Verneuil, which pass from the cortex to enter the IVC, lumbar or spermatic vessels, and are seen particularly over the posterior surface near the hilum of the kidney. They also describe the "veines adipeuses" which receive blood from the fatty capsule and from small venules on the surface of the kidney (the stellate veins of Verheyen) and communicate with adjacent veins.

In describing the lobulation of the kidney, Brodel (1901) noted that "Should, however, the kidney present not the slightest depression or lobulation, the arrangement of the large stellate veins of the capsule will serve to sufficiently locate the limits of the pyramids and the position of the important lateral longitudinal column. These veins are found to be more conspicuous and are arranged in rows along the lines where the foetal lobulation has been".

An unusual and particularly interesting drainage of a capsular vein was described by Duskes (1972) in a polycystic kidney which demonstrated this vessel traversing the anterior aspect of the kidney, joining the splenic and renal veins and emptying into the latter by a triple base.



a *Inferior vena cava*
b *vena renalis*
c *vena lienalis*
d *plexus venosus ovaricus (spermaticus)*
e *vena mesenterica inferior*
f *plexus venosus uretericus*
g *vena phrenica inferior (anastomose reno-azygo-lumbar)*
h *vena suprarenalis*
j *vena portae*
k *anomalous vein*

Fig. 5 *Semi-schematic drawing illustrating the left renal vein and the collateral anastomoses in a polycystic kidney (from Duskes 1927).*

2.1.7 AZYGOLUMBAR VEINS

Anatomists have long been aware of the renal vein connections (almost exclusively by the left renal vein) with the lumbar and azygos system of veins. Since a detailed anatomical description of the lumbar and azygos system of veins is outside the scope of this dissertation, an overview concentrating on the azygolumbar parietal connections to the renal veins will be presented. Comprehensive descriptions of the azygos and lumbar veins are presented in their monographs on the subject by Seib (1934), Franklin (1937) and Davis *et al.* (1958).

Lejars (1888) described the connection between the hemiazygos and the left renal vein (which he termed the "reno-azygo-lombaire" safety canal) in 88% of the 80 cadavers examined. This anastomosis opens by one end into the renal vein and after bifurcating near its other end, empties into the inferior hemiazygos and the first lumbar vein. Discrete

reno-lumbar and reno-hemiazygos veins were described by later anatomists (Zumstein 1896, Parsons and Robinson 1899, Hovelacque 1914, Poirier and Charpy 1920, Seib 1934 and Anson *et al.*, 1942) . Fagarasanu (1938b) noted a higher incidence than Lejars of a 92% communication between the left renal vein and the azygolumbar veins. Furthermore, he categorised them into the following types :

1) common canal of the reno-hemiazygos;
2) common reno-lumbar;
3) common vein with double reno-azygos tributaries;
4) renocaval veins of pre-caval or post-caval types,
5) double canal of reno- azygos and hemiazygos veins,
6) reno-azygo-lumbar canal (of Lejars),
7) reno-azygo caval canal;
8) triple canal of reno-hemiazygo-lumbo caval veins, with iliac communications, and
9) common canal with multiple reno-gonado-lumbar tributaries, with reno-gonado-azygos communications.

In a subsequent study Pick and Anson (1940) noted from 215 specimens, 68.8% azygolumbar and left renal vein communication.

A less cumbersome classification was proposed by Davis *et al.* (1958) when they divided the lumbar system of veins into the following components:

1) the lumbar segmental veins
2) the pre-vertebral veins, which were ventral to the lumbar vertebrae, dorsal to the aorta and the IVC, and included the roots of origin of the azygos and hemiazygos veins
3) ascending lumbar veins, which passed from the iliac vein to the subcostal vein beneath the psoas major muscle and were placed on the transverse process of the lumbar vertebrae
4) lumbar veins with relationship to anomalous veins including persistent left inferior vena cava, circumaortic venous rings and retroaortic renal veins.

The usual description of the lumbar veins as being segmental, i.e. one for each lumbar vertebral body and serving to connect two longitudinal venous channels - the IVC and the ascending lumbar vein has been seriously challenged (Anson and Cauldwell 1932). In their study of 425 anatomical specimens, they conclude that the lumbar veins are rarely segmental in character, but rather plexiform patterns in retroaortic position and commonly in the case of the second lumbar vein, terminate in the renal vein directly or indirectly by way of the gonadal vein. Whilst acknowledging the wide variation of the scheme of lumbar vein drainage, they nevertheless note the tendency towards concentration of the upper abdominal (renal) level. These variations may present the following patterns :

1) a single lumbar vein, the first, a second or third enter the renal vein
2) the first and second lumbar veins enter the renal vein independently or by a common trunk
3) the first or second lumbar veins first join in a hemiazygos tributary (of lumbar origin) before emptying into the renal vein
4) the second or third lumbar veins, one or both, independently or by a common trunk, join with the genital vein before terminating in the renal vein, and
5) a series of lumbar venous tributaries join a longitudinal trunk, a persistent left IVC before entering the renal vein.

In a subsequent study, Anson and Kurth (1955) noted that parietal vessels (i.e. lumbar veins) in more than one half of 33 specimens were tributaries of a visceral vein (i.e. the left renal vein). In 55%, communication occurred between the left renal vein and lumbar channels, in 39% the communicating vein was the second lumbar, in 9% the third lumbar and in 6% both the second and third left lumbar veins ended in the renal.

Gillot (1978) presents the azygos contribution to the azygolumbar parietal connection with the left renal vein by two routes : the external (lateral) and the internal (medial) root of the hemiazygos. The external or lateral root begins at the surface or inferior edge of the left renal vein, makes a short descent, then is diverted horizontally, in contact with the body of L1 (or of L2), crosses behind the sympathetic chain, and passes under the corresponding arcade of the psoas major muscle. After entering the psoas it takes a vertical course - justifying the name of ascending lumbar vein. In its passage it receives the veins coming

from the inter-vertebral foramen and is enriched by the subcostal vein, and eventually joins with the internal root of the hemiazygos. The internal (medial) root, which is a pre-vertebral element, perforates the diaphragm with the greater splanchnic nerve. It can be the principal or even the only root of the hemiazygos. The two roots may begin by way of a short common trunk of the left renal vein.

In the event of an intermediate azygos root being present, variously recorded as 60% (Hovelacque 1914), 28% (Andreassi 1931), 45% (Seib 1934), 34% (Davis *et al.* 1958), it may also drain into the left renal vein 10% (Andreassi 1931) and 5% (Davis *et al.* 1958).

Another significant azygo-lumbar connection to the left renal vein is the reno-lumbar or reno-caval bridge which unites the left renal vein to the subjacent lumbar veins and the azygos system. The reno-caval arch joins the renal vein by way of one or more bridges to the sub-adjacent caval trunk and sometimes to the left common iliac vein (Gillot 1978).

2.1.8 PYELO-URETERAL VENULES

The renal pelvis, major and minor calyces and the upper part of the ureter enjoy a constant rich arterial and venous anastomotic blood supply (Douville and Hollinshead 1955). The venules form plexuses in the connective tissue coat and in general the veins parallel the arteries. The anastomoses between the venules are so abundant that it is usually impossible to follow a corresponding channel for any distance - it commonly loses its identity in the venous network. The arrangement of the venous system is such that there appeared to be no prevailing direction of blood flow within the network (Douville and Hollinshead 1955).

The ureteral venules result from a fine mesh-like network spread out over the whole of the ureter. They drain, by way of a small number of superior ureteral veins, into the inferior branch of the renal vein, the trunk of the renal vein, and the terminal part of the gonadal vein. Because of their connections with the veins of the broad ligament of the uterus, the ureteral vessels can undergo extensive dilatation in women.

2.1.9 RETROPERITONEAL VEINS

Various unnamed retroperitoneal veins join the renal veins. On the right side, this occurred in 3% (Faragasanu 1938a,b and Notkovitch 1956), while this occurred much more frquently (75%) on the left side (Lejars 1888, Pick and Anson 1940 and Notkovitch 1956).

2.1.10 INTRARENAL VENOUS CIRCULATION

Early studies of intrarenal vascular patterns were made by John Hunter (1793). He stated that normally the veins in the kidney are freely anastomotic but that the renal arteries were essentially end arteries with no intercommunication.

In his classic account of the renal circulation in 1842, Bowman wrote that "the circulation through the kidney may be stated as follows: - All the blood of the renal artery (with the exception of a small quantity distributed to the capsule, surrounding fat, and the coats of the larger vessels) enters the capillary tufts of the Malpighian bodies; thence it passes into the capillary plexus surrounding the uriniferous tubes, and it finally leaves the organ through the branches of the renal vein." Bowman concluded that the cortex did not receive any direct blood supply that had not previously passed through a glomerulus and also that the arteriae rectae originated as efferent glomerular vessels.

Subsequently, Brodel (1901) also noted that the renal "veins followed quite a different arrangement" compared to the arterial distribution. He expanded this description as follows: "Around the bases of the pyramids they anastomose and form the familiar venous arches. They unite in large branches that run between the sides of the pyramids and the columns of Bertini to the necks of the calyces, where they lie between the pyramid and arterial branches. The thickness of these collecting veins accounts for the peculiar lobulated appearance of the base and sides of the pyramids. Around the necks of the calyces, both anteriorly and posteriorly, these veins form a second system of anastomoses much shorter and thicker than that at the base of the pyramids. This appears as a number of

thick loops or rings which fit like a collar around the necks of the calices. Nearly all the collected blood of the posterior region is carried anteriorly through these short thick stems, to join that of the anterior portion."

In 1924 Brown highlighted the "one outstanding feature presented in the venous system which is not exhibited in the arterial, that being the free anatomosis taking place between neighbouring veins". He also classified the renal venous system as seen in mammalian kidneys " under two headings: (1) the internal drainage type and (2) the internal and external drainage type. The internal or deep venous drainage as seen in the human being is the one characteristic of most mammals. In these, the second type to be represented in a rudimentary way is the stellate veins seen on the surface of the kidney."

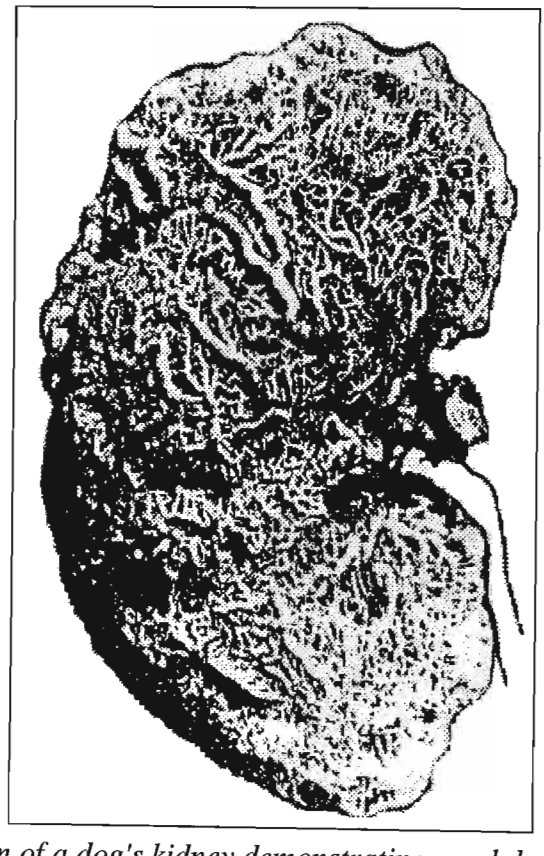


Fig. 6 *Venous system of a dog's kidney demonstrating an elaborate external venous system (from Morrison 1926).*

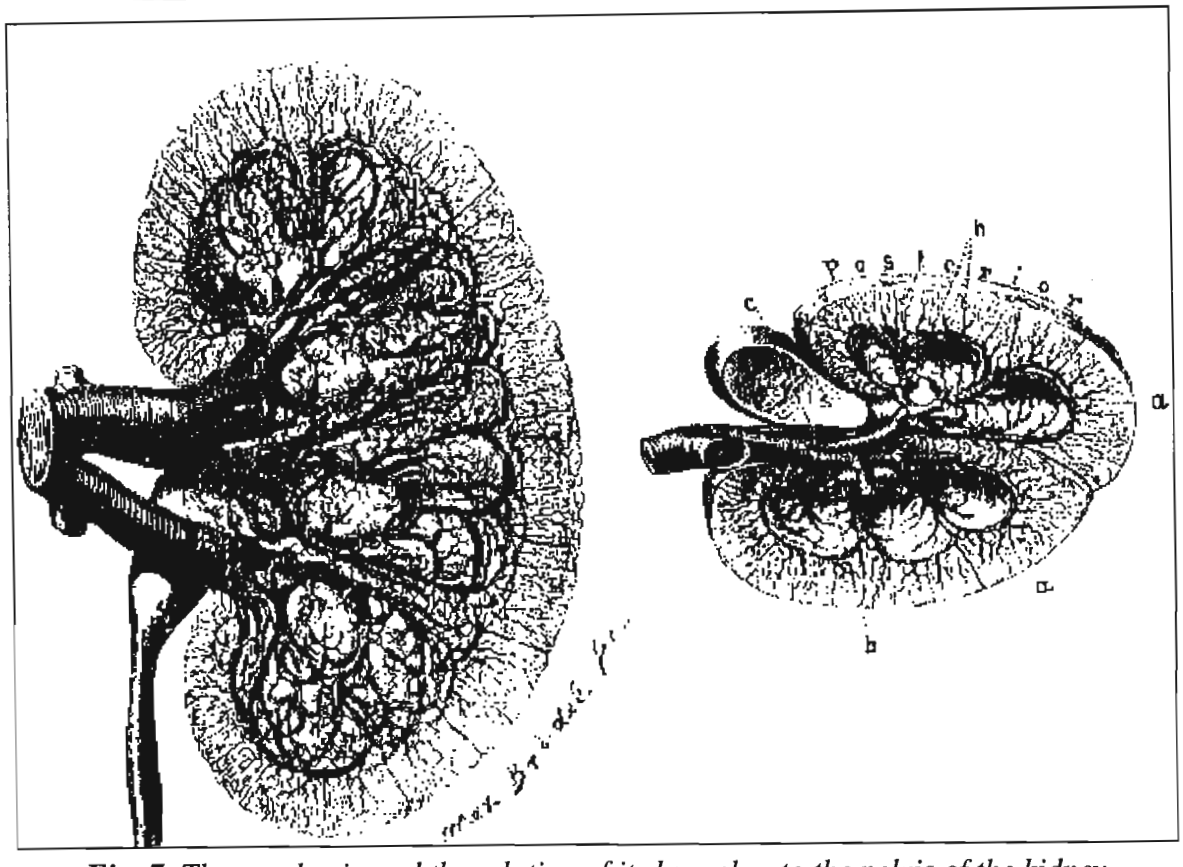


Fig. 7 *The renal vein and the relation of its branches to the pelvis of the kidney. a) anterior view of the kidney b) transverse section seen from above (from Brodel 1901)*

Both Brown and Morrison (1926) noted that vessels corresponding to the larger subdivisions of the renal artery were to be found in the venous system, i.e. interlobar, arcuate and interlobular veins, together with venae rectae. The interlobular vessels were found running in a similar course to the corresponding arteries, to empty into the arcuate veins. They may originate from a peripheral stellate or from a venous plexus situated in the cortex corticis. In their descent through the cortex they are reinforced by blood drawn from a venous plexus immediately surrounding them. Into this plexus flowed the blood derived from the efferent glomerular vessels supplying the convoluted tubules. The lobular veins which are generally rectilinear elements, give rise to the fine striations of the renal cortex in consequence of their abundance and their density (Gillot 1978). The interlobular veins opened into the convexity of the arches formed by the arcuate veins, which in the venous system formed a series of anastomosing arcades much more pronounced than those seen in the arterial system. The arcuate veins are large, thin walled and anastomose freely, almost filling the connective tissue lined vascular canals, and are attached to the lining so

that they cannot readily collapse (Sykes 1963(b), Fine and Keen 1976). These venous arcades may not be regularly arranged; they can be absent in certain territories of the kidney and differ from one individual to another (Gillot 1978).

The venae rectae of the medulla opened into the concavity of these arches. The vena rectae may originate from the five loops formed by the arteriae rectae around the collecting tubule of the medulla, and run in a cortical direction among these tubules to open into the concavities of the arches formed by the arcuate veins and into the bases of the interlobular veins. The interlobar veins are formed by the convergence of the arcuate veins which in turn unite to converge towards the hilum uniting to form the roots of the right and left renal veins.

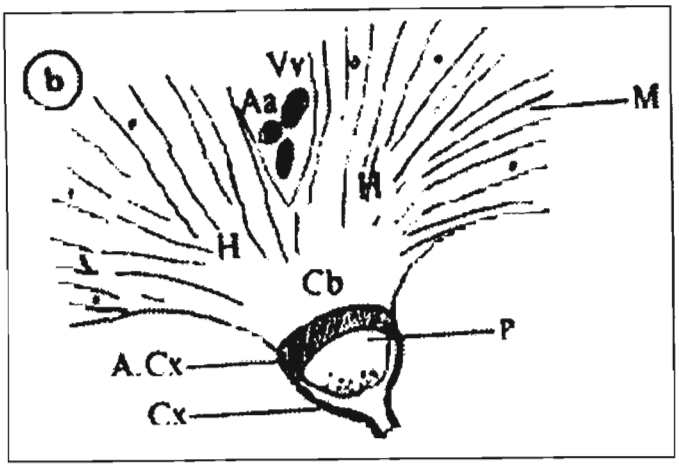
Gillot (1978) described the branches of origin of the renal vein which were properly renal as the initial segment. They drain the whole of the renal parenchyma as well as the superior excretory ducts: the calyces, the renal pelvis, the proximal ureter, as well as the renal capsule. At the periphery of the renal pyramids, venous arcades were located, the edges of which run without interruption from one renal pole to the other. The whole forms a supra-pyramidal arch - a truly continuous intrarenal anastomosis which fundamentally differentiates the venous organisation from the arterial arborization. In their convexity (which is directed towards the periphery), the arcades receive a multitude of lobular or cortical veins. Certain cortical veins appear under the capsule, forming the Verheyen stars or stellate venules. They communicate via fine branches with the veins of the adipose capsule of the kidney, thus joining the intrarenal and extrarenal circulation. A varying number of lobar veins originate from the concavity of the arcades. These radiating elements converge towards the hilum and unite to form the roots of the renal vein.

An analysis of the intrinsic intrarenal drainage contributes three additional concepts. The first in this connection are the investigations of Trueta *et al.* (1947). In experiments with rabbits, they showed that in the crush syndrome, the original injury may cause spasm of the main arteries of the affected limb and that this spasm may extend proximally and involve the renal artery and its branches. Constriction of the latter at the cortico-medullary juncture shunts the blood from the outer cortex through the inner cortex and medulla,

thereby producing cortical ischemia. According to Trueta *et al.*, the blood diverted from the outer cortex flows though an alternative renal medullary bypass mechanism composed sequentially of : afferent arterioles of the juxtamedullary glomeruli, their efferent arterioles, the vasa recta derived from them and finally the interlobular veins. The existence of such a medullary bypass mechanism or shunt was ascertained by More and Duff (1951) by means of Neoprene® casts of human autopsy kidneys. Merklin and Michels (1958) noted that the problem of arteriovenous shunts in the kidney was largely unsolved. While these shunts may be present in a random and insignificant manner, Trueta noted that they were extremely uncommon, whereas More and Duff found no evidence for them at all as claimed by Spanner (1937) and others.

The second concept proposed by Smithius (1956) described the efferent blood flow from the superior and inferior part of the kidney via the superior and inferior branch of the renal vein passing through interlobar veins which were arranged around the margins of the renal calyces in a polygonal pattern. This polygonal venous anastomosis around each calyx were the bases from which arose several arciform veins which ramified immediately at their origin. They surrounded the calyx with a hemispherical venous grating. The space between the calyx and this grating was completely filled by the pyramid. The two rows of renal calyces (dorsal and ventral) were separated by the communal sides of these venous polygonal patterns, which together formed the median vein. This median vein wandered between the calyces as a large vessel and was localised exactly in the plane of natural divisibility - the striated area which is devoid of arteries.

The last concept is the perivenous tunnel system described by Fine and Keen (1976). In describing the blood vessels in the renal sinus and parenchyma as vascular canals, they state the following, "deep in the clefts between the extensions of the pyramids, and covered by minor septa, are connective tissue lined canals which contain arcuate arteries and veins and nerves and lymphatics. These canals inter-communicate freely around their particular pyramid, as well as with those of adjacent pyramids. They form a network around the pyramid with its extensions passing through the interstices of the network.



A. *Calyceal Collar*
A.a. *Arcuate Artery*
Cb. *Body of pyramid*
Cx. *Calyx*
H. *Medullary Extension*
M *Medullary Rays*
P *Papilla (with duct orifices)*
Vv. *Veins*

Fig. 8 *Diagrammatic representation of composite pyramid with 2 extensions and demonstration of vascular relations. (from Fine and Keen 1976).*

The lining of the canal is continuous with that of the sinus. The arcuate veins are large and thin-walled, almost filling the canals, and are attached to the lining so that they cannot readily collapse. The rest of the contents occupy less space in the canals than the veins. The orifices of the vascular canals are in the sinus and are either wide and funnel shaped, or consist of deep clefts between the bodies of the pyramids and the attachments of the calyces. The orifices are linked by grooves surrounding the papillae. The grooves contain arteries or veins so that a vascular ring surrounds each calyx and papilla. The papillary zone is a slightly curved band at the lateral margin of the sinus, and is the area where most of the papillae are clustered. The long axis of the zone more or less bisects the kidney vertically across the 'flat'. Most of the interlobar vessels enter the parenchyma in the papillary zone around the papillae. A few enter at more remote points. The reason for this is that the papillary zone is the area where the cortex and medulla meet on the sinusoidal surface of the kidney. It is at this meeting point that the vessels enter the vascular canals which lie in the plane between the cortex and medulla."

2.2 EMBRYOLOGY OF THE RENAL VEINS

The kidney develops in a highly complex plexiform vascular environment. The renal vascular elements are not isolated from the blood vessels of the neighbouring regions (Anson *et al.* 1948). The venous tributaries converge upon the kidney from both adjacent and remote visceral and parietal structures, thereby providing a remarkable complexity of pattern and vascular inter-relationships. The intimate association of these vessels is of particular clinical interest since those of even small calibre may become important conduits when they serve as collateral pathways. This accommodation to additional blood volume in pathologic processes is often facilitated by the persistence in the postnatal body, of developmentally transitional channels. Due to these complexities, variations in the venous drainage may be anticipated. However, general patterns of vessels are frequently encountered in the adult that indicates that the plan of renal and pararenal vascularity varies within definable ontogenic limits (Anson *et al.* 1948).

In consideration of these complexities, the embryology of the renal veins will be presented noting its dependence on the development of the caval system which is derived from the modification of three parallel sets of veins viz., the postcardinal, the subcardinal and the supracardinal veins.

The posterior cardinal veins appear as two symmetrical, longitudinal veins at the base of the urogenital fold, dorsolateral to the mesonephros at the 14 somite (4th week) stage (Franklin 1937). They extend from the region of the septum transversum to the primitive pelvis and are concerned primarily with the drainage of the body wall, the spinal cord and the mesonephroi (McClure and Butler 1925).

The subcardinal veins appear slightly later than the posterior cardinal veins and arise on the ventrolateral aspect of the aorta, and ventromedial to the mesonephros (Lewis, 1903). They extend through the thorax and abdomen but end cranially and caudally by anastomosing with the posterior cardinal veins. A series of plexuses develops between the posterior cardinal and subcardinal trunks on each side, through which the intersegmental and mesonephric drainage may reach the subcardinal veins. Later, an important inter-

Plate 2 *Embryology of the renal veins (from Gillot 1978)*

1	Subcardinal vein	*9*	Posterior renal vein
2	Lateral sympathetic (or supra-cardinal) vein	*A*	Aorta
3	Posterior cardinal vein	*V*	Ventro-aorta (pre-aortic) anastomosis
4	Medial sympathetic vein	*D*	Dorso-aorta (retro-aortic) anastomosis
5	Sub-central vein	*M*	Mesenophros
6	Inferior vena cava	*P*	Psoas muscle
7	Internal or medial root of the hemiazygos vein	*S*	Sympathetic chain
8	External or lateral root of the hemiazygos vein		

subcardinal plexus arises at about the 10-11mm stage as a pre-aortic plexus dorsal to the superior mesenteric artery. The first modification of the posterior cardinal-subcardinal system occurs as the 7 - 8 mm (5th - 6th week) stage, when the right subcardinal vein joins the hepatic sinuses through the caval fold to form a more direct pathway to the sinus venosus (Frazier 1931).The existence of the supracardinal veins (or thoraco-lumbar line), dorso-medial to the posterior cardinal line, dorso-lateral to the aorta and the developing sympathetic trunks was emphasized by Regan and Tribe (1927). At the 8 mm stage (Frazer 1931) or later (McClure and Butler 1925), a pair of longitudinal veins arises in this axis but the terms used in naming the actual vessels are variable (Franklin 1937). The thoracic portion of thoraco-lumbar line atrophies at an early stage of 10 - 15 mm, (Gladstone 1929) but a large abdominal segment persists on the right side to form part of the IVC. Regan and Tribe (1927) have called this vessel the right paraureteric vein. At an early stage, these veins communicate caudally with the iliac vein and cranially with the subcardinal veins in the neighbourhood of the pre-aortic intersubcardinal anastomosis. In addition, the supracardinal veins communicate freely with each other through the medium of the azygos lines and the subcentral veins.

The second of the four persisting longitudinal channels that is formed dorsolateral to the aorta but medial to the sympathetic trunk, is the azygos line vein which gradually takes over the intersegmental venous drainage from the thoracolumbar line. The intersegmental veins reach their longitudinal channel by passing medial to the sympathetic trunk. Cranially the azygos lines join the persistent cranial parts of the posterior cardinal veins (Williams *et al* 1989).

Two subcentral veins are laid down directly dorsal to the aorta in the interval between the origins of the paired intersegmental arteries. These veins communicate freely with each other and with the azygos line veins, and these connections ultimately form the retro-aortic parts of the left lumbar veins and of the hemiazygos veins. Following the establishment of the intra-embryonic veins in three well defined anatomical lines (posterior cardinal, subcardinal and supracardinal), the intersegmental drainage becomes related to the

thoraco-lumbar trunks. At the 15 mm stage the posterior cardinals degenerate almost entirely except for persisting portions, which are left only at their cranial and caudal extremities. Similarly, after the right subcardinal vein has formed an anastomosis with the hepatic vessels, the subcardinal system undergoes extensive degeneration. Asymmetrical segments are left to form portions of the IVC. The gonads and adrenal glands retain their subcardinal drainage on both sides of the embryo- on the right side, the small segment of the adult IVC, which receives the right suprarenal and right gonadal veins, is a persisting portion of the right subcardinal vein.

The inter sub-cardinal anastomosis, formed in the 11 mm stage, enlarges to form the major part of the left renal vein. Caudal to the level of the renal veins, the right and left subcardinals disappear entirely.

The hepatic portion of the IVC develops from the anastomosis in the caval fold, between the liver vessels and the right subcardinal vein (Regan 1929).

Of the supracardinal system (thoraco-lumbar system), a post renal segment, on the right side, is all that normally remains. The right supracardinal vein (right paraureteric vein) persists and forms the greater part of the post-renal IVC. An anastomosis between the right subcardinal and right supracardinal (sub supracardinal anastomosis) veins is incorporated within the IVC and the right renal vein.

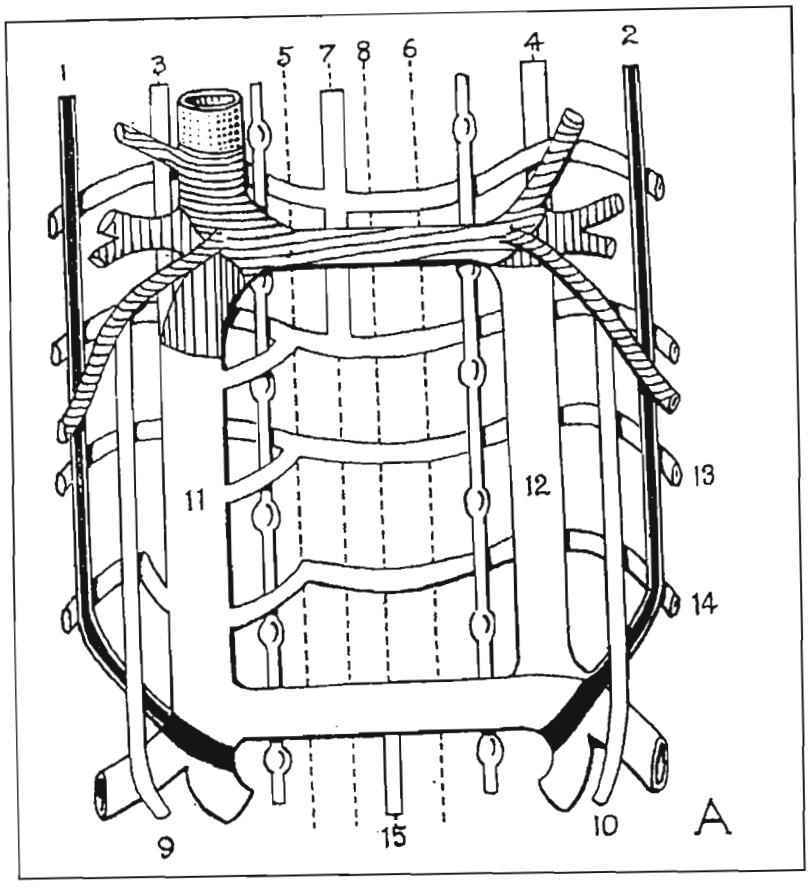
On the left side, a similar anastomosis forms part of the left renal vein, lateral to the points of entrance of the suprarenal and gonadal veins. On this basis, both Kolster (1901) and Cameron (1911), concluded that only that part of the left renal vein which lies lateral to the point of junction of suprarenal and renal veins is the homologue of the right renal vein, the more medial part of the left renal vein not having a homologous element on the right side of the body. The right gonadal vein commonly joins the IVC at a level which is within the area of the right supracardinal vein. A secondary anastomosis between the gonadal vein of subcardinal origin and the right supracardinal vein probably accounts for this condition.

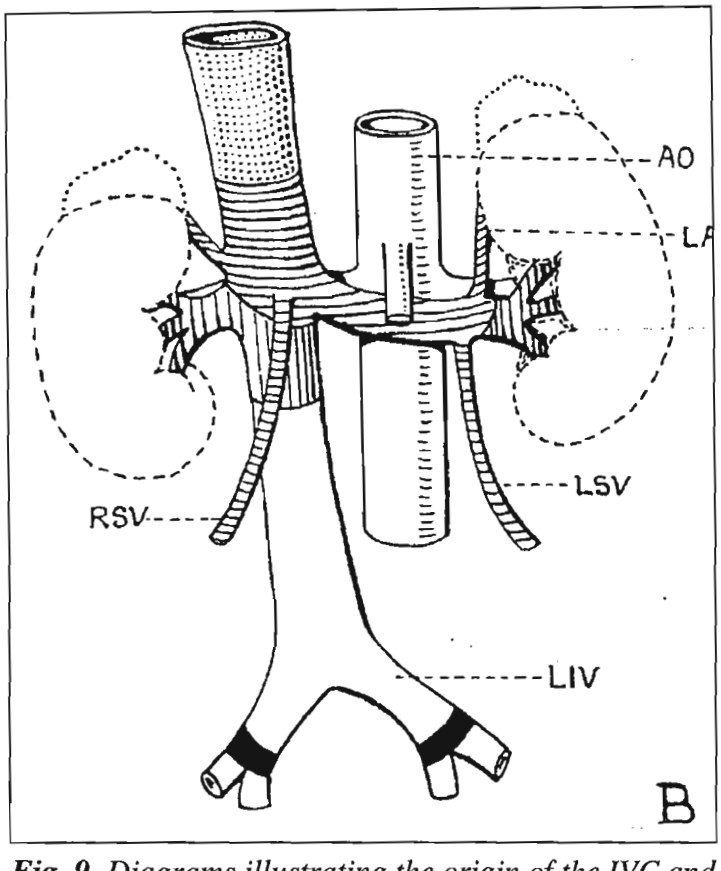
The circumaortic renal venous collar is composed from a ventral inter-subcardinal

anastomosis and by a small part of the right and left sub-posterior cardinal anastomosis (McClure and Butler 1925). On either side, the right and left sub-supracardinal anastomosis forms the ring, while dorsally it is completed by the intersupracardinal anastomosis (Kramer 1978a,b).

Usually, the ventral portion of the circumaortic plexus persists as the normal left renal vein. If the dorsal portion of this plexus persists, then the left renal vein is posterior to the aorta (retroaortic renal vein). If both the dorsal and ventral portions persist, there will be a circumaortic venous collar in the adult (Mitty 1975).

An interesting perspective on the development of the left renal vein has been presented by Gillot (1978). He argues that because the left renal vein takes its origin from the point of confluence of two major venous axes, longitudinal and transverse it should be considered as a segmental left IVC. To substantiate this argument he describes the development of the left renal vein as being fabricated into a single vein which began with two unequal entities. These are firstly, a glandular ventral one which constitutes the foundation for the future left renal vein. Represented by the left subcardinal vein, it drains practically the whole of the nephrogenic tissue, first the mesonephros and then the metanephros. As discussed earlier, its cephalic relic forms the suprarenal vein, while its caudal relic forms the left gonadal vein. The left subcardinal vein then loses its symmetry in exchange for a ventral aortic (pre-aortic) anastomosis, taking the form of a large plexiform bridge. By condensation it moulds the medial terminal segment of the left renal vein. The second entity, dorsal and parietal, Gillot concedes is poorly understood. This entity groups together the connections of the left renal veins with the vertebral plexus and the azygos system. He argues that the vector of these diversions is neither the posterior cardinal nor the supracardinal vein, but probably the medial sympathetic vein because it forms an essential part of the azygos system, giving rise to the definitive root at precisely the level of the renal veins (Regan 1927). This sympathetic vein is united to its symmetrical homologue by way of a pre-vertebral, dorso-aortic component, the subcentral vein. If Gillot's concept is accepted, the classic renal collar is therefore a hybrid. Its ventral





A *In relation to the venous lines (modified from GA Seib)*
B *Adult inferior vena cava, showing the aproximate areas contributed by the embryonic veins. Stippled areas - hepatic portion of inferior vena cava. Horizontal hatching - subcardinal. Vertical hatching - subcardino-paraureteric anastomoses. Black areas - posterior cardinal.*
1, 2 *posterior cardinal veins*
5, 4 *thoracolumbar line veins*
5, 6 *medial sympathetic lines*
7 *medial azygos root*
8 *left subcentral line*
9, 10 *subcardinal veins*
11 *right paraureteric vein*
13 *lumbar vein (3rd)*
14 *left lumbar vein*
15 *middle sacral vein*
AO *aorta*
LAV *Left adrenal vein*
LIV *left common iliac vein*
LSV *left sex vein*
RST *right sex vein*

Fig. 9 *Diagrams illustrating the origin of the IVC and its tributaries.* ***A*** *In relation to the venous lines* ***B*** *The adult IVC and renal veins showing the approximate areas contributed by the embryonic veins. (from Franklin 1937, modified from Seib)*

segment corresponds to the anastomosis of the subcardinal veins, and its dorsal retro-aortic segment to the anastomoses of the medial sympathetic veins.

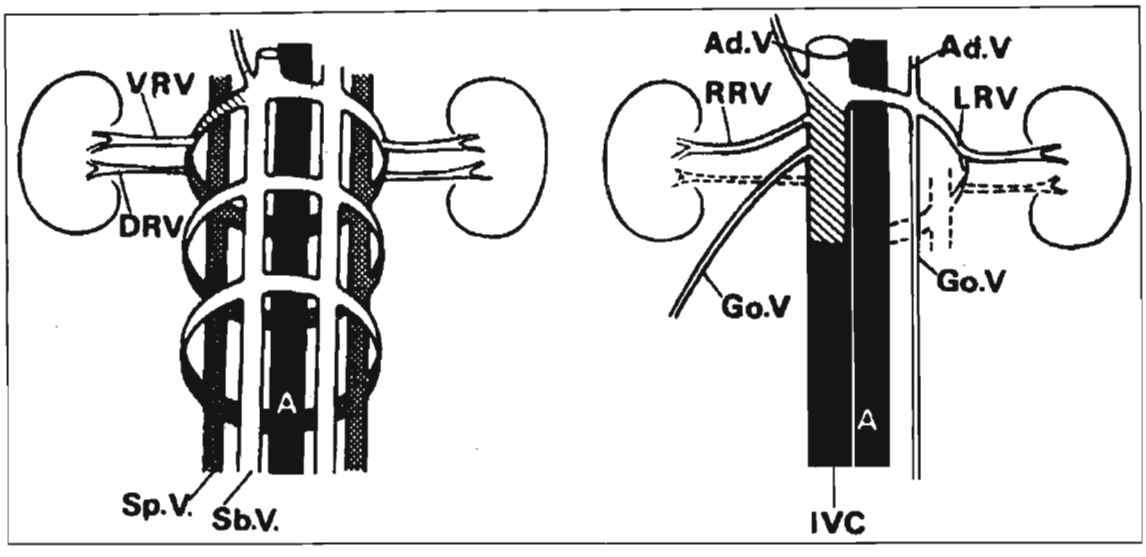


Fig. 10 *a) Development of the renal veins and superior vena cava. (from Beckmann and Abrams 1980).*
Top left*: Patterns at the eighth week of fetal life. The posterior cardinal veins have already atrophied and the venous drainage of the lower body is provided by the paired subcardinal and supracardinal veins, which are interconnected by venous rings. The venous ring at the renal level is called the renal collar.*
Top right: *Adult pattern. The IVC develops out of the right supracardinal vein, the right supracardinal-subcardinal anastomosis (diagonal lines) and portions of the intersubcardinal veins. (Sp.V. = supracardinal vein, Sb.V. = subcardinal vein, Go. V. = gonadal vein, Ad. V. = adrenal vein, A = Aorta, IVC = inferior vena cava)*

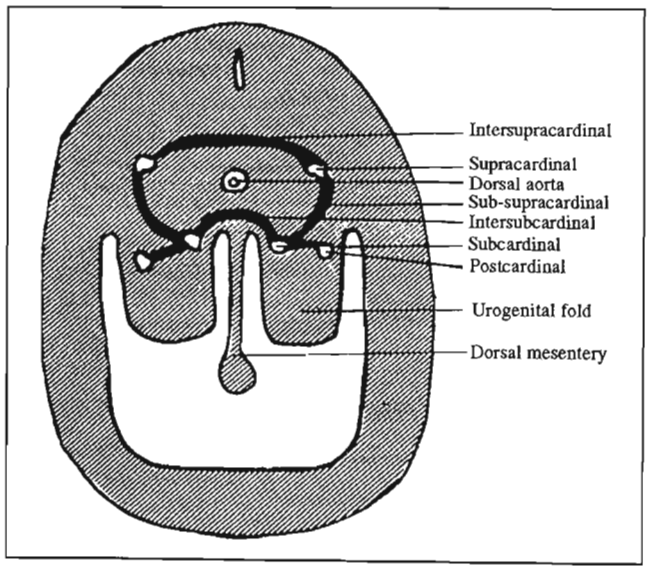


Fig. 10 *b) Cross section through an embryo showing the positions of the cardinal veins and the components of the renal collar. (from Kramer 1978)*

2.3 VARIATIONS OF RENAL VEINS

The embryological derivation of the renal veins is complex and it is therefore not surprising that these veins, the left renal vein in particular, presents an almost unlimited variation in its form. Since its development is directly linked to the definitive IVC, variations in the development of this vessel together with the congenital anomalies of the kidney present difficulty in classification (Becker 1962). In an attempt to classify the anomalies of the inferior vena cava (and of the renal veins), Edwards (1951) proposed a classification based on the topographical relationship of the vessels rather than upon their embryonic derivation (Table V).

A brief review only of the relevant variations of renal veins is presented using Edwards's classification as a basis.

2.3.1 MAJOR ANOMALIES OF THE IVC

The major anomaly affecting the renal veins occurs in the infra- renal segment and includes the double infra-renal cava and the sinistral infra-renal cava. The left infra-renal cava must be differentiated from that seen in situs inversus, in which the entire vascular system is transposed, along with the viscera. The single left sided cava is a rare anomaly: in several reviews of dissections of over 2 000 cadavers, the incidence was 0.2% to 0.5% (Seib 1934, Reis and Esenther 1959 and Milloy *et al.* 1962); whilst the duplication of infrarenal cava was noted to vary between 2.2% and 3% (Seib 1934; Davis *et al.* 1958 and Reis 1959).

2.3.2 LESSER VARIATIONS OF THE IVC AND ITS TRIBUTARIES: THE RENAL VEINS

2.3.2.1 ANOMALIES OF THE KIDNEY

A kidney may be classified as ectopic by virtue of its aberrant location, its odd shape, short low pedicle, anterior pelvis or short ureter. The location has been described by Braasch (1931) as pelvic, iliac, or abdominal. Eisendrath and Rolnick (1938) offered a more

TABLE V PROPOSED TOPOGRAPHICAL CLASSIFICATION OF ANOMALIES OF THE IVC- EDWARDS (1951)

PROPOSED CLASSIFICATION	EMBRYOLOGIC EQUIVALENT
A. Major anomalies of the IVC	
I. Left cava with situs inversus	
II. Major anomalies of the cava proper	
a. In the supra-renal segment	Pre-renal cava
1. Azygos continuation (with right, left, or double infra-renal cava)	Persistent supracardinal system (absence of the vena cava).
2. Reception of the portal vein	
3. Reception of a right pulmonary vein.	
b. In the infra-renal segment	Post-renal cava.
1. Double infra-renal (post ureteric) cava	Persistent left post-renal cava, or persistent supra-cardinal system. Persistent left supracardinal vein.
2. Left infra-renal (post ureteric) cava	
3. Lateral pre-ureteric cava	Persistent posterior cardinal vein or peri-ureteric ring.
4. Medial pre-ureteric cava	
5. Co-existent pre-ureteric post-ureteric cavae	Persistent subcardinal vein.
6. Reception of a portal tributary	
B. Lesser variations of the cava and its tributaries	
I. Attenuated or abridged representations of anomalous cavae.	
a. Partial azygos continuation	
b. Infra-renal caval rudiments.	
1. Abridged left or right cava	
2. Inter-caval anastomoses and caval diverticula	
c. Lateral pre-ureteric veins	Persistent posterior cardinal vein.
d. Medial pre-ureteric and para-aortic veins	Persistent subcardinal vein.
II Iliac veins	
a. Pre-aortic iliac confluence	Persistent sub-aortic plexus, circum-umbilical ring, or cardinal collateral vein (Marsupial cava)
b. Reduplication	
c. Contralateral course	
III Renal veins	
a. Anomalies of kidney or renal vein	
1. Associated with ectopia	
2. Persistent renal collar	Persistent renal collar (Retroaortic renocaval arch).
3. Left retro-aortic renal vein	
4. Associated with horseshoe kidney	
b. Accessory renal veins	
c. Variations of extra-renal connections	
1. Suprarenal and sex veins	
2. Ureteral and pre-ureteric veins	
3. Lumbar and azygos veins	
4. Peri-renal veins	
5. Portal tributaries	
IV. Parietal channels	
a. Lumbar and ascending lumbar veins	
b. Azygos system	
c. Retro-aortic veins	Sub-central veins (Anterior part of vertebral plexus)
d. Inferior phrenic veins	

exacting classification which, in summary, included lumbar (high, low and ilio-lumbar), iliac, ilio-pelvic and pelvic. In their analysis, these authors state that from a total of 207,321 autopsy reports in the literature, 205 cases of simple renal ectopia had been obtained, an incidence of approximately 1 case in every 1000 post-mortem studies. The clinical incidence is appreciably greater, estimates varying from 1 in 500 to 1 in 800 patients. In a much earlier study, Guizetti and Pariset (cited by Anitschkow 1912) found an incidence of1 in 1000 autopsies.

In 1905 Hill stated that "there is no vascularisation of the kidney, until it has reached its permanent position". He argued that if this permanent position was the normal position, the renal vessels have the usual normal origin and follow the usual course, but if the permanent position was abnormal, the renal vessels originated from some nearby arterial trunk and tended to take a direct course to the kidney. Strater (1906), however, maintained that the kidney during its embryonal wandering passed the region of several arteries and was, during this time, supplied by several vessels. If the wandering stopped before the normal location was reached, these properly temporary vessels became permanent ones. In his attempt to conclude this discussion, Plummer (1913) stated that there was no dispute that the permanent vascular supply was from the vascular territory where the kidney took its definitive location. The vascular supply of the kidney was abnormal, because the location of the kidney was abnormal, the supply adapting itself to the location of the kidney. The abnormal vascularisation was consequently a secondary matter and not a cause of renal dystopia.

Dorland (1911) proposed a classification of congenital anomalies of the kidney that differed slightly from that suggested by Newman (1907). Table VI shows Dorland's proposed classification of congenital anomalies of the kidney and includes the percentage incidence based on a comprehensive literature review. Of these anomalies, 53.2% occurred in males, and in slightly over 70%, the left kidney was the defective one. In a similar earlier study, Gerard (1905) arrived at practically the same conclusion as Dorland.

TABLE VI TABLE SHOWING DORLAND'S PROPOSED CLASSIFICATION OF CONGENITAL ANOMALIES OF THE KIDNEY INCLUDING PERCENTAGE INCIDENCE (Dorland 1911)

I VARIATIONS IN FORM AND SIZE	INCIDENCE (%)
1. Lobulation	3.0
2. Hypertrophy of one kidney/anomalies of vascularisation	2.0
3. Atrophy of one kidney (rudimentary kidney)	9.6
II. VARIATIONS IN NUMBER	
1. Absence of both kidneys	1.0
2. Absence of one kidney (single, solitary,unilateral, or unsymmetric kidney)	19.5
3. Presence of more than two kidneys (supernumerary kidney)	4.0
III. VARIATIONS IN LOCATION	
1. Dystopic or ectopic kidney	8.0
2. Right- or left-sided double kidney (non-fused)	3.2
3. Mural kidney	1.6
4. Pelvic kidney	7.2
IV. FUSION OF THE KIDNEYS	
1. Horseshoe kidney	29.2
2. Sigmoid kidney	6.4
3. Disc-shaped or placentoid kidney	4.8

Detailed descriptions of the renal anatomy including the venous drainage in these anomalous kidneys are presented by authors already mentioned as well as Morgagni (credited with the first accurate description of horseshoe kidney-cited by Gutierrez 1934), Botez (1912), Lipschutz and Hoffman (1918), Judd and Harrington (1919) Stewart and Lodge (1923), Eisendrath *et al.* (1925), Higgins (1928), Sokolow (1930), Thomas and Barton (1936), Thompson and Pace (1937), Mackenzie and Hawthorne (1937) and Anson *et al.* (1939, 1942).

2.3.2.2 ANOMALIES OF THE RENAL VEINS

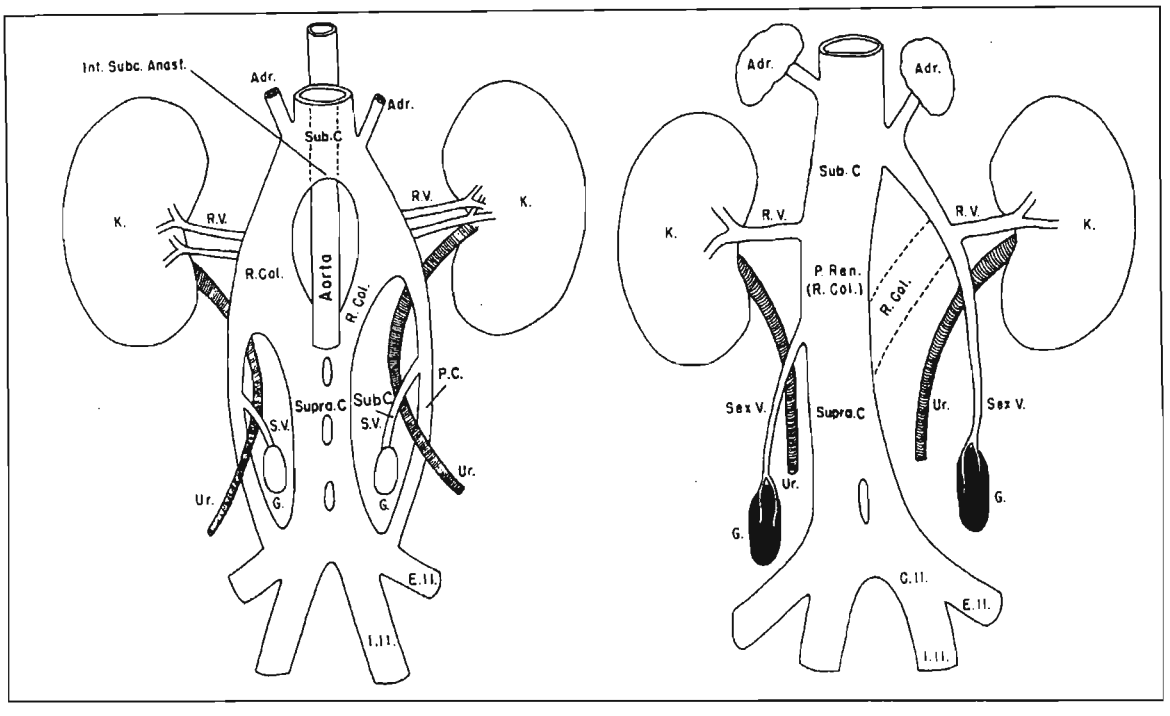
Unlike the right renal vein, its left counterpart presents at least two major variations. These are described by Edwards (1951) as the persistent renal collar and the left retro-aortic renal vein. Gillot (1978) describes these veins as the bifurcated vein and the ectopic vein.

2.3.2.3 Persistent Renal Collar

A venous renal collar, a term first used by Huntington and McClure (1907), may be defined as the occurrence of a renal venous channel coursing both anteriorly and posteriorly to the abdominal aorta. This anomaly appears to be confined to the left side (Seib 1934, Davis 1958, Reis 1959, Davis and Lundberg 1968, Brenner 1974, Mitty 1975, Kramer 1978, Beckmann and Abrams 1979. Kramer and Grine 1980). The bifurcation of the left renal vein is a splitting-partial or total, of the trunk into branches, usually of equal calibre. The partial bifurcation can be proximal or distal. The distal partial bifurcation reproduces the peri-aortic venous collar which is a very rare arrangement (Gillot 1978). The retroaortic branch supports the roots of the hemiazygos.

The circumaortic venous ring is actually triangular in outline (Anson and Caudwell 1932). The apex is the point of divergence of the two divisions, the base is the margin of the IVC into which the channels empty, and the sides are formed by the pre-aortic and post- aortic limbs of the divided trunk. The vein which constitutes the cranial side crosses transversely in front of the aorta at the level of the second lumbar vertebra; the vein on the caudal side passes obliquely (inferomedially) behind the aorta at the approximate level of the third vertebra. The limbs thus formed may be of equal size but, more frequently, the hinder segment is the smaller of the pair. Beckmann and Abrams (1979) noted that the preaortic limb diameter of 16.3 (11 -22) mm was always larger than the retroaortic vein. Usually the cranial segment receives the chief visceral tributaries (suprarenal, accessory renal and gonadal), while the caudal portion receives veins of parietal drainage (including lumbar and vertebral). The left gonadal vein may drain into the cranial segment sinistral to the entry of the caudal (retroartic) component (70%), at the same point (6%), dextral (21%) and directly into the caudal element (3%) (Gerard 1920, Seib 1934). The drainage segregation is not absolute however, since the suprarenal is commonly joined by the inferior phrenic, and the gonadal vein by a capsular tributary; similarly, the lumbar tributaries of the deep or post-caval limb receive vessels from the spinal cord and meninges directly or by the ascending lumbar vein as an intermediary (Nuzum 1914, Odgers 1931.)

The reported incidence of the renal collar varies considerably from 1.5% to 17%. (Table VII). While most authors found that the persistence of the renal collar demonstrated a marked male



Adr. (adrenal), C.Il. (common iliac vein), E.Il. (external iliac vein), I.Il. (internal iliac vein), P.C. (posterior cardinal vein), R.Col. (renal collar), RV (renal vein), S.V. (sexual or gonadal vein), Sub.C. (subcardinal vein), Supra.C. (supracardinal vein), Ur. (ureter).

Fig. 11 *a) Developmental diagrams of the circumaortic venous ring (**Left**) and normal pre-aortic left renal vein (persistence of ventral limb with regression of dorsal limb) (**Right**). (from Chaung et al. 1974)*

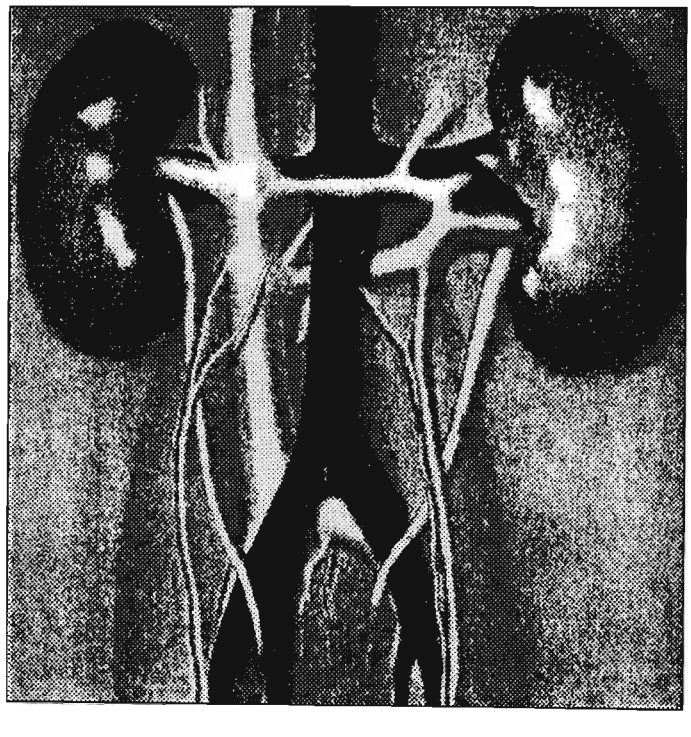


Fig. 11 *b)-The mammalian vena cava posterior - the renal collar (from McClure & Huntington 1925)*

predominance (Smith 1962 and Davis 1968), Kramer (1979) demonstrated an almost equal frequency among Black South African males and females (5.9% and 5.1% respectively.)

Beckmann and Abrams (1979) maintain that cavography was an unsatisfactory method of demonstrating these renal veins and that prior knowledge of a venous ring was important when blood samples from the adrenal or renal veins were to be collected. They cautioned that when caval interruption was planned, a circumaortic venous ring may provide a fully developed collateral pathway immediately after surgery if the procedure is planned without awareness of its presence.

2.3.2.4 Left Retroaortic Renal Vein

This vessel is a single ectopic trunk in a relatively low position which has a trajectory that is oblique inferiorly and retroaortic. Gerard (1920) applied the term "anastomose veineuse renocave retro- aortique" to this vessel, which Seib modified and called the retroaortic renocaval arch. Confusion exists in the literature regarding the terminology of this vessel and therefore its incidence. Whilst Hungtington and McClure (1920) employed the term "the renal collar" or "circum-aortic venous ring" both Seib (1934) and later Yelin (1940) noted that since the ventral limb of the circumaortic venous ring (the normal preaortic left renal vein) is occasionally lacking, the retroaortic renocaval arch assumes the renal drainage and becomes the so-called retroaortic renal vein. The veins join with the caval trunk usually below the level of the L2-3 disc (Gillot 1978). The retroaortic position of the left renal veins brings to it deep venous communications which do not exist on the right side : collateral channels connect with the lumbar veins, with extensive prevertebral plexuses, with the hemiazygos and occasionally, the iliac veins. The incidence of the retroaortic renal vein is reported to vary between 1.8% and 7.1% (Table VII).

TABLE VII-INCIDENCE OF RENAL COLLAR AND RETROAORTIC RENAL VEIN

REFERENCE	SAMPLE NUMBER	RENAL COLLAR (%)	RETROAORTIC VEIN (%)
Froriep *(1895)*	28	—	7.1
Zumstein *(1896)*	220	8.2	1.8
Jeanbrau *(1910)*	24	4.2	—
Hovelacque *(1914)*	20	30.0	—
Gerard *(1920)*	225	7.5	—
Eisendrath *(1920)*	218	—	4.1
Anson and Cauldwell *(1932)*	425	17.0	—
Seib *(1934)*	176	9.1	1.7
Fagarasanu *(1938a)*	—	8.5	7.0
Pick and Anson *(1940)*	215	16.8	3.4
Davis *et al. (1958)*	100	6.0	2.0
Reis and Esenther *(1959)*	—	2.4	—
Davis and Lundberg *(1968)*	270	1.5	1.8
Brener *(1974)*	—	1.5 - 8.7	1.8 - 2.4
Gillot *(1978)*	322	5.6	2.5
Beckmann and Abrams (1979)	76	11.0	0.0
Kramer and Grine *(1980)*	193	5.7	—
Nishimura *et al. (1986)*	31	3.2	0.0

Anomalous retroaortic left renal veins may be the site of spontaneous fistula between the aorta and itself (Lord *et al.* 1964 and Horan and Sharp 1967). The authors caution that this condition should be suspected when the renal vein is not encountered during dissection for control of the aorta proximal to the aneurysm.

Additional renal veins have been discussed (pages 12 and 15) and the variations of extra-renal connections are discussed further on page 67.

2.4 THE RENAL VASCULAR PEDICLE

Variety in the form of the renal pedicles, based on the number of constituent vessels (arteries and veins) is greater on the right than on the left. In addition, the simplest vascular pedicle, namely, single artery and vein bilaterally, occurs in less than 50% of instances (Harrison *et al.* 1978). While Anson and Daseler (1961) stressed that the simple

form of the renal pedicle as portrayed in standard anatomic texts, occurs in less than 25% of the cases studied critically in the laboratory, Pick and Anson (1940c), in his review of 200 specimens noted the following significant points regarding the renal vascular pedicle. Based on the number of vessels (and considering both sides - 400 kidneys), 39% were composed of two vessels bilaterally. He classified the renal pedicles on the basis of the number of constituent vessels into six groups. The majority, 59.8% had only two vessels. The highest number of vessels in any single pedicle was 8. Bilateral equality in the total number of vessels in the pedicles occurred in 49.5%. Thirty nine percent of this group had the simplest type of pedicle (2 right and 2 left vessels). He observed (as did Rupert 1915 and Merklin 1958) that bilateral equality in number of renal vessels was rare in the presence of supernumerary renal arteries or veins (10.5%). There were an equal number of arteries and veins in their pedicle sides in 64.3%. In the presence of supernumerary renal arteries or veins, equality was encountered in only 4.8%.

Single renal arteries and veins on both sides in the same specimen occurred in 38.5% of cadavers, whereas a single artery and vein made up the pedicle in 59.5% of sides. In attempting to classify specimens on the basis of the number of arteries and veins in the renal pedicles of 2 sides, Pick and Anson (1940c) determined 27 different varieties of arrangements. In classifying sides on the basis of the number of arteries and veins in the pedicle, he determined 12 different types. Since multiple renal veins were rare on the left side (1%) and common on the right (27.8%), Pick and Anson (1940c) concluded that the differences between renal pedicles, depending on side, were due chiefly to adult asymmetry in the renal venous drainage. The basis of this observation was the developmental transformation of a symmetrical plan into an asymmetrical caval plan.

Similar observations, although not in the detail presented by Pick ans Anson (1940c), were made by Eisendrath 1910, Rupert 1915, Anson *et al.* 1936, Merklin and Michels 1958, Ross *et al.* 1961, Sykes 1963 (b) and Harrison *et al.* 1978.

The various measurements of the left and right renal veins and the incidence of additional veins were presented under the review of the renal veins.

While a comprehensive review of the renal arteries is outside the scope of this dissertation, a very brief overview is presented. Normal renal arteries most commonly arise laterally, or anterolaterally or posterolaterally from the aorta between the levels of the lower third of the first lumbar vertebra and the upper third of the second, and slightly below the level of the origin of the superior mesenteric artery. Variations of approximately a vertebra in either direction can be expected, and supernumerary arteries and arteries to ectopic kidneys may arise from any level of the abdominal aorta, from the common, external or internal iliac arteries or, extremely rarely, from such unexpected sources as the hepatic, superior or inferior mesenteric, the right colic, or a lumbar artery (Adachi 1928). The two normal renal arteries may arise at the same or at different levels, but the right member of the pair is often higher (Adachi 1928, Merklin and Michels 1958).

From a statistical analysis of 11,000 kidneys reported in the literature, and based on 185 dissections made by Merklin and Michels (1958), the conclusion was drawn that the renal artery is single in 72% and double in 10% of the cases. Triple or quadruple renal arteries occur rarely. Superior polar arteries arise from the aorta in 7% of the cases and from the renal artery in 12%. Aortic inferior polar arteries occur in 5.5%, renal arteries in 1.4%. Graves by means of plastic corrosion casts, recently showed that the kidney is a segmental organ like the lung and liver. The segments of the kidney that he described are apical, upper, middle, lower and posterior. Merklin and Michels correlated these observations on the renal arteries with this concept and confirmed the contention of Graves that the arterial pattern inside the kidney is constant irrespective of the varied origin of the segmental artery. However Verma *et al.* (1961) concluded that a single scheme for the projection of vascular segments on the renal surface was not feasible. Like so called accessory hepatic arteries and "accessory" hepatic ducts, accessory (aberrant) renal arteries are normal structures. Anatomically and functionally considered, they take origin from the renal trunk, aorta or some other source, and severance of any renal artery produces necrosis in the area it supplies as is the case when an aberrant renal hepatic artery is severed.

The right renal artery is longer than the left and nearly always courses behind the IVC.

When multiple renal arteries are present, the caudal ones often take a pre-caval course. The length of the right renal artery from aortic origin to its point of division varies from 0.5 to 8 cm, while that of the left varies from 0.5 to 6cm (Levi 1909). Anson *et al.* (1936) noted the average length of the right renal artery as 7.1cm and that of the left 6.2 cm. The calibre of the right and left renal artery is the same, the average diameter being 0.55cm with variations from 0.4 to 0.7cm (Hou-Jensen cited by Merklin and Michels 1958). The diameter of an accessory (supernumerary) renal artery varies from 0.1 - 0.6cm and is dependent on the extent of the kidney area supplied, the superior and inferior renal polar arteries often being half the size of the main renal artery. In some cases, the superior and inferior polar arteries have the same calibre as a hilar branch (Merklin and Michels 1958).

2.4.1 RELATIONSHIP OF RENAL VEINS TO RENAL ARTERIES

The renal veins are described as being ventral to the renal arteries (Williams *et al.* 1989). However, in their analysis of 125 specimens, Anson and Daseler (1961) found significant variations to this relationship. In 47.6% of the sides (58 right and 61 left), the renal artery or arteries were dorsal to the renal vein. In 42.0% (54 right and 51 left), the renal artery descended from its more cranial aortic origin to a position ventral to the renal vein. In 2.4% (3 right and 3 left), the renal artery ascended from a more caudal aortic origin to a position ventral to the renal vein. In 8.0% of the sides (10 right and 10 left), the renal arteries and veins were not in a direct dorsal or ventral relationship - instead, the renal arteries were definitely either cranial or caudal to the veins.

Furthermore, Weinstein (1940) observed in a series of 203 specimens that while several instances of additional renal veins occurred independently, in the majority of specimens they were associated with arterial variations from the normal. Of the 18% of instances of multiple renal veins on the right side, only 5% occurred independently of arterial variations. Of the 9% instances of multiple veins on the left only four occurred independently.

2.4.2 RELATIONSHIP OF GONADAL ARTERY TO RENAL VEINS

The relationship of the gonadal arteries (testicular and ovarian arteries) to the renal pedicle, and more specifically in relation to the renal veins, is both anatomically and clinically significant since in half the population a gonadal artery is closely related to the renal pedicle (Notkovich 1956). On the left side, the renal vein is crossed by a gonadal artery in 33.8% of cases while on the right side it occurred in 16.3%. In these instances the gonadal artery may descend from a higher level than the renal vein and cross in front of it, or the gonadal artery may ascend from a lower level than the renal vein and arch around it. Notkovitch (1956) classified the gonadal arteries into three types according to their relation to the renal vein. Testicular or ovarian arteries may arise from the aorta or the renal artery: (a) behind or below the renal vein; (b) above the level of the renal vein, or (c) behind or below the renal vein, but, instead of descending, the artery on the left ascends behind the renal vein, curves over its upper border (lateral to the suprarenal vein) and then descends in front of it. The latter type (22%) constitutes the arched testicular / ovarian artery of Luschka (1863). The looped course of the gonadal artery may be in front of the renal vein when the latter passes behind the aorta.

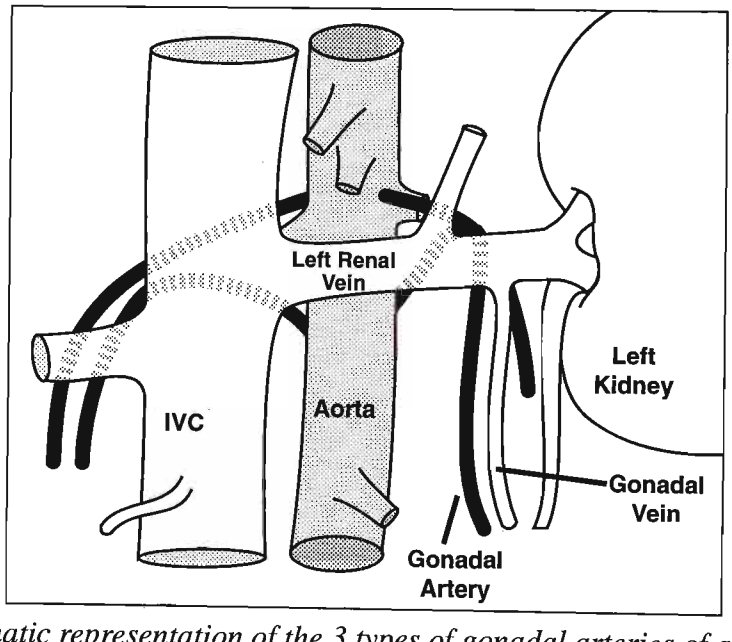


Fig. 12 *Schematic representation of the 3 types of gonadal arteries of aortic origin on both sides: Type I, descending directly; Type II, crossing in front of the renal vein; Type III, arching over the renal vein (adapted from Notkovich 1956)*

Anson and Kurth (1955) likewise stressed the fact that testicular artery presents more unfamiliar relations on the left than on the right. According to their observations, the artery may accompany the renal vein in the middle half of the pedicle, hook around the renal vein, pass through the latter in a hiatus (3%) or over a tributary thereof, loop around a lumbar tributary and course through the arms of the bifid testicular vein.

This anatomical relationship contributes directly to the gonadal artery acting as a pathologic factor in compressing the renal vein. This compression is manifested through dissections, by deformations, angulations and narrowings of the renal vein found frequently in places where it is crossed by the gonadal artery and is sometimes accompanied with a variable degree of dilatation of the testicular or ovarian veins and hence acts as a possible aetiologic factor of idiopathic varicocele in the male, an ovarian varicocele or varicocele in the broad ligament of the female. The arched gonadal artery may likewise be a factor in orthostatic albuminuria and, by compression of the renal vein have a direct influence on the direction of the blood flow from the kidney and gonads (Fagarasanu 1938a; b, Notkovitch 1956).

The varied sites of origin of the gonadal arteries from the aorta (below, above or under the renal vein) are explained embryologically by the fact that the gonadal arteries are persistent branches of the mesonephric arteries that develop cranial or caudal to the renal pedicle. By crossing the latter with the descent of the testes, the arched gonadal artery (one that loops over the renal veins) is formed, as is normally the case in fish, in which the elongated kidney is the mesonephros and receives numerous branches from the aorta.

2.5 VERTEBRAL RELATIONS, POSITION AND MOBILITY OF KIDNEYS

The normal kidneys are usually described as being situated between the twelfth thoracic and the upper three lumbar vertebrae. However, Anson and Daseler (1961) demonstrated from 194 specimens, an incidence of 8.2% on the left side and 6.2% on the right side, in which the superior pole extended above the level of the twelfth thoracic

vertebra. A higher percentage, 17.5% on the left and 33.2% on the right, of the renal poles were situated below the lower border of the third lumbar vertebra. The reverse arrangement may exist : McClellan (1956) in a study of 1500 excretory pyelograms, found the left kidney to be lower than the right in 5.1%.

However, in their investigations into the position and mobility of the kidneys, Moody and Van Nuys (1940) recommended that the kidneys like other abdominal viscera should be recognised as normally "floating viscera" and demonstrated the mobility of the kidney in the erect and supine position. They found the position of the kidneys in 450 healthy males and females in the erect position to be between L1 - L4. With the subjects erect, the cephalic pole of the right kidney was below L1 in 18% of males and in 43% of females, but the cephalic pole of the left kidney was below L1 in only a small percentage of both sexes. The caudal pole of the right kidney in the erect subjects was below L4 in 18% of males and 34% of females whereas on the left side it was not often below L4.

With the subjects supine, they found that the most common position of the cephalic pole of both kidneys in both sexes was opposite T12 and the most common position of the caudal pole of the kidneys in both sexes was opposite L3. In the erect position the cephalic pole of the right kidney in the adult male was below T12 in 29%. In the supine position, the caudal pole of the right kidney was below L3 in 38% of males and 48% of females, whereas the pole of the left was below L3 in 17% of males and 9% of females.

Moody and van Nuys noted further that the length and range in live subjects was greater than that recorded for cadaveric material. The most common length was between 12 and 14 cm and the range from 9 to 15 cm. The excursion of the kidneys due to forced respiration varied by 0.1 cm to 6.5 cm.

2.6 RENAL LOBES

As the lung is considered in terms of bronchopulmonary segments, the human kidney may also be realistically described in terms of its lobar makeup (Hodson 1978). A renal lobe may be regarded as a central mass of medulla (the pyramid) surrounded on all sides, except where the papilla emerges, by a layer of cortex. The overall shape of this cortex will therefore be in the form of a deep-sided bowl. The septa of Bertin are formed by the approximation of two layers of "septal" cortex of two adjacent lobes. In the adult these two layers are mainly fused (i.e. the late embryonic plane of cleavage is obliterated) and the grooves on the outer surface of the kidney become less distinct or disappear altogether. The renal lobe may therefore be regarded as a major renal unit, a group of which in various stages of fusion, comprise the kidney. It is generally accepted that a human kidney has an average of about 14 lobes (Lofgren 1949).

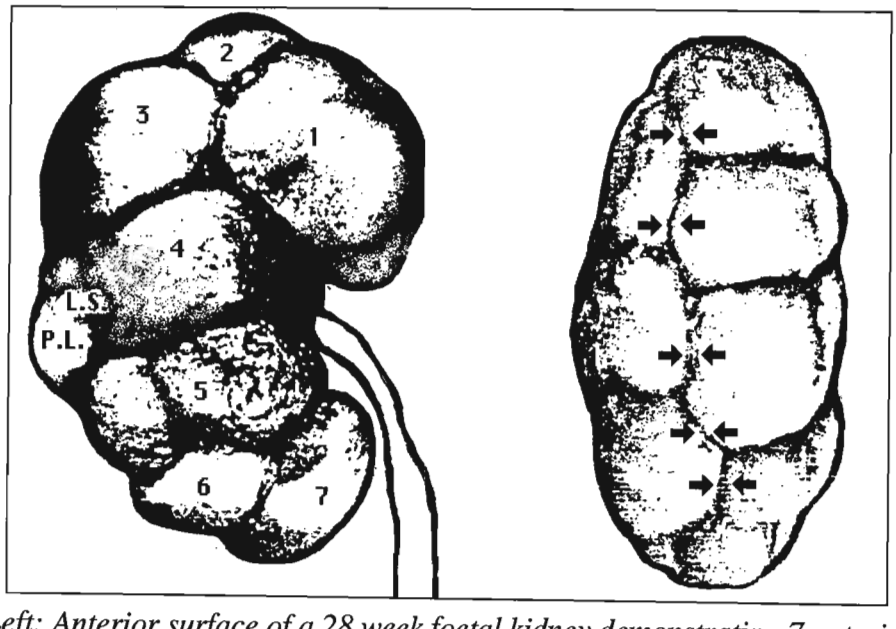


Fig. 13 *Left: Anterior surface of a 28 week foetal kidney demonstrating 7 anterior lobules, the longitudinal groove (LS) separating the posterior lobule (PL) from the anterior surface. Right: Lateral view of a 30 week foetal kidney showing the longitudinal groove. (from Sykes 1964)*

The upper pole is made of 6 lobes, in various states of fusion, that extend across the full thickness of the kidney, 3 anterior and 3 posterior. The lower pole comprises 4 lobes, also partially fused, 2 anterior and 2 posterior. In the middle zone there are 2 anterior and 2

posterior lobes, but they differ from both sets of polar lobes in two respects. First, the 2 pairs of lobes are separated from one another by the renal sinus and its contained structures. Second, they are not usually fused but are well differentiated, the pyramids of both being completely surrounded by cortical tissue except for their papillae and small circumpapillary areas. The Lofgren definition of a kidney with 14 lobes however, applies only to the majority of kidneys, with the average number of papillae being 12 to 13. However, if a lobe can be identified by the presence of a papilla, then the actual number can vary from as few as 6 to as many as 34 or more individual or partially fused renal lobes.

The renal clefts in the foetal kidney follow a constant pattern of development (Sykes 1964). The first cleft discernible to the naked eye appear at the 10th week of intra-uterine life in tissue derived from the metanephric blastema, which divides correspondingly to the branching of the ureteric diverticulum. According to Harrison (1959), the first division of the ureteric diverticulum can be seen in the 13mm embryo. There appears to be a time lag between the internal division of the ureteric diverticulum and the external division of the blastema, manifest on the surface as a cleft. The normal maximum number of 14 lobules is present not later than the 28th week of intra-uterine life, whereas division of the ureteric diverticulum ceases by the end of the 5th month. Thus there also appears to be time lag between the development of the renal clefts and their corresponding calyces. Huber (1932) states that thirteen or more generations of tubules of different orders are formed by division of the ureteric diverticulum, and the final foetal pattern is achieved by absorption of certain of the smaller divisions. The time lag may be necessary for the calyces to develop to the final number of 14; after this has occurred the renal clefts divide the surface of the kidney into 14 corresponding lobules. This theory is supported by the surface of the foetal kidney, which only shows lobules corresponding to the final caliceal structure and not to the previous complex division of the ureteric diverticulum (Sykes 1964). The incomplete fibrous septa that pass from the renal capsule towards the calyces are similar to those seen in the kidney of the Cetacea, which is essentially a number of small kidneys united by fibrous tissue. This type of kidney which is a segmental organ resembling a blackberry, contains one calyx and is supplied by a single branch of the renal artery and is

drained by a single tributary of the renal vein. These units of kidney tissue are termed either a "renculus" (Narath 1951) or a "renule" (McMinn 1984). The lobulations in the foetal kidney may be vestigial structures or represent surface marking of an underlying segmental arrangement of renal tissue (Sykes 1964). Hodson however, cautions that the pure renal lobes as described above, occur throughout in only a minority of kidneys. A state of fusion of 2, 3 or more lobes is much more commonly encountered due either to a developmental failure of separation or to fusion of previously distinct individual units in the later stages of maturation of the kidney.

In nearly 50% of subjects, some traces of foetal lobulation remain (Sykes 1964). Brodel (1901) stated that "a novice may see a perfectly smooth kidney but an experienced eye may detect lobulations". Persistent foetal lobulation was observed to occur in 3% of the population (Dorland 1911) while Weinstein *et al* (1940) noted an incidence of 6.7% from a series of 406 kidneys. Of these 3.9% occurred on the right, 2.7% on the left and 1.2% were bilateral. He also observed that of those kidneys with lobulation, 5.4% had an abnormal blood supply. Harrison *et al.* (1978) observed a 4% incidence of persistent fetal lobulation. The kidneys in neonates invariably show excellent remains of lobulated surfaces. However, during the fifth year of life, this lobulate appearance, as a rule, disappears and in the majority of adult kidneys, only a few minute white lines, with an occasional groove remain. In some cases even these lines and grooves disappear; the surface is left smooth and without markings except for the deep, short grooves that indicate the borderline between the superior pole, the central part and the inferior pole, which arise from the hilar angles on the anterior side of the kidney. In other cases, the pronounced lobulate appearance of the surface is retained until adult life (Brodel 1901, Morrison 1926, Heidenhain 1937 and Smithuis 1956).

In considering the blood supply of the renal lobe it is necessary to recall that it was Hyrtl (1882) who had first demonstrated that there was a natural division line ("naturliche Theilbarkeit der Niere") between two arterial trees, made respectively by the anterior and posterior primary divisions of the renal artery. In 1901, Brodel substantiated this

contention with corrosion casts, maintaining that the anterior division of the renal artery supplies three fourths of the kidney while the posterior division supplies only one fourth. To avoid severance of the collecting tubules of the posterior pyramids and to attain an avascular area, Brodel suggested that the incision in a kidney should be made along the kidney's lateral convex border, slightly posterior to its midline. On the basis of a thorough knowledge of intrarenal segmental distribution of the renal arteries, Graves (1954) concluded that the area involved in this incision method of Brodel is by no means a bloodless area. Graves suggested that if an incision is made on a radial and intersegmental plane, it may prove to be less vascular at operation. The lobar arterial blood supply from its distribution of the major branches of the renal artery has been described by various anatomists including Graves (1954), Boijsen (1959), Verma *et al.* (1961), Sykes (1964a), Fine and Keen (1966) and Engelbrecht *et al.* (1969). These vessels determine the major regions of supply and were important from a surgical point of view (Hodson 1972). The distribution of the more distal supply, interlobar and arcuate arteries, is governed by the lobar make-up of the individual kidney, and varies with the number of lobes. It also varies as to the number of arcuate branches given off per lobe from kidney to kidney, but much less between lobes in the same kidney.

Opposing Graves's specific and constant segmental arterial pattern of the adult kidney, Smithuis (1956) on the basis of a study of 100 plastoid corrosion specimens, maintained that although there is a natural divisibility between the ventral and dorsal lobes with their respective arteries (Hyrtl 1882 and Brodel 1901), the unit structure of the kidney itself (the lobe), precludes any uniform segmentation of the organ, for the renal lobe comprises a pyramid with the cortical layer above it. While it is desirable to accept the renal lobe as the basis of possible renal segmentation, a study of the internal vascularization showed that no renal lobe has an independent blood supply, since every lobe is supplied with blood from at least two sides, this via interlobar arteries and arciform rami. Smithuis acknowledged that in the adult kidney there are, in many cases, remnants of neonatal surface markings (grooves and white lines) localizing the division between the superior pole and the central part of the kidney and between the latter and the inferior pole. These surface projection

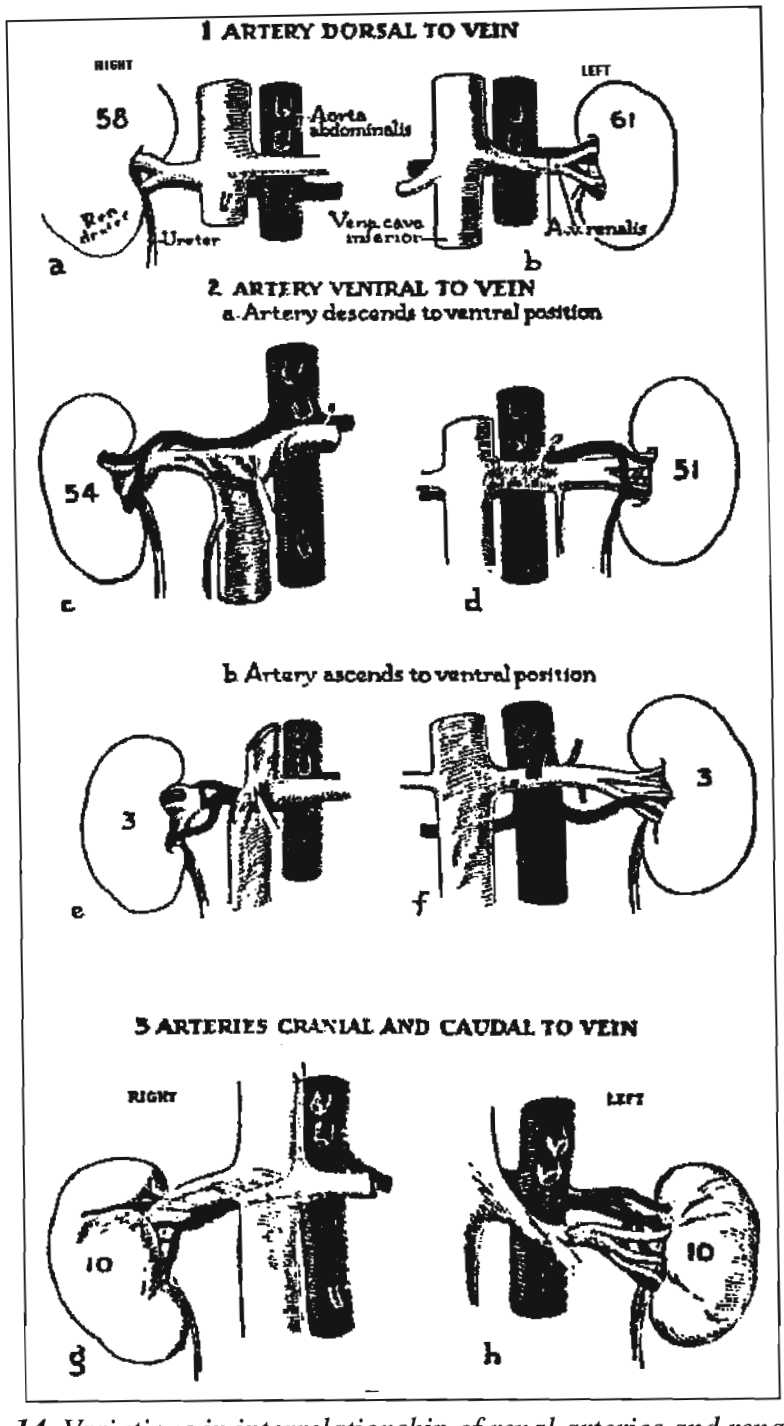


Fig. 14 Variations in interrelationship of renal arteries and renal vein (from Anson and Daseler 1961).

lines were, in his opinion, surgically meaningless, from the point of view of embryonic structure of the kidney, since the renal lobe had always been identified as the basis of renal segmentation. However, Sykes (1964a,b) concluded that the areas of kidney tissue supplied by the five segmental arteries corresponded on the surface of the organ to certain of the lobulations. He noted further that there were three lobar veins, each draining a third of the kidney substance, both anteriorly and posteriorly. He named them upper, hilar and

lobar veins. Divided by lobar clefts, the three lobes of the kidney on both surfaces, were named upper, hilar and lower lobes. Sykes concluded that these lobes corresponded approximately to the three areas of the kidney drained by the lobar veins.

He also maintained that there was no venous equivalent of Brodel's line, and that the upper lobar veins drained both the upper anterior and the upper posterior lobes. Similarly the anterior and posterior hilar and the anterior and posterior lower lobes were each combined in regard to their venous drainage.

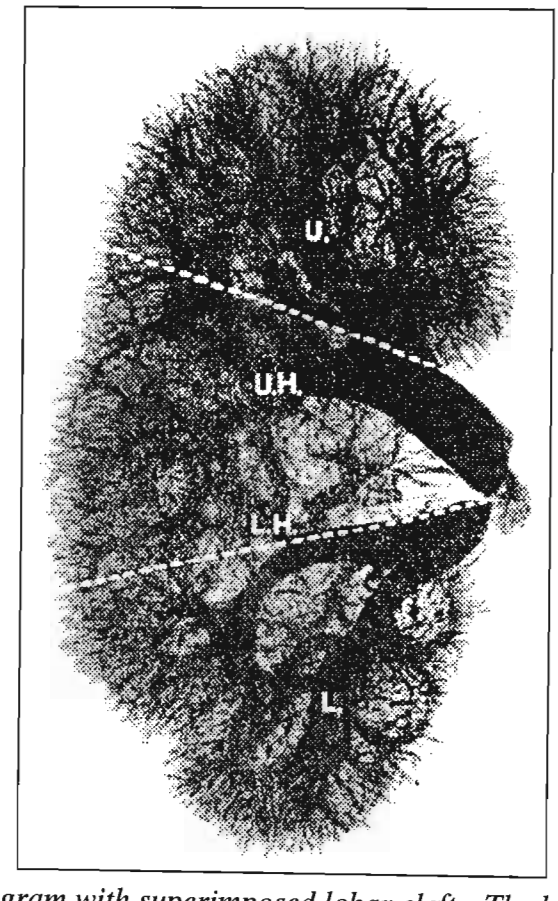


Fig. 15 *Renal veonogram with superimposed lobar clefts. The hilar lobe is drained by two veins: an upper hilar vein (U.H.) which unites with the upper lobar vein (U.) and lower hilar vein (L.H.) that unites with the lower lobar vein (L.) (from Sykes 1964).*

2.7 CLASSIFICATION OF PATTERNS OF DRAINAGE OF RENAL VEINS

Smithius (1956) was the first author to classify the course of the renal veins in an attempt "to yield a single type of extrarenal venous flowbed which would be regarded as a prototype". The prototype thus established (which suited 77% of kidneys) was a mode of ramification whereby the vein divides into a superior and an inferior branch, both of which in turn divide into rami localized ventral and dorsal to the renal pelvis, ie. in the formula.

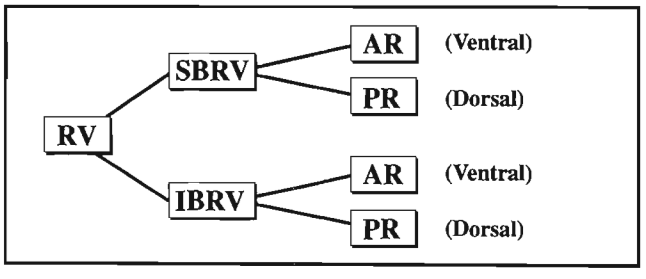


Fig. 16 *Classification of renal veins (adapted from Smithius 1956)*

The dorsal veins, less numerous than the ventral, curve round the cervix of the calyces of the superior and inferior poles and govern the efferent blood flow of the dorsal half of the kidney". Smithuis concludes this classification by mentioning the presence of polar veins and notes the independent distribution of the renal veins as compared to the arteries.

Whilst not proposing a classification, Merklin and Michels (1958) describe in detail the branching of the renal vein. They draw attention to a tributary of the renal vein from the dorsal aspect of the kidney which occurred in 30% of their series and noted Brodel's caution that this vessel's retropelvic position was an important anatomic point to be remembered in surgical intervention on the kidney.

Subsequently, Sykes (1963b) proposed a classification based on three tributaries of the renal vein viz. upper, middle and lower. He noted that the three veins each drained a third of the kidney parenchyma and that the manner in which these veins joined to form the renal vein presented six variations. The diagram presented from Sykes shows the six types of variations in diagrammatic form, the interrupted line representing the hilus of the kidney. In two of the six types illustrated, either the upper or the lower lobar vein passes directly into the IVC and these vessels were termed by Sykes accessory renal veins.

Later, Chaung *et al.* (1974) proposed a classification for the left renal vein only which was based on its variations viz. i) pre-aortic (80-90%), ii) circumaortic (2-3%), iii) retro-aortic (6-17%) and iv) supernumerary (1%).

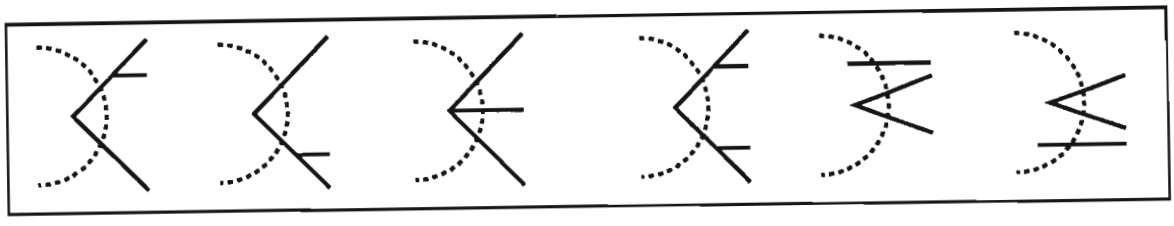


Fig 17 *Classification of renal veins (adpated from Sykes 1963b)*

Finally, Gillot (1978) proposed a classification based on grouped, branched and polar types of renal veins.

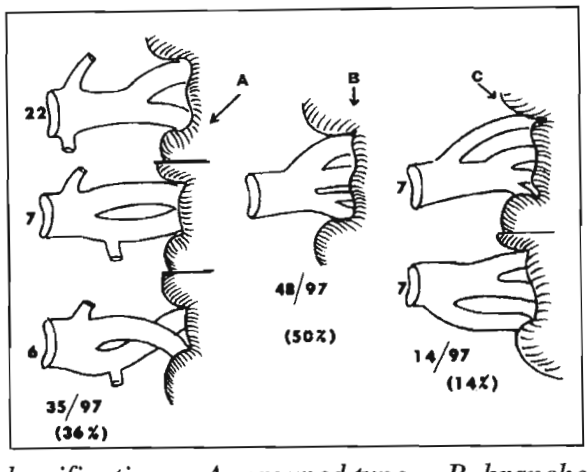


Fig. 18 *Renal vein classification: A grouped type, B branched type, C polar type (from Gillot 1978)*

2.8 RENAL VEIN VALVES

Valves in veins were first described in 1555 by Giambattista Canano. Fabricius (1603) stated that successive pairs of valves were arranged at right angles to each other and compared the position of the valves to the position of the branches of a twig of verbena. In 1603, Fabricius gave the first clear description of the semilunar valves of the vein, which later provided Harvey with a crucial point in his famous argument for circulation of blood. In 1854 de l'Aulnoit argued that the arrangement of these valves was not perfectly symmetrical. Later Bardeleben (1877) formulated his "Klappen-Distanz-Gesetz" in 1880 when he claimed that there is a fixed distance between valve-sites in the veins of the

extremities, and that "distal from every tributary lies a valve, proximal from every valve is a tributary - entry". He further claimed that of the numerous valves which were originally laid down, the greater number disappear entirely or in part during intrauterine development and post-foetal growth. These views were not supported by the subsequent investigations into the development of valves during embryonic life by Jager (1926) and Kampmeier and Birch (1927) who shed further information on valvular development. The valves at the entries of tributaries were referred to as ostial valves and those in the course of veins as parietal valves (Franklin 1937).

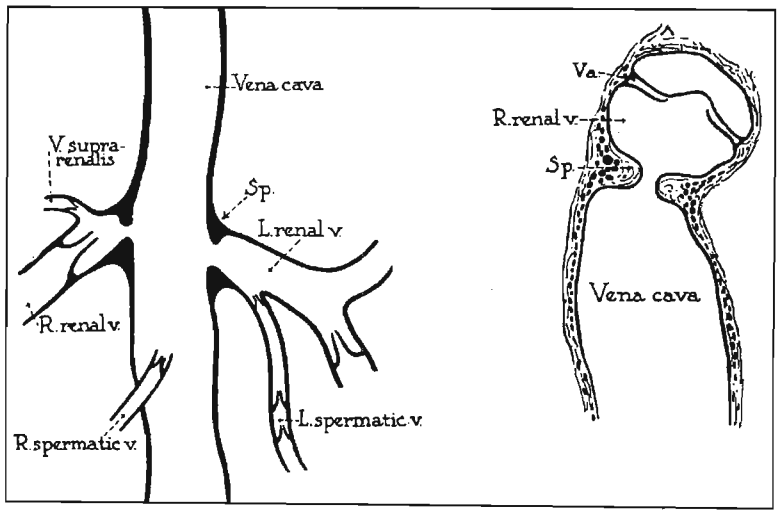


Fig 19 *Locations of sphincters and true valves (from Kampmeir and Birch 1927).*

In the literature, there are conflicting reports on the presence of valves in renal veins. Where valves have been reported, there is a striking variation in their frequency. Those that deny the existence of renal vein valves are Luschka 1863, Glantenay and Gorset (1904), Mollendorff (1943), Dalla Palma and Servello (1956), Gillot *et al.* (1960), Barry *et al.* (1962) and Blaivas *et al.* (1977). On the contrary, Henle (1868), Rivington (1873), Gengenbauer (1903), Kampmeier and Birch (1927), Fagarasanu (1938a), Kugelgen and Greinemann (1957), Hollinshead 1966, Ahlberg *et al.* (1968), Takaro *et al.* (1970), Beckmann and Abrams (1978, 1980) and Oleaga *et al.* (1978) have described the presence of valves in the renal veins.

In their description of the valves in the renal and spermatic veins in the foetus, Kampmeier

and Birch (1927) state that "the margins of the connection of both the right and the left renal vein with the vena cava protruded into the lumen as relatively massive seams or thickenings of the tunica media, which resembled sphincters. In the younger specimen there was no indication of them, except possibly on the left. Although the nature of these circular flanges suggests that they may serve as impediments to the reflux of blood towards the kidneys, I question if they can be interpreted as homologues of the other valves of the vascular system. What caused greater astonishment was to find, besides the sphincters just delineated, perfectly formed and competent valves in both renal veins. In the right vein of the newborn such a valve was situated in its terminal portion, in the left in one of its major branches"

Furthermore, he found that the apertures of the spermatic and suprarenal veins were all equipped with efficient valves in the foetus and that the short upper segment of the left spermatic vein excised for study contained three valves (Fig. 19).

In 1896, Poirier first described the valves located in the lumbar veins, which were found to be parietal and ostial, and concave on the surface facing the vena cava.

Takaro *et al.* (1970) maintained that although renal vein valves were relatively common, they were rarely detected or described during life. At autopsy, the incidence in the main right renal vein varies between 28 - 70% and the valves are found close to the entry of the renal vein into the IVC, while on the left side, valves are found in 4 - 36% of main renal veins and are located medial to the gonadal vein, within 1 - 4 cm of the caval orifice (Rivington 1873, Faragasanu 1938, Alberg *et al.* 1968 and Takaro *et al.*, 1970). Ahlberg *et al.* (1968) noted that there was a tendency towards a higher incidence of valves in renal veins that were supplied by gonadal veins without valves than by those with valves. On the right side valves occurred significantly more often in gonadal veins that terminate in the IVC than in those that empty into the renal vein. Valves of the intrarenal branches were observed in 40% of autopsied cases (Kugelgen and Greinemann 1958). The latter authors describe renal vein valves as being present in all age groups but acknowledge that partial involution may occur in adult life because of the finding of better developed valves in the newborn and children.

In their analysis of 98 renal venograms, Beckmann and Abrams (1978) found valves in 16% of patients on the right side and in 15% on the left, without predilection for any particular location. Angiographically, they appeared as thin, web-like structures which may block the passage of the catheter or of contrast material and hence cause poor venographic filling. They found very rarely, that these valves could produce total obstruction to the retrograde flow of contrast material. Oleaga *et al.* (1978) also highlighted the fact that the renal vein valves may create technical difficulties during renal venography and described their possible usefulness in selecting the site of anastomosis in patients undergoing splenorenal shunts.

2.9 RENAL ARTERIOVENOUS FISTULA

The intimate interrelationship of renal arteries and veins is the basis for renal arteriovenous fistula (Varela, 1928, Tortella 1936, Lasher and Glenn 1939, Springorum 1939); where vessels are intertwined, and where arteries pass through venous hiatuses or overlie venous plexuses, proximity serves as an important factor in the establishment of anomalous communication (Pick and Anson 1940a). John Hunter 1793 first described arteriovenous fistula more than two hundred years ago. Reid (1920) was the first to observe that organic cardiac disease was frequently associated with these vascular lesions. In 1928, Varela reported the first case of intrarenal arteriovenous fistula.

Intrarenal arteriovenous fistula may be classified as either congenital due to arteriovenous malformations or acquired (Esquivel and Grabstald 1964 and Snodgrass and Robinson 1964). In the acquired group are:

1) Fistulae following rupture of an arterial aneurysm (Boijsen and Kohler, 1962);
2) traumatic arteriovenous fistulae resulting from: penetrating trauma (Pelot *et al.* 1954 and Milloy *et al.* 1958), trauma of renal tissue in association with nephrolithotomy (Vest 1954; Boijsen and Kohler 1962); partial nephrectomy (Snodgrass and Robinson 1964) or percutaneous needle biopsy of the kidney (Boijsen and Kohler 1962, Love 1965);

3) arteriovenous fistulae in renal carcinoma, where the tumour has eroded the vein (Hamilton and Getz 1953; Myhre 1956; Edsman 1958; Scheifley and Daugherty 1959; Boijsen and Folin 1961 and Jantet and Foot 1962) and
4) stump fistulae following nephrectomy (Elliott 1961, Esquivel and Grabstald 1964 and Snodgrass and Robinson 1964).

Arteriovenous fistula of the kidney is an infrequently encountered lesion. With the increasing use of percutaneous needle biopsy of the kidney for diagnostic purposes (Bennet and Wiener 1965, Eklund and Lindholm 1971 and Meng and Elkin 1971), as well as with the escalation in the incidence of blunt and penetrating abdominal trauma, this lesion is being encountered with increasing frequency (Twigg and Pradhan 1962, Leiter and Gribetz 1972 and Angorn 1974, 1977). In addition, the widespread use of renal angiography is credited with the marked number of cases that have been diagnosed in the last three decades. An extensive review conducted in 1964, reported 55 such cases (Maldonado *et al.* 1964 and Love 1964). Renal angiography demonstrates not only the presence of a fistula but also locates it exactly. Furthermore it demonstrates the tributaries as well and thereby assists in the assessment of the operability of a given case and facilitates the planning of the operation (Boijsen and Kohler 1962). The angiographic findings of increased serpentine arteries with direct communication with the renal vein offer an unequivocal diagnosis. The amount of shunting will determine the degree of opacification of the IVC. In addition, grey scale ultrasonography may also assist with the diagnosis (Rao and Kimball 1978 and Thomas *et al.* 1979). Management of clinically significant intrarenal arteriovenous fistula has been managed by total or partial nephrectomy (Tynes *et al.* 1970, Kostiner and Bennet 1973). In an attempt to conserve more renal tissue and function, other local or segmental surgical procedures have been devised, including afferent branch renal artery ligation, direct ligation or excision of fistula, endofistulorrhaphy and obliteration of the fistula through the efferent venous channels (Waterhouse 1964, Tunner *et al.* 1970, State 1971, Leiter 1972, Cosgrove *et al.* 1973 and Angorn 1977).

Trans-catheter selective intravascular occlusion offers a non-surgical therapeutic

alternative with the potential of greater conservation of renal parenchyma. A variety of embolic material has been used, including autologous blood clot, subcutaneous tissue and muscle, absorbable gelatin sponge, formalised polyvinyl alcohol sponge, Formulation-m®, cyanoacrylates and stainless steel coils in the management of intrarenal aneurysm (Almgard and Fernstrom 1973), post biopsy arteriovenous fistula (Bookstein and Goldstein 1973 and Rizk *et al.* 1973) and post traumatic refractory haemorrhage (Kalish *et al.* 1974, Tegtmeyer *et al.* 1977 and Wallace *et al.* 1978).

2.10 RENAL COLLATERAL VENOUS CHANNELS

"All embryological growth of important organs tends to be in a rich arterial and venous field, preceded by an extensive capillary network, from which the adult pattern emerges. The vascular system is a great builder of main and secondary roads superimposed on primitive footpaths" (Harris 1941). Attracting attention are the by-passes and shunts that are frequently devised as in the transverse anastomoses between the longitudinal venous trunk across the midline such as the left renal vein crossing the aorta. When the usual communication of the renal veins, the left renal vein in particular, are grouped together the true expanse of the renal field of vascular influence becomes apparent. The left renal vein is found to be situated at the core of an impressive set of venous plexuses and veins : inferior phrenic and suprarenal tributaries enter from above, while from below and to the side come gonadal, capsular, lumbar and ascending lumbar veins and anomalous vena cava. Additionally, communication is made with the azygos and hemiazygos veins (usually through the lumbar vein) and with the extensive set of internal and external vertebral plexuses by way of intervertebral and lumbar veins..

2.10.1 EXPERIMENTAL DEMONSTRATION

For over a century experiments have been conducted on the effects of compression and/or occlusion of the renal veins and its subsequent collateralization. Experimental ligation of the renal vein was first performed in 1843 by Robinson. Similar experiments were carried out during this period by Meyer 1844, Frerichs 1851, Munk 1864 and Erythropel 1865. In 1876, Buchwald and Litter made serial studies of the development of the histologic changes in the kidneys of dogs and rabbits after obstructing the renal venous circulation. They noted that despite the decreased size of the kidneys the animals developed an excellent collateral circulation from the renal capsule to the IVC and the suprarenal, lumbar and diaphragmatic veins. Alessandri (1899), Isobe (1913) and Harrington (1921), among others, reported similar findings. Pawlicki (1906) found that when ligation of the renal vein resulted in irremediable damage to the kidney, a collateral circulation did not develop. On the other hand, if a collateral circulation developed, the organ survived and function was preserved. Jungano (1906) suggested that in man, when the renal vein was slowly occluded by a thrombus, a collateral circulation developed more readily than in the experimental animal in which the vein was occluded instantaneously by ligature. In 1913, Rowntree *et al.* used an obstructing band to produce chronic congestion in the kidneys of dogs. They observed that "...when gradual progressive obstruction to the renal veins occurred, the development of a collateral circulation is of great importance in maintaining the functional capacity of the kidney since an efficient renal function may be encountered when the venous return from the kidney is entirely collateral. On the other hand, ligation of collateral vessels, simultaneously with a moderate degree of obstruction to the renal vein usually results in renal inefficiency and death". Braun- Menendez (1933) noted a rise of more than 20mm Hg in the arterial pressure in 50% of the dogs whose renal veins had been partially tied. In 1940, Whittenberger and Huggins demonstrated that ligation of the IVC above the renal veins in the dog almost always resulted in death, whereas ligation below the renal veins was not a serious surgical procedure in both lower animals and in man. Friedberg (1944) observed that in dogs, partial venous occlusion sometimes led to transitory mild hypertension which disappeared as an extensive capsular collateral

vascular network developed. Several other workers, Blake *et al.* (1949), Selkurt (1949), Faber *et al.* (1953) performed similar experiments including detailed biochemical analysis.

In the early 1940's Batson revived interest in the vertebral system of veins by demonstrating that a thin opaque medium injected into the dorsal vein of the penis of a cadaver would spread into the sacral canal, fill the veins in the wings of the bony pelvis, and finally move up the vertebral system as far as the cranial cavity. The mode of spread was similar to that of carcinoma of the prostate, and Batson suggested that in the great venous lakes formed by the plexuses, tumour emboli might well spread from origin to final site of deposition. He also showed that the vertebral veins filled, following injection in a live monkey, if the IVC were compressed. Additionally, he also noted the rich communications which the valveless vertebral veins enjoyed with veins around the spinal column and the thoraco-abdominal wall and azygos and renal system of veins and with the veins of the pelvic viscera.

Shortly after Batson described the anatomy of the vertebral veins and expounded his theory of their role in metastases, Harris (1941) went to great lengths to prove that Batson's ideas were neither new nor original. In fact, the vertebral venous system was by no means unknown to anatomists prior to Batson's time. In recounting the history of the vertebral veins, Breschet (1819) stated that "Sylvius and Vesalius appear to be the first to have observed the branches which the vertebral veins send into the spinal canal. After them, Falloppio, found the longitudinal vertebral venous sinuses in the cervical region. Much later, Vidus-Vidius discovered a transverse vertebral sinus on the third cervical vertebra. Above all, however, the honour goes to Willis for having described and represented, although most imperfectly, the longitudinal and transverse sinuses for the entire length of the spinal cavity" (cited by Breschet 1819). Thus Willis (1664) and Winslow (1732) characterised the structure of the spinal veins. Bock (1823) described the rich plexuses within the bony canal, the posterior venous plexus and the azygos system. In 1855, Hilton stated that "the absence of valves in the whole of these venous tubes is a circumstance which is doubtless connected with a wise intention. It enables the blood to

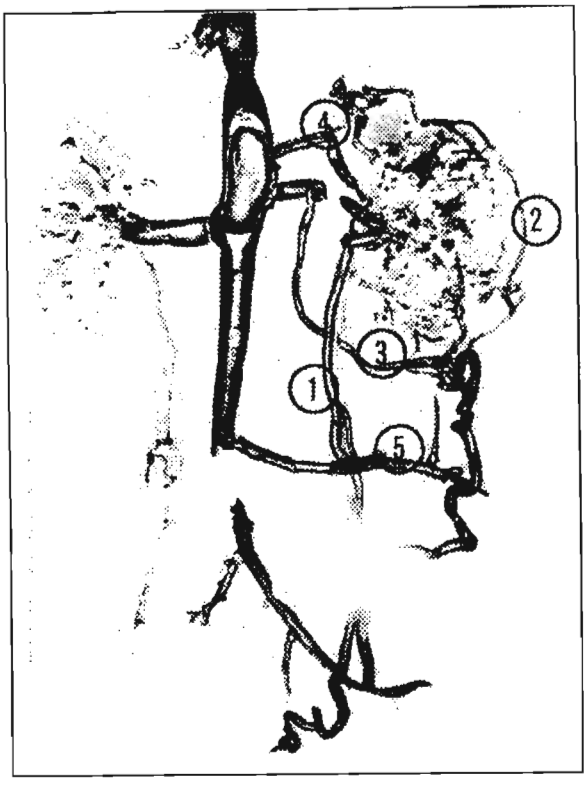
pass in either direction, and consequently greatly increases the freedom of venous circulation; a point of essential importance with an organ whose functional capacity is so liable to interruption under so slight a disturbance of the balance of its circulating fluid".

Subsequent to Batson's original reports, Anson *et al.* (1947, 1948) drew attention to the pararenal venous system. Their dissection studies indicated the close relationship of this venous complex with the vertebral venous system. They pointed out the avenues of possible haematogenic migration through the renal, lumbar, intervertebral veins and vertebral plexuses to the spongious bone of the vertebra, or, upward along the vertebral venous system to the dural or diploic veins of the cranium. In the same year, Herlihy (1947) described the role of the vertebral vein and its communication to the various viscera especially the lungs, the left suprarenal gland and the left kidney and its pathological significance.

To demonstrate this point Coman and De Long (1951) injected viable tumour cells into the femoral veins of 14 animals while abdominal compression was employed; in 12, tumours appear in the vertebral venous system. The authors agreed that the vertebral vein offers a transport avenue for tumour emboli from prostatic and breast carcinoma and that perhaps coughing or the valsalva manoeuvre- which increases intra-abdominal pressure - might suffice to shift blood from the IVC to the vertebral or azygos system. Similarly other investigators (Turner 1935, Martin 1941, Cohn *et al.* 1950 and Bowsher 1954), emphasized the importance of this system as a means of spreading infection. Anderson (1950), duplicated Batson's work in detail and extended the study to living adults. He succeeded in opacifying the vertebral veins following femoral vein injection of diodrast solution if abdominal compression were employed. Robinson (1949) injected Neoprene® into stillborn infants, but was unable to obtain satisfactory roentgenographic studies. Using intra-osseous phlebography as an alternative method of demonstrating the vertebral veins and the reno-azygo-lumbar system, Fischgold *et al.* (1952) showed both the normal pattern and the effect of metastatic tumour in creating venous obstruction. In determining experimentally in dogs which collateral venous channels are enlarged as a consequence of

obstruction of the renal vein itself, and into which vessels they empty, Hollinshead and MacFarlane (1953) concluded that similar vessels in man may harbour hypernephroma cells and thus possess the ability to give rise to a recurrence of the tumour following removal of the kidney itself. They advised removal of these collateral venous channels as completely as possible in surgical removal of the kidney for hypernephroma. In their experiment to reproduce in dogs the changes observed clinically in renal vein thrombosis, Zheutlin *et al.* (1959) observed that the diagnosis of this condition may be suspected radiologically by the demonstration of an enlarged kidney which on pyelography presented a "pseudo-cystic" appearance. Stimulated by their observations of the collateral circulation around a blocked renal vein made by John *et al.* (1961) while testing methods of replacement of the IVC, Cox *et al.* (1962) experimented on 25 dogs to note the rate of closure necessary to allow survival of the kidney and to search for the secondary channels of venous drainage into which the gonadal, ureteric and capsular veins empty their blood. Predictably, they concluded that kidney survival from renal vein occlusion is certain provided the process of occlusion is "slow", possible if it is "rapid" and impossible if it is immediate. Beres *et al.* (1964) noted that "renal vein obstruction may be suspected clinically, but in most instances the diagnosis is almost impossible to confirm and is usually made at post-mortem examination. An accurate antemortem diagnosis might be more frequently possible if the renal venous outflow could be easily demonstrated by a direct radiologic technique". They accordingly experimented with 15 dogs, partially and totally occluding the left renal veins. The venous pattern was then demonstrated via percutaneous transrenal venography which appeared to be a satisfactory direct radiologic method for demonstrating experimental renal vein obstruction. A year later, Crummy and Hipona (1965) experimented once more on dogs to evaluate, by means of retrograde aortography and selective renal angiography, the response of the kidney to occlusion of the renal vein and to see if these procedures would be of better value than previous radiological procedures in the diagnosis of renal vein thrombosis. They confirmed once more that the capability of the kidney to survive renal vein obstruction depended upon the rapid development of an adquate collateral venous drainage. They concluded that renal angiography was an excellent method of investigating

renal vein thrombosis and that its showed arteriographic, nephrographic and venographic effects of thrombosis of the renal vein. Furthermore this study may show the pattern of vascular flow in the collateral circulation



1	*Ureteric vein*
2	*Capsular venous network*
3	*Ovarian vein*
4	*Adrenal vein*
5	*Lumbar vein*

Fig. 20 *Vinylite corrosion cast of the retroperitoneal venous system demonstrating venous collaterals. (from Crummy and Hipona 1965).*

2.10.2 ANATOMICAL DEMONSTRATION

In as much as the above experimental research highlighted the renal collateral venous channels, early anatomists also demonstrated on cadaveric material, the practical and clinical significance of these collateral channels. In 1769 Morgagni (cited by Bramwit and Hummel 1968) first documented collateral circulation in a case of obstructed IVC. Hallet (1848) described the collateral venous circulation in the renal area in a case of obliteration of the IVC below the level of the renal veins. The anastomosis was accomplished through "a small vein which passes and establishes a communication between a common iliac and

renal vein", and it generally communicated with one or more lumbar veins. Despite Hallet's work, Golub (1992) claimed that it was Sappey and Dumontpallier (1862) who first documented in detail the routes of collateral venous return from inferior vena caval obstruction in postmortem studies. Leudet (1862) observed in a case of carcinoma of the kidney, that the left renal vein was obliterated at its point of junction with the IVC, but "the enveloping capsule (of the kidney) was crossed by a large network of venous branches which exceeded in width a bird's feather and were more numerous on the inferior aspect of the kidney". These capsular veins were continuous "below the lumbar muscles and farther down, with veins of the integument of the abdominal parietes". In 1911, Pleasants noted IVC to portal anastomoses by way of the left renal gonadal veins and the superior haemorrhoidal veins to the mesenteric veins. In his report on *The case of the late Dr W R Pollock*, Shattock (1915) noted that "the return of blood from the kidneys must have taken place through the veins of the capsule and thence by way of the lumbar through the azygos vessels", since the renal and infrarenal portion of the IVC was "converted into a flat, impervious ribbon".

Duskes (1927) reported a case of polycystic kidney with a collateral venous circulation represented by a varicocele connecting the renal and splenic veins. He postulated its development as an early embryonic adjustment for a deranged venous supply, beginning as a minute communicating twig between capsular and splenic venules and later becoming abnormally large. Similar reports are recorded by Wakefield and Mayo (1934) and Derow *et al.* (1939). In 1941 Keen described the collateral venous system in a dissection room specimen in which an organised thrombus involved the IVC from the level of the hepatic vein caudally to include both common iliac veins. The whole venous return from the kidneys, suprarenals, pelvic organs (except rectum) and both lower limbs, took place through the azygos veins and the superior vena cava by way of the extensive intermediate parietal channels

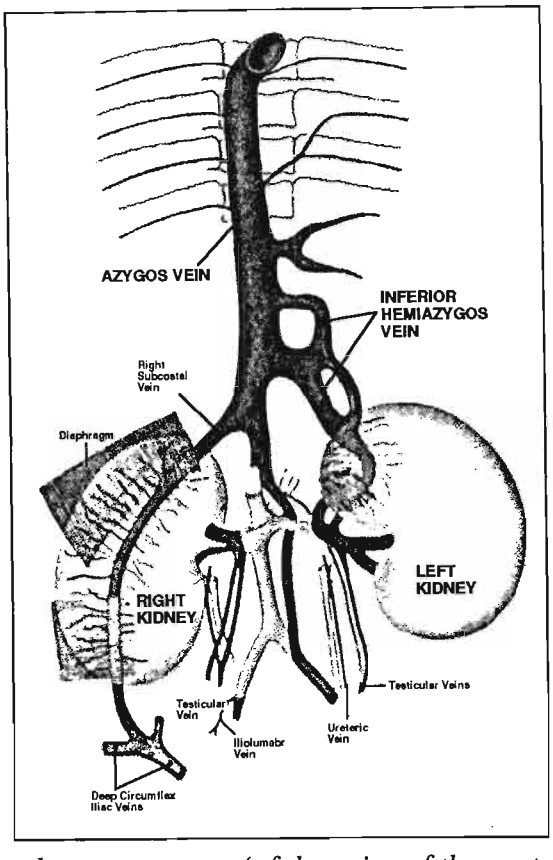


Fig. 21 *The collateral venous system (of the veins of the posterior abdominal wall) following an organised venous thrombus of the IVC from the level of the hepatic vein to both common iliac veins. (from Keen 1941).*

The anatomical dissections of Anson *et al.* (1947,1948) also drew attention to the renal vein connections with the pararenal venous system.

2.10.3 RADIOLOGICAL DEMONSTRATION

The important contribution of this experimental and dissected clinical material demonstrating the venous collaterals was recognized for its diagnostic, therapeutic and prognostic implications in renal vein and inferior vena caval obstruction. The significant role that radiological investigations could play was obvious.

IVC venography was first described by dos Santos in 1935 and was subsequently used extensively in the investigation of caval thrombosis mainly due to malignant disease (Surington and Jonas 1952 and Helander and Lindbom 1956). Indications for venography

in relation to the kidney were defined by Harrison *et al.* in 1956. Stiener (1957) reviewed renal venography describing the technique and interpretation in both normal and pathological conditions and demonstrated the adequacy of the renal collateral pathways. During this period Doehner *et al.* (1956), whilst investigating the pathological radiological anatomy of the portal venous system, demonstrated gastric and splenic connections with the left renal vein. Filler and Edwards (1962) reconsidered the collateral flow in the lower IVC by means of venography during life since most previous studies were based on postmortem dissection and left unanswered the question of choice of pathway during life. All patients with pathology of the major vessels displayed rich collateralisation. They termed the collaterals which came up from below, bypassing the obstruction to reach the renal level the "affluents" and the "effluents" the more proximal coursing vessels. Although the system of collaterals demonstrated by venography was less abundant than that revealed by anatomic dissection, venography had the advantage of demonstrating the relative clinical significance of the different groups of collaterals.

In 1965, Reuter stated that "the renal veins are one of the yet unexplored areas in angiography". Subsequently, several techniques that were aimed at improving the standards of renal phlebography were reported (Kincaid 1966 and Cherigie *et al.* 1966). In diagnosing renal vein thrombosis, Hipona and Crummy (1966) observed that renal angiography was the most informative radiological procedure because changes in the different phases of the renal circulation could be demonstrated and should be considered early in the evaluation of suspected cases of this disease. In the same year Ahlberg *et al.*(1966) maintained that pre-operative studies of the venous anatomy in carcinoma-bearing kidneys were valuable in individual cases, since they revealed not only the possible venous obstruction but also the width and site of pathologic drainage channels. He commented that when these circumstances were known to the surgeon, the risk of metastatic tumour spread and of major bleeding could be reduced. Ferris *et al.* (1968) observed that the diagnosis of renal vein occlusion could be inferred angiographically by observing the failure of opacification of the renal vein or by visualising venous collateral channels. Leiter (1966) noted that carcinoma of the kidney was the most frequent

malignancy associated with the IVC occlusion, the mechanisms usually being the extension of tumour from an involved renal vein into the lumen of the IVC. Since renal veins are usually poorly opacified by the injection of contrast medium against the strong venous outflow, Sorby (1969) described visualisation of the renal veins using a pharmacoangiographic method of renal venography (after reduction of renal blood flow by intrarenal arterial injection of adrenaline) as devised by Reuter in 1965. He preferred the retrograde approach and refined the original, non- selective technique of venacavography combined with the Valsalva manoeuvre. In order to overcome the erratic filling of the renal veins (the right vein showing more consistent and lengthier filling than the left) and the fact that selective catheterisation of a renal vein and pressure injection of the contrast medium gave opacification of the main renal vein and of veins of the second order, but filling of the peripheral veins was precluded because of the high volume/rate of renal blood flow (approximately 400ml/min/kidney), he administered a small amount of adrenaline (20 micrograms: 0.2 ml of 1/10,000 adrenaline) into the appropriate renal artery. The arrest in renal arterial and hence renal blood flow lasted for about 90 seconds. He concluded that pharmacologically assisted renal venography was relatively simple and safe, taking little extra time in patients already undergoing selective renal arteriography. This view was supported by Gillot *et al.* (1965) and Takaro *et al.* (1970), and Beckmann aand Abrams (1980). Furthermore, Sorby noted that visualisation of the intrarenal venous structure in renal mass lesions frequently gave additional information when the selective renal arteriogram was not decisive. However, Brindle (1972) in describing alternative vascular channels in renal cell carcinoma, concluded that collateral veins were not a reliable sign of renal vein occlusion.

Noting that selective renal venography is a simple but important diagnostic procedure which has few complications, Beckmann and Abrams (1980) cautioned that a thorough knowledge of renal venous anatomy is essential for its proper performance and clinical application. This is particularly true because renal venous variations are frequent and may interfere with the successful approach to retroperitoneal surgery.

The method is widely accepted for evaluation of the renal venous bed in patients with suspected renal vein thrombosis or hematuria of unknown etiology. It depicts the extent of renal venous involvement in renal carcinoma and clarifies the diagnosis in some patients with avascular tumours, renal pelvic carcinoma, and retroperitoneal tumours.

It may also be useful in defining the morphologic abnormality when the kidney fails to visualize on urography, in delineating the extent and nature of renal parenchymal disease, and in enhancing the precision of renal vein renin collection.

CHAPTER 3

MATERIALS AND METHODS

GENERAL

The human specimens used in the study of the anatomy of the renal vasculature were obtained using cadaveric material (in accordance with the Human Tissue Amendment Act, 51 of 1989) from the State Mortuary at Gale Street, Durban and the Department of Anatomy, University of Durban-Westville. Foetal material was obtained from King Edward VIII Hospital, Durban. In the animal study, cadaveric material from the non-human primate, the Chacma baboon (*Papio ursinus*) was obtained from the Biomedical Resource Centre, University of Durban-Westville and from the Department of Anatomy, University of Pretoria. These animals were euthanised for reasons other than for this investigation. The research was conducted at the Department of Anatomy, University of Durban-Westville, with clearance from the Ethics Committee and the Research Committee of the University of Durban-Westville.

3.1 GROSS ANATOMICAL DISSECTION

3.1.1 ADULT DISSECTION

In the pilot phase of the study, 20 cadavers from the Department of Anatomy, University of Durban-Westville were dissected to display the renal and pararenal vasculature. All subsequent records were obtained from 211 cadavers at the State Mortuary at Gale Street, Durban. Cadavers displaying abdominal trauma, evidence of previous surgical exploration of the abdomen or abnormal intra-abdominal macroscopic pathology were excluded. Gross anatomical details were observed and any deviation from currently accepted norms (as described by Pick and Anson 1940c, Anson and Kurth 1955, Gillot 1978 and Wiliams *et al.* 1989) were recorded. *En bloc* specimens comprising part of the retroperitoneal region from upper sacral up to approximately the tenth thoracic level, including a portion of the diaphragm were harvested as described below.

Further detailed renal vein and artery relationships were obtained during subsequent dissection of the *en bloc* renal specimens, and from the resin cast and plastinated preparations.

3.1.1.1 HARVESTING OF RENAL EN BLOC SPECIMENS

After removal of the stomach at the level of the pylorus, the entire small bowel from the duodeno-jejunal flexure and the large bowel, an *en bloc* removal of both kidneys (with the renal capsule and peri-renal fat) together with the duodenum, pancreas and frequently the spleen, was performed. The veins were sectioned caudally, at the level of the common iliac veins, and cranially, the inferior vena cava was sectioned as it entered the deep groove on the posterior surface of the liver. This was done so that any duplication of the renal veins would be detected and analysed. Similarly, the aorta was sectioned just distal to its entry into the abdomen through the median arcuate ligament of the diaphragm and at the level of its bifurcation. The ureters were sectioned at the pelvic brim. Posteriorly, part of the posterior abdominal wall musculature was removed, including part of the diaphragm. This *en bloc* removal of the tissue permitted reasonable preservation of the *in situ* architecture of the viscera that were removed.

The specimen was then immediately mounted onto a rectangular wooden frame. By using 8 to 12 anchoring sutures from the muscle tissue to the frame, further preservation of the anatomical relations was obtained.

3.1.2 FOETAL DISSECTION

Twenty unpreserved foetuses without morphological or congenital abnormalities, aged between 26 to 38 weeks, obtained from King Edward VIII Hospital, were dissected to observe similar gross anatomical details.

3.1.3 CHACMA BABOON DISSECTION

Eleven renal *en bloc* specimens were harvested in a similar manner to the human dissection to investigate intrarenal venous flow patterns and the presence of valves.

3.2 PREPARATION OF RESIN CASTS

Resin casts were prepared from 100 pairs of kidneys randomly selected from the 211 *en bloc* renal specimens.

Appropriately sized plastic cannulae were attached rostrally to the IVC and aorta and distally to the ureter. These three systems were then gently perfused with de-aerated water. At this stage any of the vessels that were severed during excision were identified and ligated. In particular, the lumbar veins required ligation while the corresponding arteries together with the coeliac trunk and superior mesenteric artery were also ligated. During perfusion, the tissues were gently massaged to encourage thorough cleansing of the three systems. On obtaining a clear perfusate, 5% formalin was introduced. Thereafter, the specimen was immersed in 5% formalin and left overnight. The next day, the specimen was warmed to approximately 25° C with warm running water. Caudal ligatures were then applied to the inferior vena cava and aorta to close the renal vascular system and the specimen was then immersed in formalin solution. This was done to minimize the influence of gravity and the weight of the resin on the renal venous architecture.

The venous system was the first to be filled with pre-warmed (25° C) blue coloured polyester cystic resin. This was achieved by gentle non-manometric injection. Thereafter, sufficient gravitational pressure was maintained by topping up the cannula to keep the large veins turgid and to replace resin that might have been lost through leakage. This was continued until the resin had set. An hour after injection of the venous system, the arterial system was injected with red resin under moderate pressure until a reddish tinge appeared at the surface of the kidneys. The uretero-pelvi-caliceal system was then injected with yellow resin an hour later. The wooden frame was inverted to allow easier access of the resin into the system. Only moderate injection pressure was exerted to avoid extravasation.

Once the resin had set, the specimen was released from the wooden frame and immersed in concentrated hydrochloric acid for tissue maceration. This process was complete within four to six days. The cast was then cleansed initially with fine jets of water and

subsequently under gentle running water for 3 to 4 hours. Pruning of the cast with a pair of fine dissecting forceps completed the resin cast preparation.

Using the above technique, 35 resin casts of the renal veins and the ureter with the pelvi-calyceal system were prepared. In addition to these two systems, the renal artery was also injected in a further 65 preparations.

This technique was also employed in making resin casts of the venous system of 5 Chacma baboon (*Papio ursinus*) *en bloc* renal specimens.

The lengths and diameters (cm) of the renal venous vasculature and the infrarenal angles (degrees) were then measured.

3.2.1 NOMENCLATURE

The lengths of the left and right renal veins (described by Sorby 1969 as the main renal vein) were measured from the union of the 2 to 5 primary (lobar) tributaries to the entry into the IVC (L-LRV and L-RRV) (Fig. 22). Additional renal veins were measured from the point of their exit from the kidney to the IVC (L-LRV2, L-RRV2 and L-RRV3). The diameters were measured at the entry of the renal vein into the IVC (D-LRV, D-RRV,D-LRV2, D-RRV2 and D-RRV3). Since the left renal vein is more complex and has the gonadal and suprarenal veins draining into it, various segments of this vein were measured. These were: the length of the left renal vein segment from the union of the primary tributaries to the entry point of the lateral margin of the gonadal vein (GV-1); the length of the left renal vein segment from the medial margin of the entry point of the gonadal vein to its entry into the IVC (GV-IVC); the length of the left renal vein segment from the union of the primary tributaries to the entry point of the lateral margin of the suprarenal vein (SRV-1) and the length of the left renal vein segment from the medial margin of the entry point of the suprarenal vein into the IVC (SRV-IVC).

The diameter of the tributaries entering the left renal vein and the diameter of the left renal vein at the point of their entry together with the diameters of the IVC under the influence of the renal veins were also measured. These were: the diameter of the gonadal vein and the suprarenal vein at their points of entry into the left renal vein, D-GV and D-SRV respectively; the diameter of the left renal vein at the point of entry of the lateral margin of the gonadal vein (D-LRV-GV), the diameter of the left renal vein at the point of entry

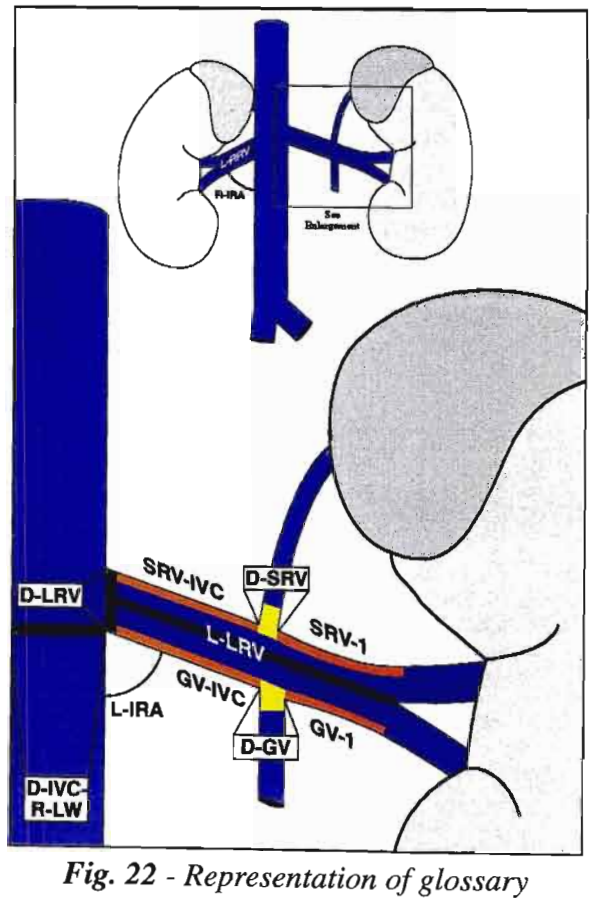


Fig. 22 - Representation of glossary

of the lateral margin of the suprarenal vein (D-LRV-SRV) and the diameter of the left renal vein at the point of entry of the lateral margin where the gonadal and suprarenal veins enter opposite each other (D-LRV-EQ); and the diameter of the IVC at the point of entry of the lower margin of the right renal vein (D-IVC-R-LW), the diameter of the IVC at the point of entry of the lower margin of the left renal vein and the diameter of the IVC at the point of entry of the lower margin where the left and right renal veins enter opposite each other.

The height of the IVC under renal vein influence was also measured as follows: height of the IVC between the points of entry of the lowest and the highest margin of the left and right renal veins (L-IVC-COM) and (L-IVC-L=R) being the distance between the lower borders of the left and right renal veins, where a zero measurement indicates entry of renal veins opposite each other, a positive value indicates the left renal vein entering higher than the right and a negative value indicates the entry of the right renal vein entering higher than the left.

Measurement of the infrarenal angle (degrees) on the left and the right sides was obtained by drawing a line through the long axes of the inferior vena cava and the main renal veins. The angles subtended by the intersecting lines on either side were designated as the left and right infrarenal angles (L-IRA and R-IRA) respectively. In addition to measuring the infrarenal angles from the resin casts (n=100) these angles were also measured from renal venograms obtained from *en bloc* renal specimens (n=47), cadavers (n=11) and foetuses (n=11).

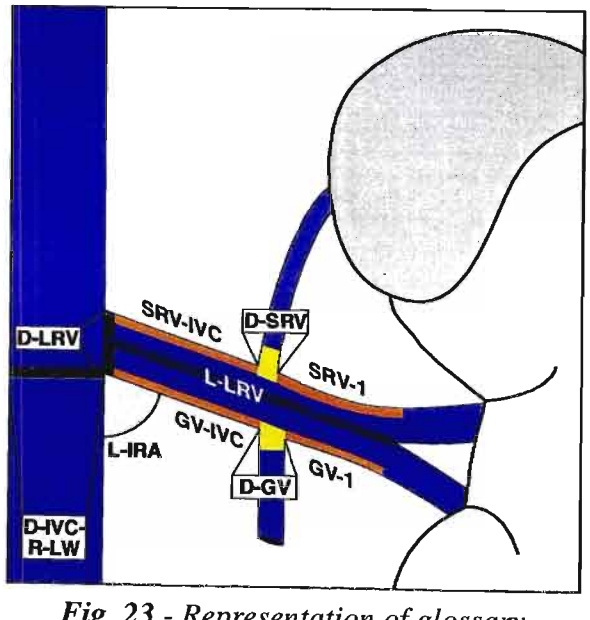


Fig. 23 - Representation of glossary

Table VIII GLOSSARY OF ABBREVIATIONS

SER	Series number.
PM	Post-mortem number.
L-LRV	Length of the left renal vein from the union of the primary tributaries to its entry into the inferior vena cava.
L-RRV	Length of the right renal vein from the union of the primary tributaries to its entry into the inferior vena cava.
GV-1	Length of left renal vein segment from the union of the primary tributaries to the entry point of the lateral margin of the gonadal vein.
D-GV	Diameter of the gonadal vein at its entry into the left renal vein.
GV-IVC	Length of the left renal vein segment from the medial margin of the entry point of the gonadal vein to its entry into the inferior vena cava.
SRV-1	Length of the left renal vein segment from the union of the primary tributaries to the entry point of the lateral margin of the suprarenal vein.
D-SRV	Diameter of the suprarenal vein at its entry into the left renal vein.
SRV-IVC	Length of the left renal vein segment from the medial margin of the entry point of the suprarenal vein to its entry into the inferior vena cava.
L-IRA	Left infrarenal angle.
R-IRA	Right infrarenal angle.
L-CL	Classification type on the left side.
R-CL	Classification type on the right side.
D-LRV-GV	Diameter of the left renal vein at the point of entry of the lateral margin of the gonadal vein.
D-LRV-SRV	Diameter of the left renal vein at the point of entry of the lateral margin of the suprarenal vein.
D-LRV-EQ	Diameter of the left renal vein at the point of entry of the lateral margin where the gonadal and suprarenal veins enter opposite each other.
D-IVC-R-LW	Diameter of the inferior vena cava at the point of entry of the lower margin of the right renal vein.
D-IVC-L-LW	Diameter of the inferior vena cava at the point of entry of the lower margin of the left renal vein.
D-IVC-L=R	Diameter of the inferior vena cava at the point of entry of the lower margin where the left and right renal veins enter opposite each other.
D-LRV	Diameter of the left renal vein at the point of entry into the inferior vena cava.
D-RRV	Diameter of the right renal vein at the point of entry into the inferior vena cava.
L-IVC-COM	Vertical distance of the inferior vena cava from the point of entry of the lowest and the highest border of the left and right renal veins.
L-IVC-L=R	Vertical distance between the lower borders of the left and right renal veins, where a zero measurement indicates entry of renal veins opposite each other, a positive value indicates the left renal vein entering higher than the right and a negative value indicates the right renal vein entering higher than the left.
L-RRV2	Length of the first additional right renal vein from the kidney to the inferior vena cava.
L-RRV3	Length of the second additional right renal vein from the kidney to the inferior vena cava.
L-LRV2	Length of the additional left renal vein from the kidney to the inferior vena cava.
D-RRV2	Diameter of the first additional right renal vein at its point of entry into the inferior vena cava.
D-RRV3	Diameter of the second additional right renal vein at its point of entry into the inferior vena cava.
D-LRV2	Diameter of the additional left renal vein at its point of entry into the inferior vena cava.

3.2.1.1 Renal Vein Indices

The Reno-Renal Index was calculated using the following formula:

$$\textit{Reno-Renal Index} = \frac{\textit{Proximal diameter of renal vein}}{\textit{Distal diameter of renal vein}} \times 100$$

where the distal diameter is D-LRV and the proximal diameter is the weighted mean of D-LRV-GV, D-LRV-SRV and D-LRV-EQ, i.e.

$$\textit{weighted mean} = \frac{\Sigma n\, x}{\Sigma n}$$

The Reno-Caval Index was calculated using the following formula:

$$\textit{Reno-Caval Index} = \frac{\textit{Distal diameter of renal vein}}{\textit{Sub-renal diameter of IVC}} \times 100$$

where distal diameter is D-LRV and the sub-renal diameter of the IVC is the weighted mean of D-IVC-R-LW, D-IVC-L-LW and D-IVC-L=R.

3.3 PREPARATION OF PLASTINATED SPECIMENS

Plastinated specimens were prepared from 53 pairs of kidneys randomly selected from the 211 *en bloc* renal specimens. The technique is a modification of the procedure described by Gunther von Hagens (1980) which enables the preservation of perishable biological specimens, especially soft, putrifiable ones with a high water content. During the plastination process, the tissue water and part of the tissue fat is replaced by a polymerizable resin which is either an elastomer or duromer. The BIODUR® S10 polymer (for plastination producing the optical property of natural appearance and the mechanical property of flexibility) was selected as the most suitable for renal and vascular tissue.

The same technique as that utilised to impregnate the specimens for the resin cast preparation was used to inject the coloured rubber latex for the plastinated specimens. The same colours viz. blue, red and yellow were employed to inject the venous, arterial and uretero-pelvi-caliceal systems respectively. Once the latex had set, careful dissection to display the venous drainage from the hilum of the kidney to the inferior vena cava and the renal branches from the aorta to the kidney and the ureter was undertaken. Once this skeletal architecture of the extra-renal vascular system of the kidney was prepared, the specimen was then subjected to plastination.

The process consists of 4 steps.

1) Fixation : The kidneys were fixed in 10% formaldehyde solution.

2) Dehydration : The specimen was subjected to the freeze-substitution procedure which required the kidneys to be placed in acetone at a temperature of -25°C for between three to five weeks. In order to avoid shrinkage, serial dilutions of acetone beginning with 10% up to 100% were employed. The acetone was changed until the water content was less than 0.5% .

3) Forced Impregnation : This stage is the central and most important step of plastination. After saturating the renal specimen with a medium of high vapour pressure (ie. low boiling point), it was immersed in a BIODUR® S10 polymer whose components have a low vapour pressure (ie. high boiling point). The volatile medium, acetone, inside the specimen was removed continuously by a vacuum pump. As the medium is removed from the specimen, a

force will be generated causing the polymer solution to be drawn into the specimen. In short, forced impregnation takes advantage of differences in vapor pressures between the medium, acetone and the BIODUR® S10 polymer solution. The impregnation of the renal tissue is carried out slowly so as to allow the polymer solution to penetrate inside the specimen where the last medium, acetone, changes to the gaseous phase and is removed (i.e. "pumped out" or boiled off). The speed of impregnation is carefully adjusted by controlled addition of air into the vacuum chamber via a bypass valve. The impregnation takes between 3 to 5 days. During this period the vacuum is intensified from a pressure of approximately 200 mm Hg, according to the desirable formation of medium sized bubbles, down to a pressure of 5 mm Hg where little or no bubbles come to the surface. The specimen is then removed from the polymer solution and transferred into a basket placed upon a grid. This "dripping off" phase was conducted at room temperature and took between 2 and 3 hours. Thereafter, grids of stainless steel, covered with filter paper, were placed into a container 5 centimeters off the bottom. The kidney tissue was wiped clean with soft paper towels and individually placed onto the filter paper. The container was then tightly sealed with polypropylene foil and spray glue. This phase is referred to as the "draining off" phase and requires at least 2 days. During this period the filter paper had to be changed 2 to 4 times a day together with thorough wiping of the specimen.

4) Final Curing : The recommended gas curing method (BIODUR®, gas-cure S6) for this final stage was employed. The specimen was placed on a grid and during the initial hours the specimen was checked for oozing of the polymer, which if present was wiped off. The process was deemed complete when the renal tissue no longer felt to be tacky. This was accomplished in between 2 to 4 days.

3.4 CLASSIFICATION OF RENAL VEINS

Three hundred and six kidneys (obtained from the 100 pairs of resin casts and 53 pairs of plastinated kidneys) were analysed in order to classify patterns of venous drainage. The primary (lobar) tributaries of the renal vein viz., upper, middle, lower and posterior and additional renal veins (when present) were identified and used as the basis for classification.

3.5 DEMONSTRATION OF INTRARENAL VENOUS DRAINAGE

3.5.1 ADULT *EN BLOC* RENAL INVESTIGATION

In order to demonstrate the pattern of intrarenal venous flow, 21 pairs of *en bloc* kidney specimens were subjected to radiological examination (Table 8). Initially, the renal hilum was dissected to demonstrate the primary tributaries of the right and left renal veins. Thereafter, a primary tributary eg. upper, middle, lower or posterior was selected at random and catheterised via the inferior vena cava and renal vein with an appropriate sized Foley® catheter. This vessel was balloon occluded and dilute barium sulfate contrast was injected distal to the occlusion under gentle non-manometric control until the contrast was seen to return via another primary tributary into the renal vein. Thereafter, single film radiography was performed.

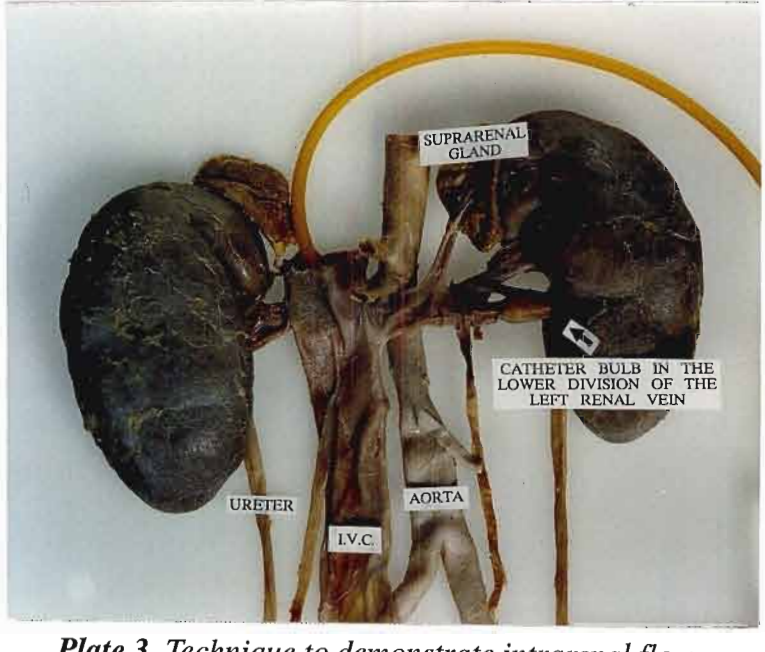


Plate 3 *Technique to demonstrate intrarenal flow.*

During further studies, a randomly selected primary renal tributary was cannulated, the proximal segment ligated and small aliquots of radio-opaque contrast medium (meglumine iothalamate-Conray® 280-May & Baker) were gently injected distal to the occlusion under radiological screening to further demonstrate the renal venogram pattern.

TABLE IX - PRIMARY TRIBUTARY OCCLUDED TO DEMONSTRATE INTRARENAL VENOUS DRAINAGE

Series No.	PM. No.	Race	Gender	Primary Tributary Occluded	
				Right	Left
154	2662	B	M	Lower	Lower
155	2647	B	M	Lower	Lower
156	2665	I	M	Upper	Upper
157	2734	B	M	Upper	Middle
158	2737	W	M	Lower	Upper
159	2738	W	M	Posterior	Upper
160	2755	B	F	Middle	Lower
161	2759	B	M	Lower	Lower
162	2972	B	M	Lower	Upper
163	2794	B	M	Upper	Upper
164	3180	B	M	Middle	Posterior
165	3181	B	F	Lower	Upper
166	3328	B	M	Lower	Lower
167	3411	B	M	Middle	Lower
168	3456	B	F	Upper	Lower
169	3459	B	M	Posterior	Middle
170	3466	B	M	Lower	Middle
171	3473	B	M	Middle	Middle
172	144	I	M	Middle	Lower
173	545	B	M	Lower	Upper
174	548	I	M	Upper	Lower

3.5.2 CHACMA BABOON (*PAPIO URSINUS*) INVESTIGATION

The intrarenal venous pattern was also studied in five pairs of Chacma baboon (*Papio ursinus*) kidneys. A primary tributary was catheterised using the method described above and serial radiography performed having ensured that there was no backflow.

3.6 INVESTIGATION TO DETERMINE THE PRESENCE OF RENAL VEIN VALVES

Twenty six pairs of kidneys randomly selected from the 211 *en bloc* renal specimens were examined for the presence of renal vein valves (Appendix A). The IVC and the renal veins were sectioned along their main axes. The primary tributaries were similarly dissected into the hilum and followed into the renal parenchyma to its secondary and

tertiary tributaries. The renal veins were then inspected macroscopically for the presence of valvular structures. A dissecting microscope was used to inspect the secondary and tertiary veins. Microscopic slide specimens using the haemotoxylin-eosin staining technique were then prepared. Serial cross sections were taken along the renal veins at its entry point into the inferior vena cava, the length of the renal veins and along the primary, secondary and tertiary tributaries

These slides together with all renal venograms obtained from cadavers, foetuses and *en bloc* renal specimens were examined for the presence of renal vein valves.

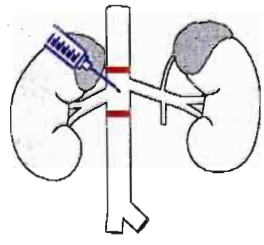
3.7 RENAL VEIN DRAINAGE AND COLLATERAL FLOW.

In order to observe the renal venous drainage and to investigate the embryological bases for renal venous collateral flow, foetal and adult specimens were studied.

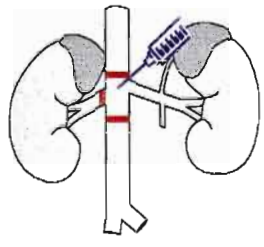
3.7.1 FOETAL SERIES

Eleven foetuses, without morphological or congenital abnormalities, ranging from 26 to 38 weeks were injected with contrast medium (meglumine iothalamate-Conray® 280-May & Baker) after selective ligation at different points within the sphere of influence of the renal veins (Fig. 24). Via an extended laparotomy incision, the stomach was excised between the cardiac orifice and the pylorus, the small bowel removed from the duodeno-jejunal flexure together with the large bowel up to the recto-sigmoid junction. With the aid of a dissecting microscope and microscopic dissecting instruments, the inferior vena cava and the common iliac veins up to their entry into the liver and both the renal veins were clearly identified. In 3 of the specimens, the thorax was opened and the azygos vein and superior vena cava were also identified. A size 22 Jelco® cannula was then inserted into the inferior vena cava. Selective ligations using 6-0 prolene sutures were placed as indicated in Fig. 24.

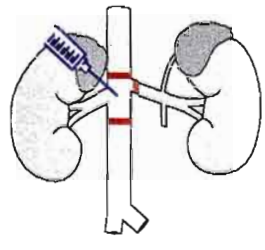
1) Ligation of the inferior vena cava below and above the renal veins (including the right suprarenal vein).



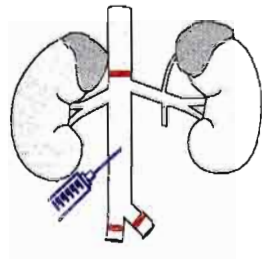
2) Ligation of the inferior vena cava below and above the renal veins and the right renal vein.



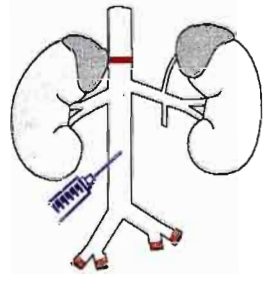
3) Ligation of the inferior vena cava below and above the renal veins and the left renal vein.



4) Ligation of the common iliac veins caudally and the inferior vena cava above the renal veins cranially.



5) Ligation of the internal and external iliac veins caudally and the inferior vena cava above the renal veins cranially.



6) Ligation of the azygos vein at its entry into the superior vena cava (SVC) cranially and the common iliac veins caudally.

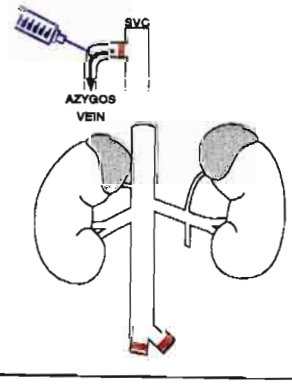


Fig. 24 *Foetal collateral flow study: Sites of ligation*

Under radiological screening, venogram perfusion was achieved by gentle non-manometric injection pressure of small aliquots of the contrast medium with the intention of initial renal perfusion and subsequent over-perfusion to demonstrate the tributaries and field of influence of the right and left renal veins.

3.7.2 ADULT SERIES

Eleven adult cadavers were subjected to a similar study in the post-mortem room at the Gale Street Mortuary (Appendix B). These adult cadavers were subjected to the same radiological investigation used for the foetal study except that the films exposed were without the benefit of fluoroscopy. Sequential single film radiographs were taken following contrast infusion (meglumine iothalamate-Conray® 280-May & Baker) of the IVC and/or the renal veins subsequent to suture ligation as described in Fig. 24.

3.8 MORPHOLOGY AND RELATIONSHIP OF RENAL LOBULATIONS TO VENOUS DRAINAGE.

The material examined consisted of both foetal and adult kidneys of both sexes taken from the original pool of kidneys. Of a total of 31 pairs studied, 10 pairs were foetal and 21 pairs were adult kidneys. The adult kidneys were derived from the same series that was used to demonstrate intrarenal venous flow (Table IX). The study of the arrangements of the lobulation was facilitated by first removing the adipose capsule. The surface of the kidney was described as being divided by a number of clefts into lobes and lobules.

In the adult kidneys, a primary renal vein tributary viz. upper, middle, lower or posterior was selected at random, the proximal segment ligated and small aliquots of radio-opaque contrast medium (meglumine iothalamate-Conray® 280-May & Baker) were gently injected under radiological screening to examine for a lobular pattern of venous flow.

In the foetal study, the right and left renal veins were ligated, a primary tributary was cannulated via the renal vein with a size 22 Jelco® cannula and small aliquots of contrast

medium were injected under gentle non-manometric pressure. The procedure was performed under radiological screening.

3.9 STATISTICAL ANALYSIS

For statistical comparisons of measurement parameters paired and unpaired samples t-tests were used. In the case of comparisons of race and classification types, a one-way analysis of variance (ANOVA) with the Scheffe *post hoc* test was performed. When analysing whether race was a determinant of classification type, several 2x2 tables were constructed and the Fisher exact test was applied. This test was performed using Epi Info® Version 5.00. All other statistical analyses were conducted using Systat® Version 5.1.

The $\alpha = 0.05$ level was considered to be significant in all statistical comparisons.

CHAPTER 4

RESULTS

4.1 SAMPLE DEMOGRAPHICS

Two hundred and eleven pairs of adult human kidneys, 20 pairs of human foetal kidneys and 10 pairs of Chacma baboon (*Papio ursinus*) kidneys were included in the study (Fig. 25).

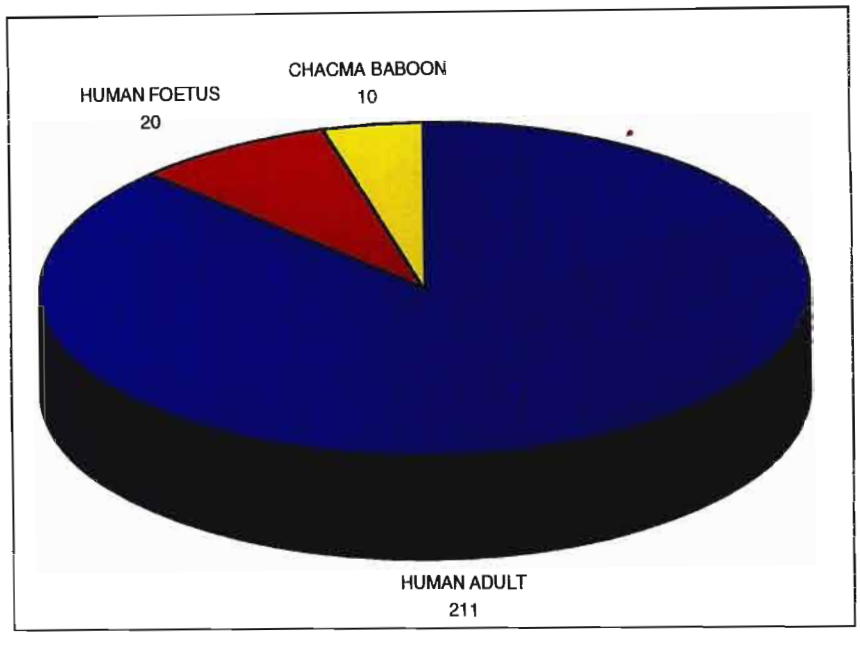


Fig. 25 *- Composition of the total number of kidneys (paired) in the study*

All measurements were performed on the resin casts (n=100 pairs), while both the resin casts (n=100 pairs) and the plastinated kidneys (n=53 pairs) were used in determining classification (n=153 pairs). Twenty one *en bloc* renal specimens were used to demonstrate intrarenal flow, while 26 pairs were used to investigate the presence of intrarenal valves and eleven cadavers were used to demonstrate renal collateral flow (Fig. 26).

Of the 211 kidneys studied, 87% were obtained from males. Blacks comprised 88% of the sample studied.

The sex and race distribution of the adult series are shown in Table X. The various sub-groups of the study of the adult human kidneys are shown in Fig. 26.

***TABLE X** - DEMOGRAPHIC DETAILS OF THE TOTAL ADULT SAMPLE UNDER STUDY.*

		Resin casts of kidneys	Plastinated kidneys	*en bloc* renal specimens used to demonstrate: Intrarenal flow	Renal vein valves	Cadaveric venograms
Total (Pairs of Kidneys)	**211**	100	53	21	26	11
Sex Male	**183**	85	46	18	24	10
Female	**28**	15	7	3	2	1
Race Black	**185**	87	46	18	23	11
Indian	**10**	3	5	2	0	0
White	**11**	7	2	1	1	0
"Coloured"	**5**	3	0	0	2	0

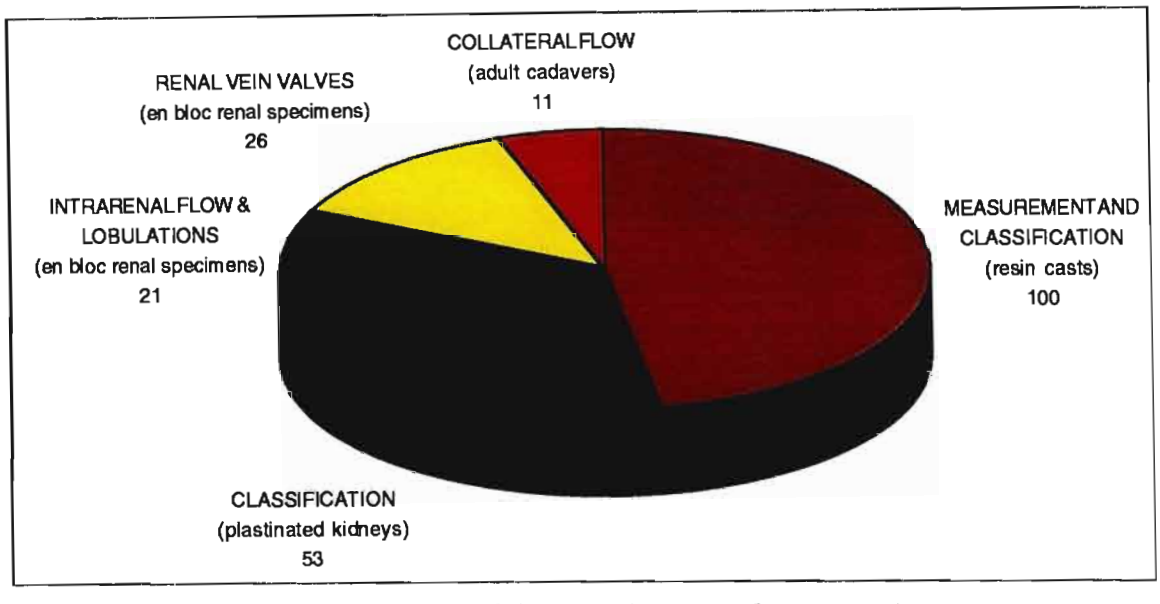


***Fig.26** - Categorisation of the adult human kidneys into the various sub-groups of the study*

Of the 20 foetuses, 11 were used to demonstrate intrarenal and renal collateral channels while the remaining 9 were used to investigate the renal lobules.

Five pairs of the Chacma baboon (*Papio ursinus*) *en bloc* renal specimens were used to prepare renal venous resin casts and five pairs of specimens were used to demonstrate intrarenal venous flow.

4.2 GROSS ANATOMY

Gross anatomical details were observed in all 211 cadavers. The position of the kidneys and the renal vessels (the renal vein and IVC in particular), the relationship of other viscera and blood vessels were noted not to vary from the gross structural description provided by Pick and Anson (1940c), Gillot (1978) and Anson and Kurth (1955). A single major variation of the IVC was found - i.e. a left infra-renal (post ureteric) cava (Series No. 66, Appendix D).

Additional renal veins were noted and are described on pages12 and 15.

Plate 4 *- Resin cast left sided IVC (anterior view)*

Plate 5 *- Resin cast left sided IVC (posterior view)*

RRV	*– Right renal vein*	***L***	*– Lower primary tributary*
LRV	*– Left renal vein*	***P***	*– Posterior primary tributary*
IVC	*– Inferior vena cava*	***Ao***	*– Aorta*
GV	*– Gonadal vein*	***RA***	*– Renal artery*
U	*– Upper primary tributary*	***Ur***	*– Ureter*

4.3 MEASUREMENTS

One hundred pairs of resin casts of kidneys were included in the study of measurements of the renal vasculature (Table X). The sex distribution was males (n=85) and females (n=15); while the race distribution comprised Blacks (n=87), Indians (n=3), Whites (n=7) and "Coloureds" (n=3).

In the text that follows all measurements are reported in centimeters(cm) as mean ± standard deviation with the minimum and maximum values shown in parenthesis. In the case of infrarenal angles, measurements are reported in degrees. The lengths and diameters of the left and right renal veins and the diameter and height of the IVC under renal vein influence are recorded for the total sample and sex; race and classification type (Table XI-A, XI-B and XI-C respectively). Figures 28, 29, 30, 32, 33 and 35 are an illustrative, rather than a statistical representation of the mean and distribution of the data.

TABLE XI-A - MEASUREMENTS (CM) OF THE RENAL VEINS IN MALES AND FEMALES AND IN THE TOTAL SAMPLE (N=100)

	MALE (n = 85)		FEMALE (n = 15)		TOTAL (n = 100)	
	Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max
LENGTH OF LEFT RENAL VEINS						
L-LRV	5.8 (1.5)	2.9 - 9.8	6.3 (1.6)	3.9-10.4	5.9 (1.5)	2.9-10.4
GV-1	2.0 (1.3)	0.0 - 4.9	2.0 (1.2)	0.0 - 4.0	2.0 (1.3)	0.0 - 4.9
GV-IVC	3.3 (1.3)	0.0 - 6.2	3.8 (1.0)	2.4 - 6.2	3.4 (1.3)	0.0 - 6.2
SRV-1	2.3 (1.2)	0.0 - 6.2	2.6 (1.3)	0.6 - 5.0	2.4 (1.3)	0.0 - 6.2
SRV-IVC	3.0 (0.9)	0.0 - 5.0	3.3 (0.9)	2.1 - 5.0	3.1 (0.9)	0.0 - 5.0
L-LRV2	5.2	— — —	5.9	— — —	5.5 (0.5)	5.2 - 5.9
LENGTH OF RIGHT RENAL VEINS						
L-RRV	2.4 (0.7)	1.0 - 4.2	2.4 (0.8)	1.0 - 4.0	2.4 (0.7)	0.7 - 4.2
L-RRV2	2.4 (1.1)	0.6 - 4.6	4.0 (0.3)	3.7 - 4.2	2.5 (1.1)	0.6 - 4.6
L-RRV3	2.4 (0.9)	1.2 - 3.3	— —	— —	2.4 (0.9)	1.2 - 3.3
DIAMETER OF LEFT RENAL VEINS						
D-LRV	1.2 (0.2)	0.7 - 1.6	1.2 (0.2)	0.7 - 1.6	1.2 (0.2)	0.7 - 1.6
D-LRV-GV	1.0 (0.2)	0.2 - 1.6	1.1 (0.2)	0.8 - 1.4	1.0 (0.2)	0.2 - 1.6
D-LRV-SRV	1.1 (0.2)	0.3 - 1.5	1.1 (0.3)	0.4 - 1.5	1.1 (0.2)	0.3 - 1.5
D-LRV-EQ	1.0 (0.2)	0.3 - 1.3	1.0 (0.1)	1.0 - 1.1	1.0 (0.2)	0.3 - 1.3
D-GV	0.5 (0.3)	0.1 - 1.2	0.4 (0.2)	0.1 - 0.8	0.5 (0.3)	0.1 - 1.2
D-SRV	0.4 (0.3)	0.1 - 1.0	0.4 (0.2)	0.1 - 0.8	0.4 (0.2)	0.1 - 1.0
D-LRV2	0.8	— — —	1.0	— — —	0.9 (0.1)	0.8 - 1.0
DIAMETER OF RIGHT RENAL VEINS						
D-RRV	1.2 (0.2)	0.7 - 1.7	1.2 (0.2)	0.9 - 1.5	1.2 (0.2)	0.7 - 1.7
D-RRV2	0.7 (0.2)	0.3 - 1.1	0.5 (0.1)	0.4 - 0.5	0.7 (0.2)	0.3 - 1.1
D-RRV3	0.7 (0.2)	0.4 - 0.9	— —	— —	0.7 (0.2)	0.4 - 0.9
DIAMETER OF IVC (RENAL VEIN INFLUENCE)						
D-IVC-R-LW	2.1 (0.3)	1.5 - 2.6	2.1 (0.2)	1.8 - 2.4	2.1 (0.2)	1.5 - 2.6
D-IVC-L-LW	2.1 (0.3)	1.5 - 2.8	2.2 (0.4)	1.9 - 2.9	2.1 (0.3)	1.5 - 2.9
D-IVC-L=R	1.9 (0.3)	1.1 - 2.3	1.9 (0.0)	1.9 - 1.9	1.9 (0.3)	1.1 - 2.3
HEIGHT OF IVC (RENAL VEIN INFLUENCE)						
L-IVC-COM	2.3 (1.0)	1.1 - 6.7	2.4 (1.0)	1.4 - 4.7	2.3 (1.0)	1.1 - 6.7
L-IVC-L=R	1.0 (0.9)	0.0 - 5.5	1.0 (0.9)	0.0 - 3.1	1.0 (0.9)	0.0 - 5.5

Number of observations

	MALE	FEMALE
L-LRV2	1	1
L-RRV2	29	2
L-RRV3	5	0
D-LRV-GV	70	13
D-LRV-SRV	70	13
D-LRV-EQ	15	2

	MALE	FEMALE
D-LRV2	1	1
D-RRV2	29	2
D-RRV3	5	0
D-IVC-R-LW	45	8
D-IVC-L-LW	30	5
D-IVC-L=R	10	2

No statistically significant differences in renal vein measurements between males and females were found (independent samples t-tests, p=0.05).

TABLEXI-B - MEASUREMENTS (CM) OF THE RENAL VEINS FOR EACH RACE GROUP (N=100)

	BLACK (n = 87)		INDIAN (n = 3)		WHITE (n = 7)		"COLOURED" (n = 3)	
	Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max
LENGTH OF LEFT RENAL VEINS								
L-LRV	5.9 (1.5)	2.9- 10.4	6.7 (1.2)	5.5 - 7.9	5.8 (2.0)	3.8 - 9.8	5.2 (1.3)	4.0 - 6.6
GV-I	2.1 (1.3)	0.0 - 4.9	1.9 (0.3)	1.5 - 2.2	0.8 (1.2)	0.1 - 3.5	1.7 (1.0)	0.8 - 2.8
GV-IVC	3.3 (1.3)	0.0 - 6.2	4.2 (0.7)	3.5 - 4.8	4.5 (1.0)	2.9 - 5.5	3.0 (2.2)	0.5 - 4.7
SRV-1	2.4 (1.3)	0.0 - 6.2	2.6 (0.6)	0.9 - 3.0	1.9 (1.6)	0.0 - 5.1	2.0 (0.5)	1.5 - 2.5
SRV-IVC	3.0 (0.9)	0.0 - 4.9	3.7 (0.5)	3.2 - 4.1	3.6 (1.2)	2.1 - 5.0	2.9 (1.0)	1.9 - 3.9
L-LRV2	5.5 (0.5)	5.2 - 5.9	— —	— —	— —	— —	— —	— —
LENGTH OF RIGHT RENAL VEINS								
L-RRV	2.4 (0.7)	0.9 - 4.1	1.8 (0.7)	0.9 - 2.2	2.4 (1.1)	0.7 - 4.2	2.2 (0.5)	1.8 - 2.7
L-RRV2	2.4 (1.1)	0.6 - 4.6	— —	— —	3.6 (0.2)	3.5 - 3.9	1.8 (1.8)	0.6 - 3.1
L-RRV3	2.6 (0.7)	2.0 - 3.3	— —	— —	3.1 —	— —	1.2 —	— —
DIAMETER OF LEFT RENAL VEINS								
D-LRV	1.2 (0.2)	0.7 - 1.6	1.1 (0.2)	0.9 - 1.3	1.4 (0.1)	1.3 - 1.6	1.1 (0.1)	1.0 - 1.1
D-LRV-GV	1.0 (0.3)	0.2 - 1.6	1.0 (0.1)	1.0 - 1.1	1.0 (0.2)	0.8 - 1.2	1.0 (0.2)	0.8 - 1.3
D-LRV-SRV	1.1 (0.3)	0.3 - 1.5	1.2 (0.2)	1.0 - 1.4	1.3 (0.2)	1.0 - 1.4	1.2 (0.1)	1.1 - 1.3
D-LRV-EQ	1.0 (0.2)	0.3 - 1.3	— —	— —	1.1 (0.1)	1.0 - 1.2	— —	— —
D-GV	0.4 (0.3)	0.1 - 1.2	0.7 (0.3)	0.5 - 1.0	0.6 (0.3)	0.1 - 0.8	0.5 (0.2)	0.4 - 0.7
D-SRV	0.4 (0.3)	0.1 - 1.0	0.5 (0.3)	1.9 - 3.0	0.4 (0.2)	0.2 - 0.7	0.3 (0.2)	1.5 - 0.6
D-LRV2	0.9 (0.1)	0.8 - 1.0	— —	— —	— —	— —	— —	— —
DIAMETER OF RIGHT RENAL VEINS								
D-RRV	1.2 (0.2)	0.7 - 1.7	1.3 (0.2)	1.1 - 1.5	1.2 (0.3)	0.7 - 1.6	0.8 (0.1)	0.7 - 1.0
D-RRV2	0.7 (0.2)	0.3 - 1.1	— —	— —	0.7 (0.2)	0.6 - 1.0	0.6 (0.1)	0.5 - 0.7
D-RRV3	0.8 (0.2)	0.6 - 0.9	— —	— —	0.4 —	— —	0.7 —	— —
DIAMETER OF IVC (RENAL VEIN INFLUENCE)								
D-IVC-R-LW	2.1 (0.2)	1.5 - 2.6	2.1 (0.3)	1.7 - 2.3	1.8 (0.0)	1.8 - 1.9	1.9 (0.1)	1.8 - 2.0
D-IVC-L-LW	2.1 (0.3)	1.5 - 2.9	— —	— —	2.1 (0.2)	1.9 - 2.4	1.6 —	1.6 - 1.6
D-IVC-L=R	1.9 (0.3)	1.1 - 2.3	— —	— —	— —	— —	— —	— —
HEIGHT OF IVC (RENAL VEIN INFLUENCE)								
L-IVC-COM	2.3 (1.0)	1.1 - 6.7	1.8 (0.1)	1.7 - 1.9	3.0 (1.2)	1.4 - 4.7	2.4 (0.9)	1.3 - 3.1
L-IVC-L=R	1.0 (0.9)	0.0 - 5.5	0.7 (0.1)	0.6 - 0.8	1.3 (0.8)	0.4 - 2.9	1.1 (0.7)	0.4 - 1.6

Number of observations

	BLACK	INDIAN	WHITE	"COLOURED"
L-LRV2	2	0	0	0
L-RRV2	26	0	3	2
L-RRV3	3	0	1	1
D-LRV-GV	73	3	4	3
D-LRV-SRV	73	3	4	3
D-LRV-EQ	14	0	3	0
D-LRV2	2	0	0	0
D-RRV2	26	0	3	2
D-RRV3	3	0	1	1
D-IVC-R-LW	45	3	3	2
D-IVC-L-LW	30	0	4	1
D-IVC-L=R	12	0	0	0

TABLE XI-C - MEASUREMENTS (CM) OF THE RENAL VEINS FOR EACH CLASSIFICATION TYPE (N=100)

	TYPE IA(n=81)		TYPE IB(n=53)		TYPE IIA(n=17)		TYPE IIB(n=16)		TYPE III(n=33)	
	Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max
LENGTH OF LEFT RENAL VEINS										
L-LRV	5.8 (1.6)	2.9-0.4	6.0 (1.5)	2.9-10.4	6.1 (1.3)	3.8-8.2	6.4 (1.8)	4.1-9.8	5.4 (1.2)	0.7-1.6
GV-I	1.9 (1.2)	0.0-4.8	2.1 (1.3)	0.1- 4.9	2.2 (1.7)	0.1-4.5	2.2 (1.2)	0.2-4.0	1.9 (1.3)	0.0-4.9
GV-IVC	3.5 (1.1)	0.5-6.2	3.4 (1.3)	0.0- 6.2	3.4 (1.6)	1.0-5.5	3.7 (1.2)	0.5-5.5	3.1 (1.6)	0.0-5.4
SRV-I	2.3 (1.3)	0.0-5.2	2.6 (1.2)	0.0- 6.2	2.6 (1.3)	1.0-6.2	2.9 (1.3)	1.1-5.1	1.9 (1.0)	0.0-3.5
SRV-IVC	3.1 (0.8)	1.0-4.9	3.0 (1.0)	0.0- 5.0	3.0 (1.1)	1.4-4.7	3.0 (0.9)	1.7-4.4	3.0 (1.1)	0.0-5.0
L-LRV2	— —	— —	— —	— —	— —	— —	— —	— —	5.5 (0.4)	5.2-5.9
LENGTH OF RIGHT RENAL VEINS										
L-RRV	2.6 (0.7)	0.9-4.1	2.3 (0.6)	0.9-3.6	2.1 (0.6)	0.7-3.1	2.3 (1.1)	0.7-4.2	2.3 (0.7)	1.2-3.6
L-RRV2	— —	— —	— —	— —	— —	— —	— —	— —	2.6 (1.1)	0.6-4.6
L-RRV3	— —	— —	— —	— —	— —	— —	— —	— —	2.4 (0.9)	1.2-3.3
DIAMETER OF LEFT RENAL VEINS										
D-LRV	1.2 (0.2)	0.9-1.6	1.2 (0.2)	0.8-1.6	1.3 (0.2)	1.0-1.6	1.2 (0.3)	4.1-9.8	1.2 (0.2)	0.7-1.6
D-LRV-GV	1.0 (0.2)	0.6-1.6	1.0 (0.2)	0.2-1.5	1.0 (0.2)	0.6-1.3	1.0 (0.3)	0.5-1.4	0.9 (0.3)	0.2-1.6
D-LRV-SRV	1.1 (0.2)	0.4-1.4	1.1 (0.3)	0.3-1.5	1.3 (0.1)	1.1-1.4	1.1 (0.3)	0.5-1.5	1.1 (0.3)	0.3-1.4
D-LRV-EQ	1.1 (0.1)	0.8-1.3	1.0 (0.3)	0.3-1.2	1.1 (0.1)	0.9-1.1	1.1 (0.2)	0.8-1.2	0.9 (0.3)	0.3-1.2
D-GV	0.4 (0.3)	0.1-1.2	0.5 (0.2)	0.1-1.0	0.5 (0.2)	0.1-1.0	0.5 (0.2)	0.1-0.8	0.5 (0.3)	0.1-1.2
D-SRV	0.4 (0.3)	0.1-1.0	0.4 (0.2)	0.1-0.9	0.4 (0.3)	0.1-0.9	0.4 (0.3)	0.1-0.9	0.5(0.3)	0.1-1.0
D-LRV2	— —	— —	— —	— —	— —	— —	— —	— —	0.9 (0.1)	0.8-1.0
DIAMETER OF RIGHT RENAL VEINS										
D-RRV	1.2 (0.2)	0.7-1.7	1.2 (0.2)	0.8 - 1.6	1.3 (0.2)	1.1 - 1.6	1.2 (0.3)	0.7 - 1.7	1.1 (0.2)	0.7-1.5
D-RRV2	— —	— —	— —	— —	— —	— —	— —	— —	0.7 (0.2)	0.3-1.1
D-RRV3	— —	— —	— —	— —	— —	— —	— —	— —	0.7 (0.2)	0.4-0.9
DIAMETER OF IVC (RENAL VEIN INFLUENCE)										
D-IVC-R-LW	2.1 (0.2)	1.5 (2.6)	2.1 (0.2)	1.7 (2.5)	2.0 (0.3)	1.7 (2.4)	2.0 (0.3)	1.5 (2.4)	2.1 (0.3)	1.5(2.6)
D-IVC-L-LW	2.1 (0.3)	1.5 (2.9)	2.2 (0.3)	1.6 (2.9)	2.0 (0.2)	1.8 (2.2)	2.0 (0.2)	1.6 (2.2)	2.1 (0.3)	1.5(2.5)
D-IVC-L=R	1.9 (0.3)	1.1 (2.3)	2.0 (0.1)	1.9 (2.2)	1.9 (0.1)	1.8 (2.0)	— —	1.8 (1.8)	1.5 (0.5)	1.1(1.1)
HEIGHT OF IVC (RENAL VEIN INFLUENCE))										
L-IVC-COM	2.2 (0.9)	1.1 (6.7)	2.4 (1.1)	1.2 (6.7)	2.2 (0.6)	1.1 (3.0)	2.0 (0.6)	1.1 (3.0)	2.7 (1.1)	1.2(5.8)
L-IVC-L=R	0.9 (0.9)	0.0 (5.5)	1.1 (1.0)	0.0 (5.5)	0.9 (0.5)	0.0 (1.8)	0.8 (0.6)	0.0 (1.9)	1.2 (0.9)	0.0(4.6)

Number of observations

	TYPE IA	TYPE IB	TYPE IIA	TYPE IIB	TYPE III
L-LRV2	—	—	—	—	2
L-RRV2	—	—	—	—	31
L-RRV3	—	—	—	—	5
D-LRV-GV	72	43	14	12	25
D-LRV-SRV	72	43	14	12	25
D-LRV-EQ	8	10	3	5	8
D-LRV2	—	—	—	—	2
D-RRV2	—	—	—	—	31
D-RRV3	—	—	—	—	5
D-IVC-R-LW	41	29	10	8	18
D-IVC-L-LW	23	20	5	8	14
D-IVC-L=R	16	4	2	1	1

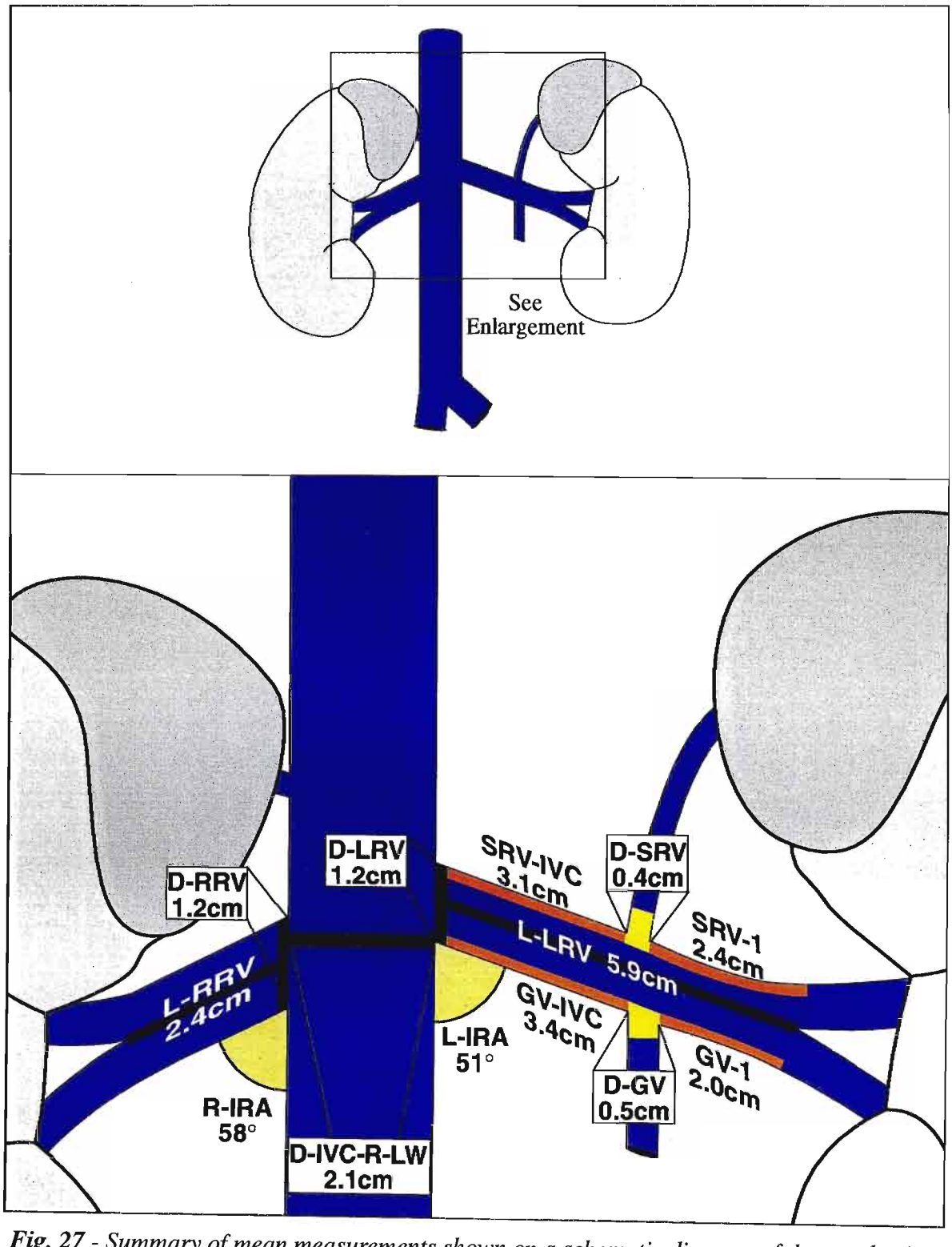


Fig. 27 - Summary of mean measurements shown on a schematic diagram of the renal veins.

4.3.1 Lengths of Left Renal Veins

The mean length of the left renal vein (L-LRV) was found to be 5.9 ± 1.5 (2.9 - 10.4)cm. No statistically significant difference could be detected between the sexes, race groups and classification types with regard to the length of the left renal veins.

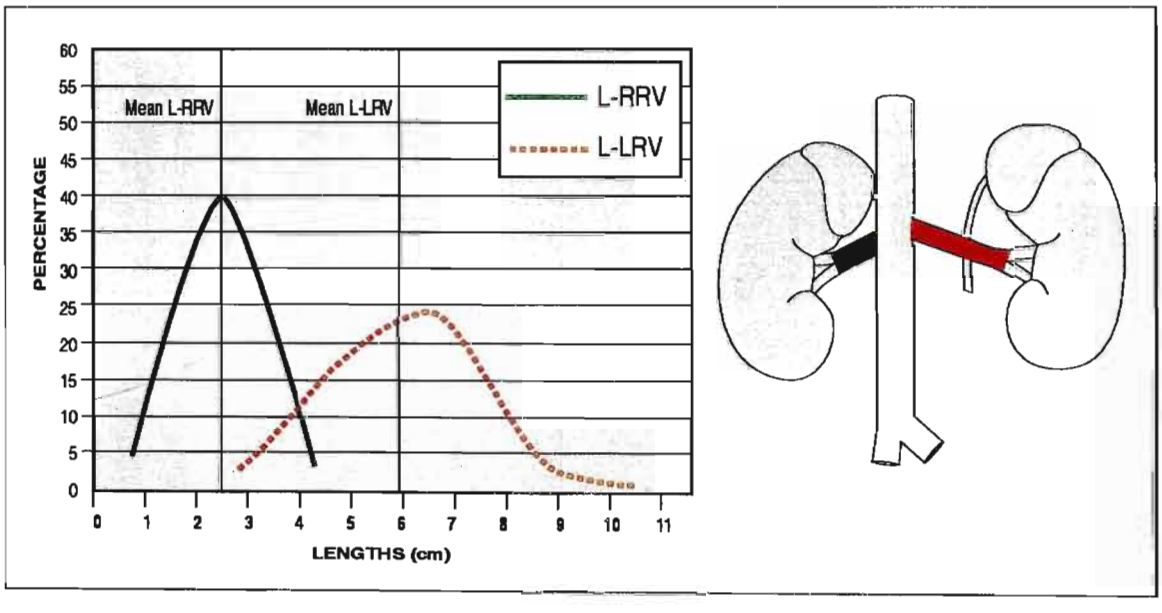


Fig. 28 - Mean lengths of the left and right renal veins (L-LRV and L-RRV) and the distribution of measurements (n=100).

The length of the renal vein segment GV-1 was 2.0 ± 1.3 (0.0 - 4.9)cm while that of SRV-1 was 2.4 ± 1.3 (0.0 - 6.1)cm.

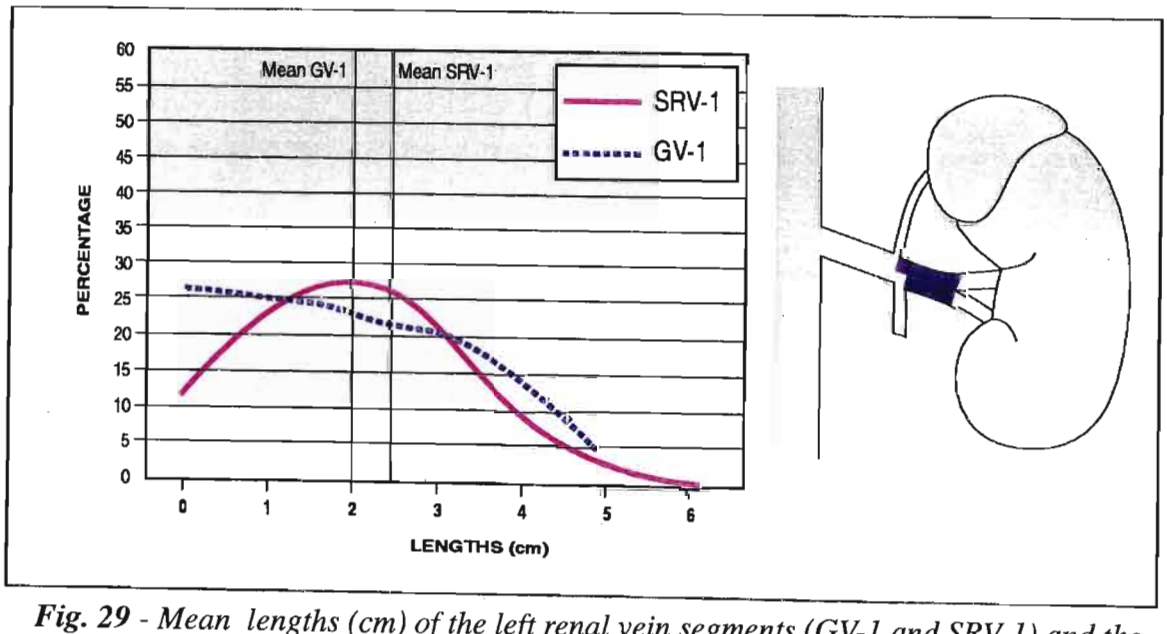
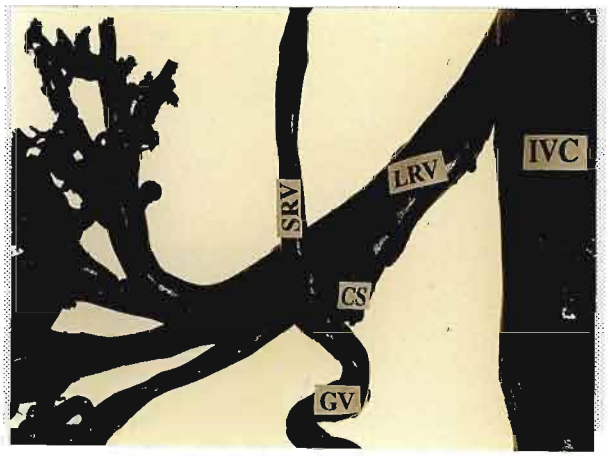


Fig. 29 - Mean lengths (cm) of the left renal vein segments (GV-1 and SRV-1) and the distribution of measurements(n=100).

In 63 cases, SRV-1 was longer than GV-1, equal in 2 and shorter in 35 cases.

When comparing the length of the renal vein segment from the primary renal vein tributaries to the suprarenal vein (SRV-1) and to the gonadal vein (GV-1), a statistically significant difference was noted ($p<0.0001$). This difference was also noted in both sexes and in all race groups except the "Coloured" (n=3) during the sub-group analyses.

A combined mean of the lengths of SRV-1 and GV-1 (2.2 cm) and the diameters of D-SRV and D-GV (0.4 cm) together yielded a proximal renal vein segment length of 2.6 cm.



LRV – *Left renal vein*
IVC – *Inferior vena cava*
GV – *Gonadal vein*
SRV – *Suprarenal vein*
CS – *Common stem*

***Plate 6** - Common origin of gonadal and suprarenal vein from the left renal vein (resin cast posterior view)*

The length of the renal vein segment GV-IVC was 3.4 ± 1.3 (0.0 - 6.2)cm while that of SRV-IVC was 3.1 ± 0.9 (0.0 - 5.0)cm. This difference was found to be statistically significant ($p < 0.001$) and was noted among both sexes and in all race groups except "Coloured" (n=3)

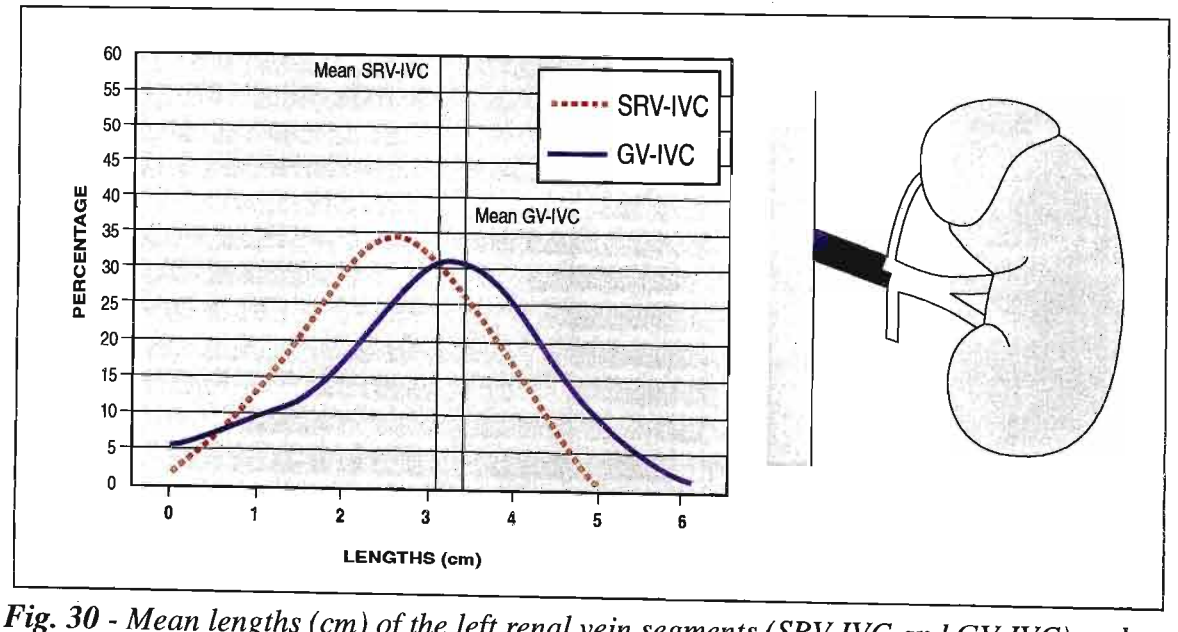


***Fig. 30** - Mean lengths (cm) of the left renal vein segments (SRV-IVC and GV-IVC) and the distribution of measurements (n=100).*

In 66 cases, SRV-IVC was shorter than GV-IVC, equal in 2 and longer in 32 cases. When comparing the length of the renal vein segment between the gonadal vein and the inferior vena cava (GV-IVC) and the supra-renal vein and the inferior vena cava (SRV-IVC), a statistically significant difference ($p<0.0001$) was noted. This difference was also noted in both sexes and in all race groups except the Indian and "Coloured", both groups having a small sample size of 3 each.

A combined mean of SRV-IVC and GV-IVC yielded a distal renal vein segment length of 3.2cm.

When GV-1 and SRV-1 were each compared to SRV-IVC and GV-IVC respectively, significant differences were noted ($p<0.0001$) (Table XIII).

An additional renal vein (L-LRV2) measuring 5.5 ± 0.5 (5.2 - 5.9)cm was detected in 2 kidneys (1 male, 1 female; both Black)

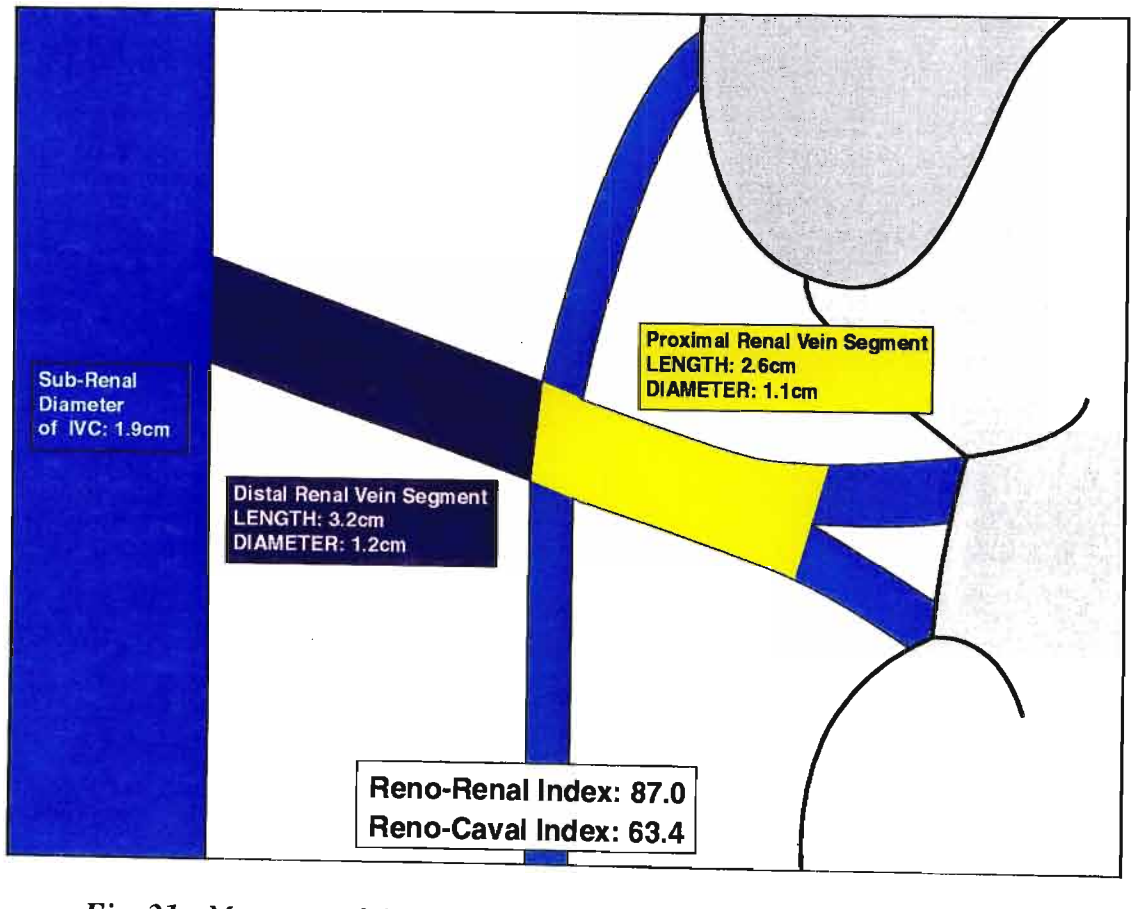


Fig. 31 *- Measures of the proximal and distal segments of the left renal vein.*

4.3.2 Lengths of Right Renal Veins

The mean length of the right renal vein was found to be 2.4 ± 0.7 (0.7 - 4.2)cm (Fig. 27).

No statistically significant difference could be detected between the sexes, race groups and classification types with regard to the length of the right renal veins.

An additional renal vein (L-RRV-2) measuring 2.5 ± 1.1 (0.6 - 4.6)cm was detected in 31 of the 100 kidneys (29 male, 2 female). The race distribution was 26 Black, 2 "Coloured" and 3 White.

A second additional renal vein (L-RRV-3) measuring 2.4 ± 0.9 (1.2 - 3.3)cm was detected in 5 kidneys, all male (3 Black, 1 White and 1 "Coloured").

The mean lengths of the additional renal veins (L-RRV2, L-RRV3) were compared with each other and with the right renal vein (L-RRV) (Table XIII). No statistically significant difference in lengths were detected.

4.3.3 Comparisons of the Lengths of the Left and Right Renal Veins

L-LRV vs L-RRV: In comparing the mean lengths of the left renal vein (L-LRV) and the right renal vein (R-RRV), it was noted that L-LRV was 2.5 times as long as L-RRV ($p<0.0001$). This difference was found to be statistically significant for males, females and all race groups except the "Coloured" ($n = 3$), where it is clearly an effect of small sample size.

When comparing L-RRV with the mean length of the renal vein segment GV-1 for the total sample, a statistically significant difference was noted ($p = 0.006$). However, no such difference was noted when L-RRV was compared to SRV-1. These findings were not always duplicated during sub-group analysis.

When the mean length of the proximal renal vein segment was compared to L-RRV, no statistically significant difference was noted.

4.3.4 Diameter of Left Renal Veins

The mean diameter of the left renal vein (D-LRV) was found to be 1.2 ± 0.2 (0.7 - 1.6)cm.

No statistically significant difference could be detected between the sexes with respect to the diameter of the left renal veins.

A marginally significant difference was found between Blacks and Whites (p = 0.048) but not with the other race groups.

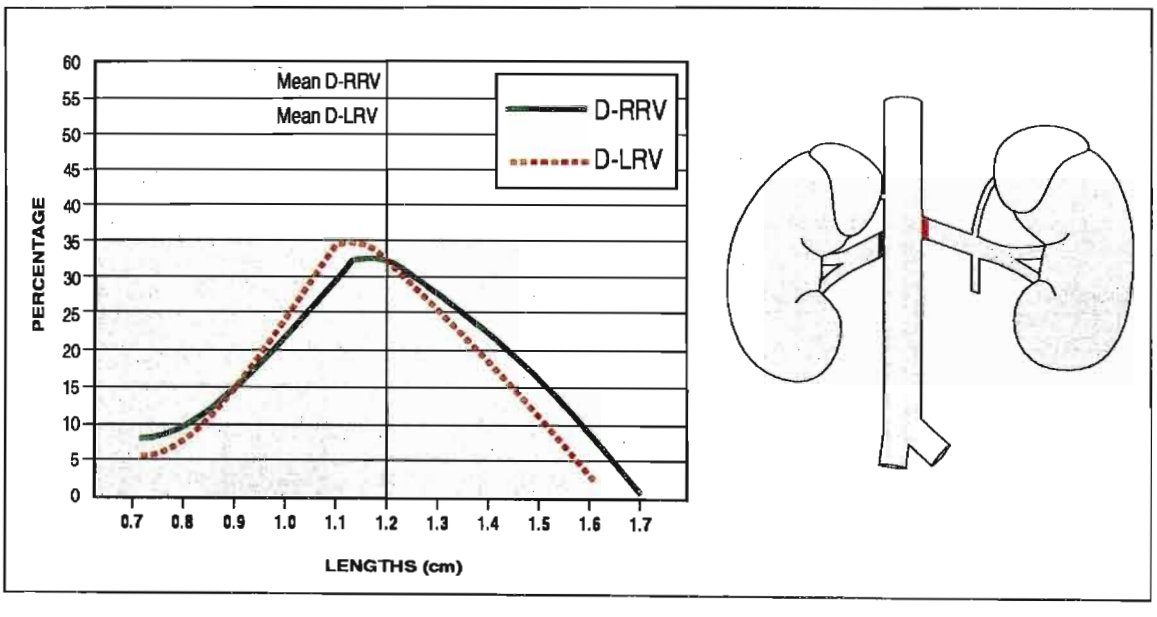


***Fig. 32** - Mean diameters of the left and right renal veins (D-LRV and D-RRV) and the distribution of measurements (n=100).*

The diameter of the left renal vein at the separate points of entry with the suprarenal vein (D-LRV-SRV) and gonadal vein (D-LRV-GV) was 1.1 ± 0.2 (0.3 - 1.5)cm and 1.0 ± 0.2 (0.2 - 1.6)cm respectively. Where they entered opposite each other (D-LRV-EQ), the diameter measured 1.0 ± 0.2 (0.3 - 1.3)cm.

The mean diameter of the left renal vein at the points of entry of the suprarenal and gonadal veins was compared to the diameter at its point of entry into the IVC. While significant differences were noted with D-LRV-GV vs D-LRV ($p<0.0001$), D-LRV-SRV vs D-LRV ($p<0.0001$) and D-LRV-GV vs D-LRV-SRV ($p<0.0001$), this was not always duplicated during the sub-group analyses for sex and race (Table XIII). No significant difference was noted during the comparison of D-LRV-EQ vs D-LRV.

A weighted combined mean diameter of D-LRV-GV, D-LRV-SRV and D-LRV-EQ yielded a proximal renal vein diameter of 1.1cm.

The Reno-Renal Index, a ratio of the proximal to the distal diameter of the renal vein, was calculated to be 87.0.

The diameter of the additional left renal vein (D-LRV2) was 0.9 ± 0.1 (0.8 - 1.1)cm.

The diameter of the gonadal vein at its point of entry into the left renal vein (D-GV) was found to be 0.5 ± 0.3 (0.1 - 1.2)cm while that of the suprarenal vein (D-SRV) was 0.4 ± 0.2 (0.1 - 1.0)cm.

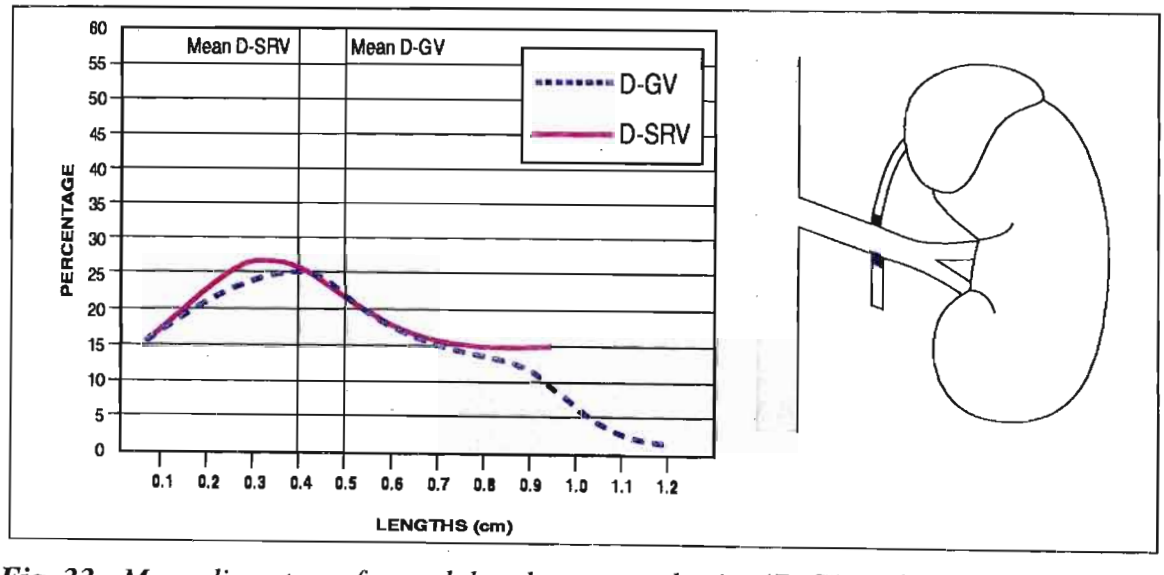


***Fig. 33** - Mean diameters of gonadal and suprarenal veins (D-GV and D-SRV) and the distribution of measurements (n=100).*

4.3.5 Diameter of Right Renal Veins

The mean diameter of the right renal vein was 1.2 ± 0.2 (0.7 - 1.7)cm. (Fig. 32)

No statistically significant difference could be detected in the diameter of right renal veins between the sexes and race groups.

The mean diameters of the additional renal veins, D-RRV2 and D-RRV3 were 0.7 ± 0.2 (0.3 - 1.1)cm and 0.7 ± 0.2 (0.4 - 0.9)cm respectively.

Significant differences (p=0.027) were found during the comparison of the diameters of

these additional renal veins. However, when 1 or 2 additional renal veins were present, their combined diameters together with that of the main right renal vein were found to be the same as D-RRV (1.2 cm).

4.3.6 Comparisons of the Diameters of the Left and Right Renal Veins

The diameters of the left and right renal veins were compared and no statistically significant difference was noted except in Indians (p=0.030; n=3).

When comparing the diameter of the right and left renal veins (D-RRV and D-LRV, respectively) at the point of entry of the gonadal vein (D-LRV-GV), and at the point where it drains directly opposite the suprarenal vein (D-LRV-EQ), a statistically significant difference was noted i.e. D-RRV vs D-LRV-GV: ($p<0.0001$) and D-RRV vs D-LRV-EQ : (p=0.029) respectively. No such difference was noted with respect to D-RRV vs D-LRV-SRV. However, statistically significant differences in diameters were not always duplicated during sub-group analysis for sex and race (Table XIII).

4.3.7 Diameter, Vertical Distance and Level of Entry of Renal Veins into IVC and of IVC (Under the Influence of Renal Veins)

4.3.7.1 Diameters

The diameter of the IVC where the left and right renal vein entered the IVC directly opposite each other (D-IVC-L=R, n=12) was found to be 1.9 ± 0.3 (1.1 - 2.3)cm. The diameter of the IVC where the left and right renal veins entered the IVC at different levels were found to be similar viz. left lower (D-IVC-L-LW, n=35): 2.1 ± 0.3 (1.5 - 2.9)cm and right lower (D-IVC-R-LW, n=53): 2.1 ± 0.2 (1.5 - 2.6)cm.

A weighted combined mean diameter of D-IVC-L=R, D-IVC-L-LW and D-IVC-R-LW yielded a sub-renal diameter of the IVC of 1.9cm.

The Reno-Caval Index, a ratio of the distal diameter of the renal vein to the sub-renal diameter of the IVC, was calculated to be 63.4.

4.3.7.2 Vertical Distances and Level of Entry

Tables XII-A and XII-B display the vertical distance (cm) between the lower borders of the left and right renal veins at the point of entry into the IVC for males and females and the different race groups. Of the kidneys examined (n = 100 pairs), the left renal vein entered the IVC higher (1.0 ± 0.7)cm than the right in 54 cases, lower (1.2 ± 1.1)cm in 36 and at the same level in 10 cases. No statistically significant difference was observed when males and females and the different race groups were compared with respect to level of entry into the IVC. The height of the IVC at the points of convergance with the left and right renal veins (L-IVC-COM) was 2.3 ± 1.0 (1.1 - 6.7)cm. In the case of the right renal vein entering the IVC higher than the left renal vein, the distance between their lower borders measured 1.2 ± 1.1(0.2 - 5.5)cm. Where the left renal vein entered the IVC higher than the right renal vein, the distance between their lower borders was 1.0 ± 0.7 (0.0 - 3.1)cm (Plate 7). No statistically significant difference could be detected in the diameter of the IVC between the sexes, race groups and classification types. A statistically significant difference (p=0.036) was noted in L-IVC-COM among the classification types only and not for sex and race.

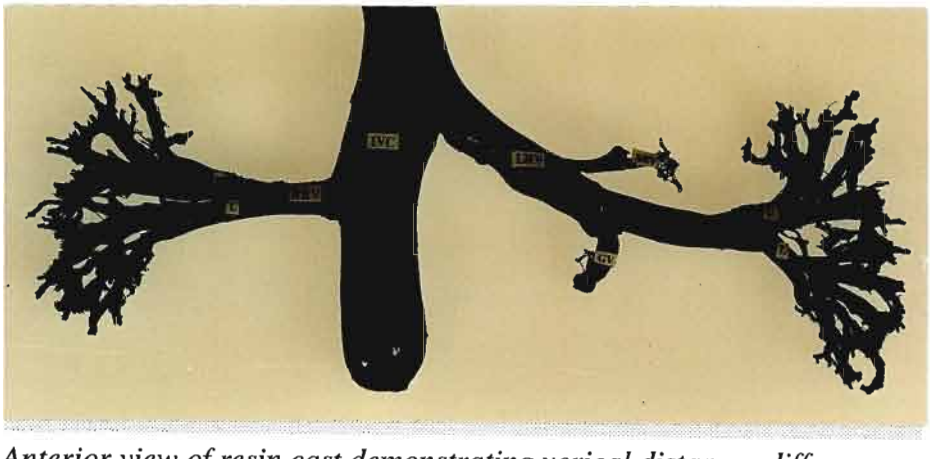


***Plate 7** - Anterior view of resin cast demonstrating verical distances differences of left and right renal vein entry into IVC*

RRV	–	Right renal vein	**GV**	–	Gonadal vein
LRV	–	Left renal vein	**U**	–	Upper primary tributary
IVC	–	Inferior vena cava	**L**	–	Lower primary tributary
SRV	–	Suprarenal vein			

TABLE XII-A *- VERTICAL DISTANCE BETWEEN LOWER BORDERS OF LEFT AND RIGHT RENAL VEINS AT POINT OF ENTRY INTO INFERIOR VENA CAVA FOR MALES AND FEMALES*

	MALE		FEMALE		TOTAL	
	NUMBER	MEAN (SD)	NUMBER	MEAN (SD)	NUMBER	MEAN (SD)
LEFT HIGHER	46	1.0 (0.7)	8	1.4 (0.9)	54	1.0 (0.7)
%	*54.1*		*53.3*		*54*	
RIGHT HIGHER	31	1.2 (1.2)	5	1.0 (0.6)	36	1.2 (1.1)
%	*36.5*		*33.3*		*36*	
EQUAL	8	— —	2	— —	10	— —
%	*9.4*		*13.3*		*10*	
TOTAL	85		15		100	
%	*100*		*100*		*100*	

TABLE XII-B *- VERTICAL DISTANCE BETWEEN LOWER BORDERS OF LEFT AND RIGHT RENAL VEINS AT POINT OF ENTRY INTO INFERIOR VENA CAVA FOR EACH RACE GROUP*

	RACE GROUP							
	BLACK		INDIAN		WHITE		"COLOURED"	
	Number	Mean (SD)	Number	Mean (SD)	Number	Mean (SD)	Number	Mean (SD)
LEFT HIGHER	46	1.0 (0.7)	3	0.7 (0.1)	3	1.8 (1.0)	2	1.5 (0.1)
%	*52.9*		*100*		*42.9*		*66.7*	
RIGHT HIGHER	31	1.2 (1.1)	—	— —	4	1.0 (0.7)	1	0.4 —
%	*35.6*		—		*57.1*		*33.3*	
EQUAL	10	— —	—	— —	—	— —	—	— —
%	*11.5*							
TOTAL	87		3		7		3	
%	*100*		*100*		*100*		*100*	

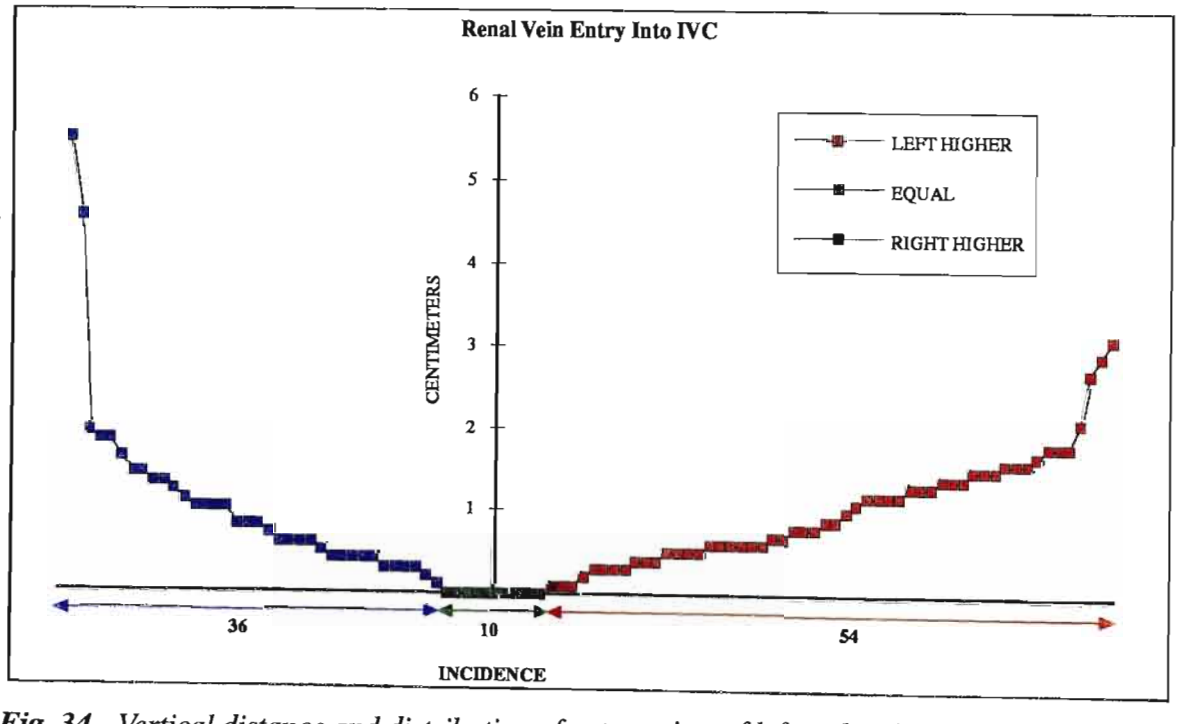


Fig. 34 *- Vertical distance and distribution of entry points of left and right renal veins into IVC. Each square (□) represents 1 pair of kidneys*

***TABLE XIII** - PAIRED SAMPLES T-TESTS ON SELECTED COMPARISONS OF RENAL VEIN MEASUREMENTS*

	TOTAL	SEX		RACE			
	SAMPLE	MALE	FEMALE	BLACK	INDIAN	WHITE	"COLOURED"
L-LRV *vs* L-RRV	0.0001	0.0001	0.0001	0.0001	0.004	0.0001	*n.s.*
L-LRV *vs* L-LRV2	*n.s.*	—	—	*n.s.*	—	—	—
L-LRV2 *vs* L-RRV2	*n.s.*	—	—	*n.s.*	—	—	—
L-LRV *vs* L-RRV2	*n.s.*	—	—	0.0001	—	*n.s.*	0.010
SRV-1 *vs* GV-1	0.0001	0.002	0.025	0.003	0.044	0.008	*n.s.*
GV-1 *vs* GV-IVC	0.0001	0.0001	0.0001	0.0001	0.007	0.0001	*n.s.*
SRV-1 *vs* SRV-IVC	0.0001	0.0001	*n.s.*	0.002	0.011	*n.s.*	*n.s.*
GV-IVC *vs* SRV-IVC	0.0001	0.001	0.019	0.001	*n.s.*	0.007	*n.s.*
GV-1 *vs* SRV-IVC	0.0001	0.0001	0.003	0.0001	0.002	0.003	*n.s.*
L-RRV *vs* GV-1	0.006	0.012	*n.s.*	0.045	*n.s.*	0.005	*n.s.*
L-RRV *vs* SRV-1	*n.s.*	*n.s.*	*n.s.*	*n.s.*	0.015	*n.s.*	*n.s.*
L-RRV *vs* GV-IVC	0.0001	0.0001	0.001	0.0001	0.001	0.011	*n.s.*
L-RRV *vs* SRV-IVC	0.0001	0.0001	0.003	0.0001	0.011	0.036	*n.s.*
L-RRV *vs* L-RRV2	*n.s.*	*n.s.*	*n.s.*	*n.s.*	—	*n.s.*	*n.s.*
L-RRV *vs* L-RRV3	*n.s.*	*n.s.*	—	*n.s.*	—	—	—
L-RRV2 *vs* L-RRV3	*n.s.*	*n.s.*	—	*n.s.*	—	—	—
D-LRV *vs* D-RRV	*n.s.*	*n.s.*	*n.s.*	*n.s.*	0.030	*n.s.*	*n.s.*
D-GV *vs* D-SRV	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	0.035
D-LRV-GV *vs* D-LRV	0.0001	0.0001	0.004	0.0001	*n.s.*	0.0001	*n.s.*
D-LRV-SRV *vs* D-LRV	0.0001	0.0001	*n.s.*	0.0001	*n.s.*	*n.s.*	*n.s.*
D-LRV-GV *vs* D-LRV-SRV	0.0001	0.0001	*n.s.*	0.001	*n.s.*	*n.s.*	*n.s.*
D-LRV-EQ *vs* D-LRV	*n.s.*	*n.s.*	*n.s.*	*n.s.*	—	*n.s.*	—
D-LRV2 *vs* D-RRV2	*n.s.*	—	—	*n.s.*	—	—	—
D-RRV *vs* D-SRV	0.0001	0.0001	0.0001	0.0001	0.018	0.002	*n.s.*
D-RRV *vs* D-GV	0.0001	0.0001	0.0001	0.0001	0.012	0.0001	*n.s.*
D-RRV *vs* D-LRV-GV	0.0001	0.0001	0.035	0.0001	*n.s.*	*n.s.*	*n.s.*
D-RRV *vs* D-LRV-SRV	*n.s.*	*n.s.*	*n.s.*	0.021	*n.s.*	*n.s.*	*n.s.*
D-RRV *vs* D-LRV-EQ	0.029	*n.s.*	*n.s.*	*n.s.*	—	*n.s.*	—
D-RRV2 *vs* D-RRV3	0.027	0.027	—	0.025	—	—	—
L-IRA *vs* R-IRA	0.0001	0.006	0.013	0.0001	*n.s.*	*n.s.*	*n.s.*

n.s. = not significant

4.3.8 INFRARENAL ANGLES

Measurements (degrees) of the infrarenal angles obtained from a) resin casts b) *en bloc* renal specimens c) cadavers d) foetuses e) combined samples are shown in Tables XIV-A, XIV-B, XIV-C, XIV-D and XIV-D, respectively.

TABLE XIV-A *- LEFT AND RIGHT INFRARENAL ANGLE (L-IRA AND R-IRA) MEASUREMENTS (DEGREES) FROM THE RESIN CAST SERIES (N=100 PAIRS)*

Males and Females and the Total Sample

	MALE (n = 85)		FEMALE (n = 15)		**TOTAL (n = 100)**	
	Mean (SD)	Min-Max	Mean (SD)	Min-Max	**Mean (SD)**	**Min-Max**
L-IRA	51° (14°)	20°- 86°	49°(11°)	27°-72°	**51° (13°)**	**20° - 86°**
R-IRA	57° (18°)	10°- 90°	64°(19°)	25°-93°	**58° (18°)**	**10° - 93°**

Race Group

	BLACK (n = 87)		INDIAN (n = 3)		WHITE (n = 7)		"COLOURED" (n = 3)	
	Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max
L-IRA	50° (13°)	20° - 86°	62° (10°)	52° - 71°	50° (18°)	32° - 84°	56° (8°)	49° - 64°
R-IRA	58° (18°)	10° - 23°	76° (13°)	65° - 90°	54° (24°)	26° - 86°	53° (14°)	37° - 63°

Classification Type

	TYPE IA(n=81)		TYPE IB(n=53)		TYPE IIA(n=17)		TYPE IIB(n=16)		TYPE III(n=33)	
	Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max	Mean (SD)	Min-Max
L-IRA	51°(13°)	20°-86°	50°(13°)	20°-86°	56°(9°)	38°-70°	52°(14°)	30°-68°	47°(15°)	20°-84°
R-IRA	60°(17°)	10°-93°	60°(19°)	25°-93°	56°(21°)	20°-88°	54°(16°)	26°-86°	54°(18°)	10°-88°

***TABLE XIV-B** - MEASUREMENT (DEGREES) OF INFRARENAL ANGLES FROM RENAL VENOGRAMS OBTAINED USING* EN BLOC *RENAL SPECIMENS (N=21).*

SERIES NO.	P.M. NO.	RACE	SEX	INFRARENAL ANGLE		SERIES NO.	P.M. NO.	RACE	SEX	INFRARENAL ANGLE	
				Left	Right					Left	Right
154	2662	B	M	85	74	164	3180	B	M	75	70
155	2647	B	M	82	80	165	3181	B	F	62	72
156	2665	I	M	54	67	166	3328	B	M	56	62
157	2734	B	M	86	77	167	3411	B	M	38	60
158	2737	B	M	26	36	168	3456	B	F	67	72
159	2738	W	M	66	82	169	3459	B	M	78	72
160	2755	B	F	63	60	170	3466	B	M	80	58
161	2759	B	M	102	78	171	3473	B	M	64	68
162	2972	B	M	52	36	172	144	I	M	70	80
163	2794	B	M	63	72	173	545	B	M	60	78
						174	548	I	M	90	90

***TABLE XIV-C** - MEASUREMENT (DEGREES) OF INFRARENAL ANGLES FROM CADAVERIC VENOGRAMS AND VERTEBRAL LEVEL OF THE RENAL VEIN ENTRY INTO THE IVC (N=11).*

SERIES NO..	P.M.	SEX	RACE	INFRARENAL ANGLE		VERTEBRAL LEVEL*	
				L	R	L	R
201	2069	M	B	62	51	L1*u*	L1*m*
202	2195	M	B	63	82	L1*u*	L1*u*
203	2367	F	B	94	60	L1*m*	L1*u*
204	2553	M	B	77	54	L1*m*	L1*l*
205	2560	M	B	56	56	L1*l*	T12*l*
206	2580	M	B	64	85	L1/2*D*	L2*u*
217	2585	M	B	75	58	L1*l*	L1*u*
208	2682	M	B	62	64	L1*l*	L2*u*
209	3305	M	B	77	81	L1*m*	L1*u*
210	3578	M	B	70	61	L1*l*	L2*u*
211	707	M	B	75	42	L1*l*	T12/L1*D*

**Vertebral level of the central axis of the renal vein entry into the IVC is described by dividing the vertebral body into thirds i.e. upper (u), middle (m) and lower (l) and the level of the inter-vertebral disc (D).*
T =Thoracic and L= Lumbar.

***TABLE XIV-D** - MEASUREMENT (DEGREES) OF INFRARENAL ANGLES AND VERTEBRAL LEVEL OF THE RENAL VEIN ENTRY INTO THE IVC IN THE FOETUS (N=11).*

SERIES NO.	INFRARENAL ANGLE		VERTEBRAL LEVEL*	
	LEFT	RIGHT	LEFT	RIGHT
1	90	54	L2	L3
2	74	61	L2	L2
3	60	i) 61	L2	i) L2
		ii) 108		ii) L2/3D
4	64	40	L1	L1
5	45	i) 61	T12	i) T12
		ii)110		ii) L1
6	65	59	L1/2D	L2
7	70	60	L1	L2
8	61	55	L1/2D	L2
9	62	54	L1	L1
10	50	60	L2/3D	L2
11	71	70	T12	L1/2D

**Foetal series numbers 3 and 5 displayed an additional right renal vein, hence both angles are given. Vertebral level of the central axis of renal vein entry into IVC is described opposite the body of the vertebra or the inter-vertebral disc. L=lumbar, T=thoracic and D=inter-vertebral disc level.*

***TABLE XIV-E** MEASUREMENT (DEGREES) OF INFRARENAL ANGLES FROM RESIN CASTS AND RENAL VENOGRAMS OF EN-BLOC RENAL SPECIMENS, CADAVERS AND FOETUSES.*

	RESIN CASTS (n=100)		*en bloc* RENAL SPECIMENS (n=21)		CADAVERS (n=11)		COMBINED MEAN ADULT INFRARENAL ANGLES (n=132)		FOETUSES (n=11)	
	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT
MEAN	51°	58°	68°	68°	70°	66°	55°	60°	65°	58°
SD	13°	18°	18°	14°	12°	13°	16°	17°	12°	7°
(Min-Max)	(20°-86°)	(10°-93°)	(26°-102°)	(36°-90°)	(56°-94°)	(51°-85°)	(20°-102°)	(10°-93°)	(45°-90°)	(40°-70°)

The left and right infrarenal angle (L-IRA and R-IRA respectively) in the 100 resin casts were 51° ± 13° (20° - 86°) and 58° ± 18° (10° - 93°) respectively. Although no sex, classification type or racial difference was noted in the resin series, a difference was noted between the left and right infrarenal angles ($p<0.0001$).

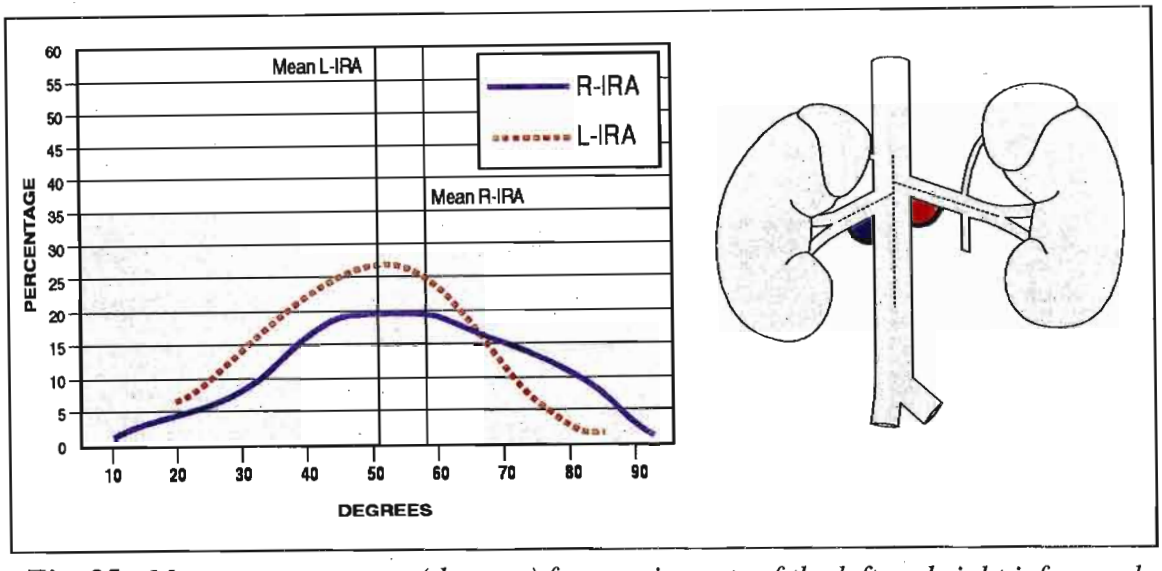


***Fig. 35** - Mean measurements (degrees) from resin casts of the left and right infrarenal angles (L-IRA and R-IRA) and the distribution of measurements (n=100).*

In comparing the left and right infra-renal angles, significant differences were found for the total sample, males, females and Blacks. However, no differences were noted for the other race groups, due most probably to small sample sizes.

The infrarenal angle for *en bloc* renal specimens (acknowledging the detected difference between the left and right sides) were similar to those obtained from the cadaveric renal venograms. However, statistically significant differences were noted in comparisons of cadaveric vs resin casts (p=0.032 on the left; p=not significant on the right) and *en bloc* renal specimens vs resin casts (p=0.003 on the left; p=not significant on the right).

The combined mean adult infrarenal angle measurement (obtained from the resin casts and venograms from the resin casts and venograms from the *en bloc* renal specimens and adult cadavers, (n=132) was 55° ±16° (20°-102°) on the left side, while the right was 60° ±17° (10°-93°).

In the foetal series, the left infrarenal angle was found to be 65° ±12° (45°-90°) while on the right side this angle measured 58° ±7° (40°-70°).

4.4. VERTEBRAL LEVEL OF RENAL VEINS

The percentage distribution and vertebral level of the main renal veins are shown in Fig. 36 (adults) and Fig. 37 (foetuses). Of the 11 adult renal venograms studied, the central axis of the left renal vein was most frequently (45.5%) observed opposite the lower third of the body the first lumbar vertebra, while the right renal vein was found most frequently (36.4%) opposite the upper third of the body of the first lumbar vertebra. The usual site of entry of the right renal vein into the IVC was opposite L1 in 54.6% of cases, with half of these entering opposite the upper third of the body of L1. The variation in entry into the IVC ranged from the lower third of the body of T12 to the upper third of the body of L2. On the left side the renal vein entered into the IVC opposite the body of L1 in 91% of cases. Of these 45.5% entered opposite the lower third of L2. The variation in entry of the left renal vein into the IVC ranged from the upper third of L1 to the intervertebral disc between L1 and L2. In the foetal study the left renal vein was most frequently (27.3%) observed opposite the body of the first lumbar vertebra as well as the second lumbar vertebra, while the right renal vein was found most frequently (54.5%) opposite the body of the second lumbar vertebra.

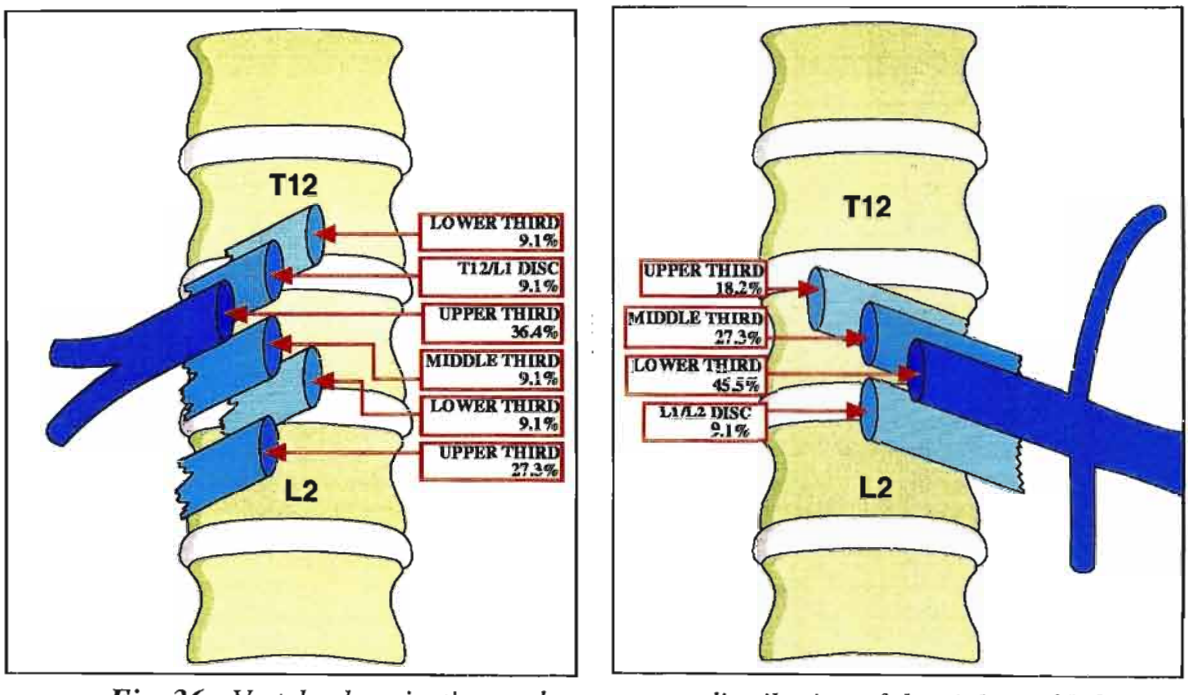


Fig. 36 *- Vertebral projection and percentage distribution of the right and left renal veins in the adult.*

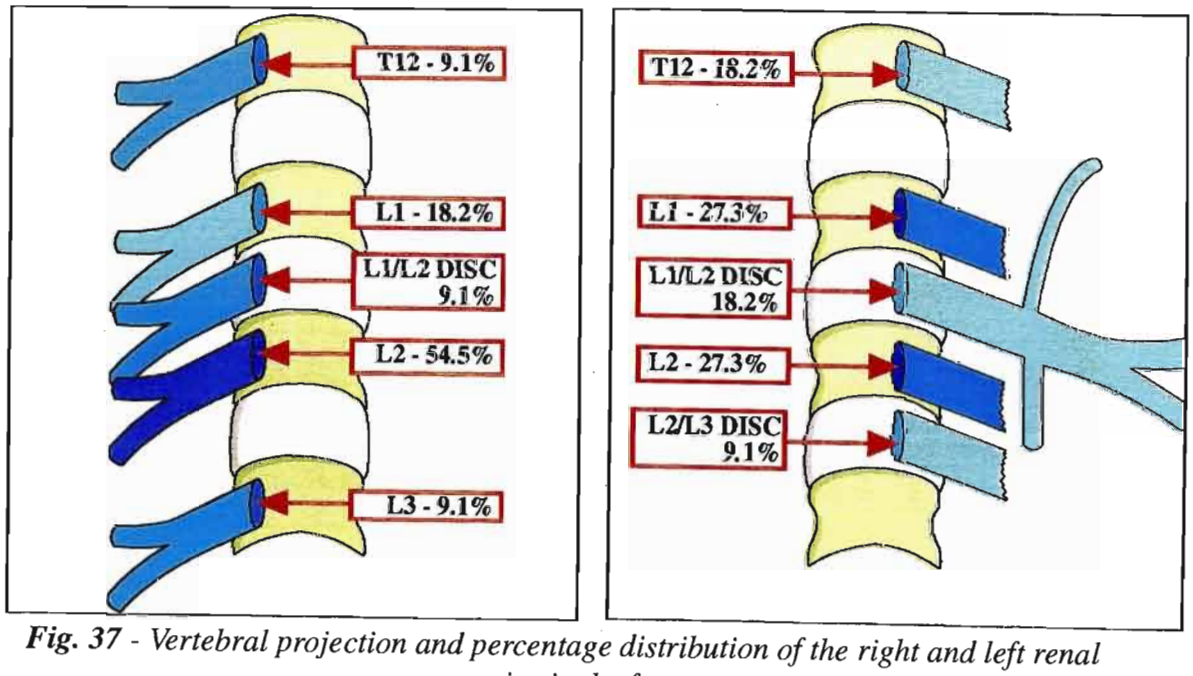
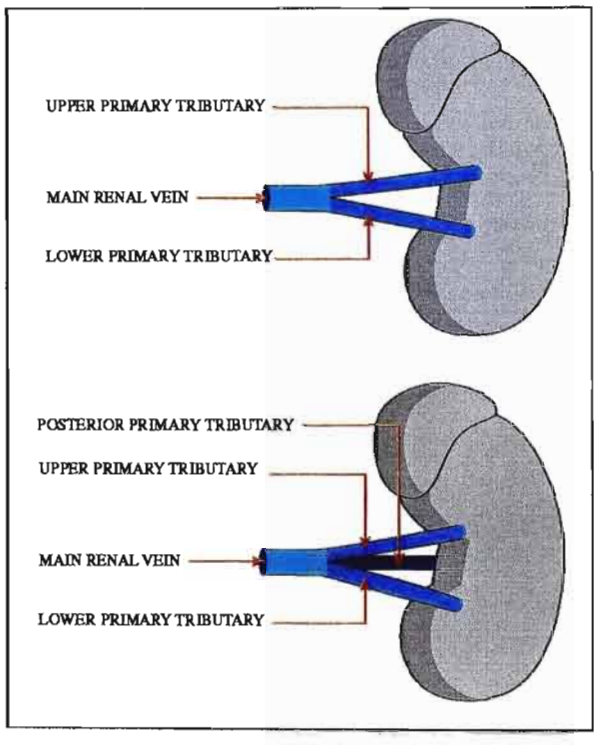


Fig. 37 *- Vertebral projection and percentage distribution of the right and left renal veins in the foetus.*

4.5 CLASSIFICATION OF VENOUS PATTERNS OF RENAL VEINS

The 306 kidneys were classified into 3 major types (Types I, II and III) using the drainage pattern of the primary renal vein tributaries and the renal vein proper as a basis on both the left and right sides.

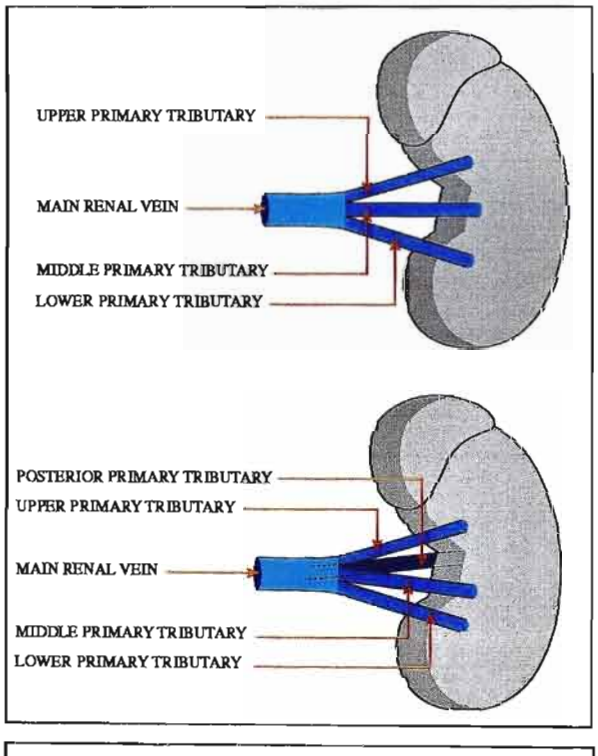


TYPE I A

This group consisted of two primary tributaries only - an upper and a lower.

TYPE I B

In addition to upper and lower primary tributaries, a posterior primary tributary is present.

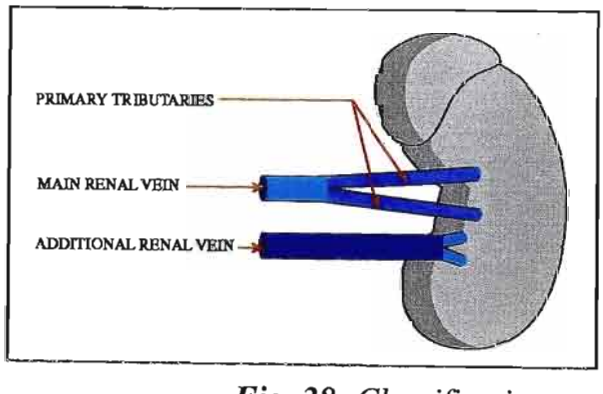


TYPE II A

More than two tributaries eg. an upper, middle and lower formed this type.

TYPE II B

In addition to the primary tributaries present in Type II A, a posterior primary tributary is present.



TYPE III

This group consisted of any of the above combinations and displays an additional renal vein(s).

***Fig. 38**- Classification types of renal venous drainage*

CLASSIFICATION TYPE IA

This group consisted of two primary tributaries only - an upper and a lower and occurred in 118 (38.6%) of the 306 kidneys.

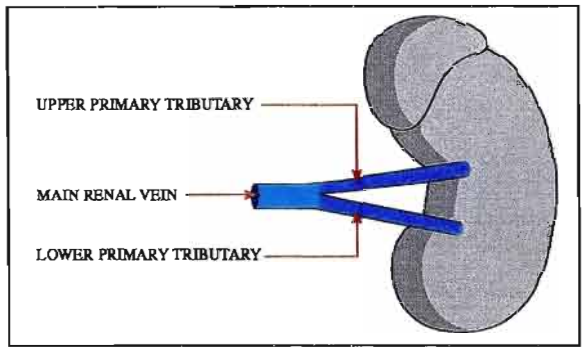


***Fig. 39** - Classification Type I A*

***Plate 8** - Anterior view of resin cast of left kidney demonstrating Type I A renal venous drainage.*

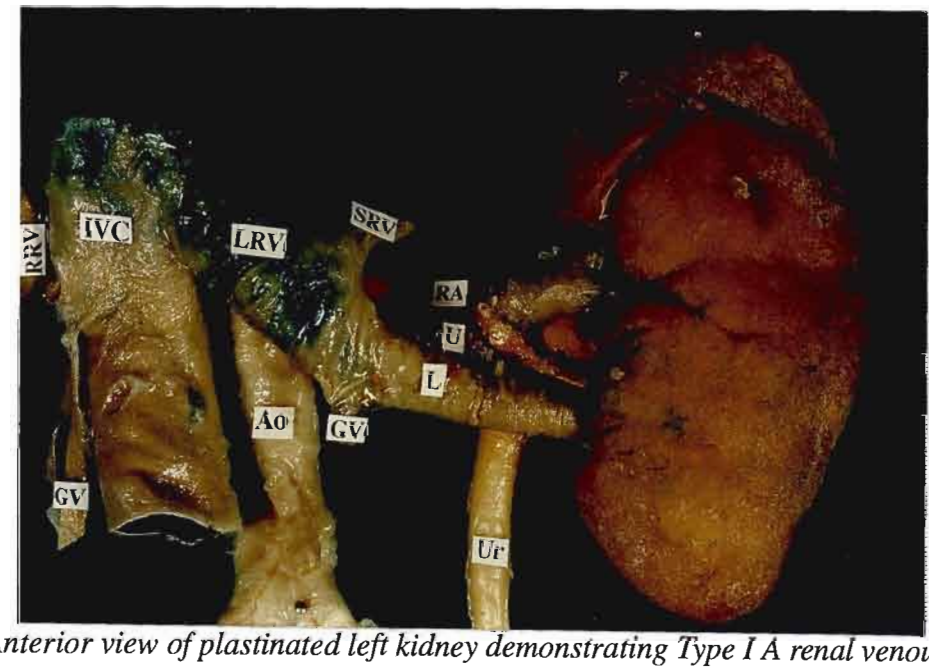


***Plate 9** - Anterior view of plastinated left kidney demonstrating Type I A renal venous drainage.*

RRV	– Right renal vein	**L**	– Lower primary tributary
LRV	– Left renal vein	**Ao**	– Aorta
IVC	– Inferior vena cava	**RA**	– Renal artery
GV	– Gonadal vein	**Ur**	– Ureter
U	– Upper primary tributary	**SRV**	– Suprarenal vein

CLASSIFICATION TYPE IB

In addition to upper and lower primary tributaries, a posterior primary tributary is present. This type was observed in 77 (25.2%) cases.

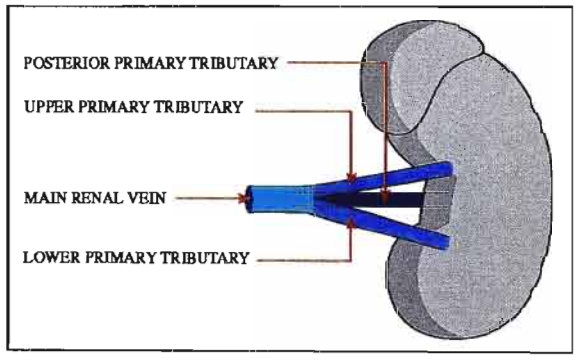
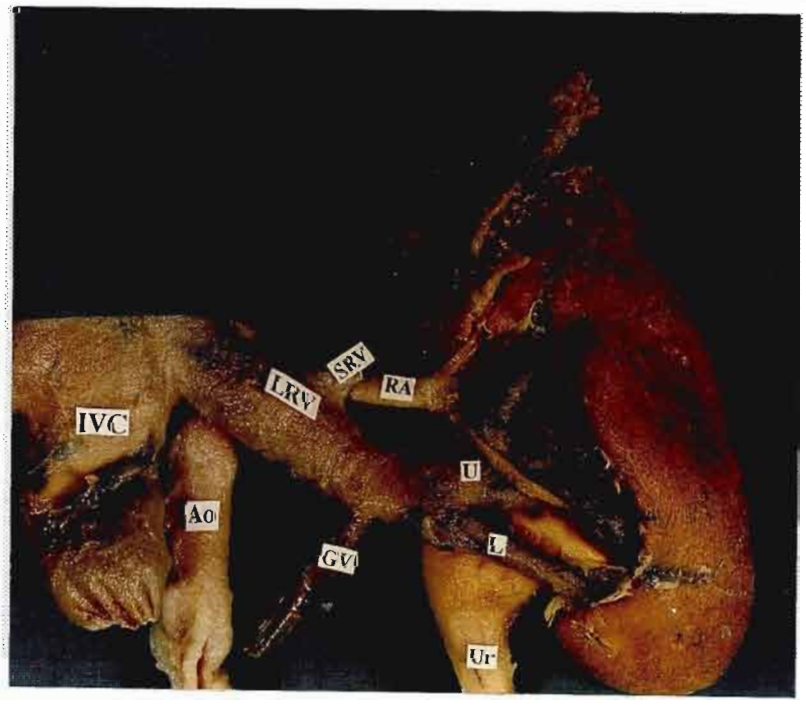


***Fig. 40** - Classification Type IB*

***Plate 10** - Anterior view of resin cast of left kidney demonstrating Type IB renal venous drainage.*



LRV	– Left renal vein
IVC	– Inferior vena cava
GV	– Gonadal vein
SRV	– Suprarenal vein
U	– Upper primary tributary
L	– Lower primary tributary
P	– Posterior primary tributary
Ao	– Aorta
RA	– Renal artery
Ur	– Ureter

***Plate 11** - Anterior view of plastinated left kidney demonstrating Type IB renal venous drainage.*

CLASSIFICATION TYPE IB (*CONTINUED*)

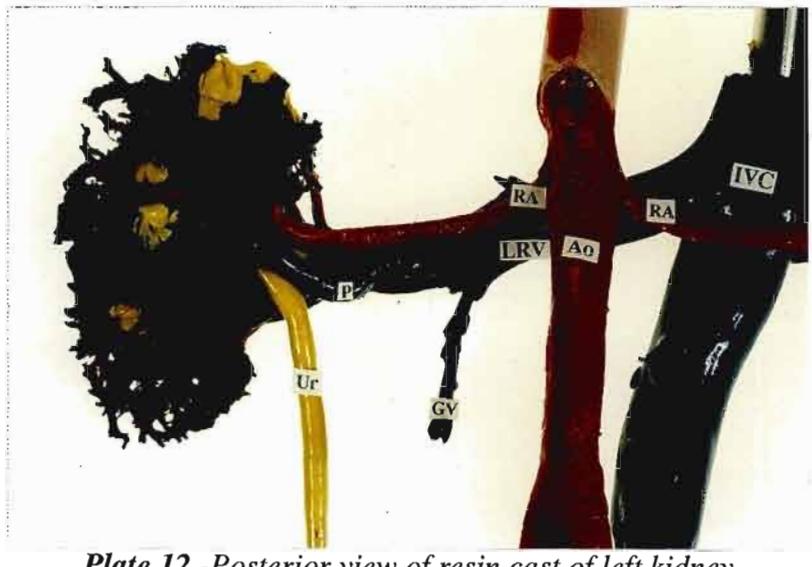


Plate 12 *-Posterior view of resin cast of left kidney demonstrating Type IB renal venous drainage*

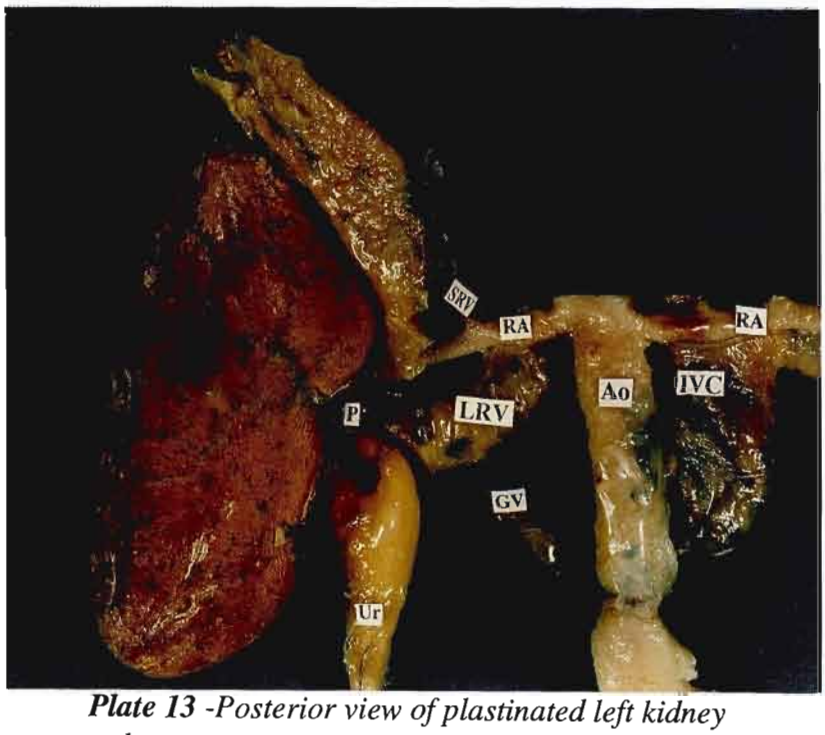


Plate 13 *-Posterior view of plastinated left kidney demonstrating Type IB renal venous drainage.*

LRV	– Left renal vein	**P**	– Posterior primary tributary
IVC	– Inferior vena cava	**Ao**	– Aorta
GV	– Gonadal vein	**RA**	– Renal artery
SRV	– Suprarenal vein	**Ur**	– Ureter

CLASSIFICATION TYPE II A

More than two tributaries eg. an upper, middle and lower formed this type. A maximum of five primary tributaries were identified. Type II A was noted in 36 (11.8%) cases.

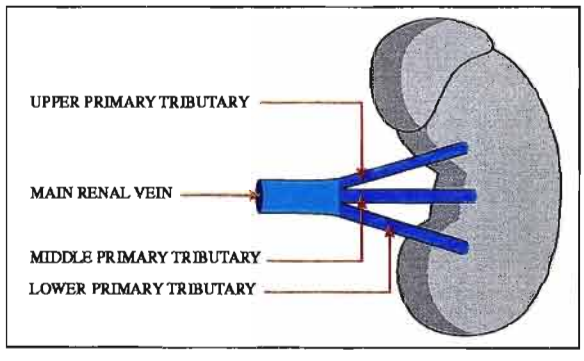


Fig. 41 - Classification Type II A

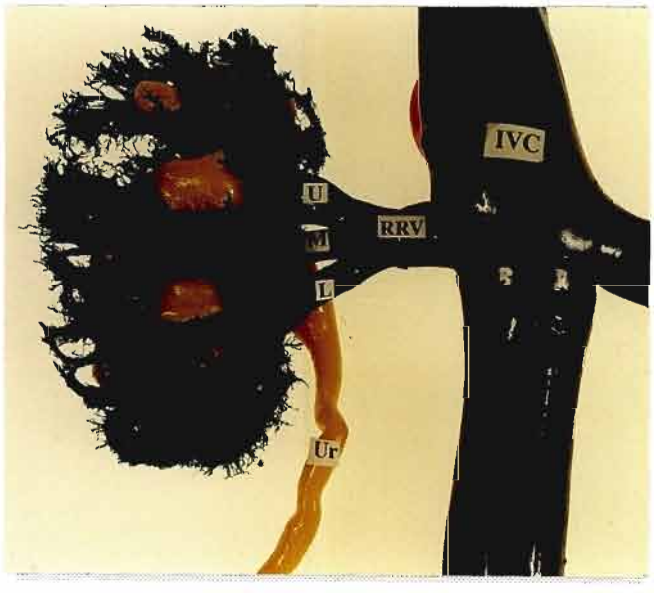
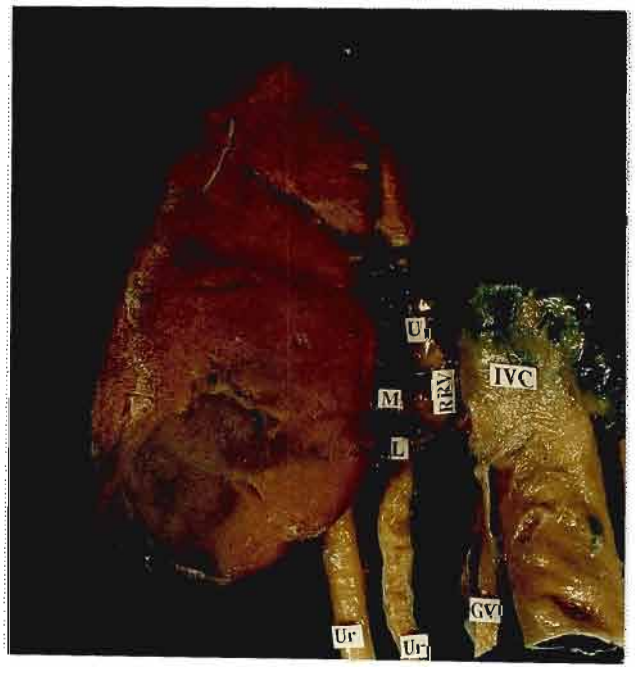


***Plate 14** - Anterior view of resin cast of right kidney demonstrating Type II A renal venous drainage.*

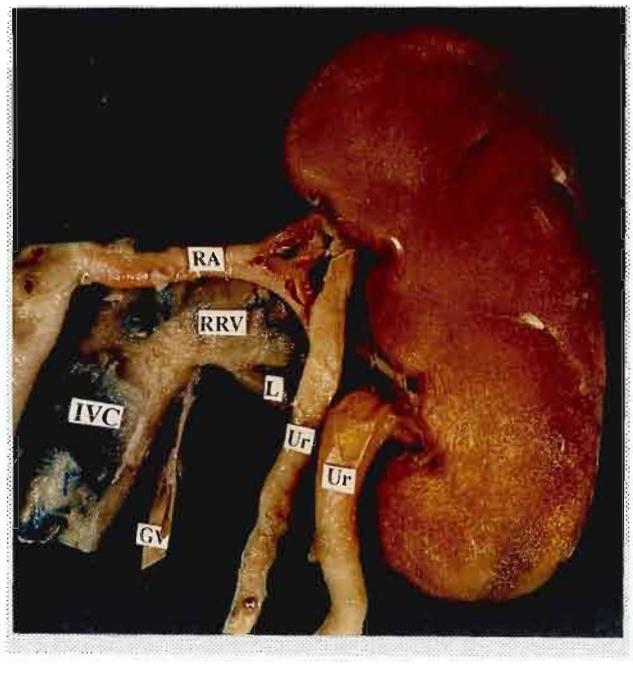


RRV	– Right renal vein
IVC	– Inferior vena cava
GV	– Gonadal vein
U	– Upper primary tributary
M	– Middle primary tributary
L	– Lower primary tributary
Ur	– Ureter

***Plate 15** - Anterior view of plastinated right kidney demonstrating Type II A renal venous drainage.*

CLASSIFICATION TYPE II A *(CONTINUED)*

Plate 16 *- Posterior view of resin cast of right kidney demonstrating Type IIA renal venous drainage.*



RRV	– Right renal vein
IVC	– Inferior vena cava
GV	– Gonadal vein
U	– Upper primary tributary
M	– Middle primary tributary
L	– Lower primary tributary
Ur	– Ureter
RA	– Renal artery

Plate 17 *- Posterior view of plastinated right kidney demonstrating Type IIA renal venous drainage. (Note double ureter)*

CLASSIFICATION TYPE II B

In addition to the primary tributaries present in Type IIA, a posterior primary tributary was present in 31(10.1%) of the 306 kidneys.

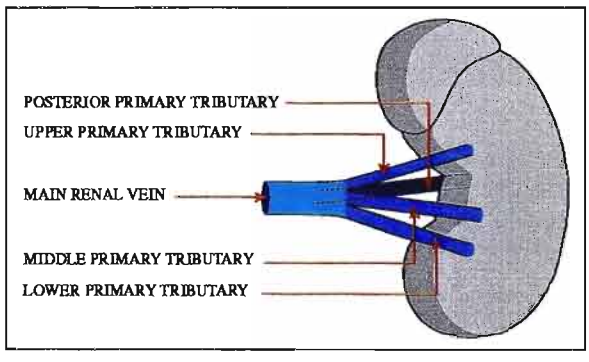
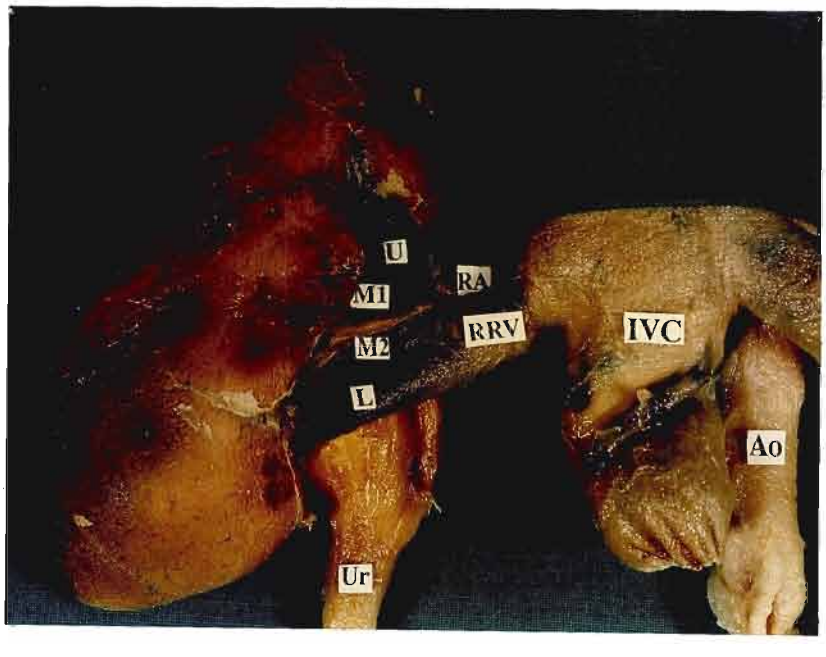


Fig. 42 - Classification Type II B.

LRV	– Left renal vein
GV	– Gonadal vein
SRV	– Suprarenal vein
U	– Upper primary tributary
M1/M2	– Middle primary tributaries
L	– Lower primary tributary
P	– Posterior primary tributary

***Plate 18** - Anterior view of resin cast of left kidney demonstrating Type II B renal venous drainage.*

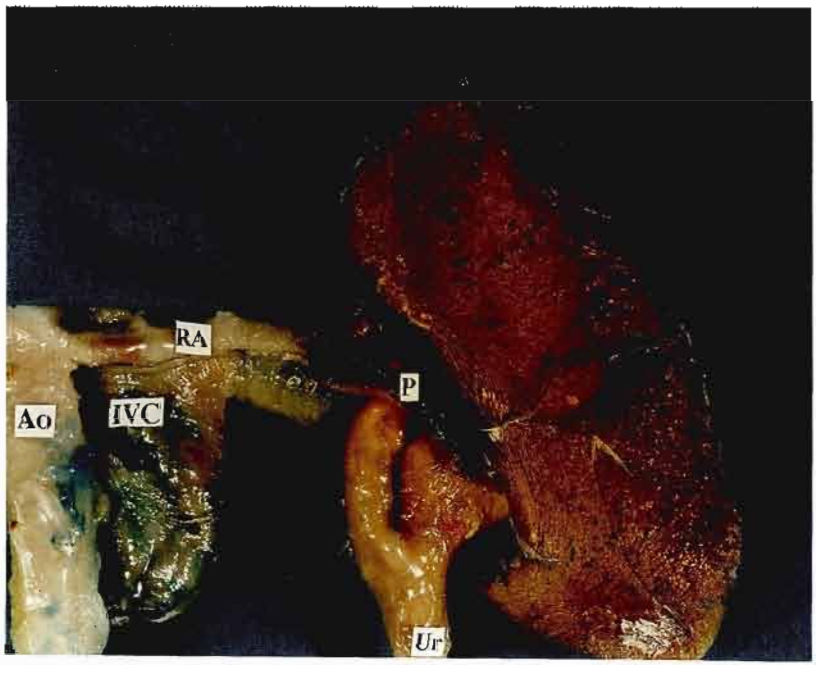


RRV	– Right renal vein
IVC	– Inferior vena cava
U	– Upper primary tributary
M1/M2	– Middle primary tributaries
L	– Lower primary tributary
RA	– Renal artery
Ao	– Aorta
Ur	– Ureter

***Plate 19** - Anterior view of plastinated right kidney demonstrating Type II B renal venous drainage.*

CLASSIFICATION TYPE II B *(CONTINUED)*

Plate 20 *- Posterior view of resin cast of left kidney demonstrating Type II B renal venous drainage.*



LRV	– Left renal vein
IVC	– Inferior vena cava
SRV	– Suprarenal vein
P	– Posterior primary tributary
RA	– Renal artery
Ao	– Aorta
Ur	– Ureter

Plate 21 *- Posterior view of plastinated right kidney demonstrating Type II B renal venous drainage.*

CLASSIFICATION TYPE III

This group consisted of any of the previous classification types as well as displaying an additional renal vein or veins and occurred in 44 (14.4%) cases.

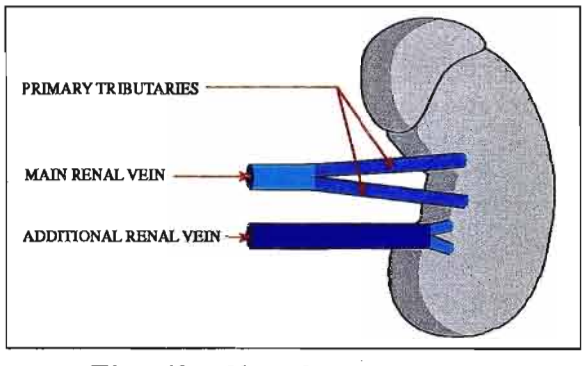


***Fig. 43** - Classification Type III*

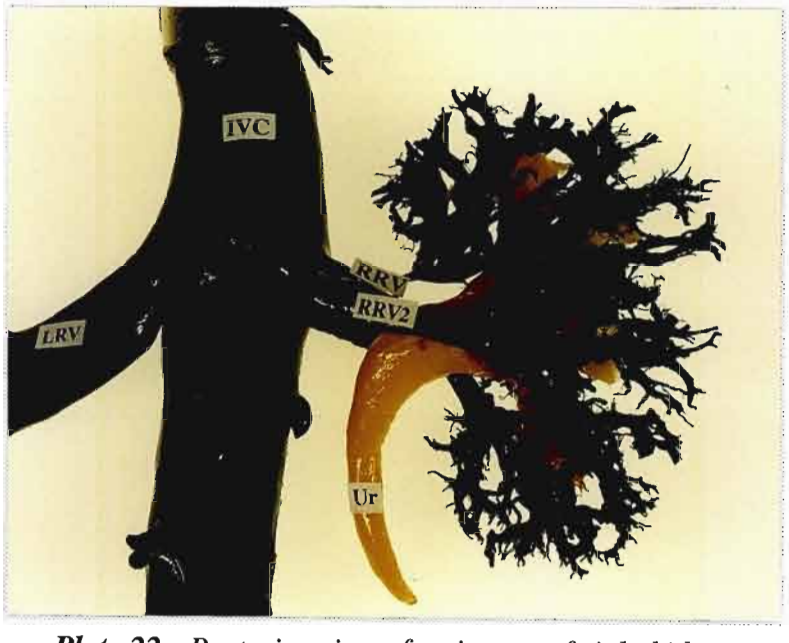


***Plate 22** - Posterior view of resin cast of right kidney demonstrating Type III renal venous drainage.*

RRV	– Right renal vein	**IVC**	– Inferior vena cava
RRV2	– Additional right renal vein	**LRV**	– Left renal vein
		Ur	– Ureter

CLASSIFICATION TYPE III *(CONTINUED)*

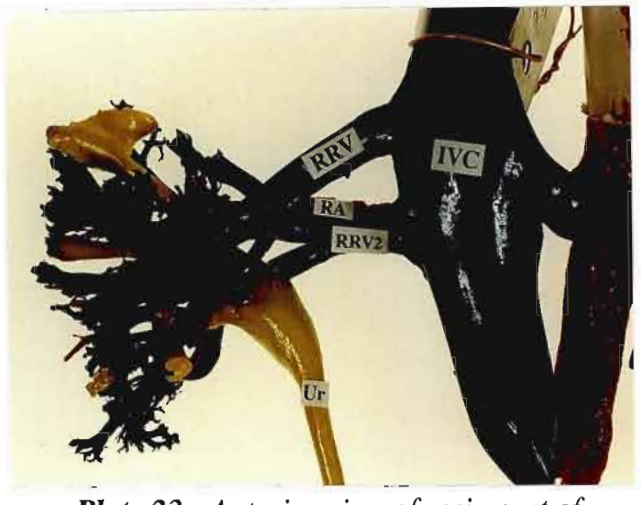


Plate 23 *- Anterior view of resin cast of right kidney demonstrating Type III renal venous drainage.*

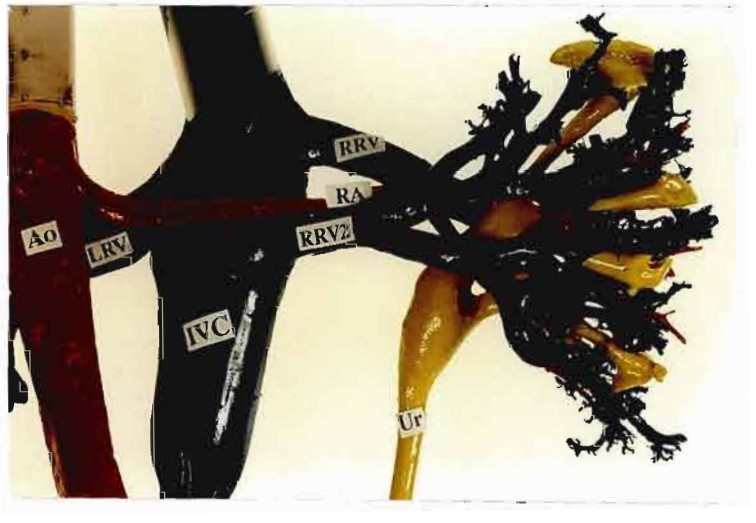


Plate 24 *- Posterior view of resin cast of right kidney demonstrating Type III renal venous drainage.*

RRV	– Right renal vein	**LRV**	– Left renal vein
RRV-2	– Additional right renal vein	**RA**	– Renal artery
		Ao	– Aorta
IVC	– Inferior vena cava	**Ur**	– Ureter

Table XVI-A and XVI-B shows the number of kidneys in each of the 5 classification types arranged by side (left and right), sex and race.

***TABLE* XV-A** - *NUMBER OF KIDNEYS IN EACH OF THE 5 CLASSIFICATION TYPES ARRANGED IN TERMS OF SEX*

TYPE	MALE			FEMALE			SIDES		TOTAL
	RIGHT	LEFT	SUB TOTAL	RIGHT	LEFT	SUB TOTAL	RIGHT	LEFT	
IA	45	54	99	11	8	19	56	62	118
%	*17.2*	*20.6*	*37.8*	*25.0*	*18.2*	*43.2*	*18.3*	*20.3*	*38.6*
IB	22	42	64	4	9	13	26	51	77
%	*8.4*	*16.0*	*24.4*	*9.1*	*20.5*	*29.5*	*8.5*	*16.7*	*25.2*
IIA	16	16	32	4	0	4	20	16	36
%	*6.1*	*6.1*	*12.2*	*9.1*	*0.0*	*9.1*	*6.5*	*5.2*	*11.8*
IIB	11	16	27	0	4	4	11	20	31
%	*4.2*	*6.1*	*10.3*	*0.0*	*9.1*	*9.1*	*3.6*	*6.5*	*10.1*
III	37	3	40	3	1	4	40	4	44
%	*14.1*	*1.2*	*15.3*	*6.8*	*2.2*	*9.1*	*13.1*	*1.3*	*14.4*
TOTAL	131	131	262	22	22	44	153	153	306
%	*50.0*	*50.0*	*100.0*	*50.0*	*50.0*	*100.0*	*50.0*	*50.0*	*100.0*

TABLE XV-B - *RACE GROUP DISTRIBUTION IN EACH OF THE FIVE CLASSES*

TYPE	BLACK			INDIAN			WHITE			"COLOURED"			TOTAL
	Right	Left	Sub Total	Right	Left	Sub Total	Right	Left	Sub Total	Right	Left	Sub Total	
IA	52	55	107	3	3	6	0	3	3	1	1	2	118
%	*19.6*	*20.7*	*40.2*	*18.8*	*18.8*	*37.5*	*0*	*16.7*	*16.7*	*16.7*	*16.7*	*33.3*	*38.6*
IB	24	46	70	2	1	3	0	3	3	0	1	1	77
%	*9.0*	*17.3*	*26.3*	*12.5*	*6.3*	*18.8*	*0*	*16.7*	*16.7*	*0*	*16.7*	*16.7*	*25.2*
IIA	14	13	27	2	3	5	4	0	4	0	0	0	36
%	*5.3*	*4.9*	*10.2*	*12.5*	*18.3*	*31.3*	*22.2*	*0*	*22.2*	*0*	*0*	*0*	*11.8*
IIB	9	16	25	0	1	1	2	2	4	0	1	1	31
%	*3.4*	*6.0*	*9.4*	*0*	*6.3*	*6.3*	*11.1*	*11.1*	*22.2*	*0*	*16.7*	*16.7*	*10.1*
III	34	3	37	1	0	1	3	1	4	2	0	2	44
%	*12.8*	*1.1*	*13.9*	*6.3*	*0*	*6.3*	*16.7*	*5.6*	*22.2*	*33.3*	*0*	*33.3*	*14.4*
TOTAL	133	133	266	8	8	16	9	9	18	3	3	6	306
%	*50*	*50*	*100*	*50*	*50*	*100*	*50*	*50*	*100*	*50*	*50*	*100*	*100*

Type IA was most frequently observed (38.6%). The majority of the Type IA kidneys (52.5%) occurred on the left side.

Type IB was the second most frequently observed (25.2%), with the other three types showing similar frequencies (10.1 - 14.4%).

Statistically significant differences were noted between left and right kidneys with regard to the classification into the different types ($p<0.0001$). In only 41 (26.8%) of 153 pairs of kidneys examined was the same classification type observed for both the left and right kidneys within the same individual. Twenty four of these pairs belonged to Type I A, 9 were classified as Type IB, 4 as Type II A and 2 each as Types IIB and III.

Types IB and IIB occurred twice as frequently on the left side compared to the right. However, in the case of Type III, there was a tenfold increase in the number of kidneys on the right side (13.1% vs 1.3%).

The 5 types appeared with approximately equal frequencies in males and females and no statistically significant difference was noted.

There were insufficient numbers in race groups other than black to enable statistical comparisons to be made. Despite this limitation, various permutations of race groups were tested to ascertain whether race was a determinant of a Type III classification. No difference was noted.

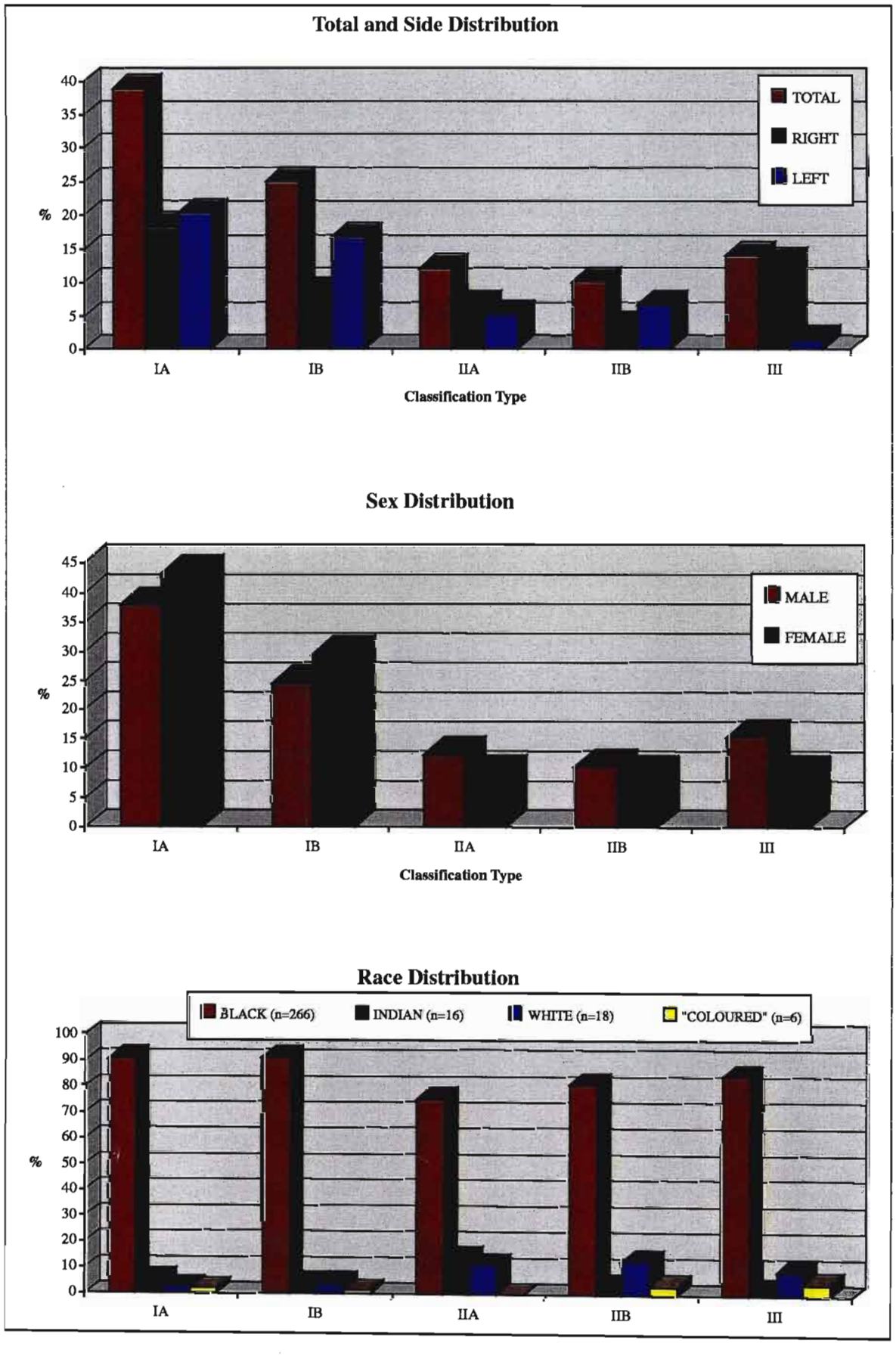


Fig. 44 *- Frequency histograms of the classification types demonstrating side, sex and race distribution.*

4.6. INTRARENAL VENOUS FLOW

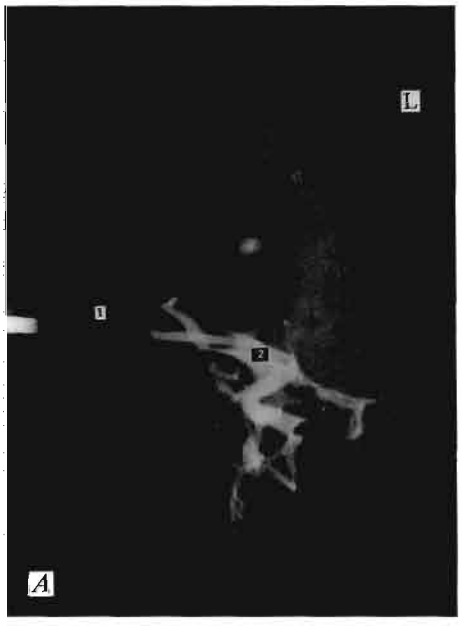
4.6.1 ADULT *EN BLOC* RENAL STUDY

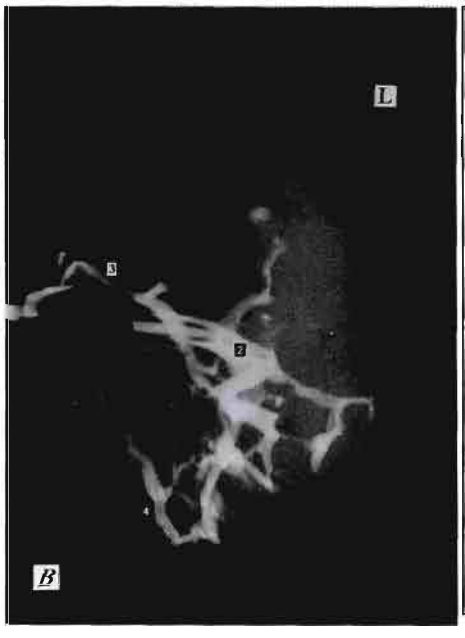
All 21 pairs of the adult *en bloc* kidneys subjected to radiological investigation of the intrarenal venous flow demonstrated a non-segmental venous flow pattern.

Following contrast perfusion of any primary tributary of the renal vein, there was free filling of the remaining primary tributaries via interlobar, interlobular arcuate arborisations. In certain instances, there was also filling of the cortical and capsular veins. Multiple venous arcades were demonstrated at both the secondary and tertiary levels. In all instances filling of the main renal vein was achieved.

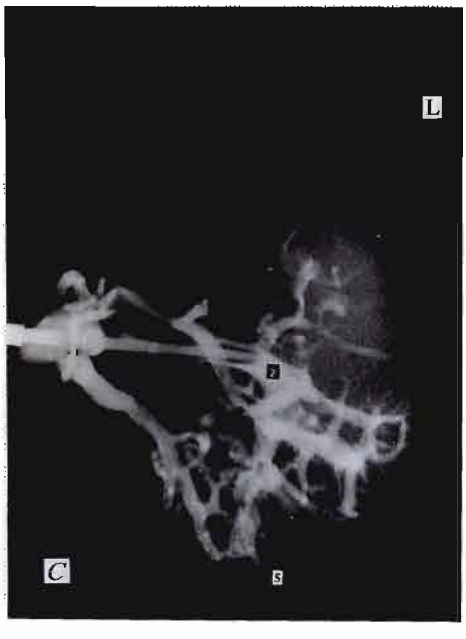
No valves were observed.

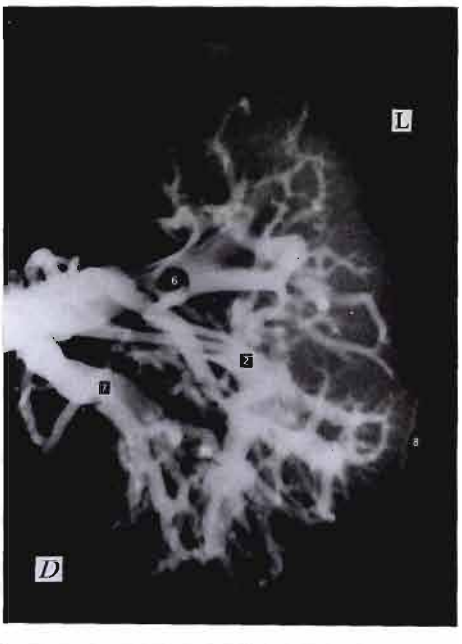
Plate 25 (A - F) is a representative set of radiographs that exhibits this concept. The cannula is shown in the middle primary tributary of the left kidney which was perfused under gentle non-manometric control and sequential radiographs demonstrate the intrarenal flow pattern. Plate A - Injection of contrast into the middle primary tributary demonstrates immediate filling (by intrarenal collaterals) of a tributary of the upper and lower primary renal veins (Plate B). Further perfusion allows demonstration of intrarenal venous arcades (Plate C). Plate D demonstrates to better effect the abundance of renal tributaries and collaterals. In addition, there is filling of the gonadal veins. Further injection (Plate E) shows filling of capsular vessels noted best in the midzone, and the suprarenal vein. The final radiograph (Plate F) taken just prior to bursting pressure demonstrates the suprarenal vein, the intrarenal arborisations, the capsular veins (being filled from intrarenal communicating vessels), the gonadal and ureteric veins and the main renal vein.

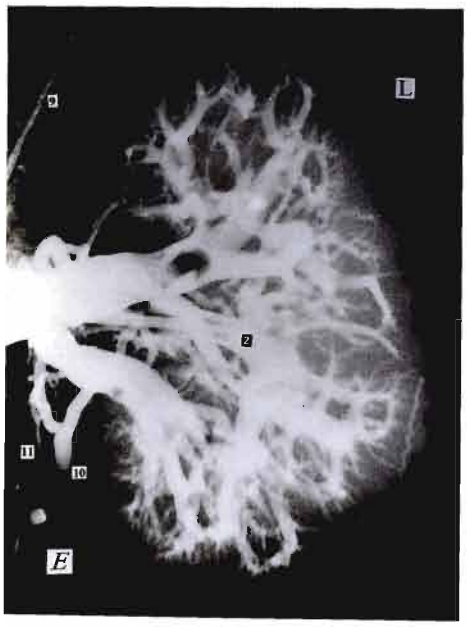




1	– Cannula
2	– Middle primary tributary
3	– Tributary of upper primary
4	– Tributary of lower primary.
5	– Venous arcade
6	– Upper primary tributary
7	– Lower primary tributary
8	– Capsular vein
9	– Suprarenal vein
10	– Gonadal vein
11	– Ureteric vein







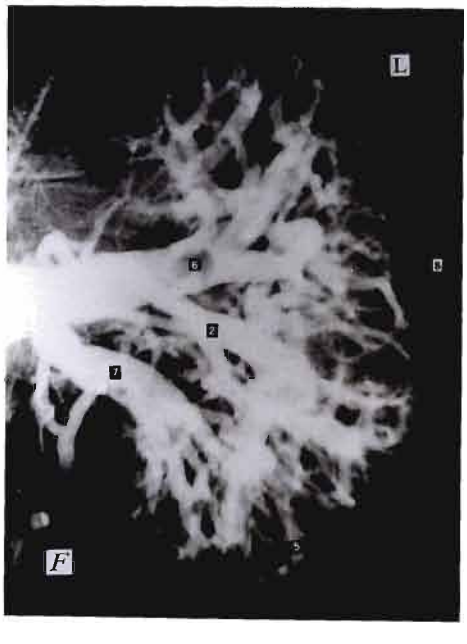


Plate 25 (A – F) *Demonstration of intrarenal non-segmental venous flow.*

4.6.2 CHACMA BABOON (*PAPIO URSINUS*) *EN BLOC* RENAL STUDY

The 5 pairs of Chacma baboon (*Papio ursinus*) *en bloc* kidneys that were radiographed also demonstrated a non-segmental intrarenal flow pattern. Plate 26 (A – D) is a representative set of radiographs exhibiting this concept.

In general all 10 kidneys (5 left and 5 right) had single renal veins. The catheter tip is observed in a middle primary tributary and on perfusion with small aliquots of contrast there is retrograde filling of secondary and tertiary tributaries via abundant intrarenal collaterals. There are several arcades at primary, secondary and tertiary levels. A non-segmental intrarenal flow pattern is observed.

No valves were observed.

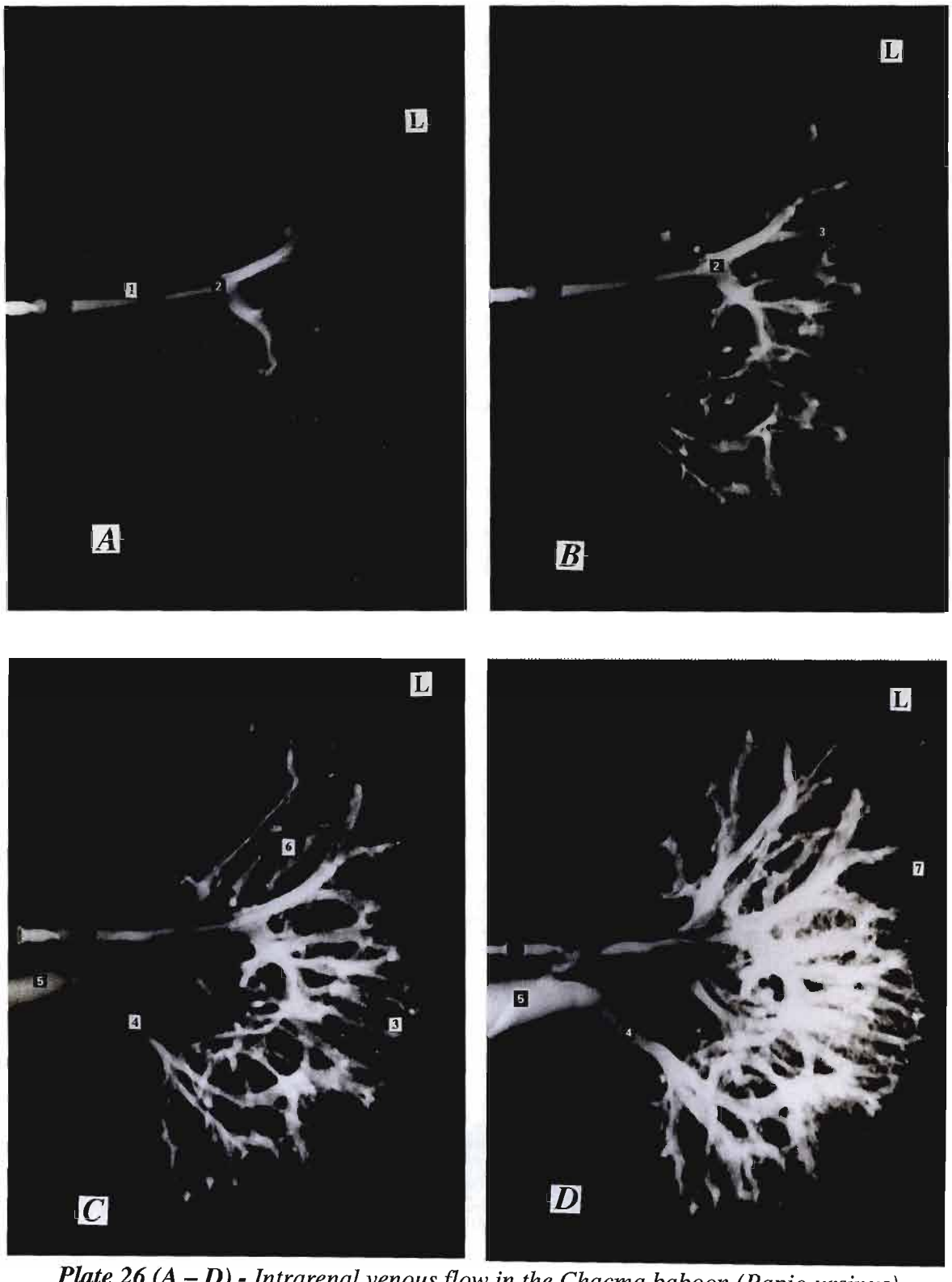


Plate 26 (A – D) - Intrarenal venous flow in the Chacma baboon (Papio ursinus) demonstrating non-segmental venous pattern.

1 –	Cannula	5 –	Left renal vein
2 –	Middle primary tributary	6 –	Secondary tributary
3 –	Venous arcade	7 –	Tertiary tributary
4 –	Lower primary tributary		

4.7 THE RENAL VEINS AND COLLATERAL VENOUS CHANNELS.

Eleven foetuses and eleven adult cadavers were investigated. Following cannulation of selected veins within the sphere of influence of the renal veins, with proximal or distal occlusion (as decribed in Chapter 3, page 93) sequential radiographs were exposed during contrast infusion as shown in the radiographs presented below:

From an analysis of venographic investigations concentrating around the renal-lumbar-azygos-vertebral axis conducted with foetal and adult cadavers, the following were observed.

1) The right renal vein contributes little, if any, to the collateral channels.

2) In contradistinction to the above, the left renal vein via its existing and potential collaterals has the capacity to provide an extensive suprarenal, renal and infrarenal pathway.

3) At the renal level, the intra/extrarenal communication is demonstrated via the capsular and pelvi-ureteric venules.

4) The lumbar collaterals, in particular, via the ascending lumbar and vertebral plexuses provide the infrarenal communicating channels.

5) The azygo-vertebral axis constitutes the suprarenal pathway.

6) Retrograde perfusion studies of the major collaterals (both proximal and distal veins) revealed the potential of these available collateral channels.

7) In no instance were renal vein valves demonstrated.

4.7.1 FOETAL STUDY

Plates 27 – 38 demonstrate representative radiographs of the collateral channels that are available after selective ligation and venous perfusion.

LIGATION OF THE IVC BELOW AND ABOVE RENAL VEINS (INCLUDING THE RIGHT SUPRARENAL VEIN)

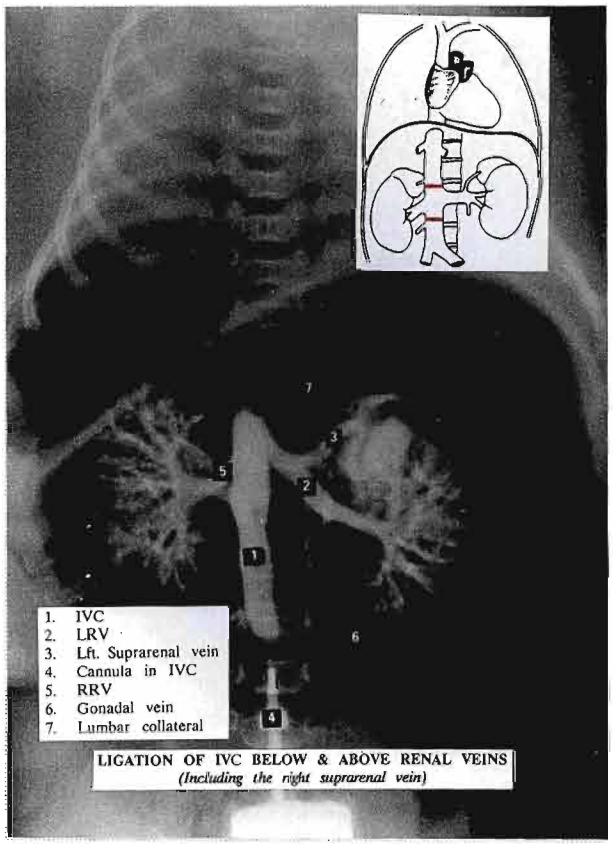


Plate 27 - On perfusion, there is collateral filling from the left renal vein and the ipsilateral suprarenal vein. In addition, there is filling of the gonadal veins. There are no collaterals emanating from the right renal vein.

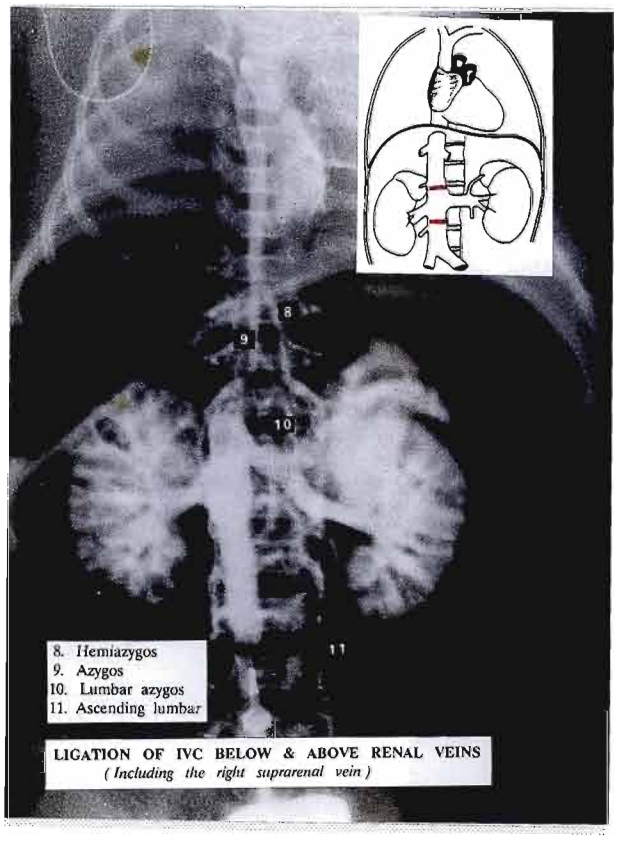


Plate 28 - A subsequent radiograph taken after further contrast injection and just prior to bursting pressure. There is craniad filling of the hemiazygos and azygos veins and caudad retrograde filling of the ascending lumbar channels. Despite excessive perfusion pressure, there are still no collaterals relating to the right renal vein.

Plates 27 and 28 *Ligation of the IVC below and above renal veins (including the right suprarenal vein)*

LIGATION OF IVC BELOW AND ABOVE THE RENAL VEINS AND THE RRV

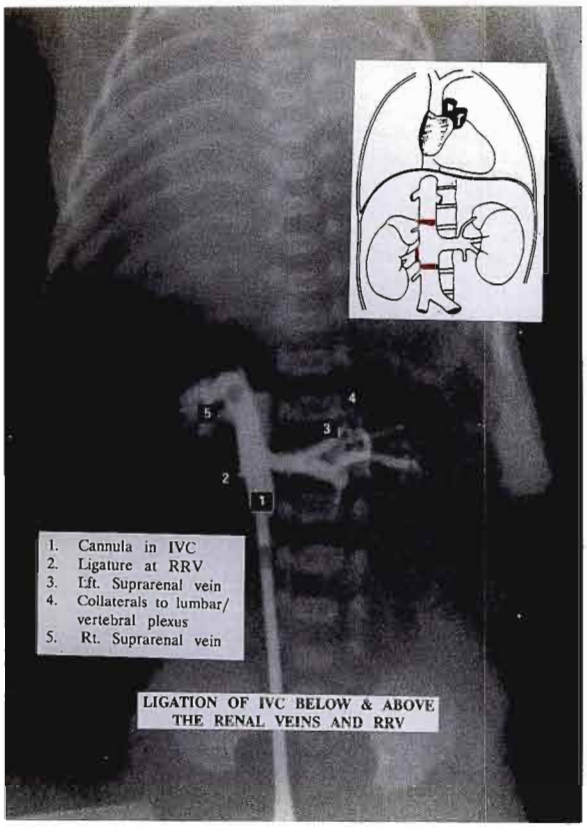


Plate 29 - The left renal vein is demonstrated. Draining into it is a large suprarenal vein which is feeding curvilinear collaterals into the lumbar vertebral plexus.

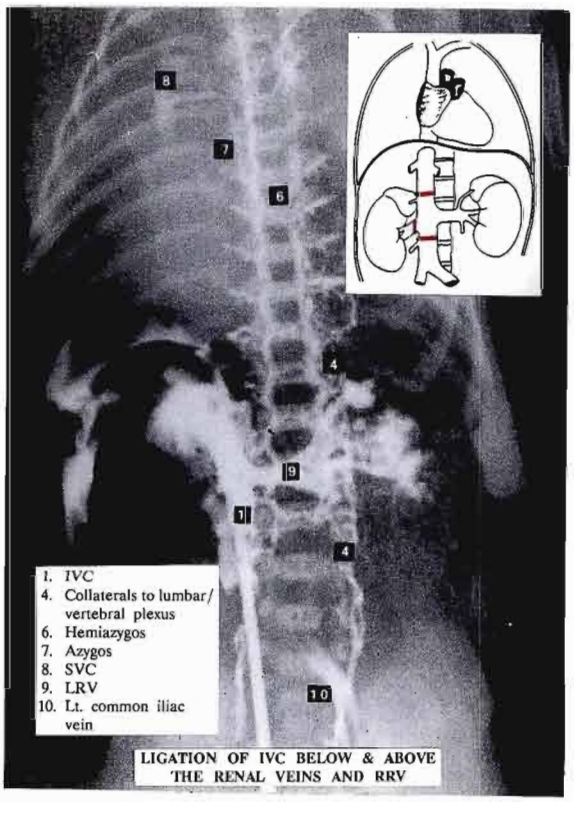


Plate 30 - Further injection shows craniad and caudad filling of the plexuses. Superiorly there is filling of the azygos and hemiazygos veins. The azygos system is noted to enter the SVC. Inferiorly, the collaterals fill the ascending lumbar and iliolumbar veins to perfuse the left common iliac vein. Also note several anastomotic 'bridging' veins from the left to the right.

***Plate 29 and 30** - Ligation of IVC below and above the renal veins and the RRV*

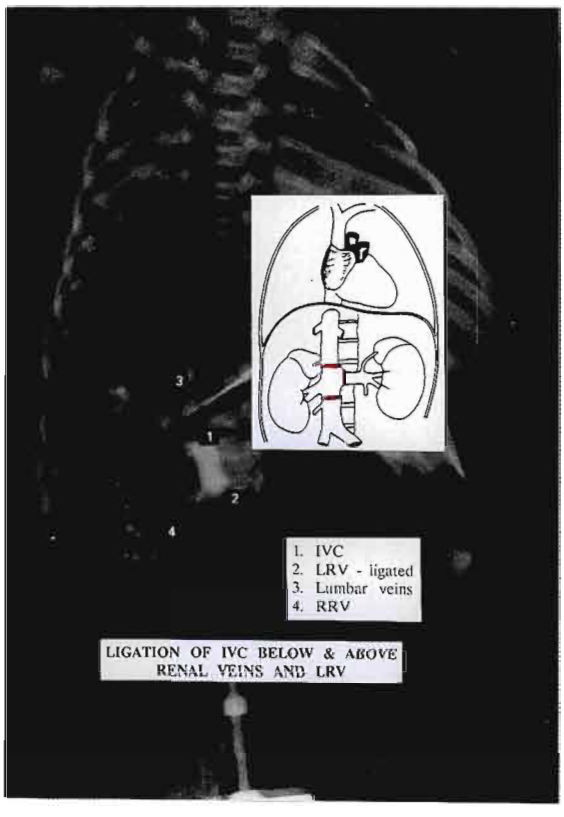


Plate 31 - Negligible collateral flow from the RRV is demonstrated via the lumbar veins.

***Plate 31**. Ligation of IVC below and above the renal veins and LRV*

LIGATION OF THE COMMON ILIAC VEINS CAUDALLY AND THE IVC ABOVE THE RENAL VEINS CRANIALLY

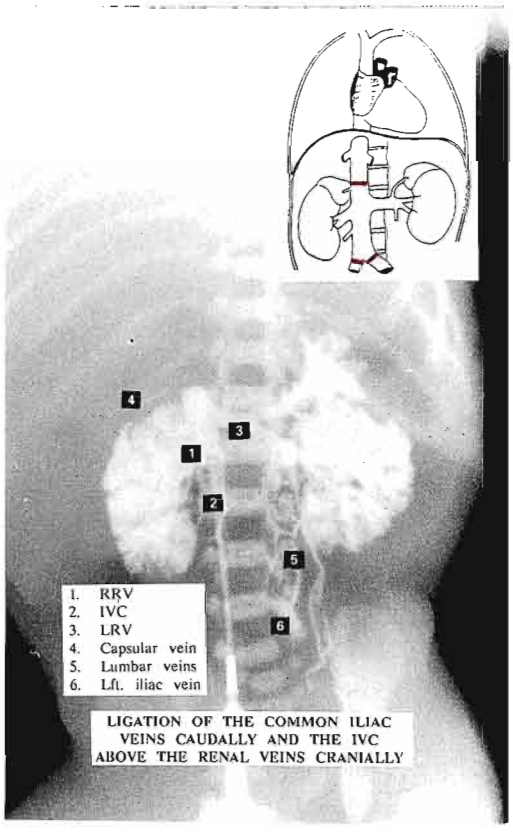


Plate 32 - There is filling of the left common iliac veins from collaterals emanating from the left renal veins via the lumbar collaterals and iliolumbar vein.

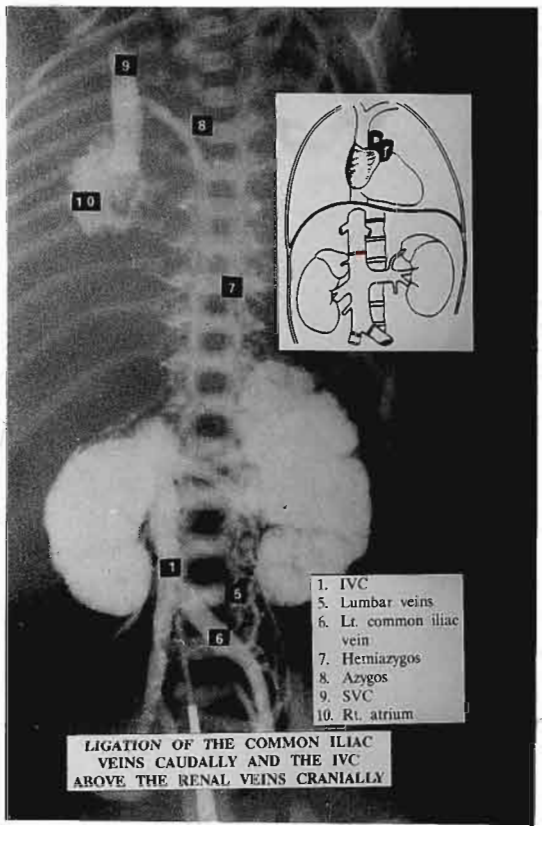


Plate 33 - After further injection of contrast, there is the filling of the iliac vessels, the hemiazygos and azygos veins, SVC and the right atrium. There are no collaterals on the right.

***Plate 32 and 33**. Ligation of the common iliac veins caudally and the IVC above the renal veins cranially*

LIGATION OF INTERNAL AND EXTERNAL ILIAC VEINS CAUDALLV AND THE IVC ABOVE THE RENAL VEINS CRANIALLY.

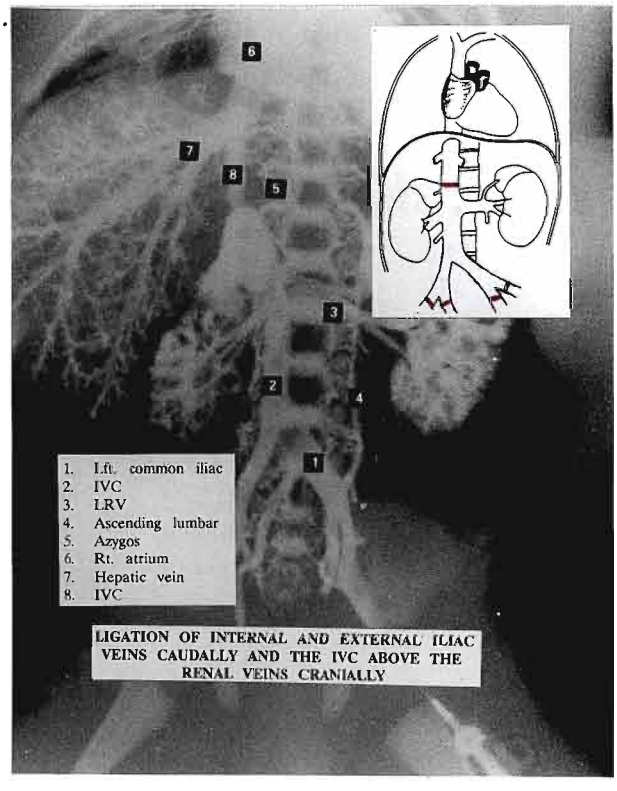
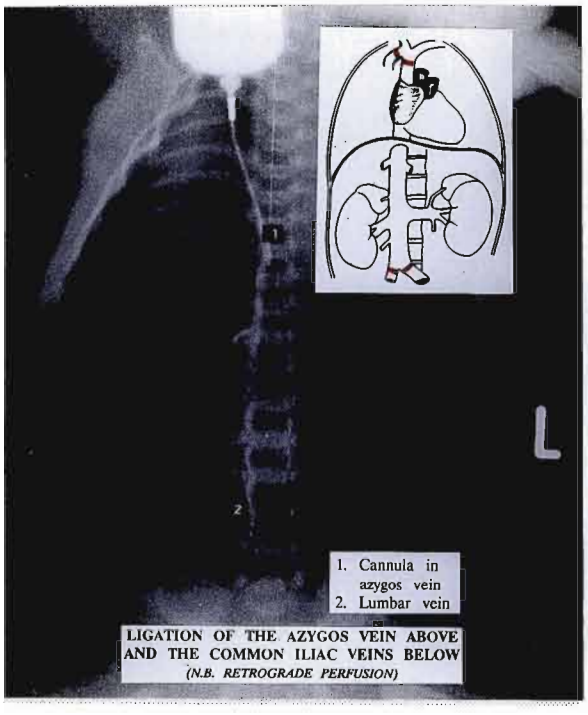


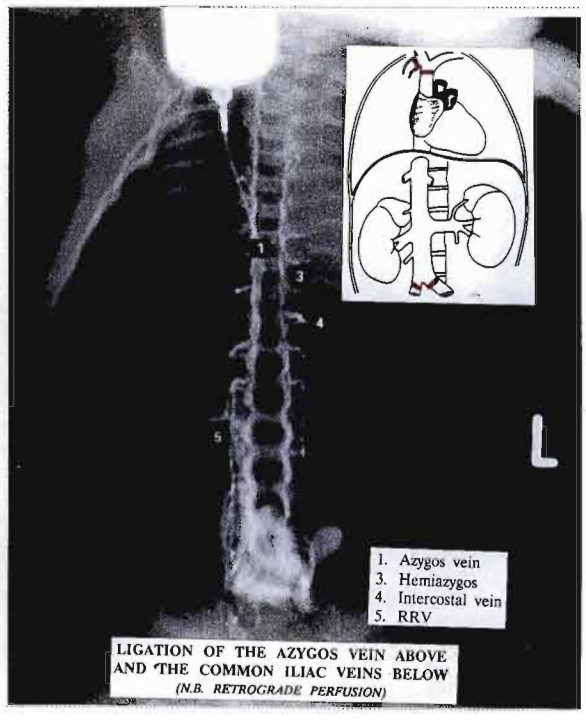
Plate 34 - The iliac, IVC and renal veins fill. Rich anastomotic collaterals fill to perfuse a dominant ascending lumbar on the left and to a lesser extent on the right. Subsequent filling of the azygos system, SVC, right atrium, IVC, hepatic veins and the short segment of IVC, proximal to the ligature is displayed.

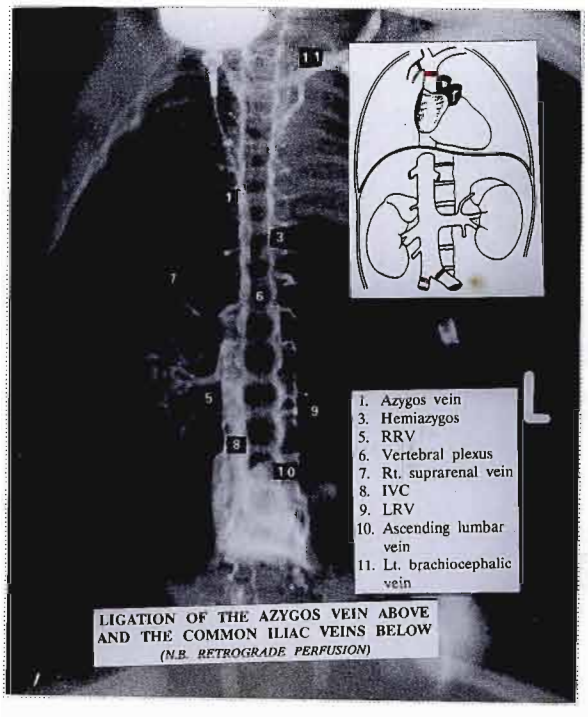
***Plate 34**. Ligation of internal and external iliac veins caudally and the IVC above the renal veins cranially.*

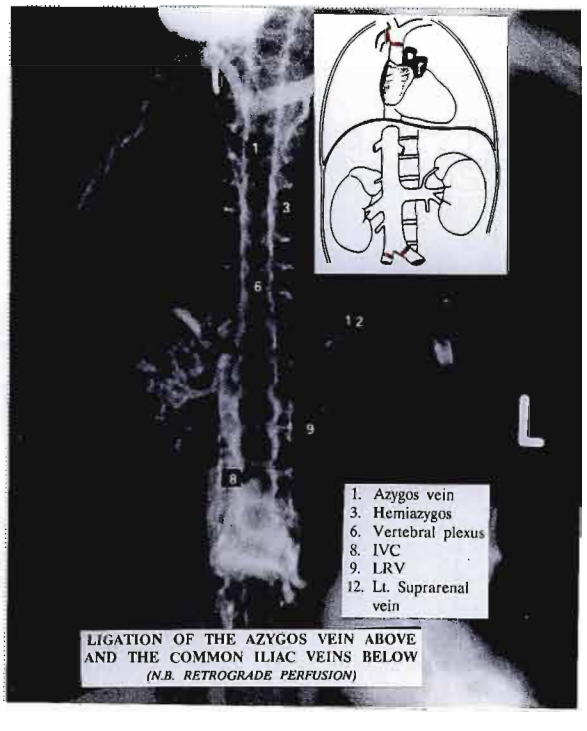
LIGATION OF THE AZYGOS VEIN ABOVE AND THE COMMON ILIAC VEINS BELOW - (N.B.-RETROGRADE PERFUSION).

Retrograde flow of the azygos vein (with the common iliac veins ligated) reveals filling of the azygos and lumbar channels (Plate 35). Via iliolumbar collaterals there is opacification of the iliac veins and sub-renal IVC. There is immediate filling of the right renal vein (Plate 36). In Plate 37, the right suprarenal vein and the left renal vein are opacified. The vertebral plexuses are noted, and proximally there is filling of the left brachiocephalic vein via the internal mammary vein. The left suprarenal vein is opacified and the confluence of the brachiocephalic vein is demonstrated (Plate 38).









Plates 35 – 38 *Ligation of the azygos vein above and the common iliac veins below* - (N.B.-Retrograde Perfusion).

4.7.2 ADULT STUDY

Eleven adult cadavers were investigated. Plate 39 (A-C) consists of representative radiographs that demonstrate the available collateral venous channels under renal vein influence.

Plate A - The main left renal vein was ligated in the proximal segment excluding the suprarenal and gonadal veins. The catheter was placed in the lower primary tributary and sequential radiographs were exposed following a steady perfusion of contrast.

Plate B - Via the lower primary tributary, through rich arcuate collateral channels, there is filling of the proximal segment of the main renal vein which contributes to collateral filling of the ascending lumbar vein in a retrograde direction and there is prograde filling of the azygos system.

Plate C - Further perfusion fills the azygos arch, superior vena cava and right atrium (which contains post-mortem clot). There is filling of the hepatic portion of the IVC, the right renal vein and the sub-renal IVC. Early filling of the capsular vein on the left, and the hepatic vein are demonstrated .

The adult study demonstrates filling of the available collateral channels from the left renal vein. A right renal venogram is obtained via the ascending collateral pathways (azygos system) from perfusion of a lower primary tributary of the left renal vein.

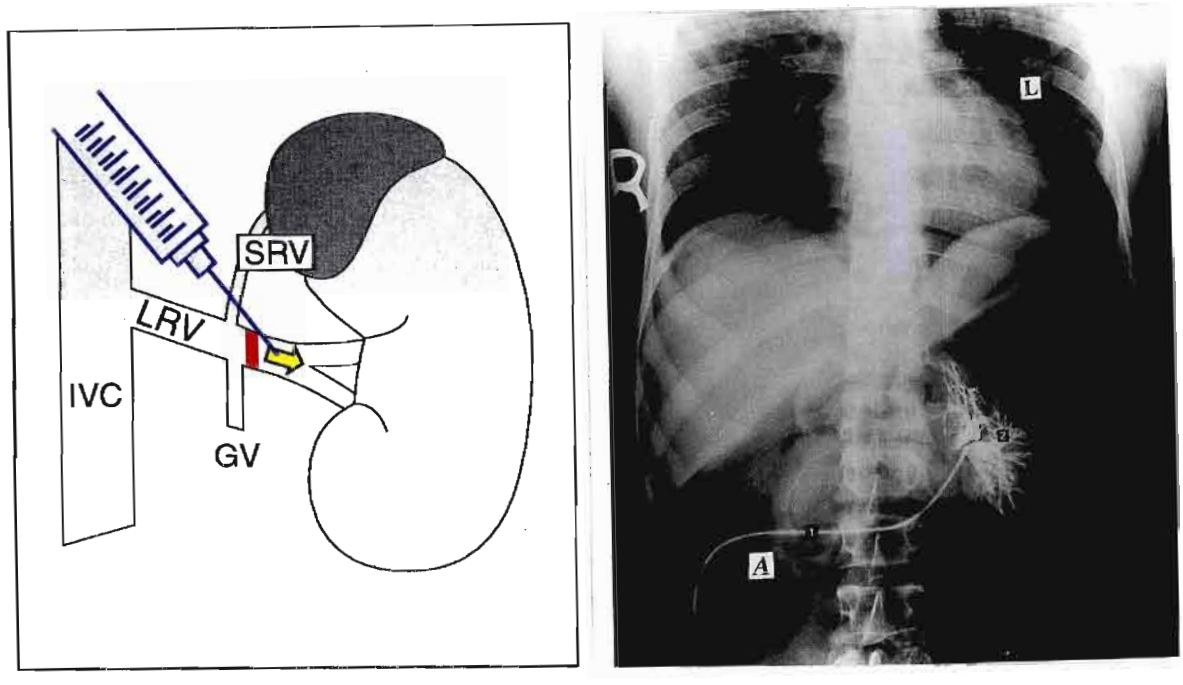


Fig. 45 *Suture ligation and retrograde contrast injection into proximal renal segment.*

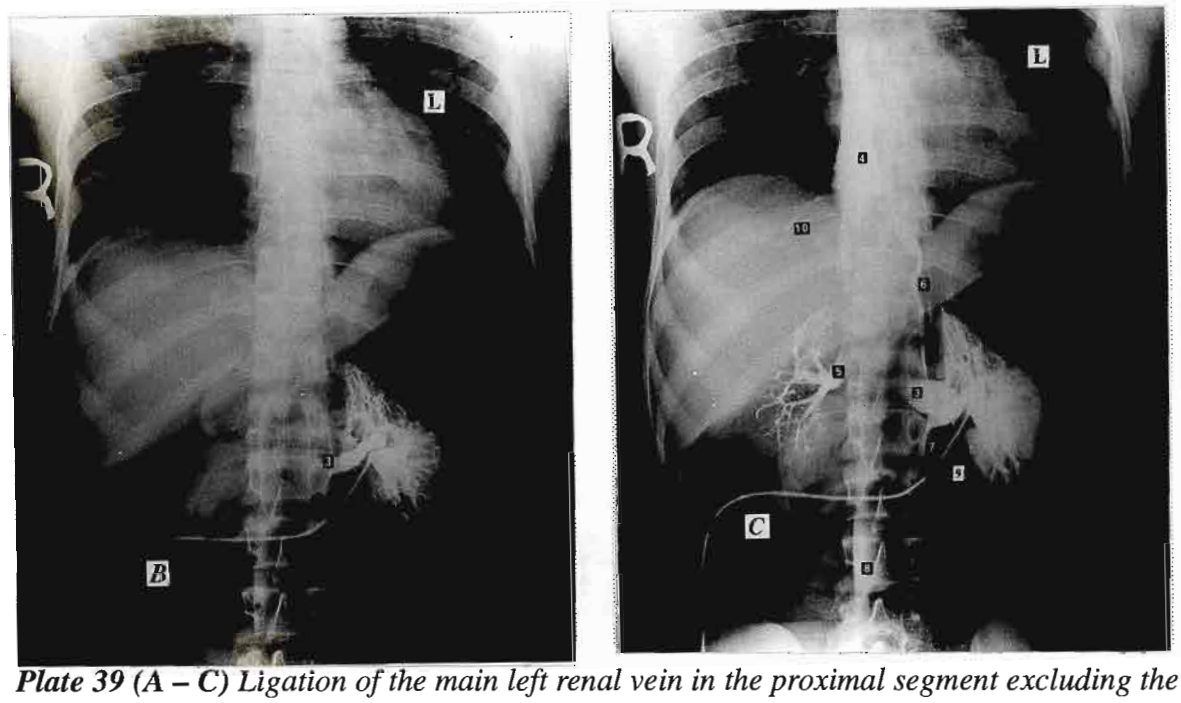
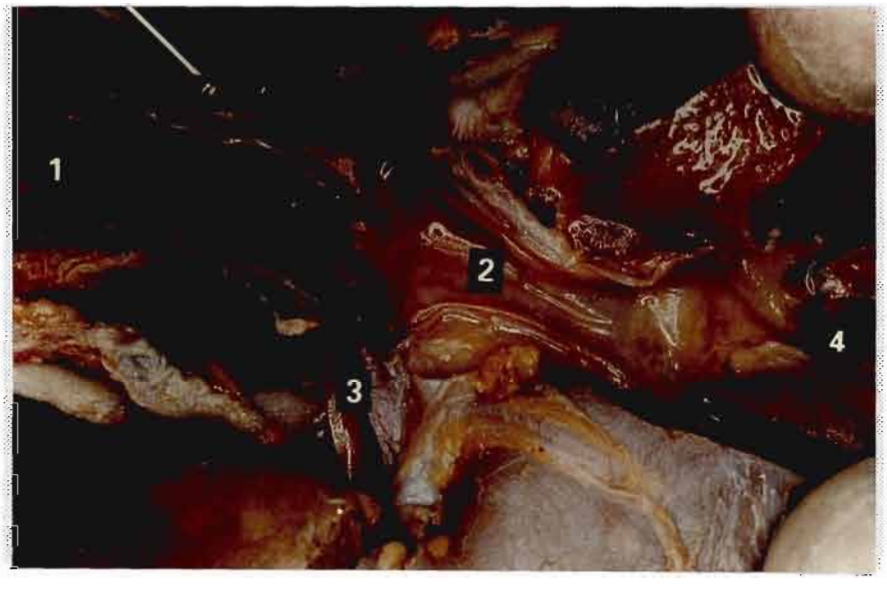


Plate 39 (A – C) *Ligation of the main left renal vein in the proximal segment excluding the suprarenal and gonadal veins and perfusion of the lower primary tributary.*

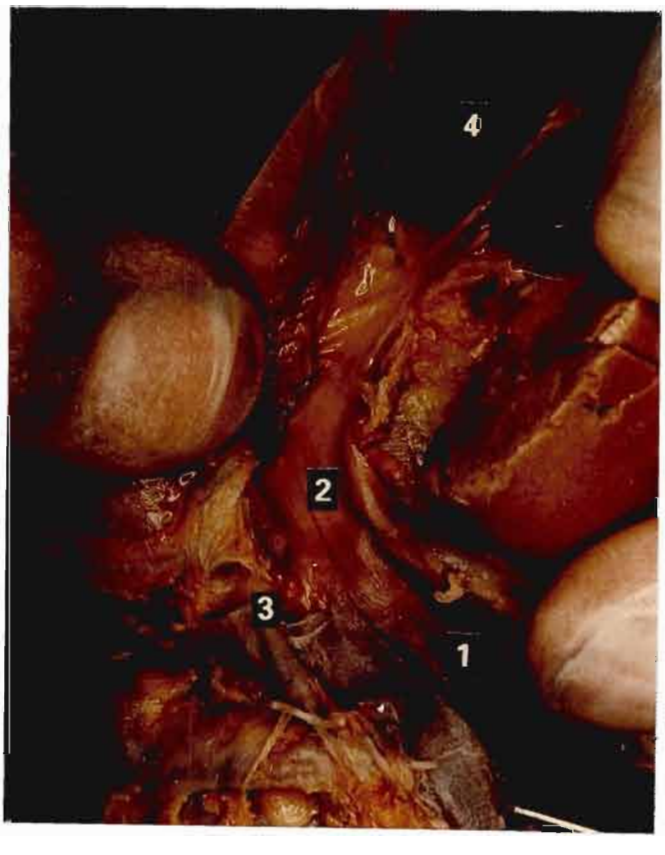
1 –	Cannula	**6 –**	Azygos system of veins
2 –	Left renal venogram	**7 –**	Ascending lumbar vein
3 –	Left renal vein	**8 –**	Inferior vena cava
4 –	Right atrium	**9 –**	Capsular vein
5 –	Right renal vein	**10 –**	Hepatic vein

4.8. INTRARENAL VALVES

Intrarenal valves were not observed in any of the 52 kidneys (26 pairs) that were subjected to macroscopic and microscopic dissection (Appendix A). Histological examination also yielded a negative result. Radiological examination of the renal venograms obtained from cadavers (n=11), foetuses (n=11) and *en bloc* renal specimens (n=21) failed to reveal the presence of renal vein valves.



1 – Left renal vein
2 – Middle primary tributary
3 – Lower primary tributary
4 – Interlobular vein



1 – Right renal vein
2 – Upper primary tributary
3 – Middle primary tributary
4 – Interlobular vein

Plates 40 and 41 -
Left and right kidneys incised along the renal veins and splayed open, demonstrating an absence of valves.

4.9. MORPHOLOGY AND RELATIONSHIP OF RENAL LOBULATIONS TO VENOUS DRAINAGE

4.9.1 MORPHOLOGY

4.9.1.1 The Surface of the Foetal Kidney

The surfaces of the 18 foetal kidneys obtained from 9 foetuses aged from 26 to 38 weeks were examined for the prescence of lobulations. All the kidneys were lobulated, the maximum number of lobules being 14. Fourteen kidneys possessed 7 anterior and 7 posterior lobules. On the remaining 4 specimens lobules varied from 8 to 12.

4.9.1.2 The Surface of the Adult Kidney

Forty two kidneys (from the 21 cadaveric pairs of kidneys) were studied for persistent foetal clefts. These comprised 18 male and 3 female; 17 Black, 3 Indian and 1 White (Table VIII). Eighteen kidneys (43 %) displayed evidence of renal clefts. Clefts were present on the anterior surface and not on the posterior surface in 14 kidneys, whilst 4 kidneys had clefts on both anterior and posterior surfaces. The number of lobules varied from 2 to 7 on the anterior surface and 2 to 4 on the posterior surface.

4.9.2 RELATIONSHIP OF LOBULATIONS TO THE VENOUS DRAINAGE

In both the foetal and the adult study, lobar or segmental venograms could not be produced because multiple anastomoses exist between the intrarenal veins and a free intrarenal venous flow pattern was demonstrated (Page 135).

CHAPTER 5

DISCUSSION OF RESULTS

"... once again the marvellous serendipity of Nature, which has required our great veins to evolve from the embryonic cardinal system ...provides us with a left renal vein, unexpectedly capable of serving the sick"

Simeone (1967).

5.1 GROSS ANATOMY

The gross anatomical features of the specimens in this study were found to be macroscopically similar to the currently accepted norms as described by Pick and Anson (1940), Anson and Kurth (1955), Gillot (1978) and Williams *et al.* (1989). This study was conducted on an apparently normal sample in kidneys that were located in the usual anatomical position. While no gross anatomical variations were noted, several venous variations were observed. This included the rare observation of a single left sided IVC.

Although the vascularisation of the kidney has been the topic of repeated anatomical investigation, statistical analyses and descriptions, it is surprising to find that there is no unanimity in the literature regarding nomenclature when there is more than one renal vein. These have been variously referred to as abnormal, accessory, extrahilar, multiple, supernumerary or aberrant (Smithuis 1956 and Merklin and Michels 1958). This confusion in the anatomical nomenclature therefore makes it difficult to compile reliable statistics as to the exact kind, number, site of origin and mode of distribution of these renal vessels. Consequently, the following definition is proposed:

> *A renal vein is one which is constituted from the convergence and union of a varying number of primary tributaries emerging from the kidney and which terminates separately in the IVC. Any additional vessel that drains separately from the kidney and independently into the IVC should be considered as a normal variation and be named an additional renal vein.*

This definition and nomenclature have been used in this dissertation.

5.1.1 RELATIONS OF THE RENAL VEINS

The present series has confirmed without exception the anatomical relations as presented in Gillot's comprehensive monograph on the left renal vein (*vide* Fig. 1, page 12)(Gillot 1978).

In summary, the left renal vein is longer and embryologically more complex. Since the left metanephrogenous tract is especially prone to developmental variations, the relations of the left renal vein are far more complex than the right. Furthermore, since the left renal vein is flattened in a sagittal plane, it presents two surfaces, anterior and posterior, and two edges, superior and inferior (*vide* Chapter 2, page 10). On the contrary, the right renal vein is shorter, less complex in its embryological derivation and less prone to developmental variations. Its relations are therefore anatomically uncomplicated.

5.1.2 THE RENAL VASCULAR PEDICLE

While it was not the purpose of the present study to investigate the renal arteries, it was apparent from examination of the resin casts and plastinated renal specimens that an extensive variation in the form of the renal pedicle (arteries and veins) exits.

In this regard, Anson and Daseler (1961) stressed that the simple form of the renal pedicle as portrayed in standard textbooks of anatomy occurred in less than 25% of the cases. Furthermore "the variety in the form of the renal pedicles, based on the number of constituent vessels (arteries and veins) is greater on the right than on the left. In addition, the simplest vascular pedicle, namely, single artery and vein bilaterally, occurs in less than 50% of instances" (Harrison *et al.* 1978). In appreciating the extensive variation in the form of the renal vascular pedicles, Pick and Anson (1940) proposed a classification of the renal pedicles into six groups.

It is known that extensive research has been conducted on the renal arteries (Adachi 1928 and Merklin and Michels 1958) but it is apparent that a combined classification of both the renal arteries and the renal veins is extremely confusing and problematic. Therefore, the description and classification of arteries and veins should be dealt with independently .

Accordingly, a classification of the renal veins is proposed in this study.

To the surgeon concerned with the problem of renal transplantation, the morphology of the renal vessels acquires a special significance, since variations and anomalies may greatly influence the technical feasibility of the operation (Ross *et al.* 1961 and Warren *et al.* 1972 and 1974). Pollak *et al.* (1986) studied 400 cadaver organ donors for the presence of renal arterial, venous and ureteric anomalies. It is evident from their study that 49% of cadaver kidneys harvested for the purposes of renal transplantation can be expected to have an anatomical variation. Pollak observed that venous diversity was more likely to occur on the right than on the left and the presence of variation on one side was not predictive of finding an anatomic variant on the contralateral kidney. In recent reports Coen and Raftery (1992) confirmed Pollak's findings and further highlighted the importance of anatomical variations of the renal vasculature. The present study confirmed the view of Pollak *et al.* that venous variations was more likely to occur on the right.

Pollak (1993) further emphasises the importance of both the recovery and implant surgeons being conversant with the variations of the anatomical vascular patterns of procured cadaver kidneys. This may obviate inadvertent injury thus maximising the use of a scarce resource.

5.1.3 VARIATIONS OF THE RENAL VEINS

Of the 211 adult kidney pairs that were studied, no major anomalies of the renal veins were observed. One major variation (0.5%) of the IVC was noted i.e. the presence of a left IVC. This is embryologically equivalent to a persistent left supracardinal vein. Sarma (1966) described this variation in his classification as Type II (based on clinical and surgical considerations) while Chaung *et al.* (1974) categorises this variation of the IVC as Type C (on an embryological basis). This low incidence of 0.5% compares favourably with that recorded by Seib (1934), Reis and Esenther (1959) and Milloy *et al.* (1962) which ranged between 0.2% and 0.5%.

The recorded incidence of the presence of circumaortic renal collar is 1.5% to 30% and for retroaortic renal veins from 1.8% to 7.1% (Table VII, Page 50). A weighted average calculated from the observations of the authors listed in Table VII places the incidence of a circumaortic renal collar at 9.4% and a retroaortic renal vein at 2.4%. However, in this series of 211 paired specimens it is interesting to note that neither of these variations was noted. While it would be expedient to ascribe the absence of these renal vein variations in the present study to a small sample size, examination of Table VII reveals that these variations were noted by several other researchers with similar or smaller sample sizes.

Alternately, it may be argued that the present series comprised a select population of predominantly Black South African males. However, Kramer (1980) demonstrated an almost equal frequency among Black South African males and females of 5.9% and 5.1% respectively.

The discrepancy of this observation warrants further epidemiological analysis. It is, however, necessary to emphasise that the presence of these renal vein variations in particular must be acknowledged since they have significant clinical importance. Prior knowledge of a circumaortic venous ring is important when blood samples from the suprarenal or renal veins are to be collected. When performing venous sampling procedures of the suprarenal vein (e.g. for hormonal assays), in the presence of a circumaortic venous ring, the pre-aortic segment should be selected since the suprarenal vein always drains into this segment. If a solitary retroaortic vein is present, the adrenal vein may drain either into the prehilar portion of this renal vein, or into the IVC directly (Field and Saxton, 1974).

A circumaortic venous ring may provide a fully developed collateral pathway immediately after surgery if caval interruption is planned without awareness of its presence (Krause *et al.* 1963 and Piccone *et al.* 1970). Therefore, a careful search for this anatomic anomaly must be made by renal venography before operation. Should a circumaortic venous ring be found, the caval interruption ought to be performed at a level below the orifice of the retroaortic renal vein in the lower lumbar region (Ferris *et al.* 1967 and Gurewich *et al.* 1966).

An additional surgical significance of the occurrence of these congenital variations is that they restrict the availability of the left renal vein for mobilisation procedures (e.g. spleno-renal shunts) and nullify the advantages which normally accrue from their greater length (e.g.. left renal transplant) (Davis and Lundberg, 1968). In repair of an abdominal aortic aneurysm where the aorta is mobilised, the retroaortic vein becomes especially important. During retroperitoneal surgery, the surgeon may visualise a pre-aortic vein but may be unaware of an additional retroaortic component and thus may tear it while mobilising the kidney or clamping the aorta (Warren *et al.* 1972 and 1974, Mitty 1975).

5.2 MEASUREMENTS

5.2.1 LENGTH OF THE RENAL VEINS

The lengths of the renal veins (left - 5.9 cm and right - 2.4 cm) reported in the present study are compared to reviewed literature in Table XVI. The fact that the left renal vein is longer and more complex than its counterpart, confirms Arey's embryological precept that the primitive left renal vein opens into the sub-supracardinal anastomosis which in turn finds its way to the vena cava through the great anastomosis between the supracardinals. (Arey, Revised 7th Ed., 1974)

Although the length of the renal veins compare favourably with the literature reviewed (Table XVI), Williams *et al* (1989) reports a higher value of 7.5 cm for the left renal vein. Furthermore the length of the left renal vein is 2.5 times the length of the right renal vein unlike that quoted in Williams *et al.* (1989) where the left renal vein is thrice the length of the right. The mean length of the right renal vein measured 2.4cm. The first and second additional right renal veins have similar measurements. These findings differed from the weighted average obtained from the literature which was 2.8 cm (obtained from a sample size of 87).

It is apparent from these comparisons that the length of the RRV available for surgical manipulation is notably shorter. In addition to other considerations, the shorter size of the

TABLE XVI COMPARISON OF LENGTHS OF RENAL VEINS

REFERENCE	SAMPLE SIZE	LENGTH (CM) LEFT	LENGTH (CM) RIGHT	RATIO LEFT : RIGHT
Anson *(1934)*	23	9.0	3.5	2.6
Anson and Daseler *(1961)*	30	8.4	3.2	2.6
Ross *et al. (1961)*	34	5.7	2.0	2.9
Gillot *(1978)*	181	4.6	–	–
Williams *et al. (1989)*	–	7.5	2.5	3.0
Weighted Mean		**5.6**	**2.8**	**2.7**
PRESENT AUTHORS FINDINGS	**100**	**5.9**	**2.4**	**2.5**

Footnote: Calculation of weighted mean excludes Gillot (1978) for lengths of right renal vein (no reported value) and Willams et al. 1989 (no reported sample number). Consequently, the total sample number is: Left = 268; Right = 87.

right renal vein and the common occurrence of additional veins makes the right kidney a less suitable choice for renal transplantation. Ross *et al.* (1961) summarised the criteria that should be considered when evaluating kidneys suitable for transplantation. These included a requirement that both artery and vein should be of reasonable length to permit safe anastomosis and that they should be a single channel. They recommended minimum satisfactory lengths of 3 cm for veins and 2 cm for arteries. The mean length of the left renal vein of 5.9 cm and the right renal vein of 2.4 cm in the present study confirms that the kidney of choice for transplantation is the left one. Indeed, if this is found not suitable, various authors concur that it is doubtful if it is worthwhile exploring the right side (Ross *et al.* 1961, Banowsky *et al.* 1974, Ploeg *et al.* 1984 and Pollak 1986 and 1993).

5.2.2 RENAL VEIN SEGMENTS

In this dissertation the segments GV-1 and SRV-1 are described in relation to the renal vein itself and not to the aorta (as done by Gillot 1978 -proximal or pre-aortic segment) or the IVC (as done by Anson and Kurth 1955 - lateral segment). In the nomenclature of the left renal vein it is proposed that the term proximal segment be used to describe the segment from the union of the primary tributaries to the entry of the suprarenal and gonadal veins and the distal segment describes the remaining portion of the main renal vein up to its entry into the IVC. The description and measurement of these segments has surgical and embryological significance.

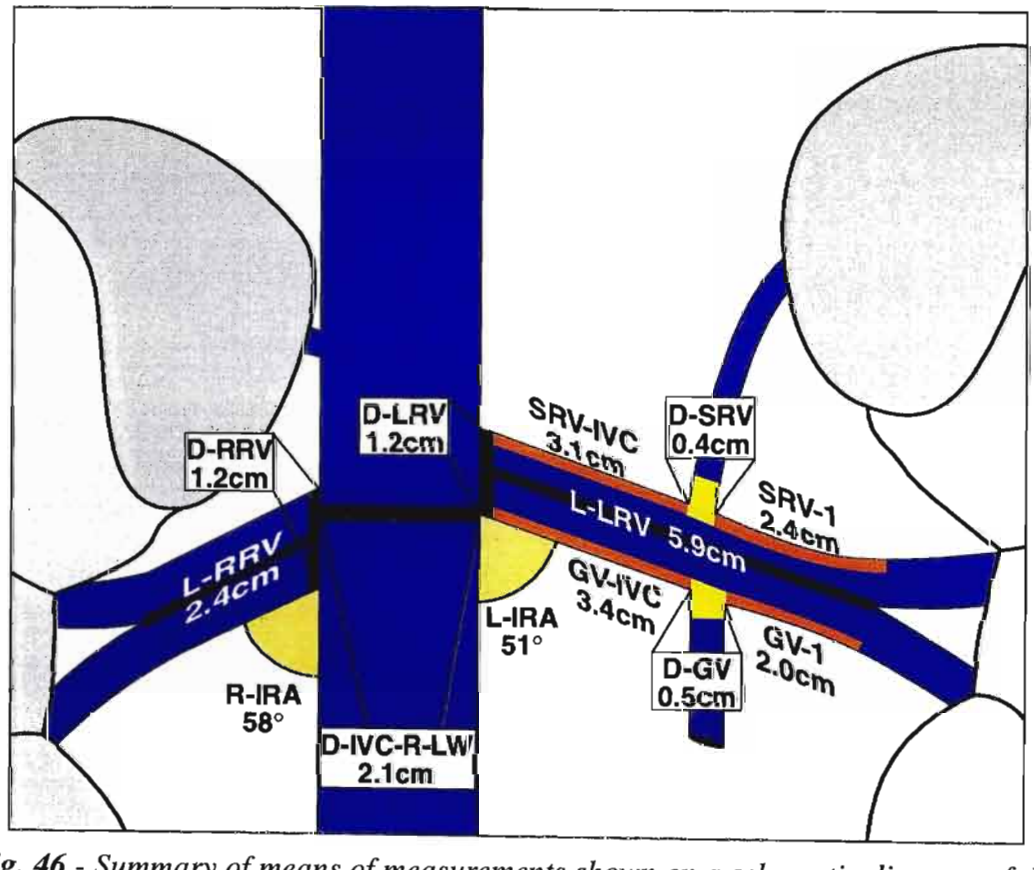


Fig. 46 - Summary of means of measurements shown on a schematic diagram of the renal veins.

The length of the proximal segment of the left renal vein of 2.6 cm [the mean of (SRV-1 and D-SRV) and (GV-1 and D-GV)] and its similarity to that of the RRV (2.4 cm) is of significance from the point of view of embryological development. Kolster (1901) and

Cameron (1911) described the proximal segment as the homologue of the right renal vein', a view also shared by Pick and Anson (1940). This finding is in keeping with those of the present study since the length of the proximal segment was found to be not significantly different from the L-RRV. A foetal study measuring and comparing these segments may provide further verification of this embryological link.

While the proximal segment represents an embryological homologue for the RRV, the distal segment does not have a homologous remnant on the right side of the body. The present study has found the mean length of the distal segment to be 3.2 cm. The distal renal segment, simultaneously aortic and post aortic, is the common terminal collecting channel. Embryologically variable in number, they derive from the anastomosis between the left and right subcardinal veins. This trunk is of large calibre and free of notable tributaries. Relatively fixed, even in cases of renal displacement (associated with splenomegaly for example), it lends itself to surgical manipulations: incision of the vein for clearing an obstruction, sectioning of the vein for debridement of the aorta, or mobilising the vein for its implantation into the portal vein. A large duodeno-pancreatic detachment exposes the whole of the trunk. The close proximity of the left renal vein and the portal vein suggested to Erlik *et al.* (1964) and later to Simeone and Hopkins (1967) that an anastomosis of the two was a feasible procedure. The length of vein available for anastomosis during shunt operations involving the LRV e.g. porto-renal shunting, is an important consideration in the planning of such procedures (Warren *et al.* 1972 and 1974). Additionally, it may assist in deciding on a mesenteric-renal shunt instead of the problematic cavo-mesenteric anastomosis. The present study concurs with the recommendation of Gillot (1978) that the distal renal segment be termed the *surgical trunk* of the left renal vein.

5.2.3 VERTICAL DISTANCE OF RENAL VEIN ENTRY INTO IVC AND OF IVC (UNDER RENAL VEIN INFLUENCE)

Pick and Anson (1940) state that the usual arrangement is for the left renal vein to enter the IVC higher than the right renal vein. This study confirmed this finding in 54% of cases and corroborates the 53% incidence reported by Kolster (1901). However, Kolster's finding of a 13% incidence of the right renal vein entering the IVC higher than the left renal vein differed from the present study's finding of a 36% incidence. In the case of bilateral equality of entry of these veins, Kolster found a 34% incidence while this study found a much lower incidence of 10%. It may be that this discrepancy results from a difference in the method of observation and classification. These findings, including the present study, disagree with Williams *et al.* (1989) that "the left renal vein enters the inferior vena cava a little superior to the right".

While previous authors have recorded the incidence of entry level into the IVC, the present study has, in addition, quantitated the actual height difference between the lower borders of the left and right renal veins to be between 1.0 cm (left higher) and 1.2 cm (right higher).

The mean height of the IVC between the points of the entry of the lowest and the highest margin of the left and right renal veins (L-IVC-COM) was found to be 2.3 cm with a range from 1.1 to 6.7 cm. The large range is accounted for primarily by the presence of additional left and right renal veins.

The study did not concur with the findings of Pick and Anson (1940) in that when additional renal veins were present they were not necessarily close together and that on the left side these veins were a considerable distance apart. This information may assist the angiologist in the performance of renal venography.

5.2.4 DIAMETERS OF THE LEFT AND RIGHT RENAL VEINS

The diameters of the renal veins on the left and right sides were found to be the same (1.2 cm). These findings compared favourably to those of Abrams *et al.* (1964), Kahn (1969) and Beckmann and Abrams (1980). However, when the diameter of the proximal renal vein segment of the present series of 1.1 cm was compared to the results obtained by Gillot (1978) of 1.6cm and that of Beckmann and Abrams (1980) of 1.9 cm, significant differences are noted. Since the usual point of section of the left renal vein is distal to both the suprarenal and gonadal vein, the calibre of this portion of the left renal vein is suitable for porto-renal shunts (Erlik *et al.* 1964 and Simeone and Hopkins 1967). This is despite the hepato-distal diameter of the portal vein being 2.2 (1.1 - 3.0) cm (Doehner *et al.* 1954).

It is of interest that when additional right renal veins were present, their combined diameters, together with that of the main right renal vein are the same as in a right kidney with a single vein.

Whilst Gillot (1978) obtained closely similar mean index values for the reno-renal index and the reno-caval index (75.5 and 75.7 respectively) the present study demonstrated different indices i.e. mean values of the reno-renal index and reno-caval index of 87.0 and 63.4 respectively.

5.2.5 DIAMETER OF THE GONADAL AND SUPRARENAL VEINS

The mean diameter of the gonadal vein was larger (0.5cm) than the mean diameter of the suprarenal vein (0.4cm) at their entry points into the left renal vein. The mean diameter of the gonadal vein is slightly larger than the 0.35 quoted by Gillot (1978). While Ahlberg *et al.* (1966) noted that the diameter of the gonadal vein on both sides was greater in women than in men (diameter females - right 0.32 cm and left 0.33 cm and males -right 0.26 and left 0.28 cm), in the present study, not statistically significant differences were observed between males and females.

5.2.6 INFRARENAL ANGLES

In this study, which examined only cadaveric material, the combined adult mean infrarenal angle was found to be 55° ± 16° (20°-102°) on the left side, and the right side measured 60° ± 17° (10°-93°) whilst the foetal mean infrarenal angle similarly measured 65° ± 12° (45°-90°) and 58° ± 7° (40°-70°) on the left and right sides, respectively. When these measurements were compared to those obtained from the literature, similar values were noted on the right side but differences were observed on the left side. A weighted average calculated from the combined series of a sample size of 128 from Abrams *et al.* (1964), Kahn (1969) and Beckmann and Abrams (1980) yielded a right infrarenal angle of 51° (26°-100°). The same calculation using a sample size of 273 from Abrams *et al.* (1964), Kahn (1969), Lein and Kolbenstveldt (1977) and Beckmann and Abrams (1980) yielded a mean left infrarenal angle of 77° (43°-94°). This clearly differs from the statement in Williams *et al.* (1989) that the renal veins "open into the inferior vena cava almost at right angles".

The large variation in the infrarenal angles observed is not surprising when one considers the recommendation of Moody and Van Nuys (1940) that the kidneys should be considered as normally "floating viscera". They demonstrated the mobility of the kidney in the erect and supine position and further noted that the length and range in live subjects was greater than that recorded for cadaveric material. In addition to body position affecting infrarenal angle measurements, the influence of respiration must also be considered, together with the fact that the renal vessels move around two relatively fixed points i.e. the IVC and the abdominal aorta. It is, however, necessary for the angiographer to have a clear idea of the range of infrarenal angle measurements particularly when performing renal venography. The mobility of the kidney is employed by angiologists to alter the infrarenal angle to facilitate selection in problematic cases. This knowledge may also assist in the design and formulation of renal venographic catheters. Furthermore, Simeone and Hopkins (1967) recognised that when a porto-renal shunt operation is planned in the presence of an acute infrarenal angulation, bevelling of the left renal vein

may be necessary in order to avoid upward rotation and consequent folding of the segment of the left renal vein. In view of these considerations it is apparent that the renal veins entering almost at right angles into the IVC are more an exception rather than the rule.

5.2.7 ADDITIONAL RENAL VEINS

In the "embryonal wandering" of the kidney described by Pohlman (1902), the permanent vascular supply is from the vascular territory where the kidney takes its definitive location (Plummer 1913). Hill (1905) agreed by stating that " there is no vascularisation of the kidney until it has reached its permanent position". When the location of the kidney is abnormal, the vascular supply may be abnormal since the blood supply adapts itself to the location of the kidney. Therefore all vessels of the normally positioned kidney, in addition to the usual single renal artery or vein, should be described as normal vasculature.

One additional renal vein was found in 33 kidneys of the 100 pairs of resin casts. Similar to the findings of several authors listed in Table XVII, the majority (31) of these occurred on the right side and 2 on the left side. A second additional right renal vein was found in 5 cases while a third additional right renal vein was not detected. The weighted mean incidence for 1 additional right renal vein (15.4%) calculated from a comprehensive literature review (Table XVII) differed significantly from the present findings of 31%. When compared to individual authors, similarities were noted with the findings of Rupert (1915) and Pick and Anson (1940) who reported incidences of 27% and 27.8% respectively.

The weighted mean values for the left side compared favourably with the present findings for both 1 additional renal vein (2.2% vs 2.0% respectively) as well as for the second additional right renal vein (2.3% vs 4.0%).

While the presence of additional renal veins has been noted by several researchers, comparisons of their measurements cannot be made as the lengths and diameters were not specifically recorded as in this study. It is significant that no sex or racial differences of note were detected with regard to the presence of additional renal veins.

Table XVII - Incidence of Additional Renal veins

REFERENCE	SAMPLE SIZE (Total 2315)	ADDITIONAL RENAL VEINS (%) LEFT SIDE (Total 1890)	RIGHT SIDE (Total 2315)		
			1	2	3
Rupert *(1915)*	118	1.0	27.0	—	—
Anson *et al (1936)*	200	3.0	10.0	1.0	—
Pick and Anson *(1940)*	194	1.0	27.8	—	—
Weinstein *(1940)*	203	6.0	12.0	4.0	—
Anson & Caudwell *(1947)*	425	—	22.0	3.0	—
Merklin and Michels *(1958)*	185	3.1	16.3	3.3	1.1
Reis and Esenther *(1959)*	500	0.8	10.2	1.0	—
Ross *et al. (1961)*	34	3.0	21.0	—	—
Beckmann and Abrams *(1980)*	56	1.0	23.0	5.0	—
Pollak *et al. (1986)*	400	2.0	8.0	—	—
Weighted Mean		**2.2**	**15.4**	**2.3**	**1.1**
PRESENT AUTHOR'S FINDINGS	**100**	**2.0**	**31.0**	**4.0**	**0**

The present findings on renal veins are similar to the study of de Beer (1966) on renal arteries who found no sex differences in the incidence of accessory renal arteries in the "South African Negro", but different in that he found significant racial differences between the occurrence of these arteries in "South African Negroes" and "South African Whites". No such significant racial differences were found in the present study.

It is interesting to note that accessory renal arteries of aortic origin arise more frequently on the left side and those of renal origin more frequently on the right (de Beer, 1966). While in general accessory renal arteries occur more frequently on the left side of the body (Williams *et al* 1989) the present study finds exactly the opposite arrangement in the preponderance of additional renal veins on the right and its infrequent occurrence on the left. The developmental theory for the arteries as proposed by de Beer (1969) may be extrapolated to the renal veins. In summary, four embryologically important developments occur.

1) The venous transformation of the cardinal system of veins leading to the formation of the IVC is largely accomplished by the eighth week of intrauterine life.

2) The kidney has reached its definitive level .

3) The "venous shift" to the right side of the body has occurred i.e. when the bilateral symmetrical cardinal system converts to a unilateral right sided IVC.

4) The consequent establishment of the IVC to the right of the aorta.

It is proposed that these developments might " discourage" the retention of any additional left sided renal veins which would be required to reach across the aorta. Furthermore, the complex embryogenesis of the left renal veins would further "discourage" this process. Since the right side is free of these impediments, additional right renal veins would be retained. This may explain the statistically significant finding of almost a third of kidneys on the right side possessing an additional renal vein and also of having multiple additional renal veins while the left side displayed an additional renal vein infrequently, and multiple additional veins in none of the kidneys.

The clinical significance of multiple right renal veins is that they may serve as an alternative collateral route if the IVC has been interrupted between these veins (Greweldinger *et al* 1969).

Since additional renal veins may be encountered more than occasionally, it is worthwhile emphasising their presence particularly to the transplant surgeon and the angiologist. In addition, an appropriate system to classify these renal veins is necessary and has accordingly been proposed in this dissertation.

5.3 VERTEBRAL LEVEL OF THE RENAL VEINS

The anatomical position of the renal veins in relation to the vertebral level facilitates renal venography. Of the 11 adult renal venograms studied, the central axis of the left renal vein was most frequently observed (45.5%) opposite the lower third of the body of the first

lumbar vertebra, while the right renal vein was found most frequently (36.4%) opposite the upper third of the body of the first lumbar vertebra. In general, the usual site of entry of the renal veins into the IVC together with their variations of entry compares favourably to that described by Abrams (1964), Kahn (1969), Lein and Kolbenstveldt (1977) and Beckmann and Abrams (1980).

In the foetal study, there was a distribution of renal vein entry from T12 to L3 with 55% concentrated around L2 on the right side. On the left side there was a range from T12 to the L2/L3 intervertebral disc with a distribution ranging from 9 to 27%. Although this foetal study consisted of a small sample size, the data presented appears to be the first documentation of the vertebral level of entry of the renal veins into the IVC. In view of the paucity of comparative studies, further investigation with a larger, more representative sample is warranted to confirm these findings.

When comparing the vertebral level of the renal vein entry of the foetuses with that of the adult study, the observed differences may be accounted for by the expected vertebral growth characteristics. The vertebral disc:body ratio in the foetus of 1:1 and in the adult of 1:3 supports this view.

5.4 CLASSIFICATION PATTERNS OF DRAINAGE OF THE RENAL VEINS.

Smithuis (1956) was the first to classify the course of the renal veins in an attempt "to yield a single type of extrarenal venous flowbed which could be regarded as a prototype". Whilst this author and others (Merklin and Mitchels 1958, Sykes 1963 b, and Gillot 1978) recognised the need to classify the patterns of drainage of the renal veins, each one of their proposed classification system has apparent deficiencies.

Smithuis (1956) recognised only two primary tributaries of the renal vein viz. an upper and lower. Other tributaries, in particular the posterior primary tributary are not included.

However, he does mention ventral and dorsal secondary tributaries and the presence of an additional renal vein. Merklin and Mitchels (1958), whilst not specifically proposing a classification, highlight the tributary of the renal vein from the dorsal aspect of the kidney. On the other hand, the classification proposed by Sykes (1963b) recognised only three primary tributaries viz. upper, middle and lower, each of which drained a third of the kidney parenchyma. In dividing the intrarenal venous drainage into thirds, the contribution of free intrarenal anastomoses was not considered. Furthermore, no mention was made of the posterior primary tributary of the renal vein. However, Sykes made provision for an accessory renal vein in two of the six types of his classification. Chaung *et al.* (1974) proposed a classification based on the variations of left renal vein only and while mentioning additional renal veins, they do not distinguish between the main renal vein and its primary tributaries, nor do they mention the presence of posterior tributaries. Finally, whilst Gillot (1978) recognised the importance and embryological significance of a posterior renal vein tributary he failed to accommodate this vessel in his classification types, neither did he make provision for additional renal veins. He did, however, recognise variations in the primary renal tributaries.

The classification types that are presented in this dissertation (Fig. 38) attempt to address these deficiencies. Whilst it is well known that venous drainage patterns are extremely variable, the criteria used for the present classification system takes into consideration the number of primary tributaries (including the posterior), additional renal veins and renal vein anomalies.

Thirty eight percent of kidneys presented the simple pattern of an upper and lower primary tributary (Type IA). This classification type is similar to that described by Smithuis (1956). Forty seven percent had more than 2 primary tributaries (including the posterior primary tributary) - Types IB, IIA and IIB. A posterior primary tributary was identified in 35% of cases - Types IB and IIB. This finding was similar to the 30% obtained by Merklin and Michels (1958). The relatively common occurrence of this posterior primary tributary justifies Brodel's caution that this vessel's retro-pelvic position is an important anatomical

point to be remembered during surgical intervention in the kidney (Brodel 1901).

The present study found a 14% incidence of additional renal veins on both sides which is classified as Type III. It is appropriate that these renal veins be called additional renal veins and not aberrant, supernumerary or abnormal renal veins as they drain directly into the IVC. Further, they are capable of providing an alternative renal venous drainage, due to the rich, free intrarenal anastomoses. The presence of additional renal veins both on the left and the right justifies the separate classification type.

Although not noted in the present study, renal vein variations such as the circumaortic renal vein, or the retroaortic renal vein may be accommodated in the proposed classification depending on the pattern of the primary venous tributaries. Since statistically significant differences were noted between the left and the right sides, a particular classification type on one side was therefore not predictive of similar findings on the contralateral side.

A knowledge of the classification types of the renal venous pattern of the kidney may assist the renal angiographer especially for selection for segmental vein renin assay sampling. Beckmann and Abrams (1980) recommended an additional downward deflection of 30° of the catheter tip during segmental vein sampling. In addition, the information of the classification type may assist the transplant surgeon in deciding on the suitability of a donor kidney.

There were no differences between the sexes with respect to classification type. There were also no significant differences of note between race groups.

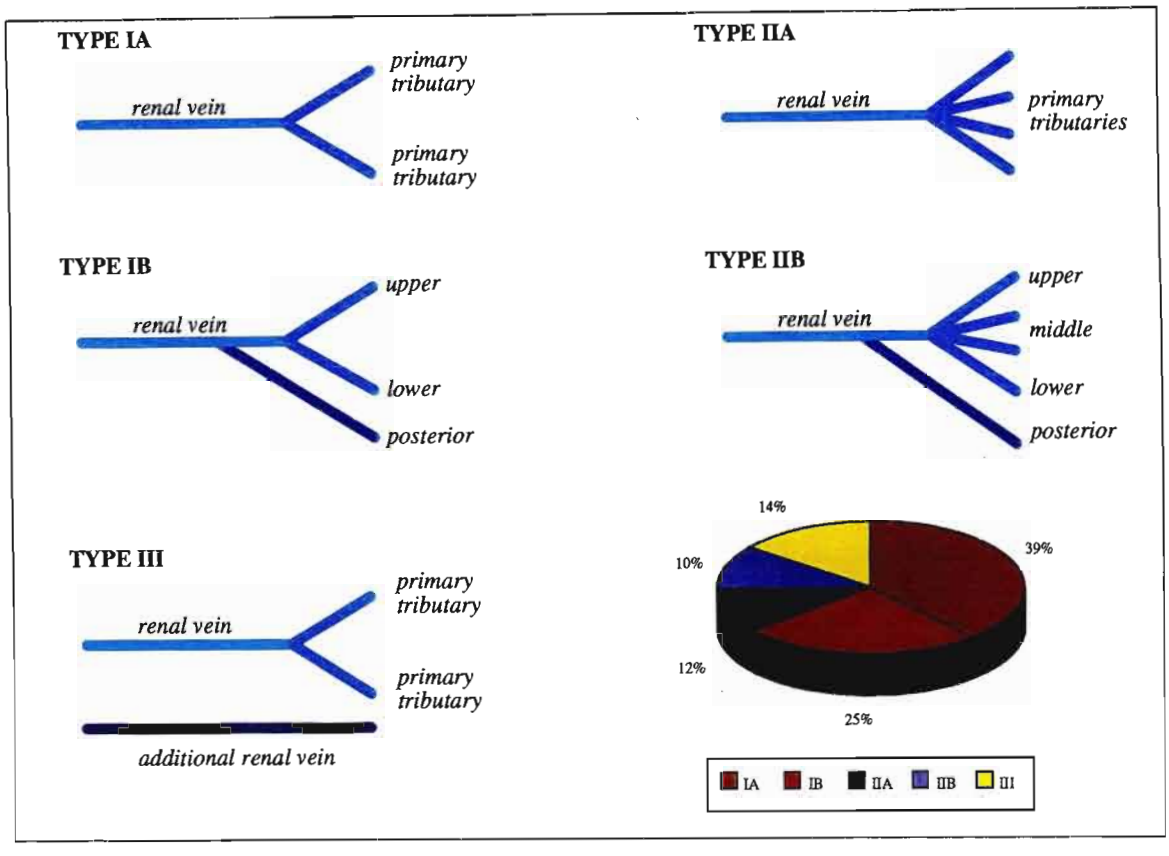


Fig. 47 *Classification types of renal venous drainage patterns with percentage distribution in the total sample.*

In the animal study, it was noted that the primary tributaries of the renal vein of the Chacma baboon were more numerous than those in the human and were noted to converge to form the main renal vein directly at the renal hilum. These primary tributaries were predominantly intrarenal. In view of this anatomical relationship, the classification proposed for the human venous patterns cannot be applied.

5.5 INTRARENAL VENOUS FLOW

Unlike the well described segmental arterial supply (Graves 1954, Boijsen 1959, Verma *et al.* 1961, Sykes 1964, Fine and Keen 1966, Engelbrecht *et al.* 1969), the renal venous system enjoys an abundant and free intrarenal non-segmental flow pattern.

The present study investigated each renal vein tributary as described in the proposed

classification and confirmed the work of Brodel 1901, Brown 1924, Morrison 1926 and Smith 1963 among others who described the intrarenal veno-venous anastomoses. However, unlike previous authors, this study methodically investigated each renal vein tributary and confirmed and demonstrated a non-segmental flow pattern. Significantly, this also included the cannulation of the posterior primary tributary, which has not been previously reported.

On perfusion studies, small interlobular vessels were demonstrated to drain the renal cortex and join the medullary veins to form the arcuate veins which in turn, run along the cortico-medullary junction. Free anastomoses between these arcuate veins drain into the interlobar vessels which then form the primary (lobar) tributaries. The union of these primary tributaries constitute the main renal vein. Multiple communications were noted at the arcuate and interlobar levels. These findings were demonstrated on injection of a single primary tributary with prior distal balloon occlusion of this vessel resulting in filling of the other primary tributaries and the main renal vein. In no instance, was there any impedance of contrast flow or were valves demonstrated at any level.

Anastomoses between the above intrarenal arrangement and extrarenal veins (capsular and periureteric venules) were also demonstrated.

However at microscopic level, the periarterial spaces (Swann and Norman 1976) and the perivenous tunnel system (Fine and Keen 1976), and their relationship to the possible existence of a medullary bypass shunt mechanism (Trueta *et al.* 1947, More and Duff 1944 and Merklin and Michels 1958) remains largely unsolved and was outside the scope of this study. This requires further investigation.

In demonstrating the intrarenal, interlobar, interlobular and arcuate arborisations and the free intrarenal anastomoses of the renal veins, this study confirms the non-segmental pattern of intrarenal venous flow. This justifies a surgical approach to segmental resection of the kidney based on renal arterial patterns rather than on venous drainage patterns which were demonstrated in this study to be non-lobar and non-segmental (Graves 1954,

Verma *et al.* 1961, Fine and Keen 1966, Engelbrecht *et al.* 1969 and Angorn 1977).

In the Chacma baboon the intrarenal venous pattern was similar to the human study but the arborisations and anastomoses appeared to be more abundant. A detailed comparative anatomical study may explain this variance.

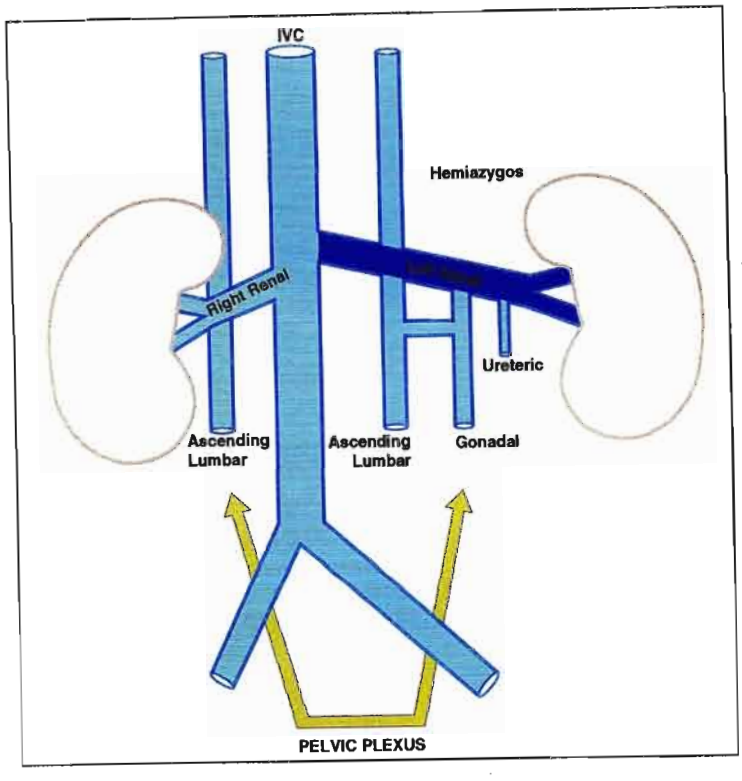
5.6 RENAL VEINS AND COLLATERAL FLOW

Despite numerous reports on experimental, pathological and clinical investigation into the collateral venous channels focusing on the collaterals of the IVC and the vertebral plexuses, none have emphasised the importance of the renal veins in terms of their potential capacity to provide collateral flow.

The left renal vein may be manipulated surgically (temporarily clamped, divided and or reconstructed and retracted) during surgical procedures such as those involving ruptured aortic aneurysms and right renal artery angioplastic procedures without significantly impairing the function of the left kidney (Simeone and Hopkins 1967 and Szilagyi *et al.* 1969). This is facilitated by renal vein collaterals that adequately maintain the function of the left kidney.

Several researchers assert that the balance between the speed with which a collateral system develops and the rapidity of the renal vein occlusion, will determine the outcome (Koehler *et al.* 1966, Hipona and Crummy 1966, Wegner *et al.* 1969 and Beckmann and Abrams 1980). If the occlusion is rapid and complete, haemorrhagic infarction may occur. If the occlusion is gradual, collaterals may develop.

In all experimental studies in this series both in foetuses and adults, the left renal vein opacification was constantly achieved via collateral veins when contrast perfusion was undertaken with proximal or distal occlusion as described. Likewise prograde and retrograde collateral flow was also achieved when the left renal vein per se was contrast perfused. On the other hand, the right renal vein contributed little towards collateral flow when injected in a similar manner.



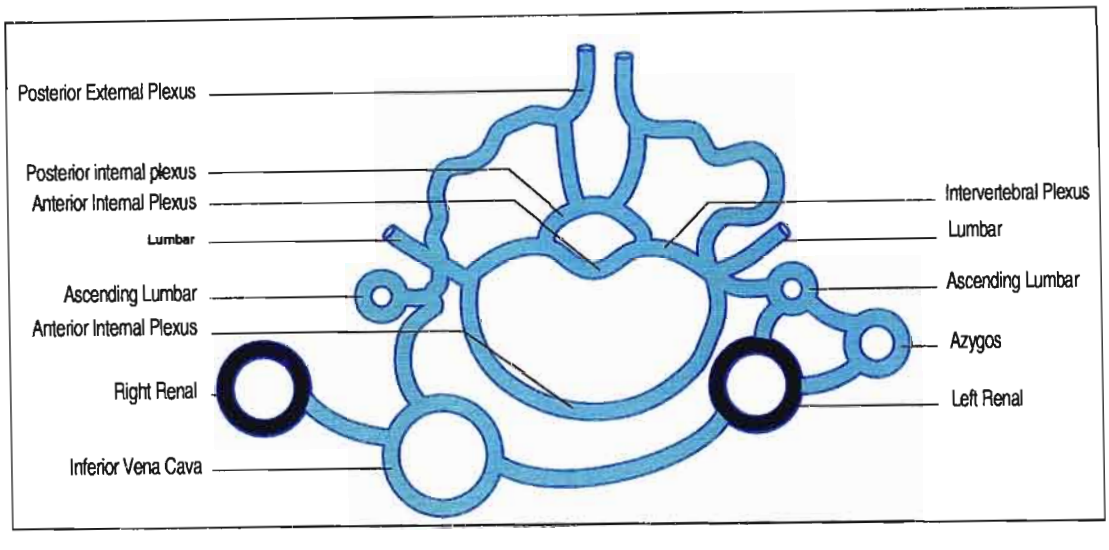


Fig. 48 *(Top and Bottom) Schematic diagram demonstrating the renal veins and the available collateral channels in the foetus and adult.*

5.6.1 FOETAL STUDY

From a review of numerous reports, it is apparent that specific investigation into the renal venous collateral anatomy is lacking in the foetus while this concept is both well recognised and researched in the adult.

Perfusion of the foetal right renal vein with selective ligation demonstrated a paucity of collaterals emanating from this vein. The major collateral flow when present was via the

ascending lumbar and vertebral venous plexuses.

However perfusion studies of the left renal vein in a similar manner revealed bi-directional craniad and caudad flow. The preferential pathway was via the azygos system but this does not detract from the significance of the combined lumbar, vertebral and gonadal pathways. The contribution of the capsular and ureteric veins as collateral channels was not as significant.

Acknowledging the fact that the study was conducted on morphologically normal foetuses without overt congenital aberration, it is conceded that in disease states any of the collateral pathways described may play a predominant role (Keshin and Joffe 1956, Blaivas *et al.* 1977 and Beckmann and Abrams 1980).

That the left renal vein is a major source of collateral tributaries in the foetus is established from this study. Moreover, this potential for collateralisation may be operative should the need arise. It is notable that in spite of prograde and retrograde perfusion studies there was a striking absence of valves. Could there not be a correlation between the absence of valves and the propensity for collaterals? A study into this premise is warranted.

5.6.2 ADULT STUDY

Clinical, anatomical and experimental investigations have been conducted into the collateral circulation of the adult kidney in both normal and diseased states (*vide* Chapter 2, Page 67).

This anatomical - radiological study, investigating the collateral flow in the sphere of influence of the renal veins in morphologically normal kidneys confirms these findings. In this study, the contribution of the left renal vein was impressive. Selective ligation and perfusion demonstrated the abundant potential collateral pathways that exist. Perfusion of a single primary tributary of the left renal vein with distal occlusion revealed filling of the remaining primary tributaries via the rich intrarenal anastomotic pathways. Craniad flow was via the azygos, lumbar and vertebral channels and caudad flow via the ascending

lumbar, vertebral and iliac veins. The capsular and peri-ureteric venules contributed to the intra/extrarenal collaterals.

The study confirms the adequacy of collateral veins in the adult. Furthermore, as in the foetus it shows that the right renal vein contributes little to the collateral flow.

The significant role of the posterior primary tributary of the left renal vein (also referred to as "the collector" by Gillot) in facilitating collateral flow has been established (Gillot 1978). This tributary which occurred twice as frequently on the left side compared to the right - Classification Type IB and IIB) emphasises the role of the left renal vein as an impressive pathway for collateral flow. These findings support Gillot's contention that this tributary belongs to the dorsal and parietal component of the left renal vein by its retro-pelvic trajectory, its frequent azygo-lumbar anastomoses and as such, establishes the liaison between the ventral visceral and the dorsal parietal components of the left renal vein (Gillot 1978).

The potential capacity for collateralisation in the foetus has been shown to persist in the adult. These channels that are central to the renal veins play a pivotal role in pathological states of the kidney. In this regard, the formation of collateral venous circulation as a consequence of renal vein thrombosis is of clinical significance. One of the factors contributing to the viability of the kidney is the efficacy of the collateral veins. Since the collateral flow is more abundant on the left than on the right side (as has been demonstrated in this study), it is postulated that these preferential collateral veins may favour preservation of renal function on this side. Further clinical evaluation and experimental investigation may confirm this view. Furthermore, haematogenous metastases from carcinoma of the kidney associated with renal vein thrombosis may be expected to be more common and numerous from the left side. The higher incidence of periureteric and renal vein varices on the left (Eisen *et al.* 1965, Weiner *et al.* 1974 and Beckmann and Abrams 1982) may be explained by the increased collaterisation that occurs on the left side.

As with the foetal study, no valves were observed in the renal veins. The absence of valves may be conducive to the formation of collateral circulation, a concept that needs further evaluation.

5.7 RENAL VEIN VALVES

The present study examined foetal, adult and baboon kidneys for the presence of renal vein valves. These kidneys were subjected to macroscopic, microscopic and radiological examination. In all specimens examined, no renal vein valves were noted.

This absence of renal vein valves is not surprising in view of the dichotomy of opinion on their presence in both anatomical and radiological literature. Ahlberg *et al* (1968) and Takaro *et al.* (1970), in addition to several other authors demonstrated valves in 28 - 70% of right renal veins and 4 - 36% of left renal veins in their study. On the other hand, Lushka (1863), Mollendorff (1943), and more recently Blaivas *et al.* (1977) amongst others failed to demonstrate their presence. (*vide* Chapter 2, page 62)

The inability to demonstrate the valves may be due to the fact that they are very thin, often rudimentary and can easily be overlooked and obscured in the venogram (Takaro *et al.* 1970 and Beckmann and Abrams 1980). Valves located near the ostia are naturally difficult to demonstrate with catheter techniques because the catheter is placed beyond the valve location. Also, during injection of contrast at high rate and volume, the valves are flattened against the vein walls by the retrograde flow of contrast and therefore are not visible. Valves located centrally are kept open by flow of blood from non-opacified veins and hence not visualised (Beckmann and Abrams 1978). In addition, valves detract from the quality of venograms and may partially obstruct the retrograde flow of contrast and cause diminished peripheral filling. Takaro *et al* (1970) encountered a 7% incidence of unsuccessful venogram studies in which renal vein valves blocked passage of either the catheter or of contrast material.

When total obstruction to retrograde flow of contrast material is present, produced by a competent valve, distinction from renal vein thrombosis and renal vein invasion must be made (Beckmann and Abrams 1978). Valves may also infrequently interfere with catheterisation of segmental renal vein branches.

While the possible reasons advanced may account for the striking variations in the

reported frequency of renal vein valves in the literature, directed research in this field is warranted.

It is of interest that in the animal study, the renal vein of the Chacma baboon also displayed an absence of intrarenal valves. Further comparative investigation of these non-human primate models is warranted.

5.8 RENAL LOBES

The renal lobe may be regarded as a major renal unit, a group of which in various stages of fusion, comprise the kidney (Lofgren 1949).

The average number of lobules in the foetus (age range 26 to 38 weeks) was found here to be 14 which compares favourably with the work of Lofgren (1949), Sykes (1964a) and Hodson (1978). Further, the number of lobules for the age range is in keeping with the observation by Harrison (1959) that a maximum number of 14 lobules is present not later than the 28th week of intra-uterine life. The 43% incidence of persistent foetal clefts in the present study is similar to those obtained by Sykes (1964a) of 51% and Hodson (1978) of 50%.

In the present study, fluoroscopic and radiographic examination of human foetal and adult cadaveric kidneys clearly demonstrated non-segmental venous flow patterns (Plates 25 and 26)that do not conform to any renal lobe or segmental pattern. Anastomoses that were present may be divided into two types - the larger interlobar and the smaller interlobular anastomoses. Because these intrarenal anastomoses were multiple, and displayed free intrarenal venous flow, segmental venograms could not be produced. One of the features of all the radiographs of the renal veins was a number of curvilinear shaped structures, the "pillars" which are formed by the interlobar veins and the "arches" by the arcuate veins. Interestingly, a similar observation was noted in the Chacma baboon.

The lobar arterial blood supply has been described by various authors (Graves 1954, Boijsen 1959, Verma *et al.* 1961, Sykes 1964a, Fine and Keen 1966 and Engelbrecht *et al.* 1969).

While it is desirable to accept the renal lobe as the basis of possible renal segmentation, a study of the internal vascularisation showed that no renal lobe has an independent blood supply, since every lobe is supplied with blood from at least two sides, via interlobar arteries and arciform rami (Smithuis 1956). Furthermore, Hodson (1978) stated that "For a whole lobe to be infarcted, a segmental vessel must be involved and that not just one lobe but also roughly half the lobes on either side of it are also affected."

The renal lobules therefore do not appear to depend on individual vascular elements. However, groups of lobules may have such arterial patterns. On the other hand, venous drainage is non-lobar and non-segmental.

CHAPTER 6

CONCLUSION

"Lastly, for the nephrophile there is something more, namely an intellectually satisfying logic governing renal architecture which provides a working basis for analysis of the wide normal variation that ... make each pair of kidneys as individual as its owner's fingerprints."

Hodson (1978)

1. GROSS ANATOMY

The gross anatomy of the renal veins and its relations were confirmed to be similar to currently accepted norms.

The renal vein of a normally situated kidney should be defined as one which is constituted from the convergence and union of a varying number of primary tributaries emerging from the kidney and which terminates separately into the IVC. Any additional vessel that drains separately from the kidney and independently into the IVC should be considered as a normal variation and be named an additional renal vein.

VARIATIONS OF THE RENAL VEINS

While a circumaortic renal collar and a retroaortic renal vein were not observed, a left sided IVC (0.5% incidence) was noted.

2. MEASUREMENTS

Detailed morphometric analyses of the various parameters of the renal veins corroborated and augmented previous anatomical studies.

LENGTH

The left renal vein is 2.5 times the length of its counterpart.

The view that the distal renal segment should be termed the surgical trunk of the left renal vein is supported.

The proximal segment of the left renal vein is confirmed to be the homologue of the right renal vein.

DIAMETER

The diameter of the renal veins as it entered the IVC is 1.2 ± 0.2 cm on both sides.

The calibre of the proximal renal vein segment of 1.1cm is suitable for venous shunt procedures.

When additional renal veins are present on the right side, their combined diameters together with that of the main right renal vein are the same as the diameter in a kidney with a single vein.

The diameter of the gonadal vein is 0.5 ± 0.3 cm and suprarenal vein is 0.4 ± 0.2 cm.

ENTRY LEVEL OF RENAL VEINS INTO IVC

The left renal vein entered the IVC higher than the right in 54% of cases, lower in 36% and opposite each other in 10% of cases.

The vertical distance between the lower borders of the renal veins is 1.0 ± 0.9 cm.

VERTICAL DISTANCE OF IVC (UNDER RENAL VEIN INFLUENCE)

The vertical distance of the IVC under renal vein influence is 2.3 ± 1.0 cm.

INFRARENAL ANGLES

Cadaveric infrarenal angles on the right of 55° ± 16° and on the left of 60° ± 17° are different from the 90° suggested by standard textbooks of anatomy.

3. ADDITIONAL RENAL VEINS

Additional renal veins are common on the right side (31%) while it is rare on the left side (2%). A third renal vein is infrequently present on the right side (5%). The predominance of additional veins on the right side is explained on developmental theories. When additional renal veins are present they are not necessarily close together.

4. VERTEBRAL LEVELS

The vertebral level of the renal veins in normally situated adult kidneys lies between T12 and L2 and, in foetuses, between T12 and L3. These differences are accounted for on the basis of vertebral growth characteristics.

5. CLASSIFICATION OF VENOUS PATTERNS OF RENAL VEINS

The venous patterns of renal veins should be classified according to the number of primary tributaries (including the posterior primary tributary), additional renal veins and anomalies.

The presence of a particular classification type on one side is not predictive of a similar finding on the contralateral kidney.

Neither sex nor race is predictive of a particular classification type.

6. INTRARENAL VENOUS FLOW

Intrarenal venous architecture is non-segmental.

Venous flow is free and unimpeded through the primary tributaries via interlobar and interlobular arcuate arborisations.

7. RENAL VEINS AND COLLATERAL VENOUS CHANNELS

Extensive venous collaterals centering on the renal veins exist in the foetus which persist in the adult. These collateral pathways are constituted by the renal-lumbar-azygos-vertebral axis. The infrarenal pathway is predominantly via the ascending lumbar veins and the vertebral plexuses. The suprarenal pathway is by the azygos-vertebral axis.

The capsular and periureteric venules provide an intra/extrarenal communication.

The major contributor of these collateral pathways is from the left renal vein. The right renal vein contributes little, if any, to the collateral channels. The predominance of collateral veins relating to the left kidney rather than the right is explained on developmental theories.

These collateral channels present in the foetus, and persisting in the adult may be operative and of clinical significance in pathological states.

The presence of collateral veins explains the constellation of clinico-radiological findings in pathological states.

8. RENAL VEIN VALVES

No valves were demonstrated in this study but the dichotomy of opinion relating to their presence is recognised.

9. RENAL LOBES

Intrarenal venous drainage shows neither lobar nor segmental patterns.

The average number of lobules in the foetus is 14. Persistent foetal clefts are present in 43% of kidneys.

10. GENDER AND RACE

No sex differences and no race differences of note were recorded.

11. ANIMAL STUDY

The Chacma baboon displayed the same intrarenal non-segmental flow pattern and an absence of valves as in the human study. The proposed classification was found to be unsuitable to apply to this model.

12. EPILOGUE

The applied clinical anatomy of these conclusions, with particular regard to renal surgery and uro-radiology, is emphasised.

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APPENDIX

APPENDIX A

INVESTIGATION OF RENAL VEIN VALVES

SERIES NO.	PM. NO.	RACE	SEX
175	1383	B	M
176	1412	B	M
177	1449	B	M
178	1461	B	M
179	1558	B	M
180	1566	B	M
181	1575	C	M
182	1629	B	M
183	1636	C	M
184	1639	B	F
185	1694	B	M
186	1696	B	M
187	1872	B	M
188	1919	B	M
189	1924	B	M
190	1926	B	M
191	2051	B	M
192	2117	B	M
193	2851	W	M
194	2882	B	M
195	3197	B	M
196	3411	B	M
197	3461	B	M
198	3473	B	M
199	1421	B	M
200	2195	B	F

APPENDIX B

DEMONSTRATION OF RENAL VENOUS FLOW AND COLLATERAL CHANNELS (ADULT SERIES)

SERIES NO.	PM. NO.	SEX	RACE
201	2069	M	B
202	2195	M	B
203	2367	F	B
204	2553	M	B
205	2560	M	B
206	2580	M	B
217	2585	M	B
208	2682	M	B
209	3305	M	B
210	3578	M	B
211	707	M	B

APPENDIX C
DEMOGRAPHIC DETAILS OF PLASTINATED PAIRS OF KIDNEYS

SERIES NO.	PM. NO.	SEX	RACE	CLASSIFICATION TYPES Left	Right
101	507	M	B	2A	1A
102	581	M	B	3	1A
103	584	M	I	2A	2A
104	585	M	B	2B	1A
105	672	M	I	2A	2A
106	999	M	B	2A	2A
107	1002	M	B	1B	3
108	1043	M	B	2B	1B
109	1073	M	B	1B	3
110	1129	M	B	2B	1B
111	1149	M	B	1B	3
112	1184	M	B	1B	1B
113	1210	M	B	2B	1B
114	1211	M	B	1A	3
115	1234	M	B	2B	2B
116	1276	M	B	1B	1B
117	1285	M	B	1B	3
118	1290	M	B	1B	1A
119	1347	M	W	1B	2B
120	1393	F	B	1A	2A
121	1401	M	B	1A	1A
122	1402	M	B	2A	1A
123	1420	M	B	1A	1A
124	1465	M	B	1B	2A
125	1484	M	B	1A	2A
126	1872	M	B	1B	2B
127	1907	F	B	1B	1A
128	1909	F	B	1B	1A
129	1918	M	B	2B	3
130	1991	M	B	1A	1A
131	1923	M	B	2A	1A
132	1925	F	B	1A	1A
133	2006	M	B	1B	2B
134	2065	F	B	1B	3
135	2069	M	B	1A	1A
136	2072	M	B	2A	1A
137	2132	F	B	1B	1A
138	2149	M	I	2B	3
139	2157	M	B	1A	1A
140	2216	M	B	1A	1A
141	2227	M	I	1A	1A
142	2238	M	I	1B	1A
143	1234	M	B	2A	2A
144	1352	M	B	1B	1A
145	2214	M	B	1A	2B
146	1850	M	W	3	2A
147	2515	M	B	2B	1A
148	2347	M	B	1A	1A
149	2508	M	B	2A	1A
150	2510	F	B	2B	2A
151	2416	M	B	1A	3
152	2418	M	B	1A	2A
153	2414	M	B	1B	1B

APPENDIX D

DEMOGRAPHIC AND MORPHOMETRIC DETAILS OF RESIN CASTS OF KIDNEYS

SERIES NO.	.	2	SEX	L-LRV	L-RRV	GV-1	D-GV	GV-IVC	SRV-1	D-SRV	SRV-IVC	L-IRA	R-IRA	L-CL	R-CL	D-LRV-GV	D-LRV-SRV	D-LRV-IVC	D-IVC-R-LW	D-IVC-L-LW	D-IVC-L-R	D-LRV	D-RRV	L-IVC-COM	L-IVC-L=R	L-RRV2	L-RRV3	L-LRV2	D-RRV2	D-RRV3	D-LRV2
1	194	W	M	6.4	2.5	0.6	0.5	5.3	2.3	0.4	3.8	42.0	65.0	IA	IIA	1.2	1.1	0.0	1.8	0.0	0.0	1.6	1.2	2.5	1.3	0.0	0.0	0.0	0.0	0.0	0.0
2	198	B	M	6.7	3.7	2.9	0.5	3.4	3.0	0.6	3.1	51.0	63.0	IA	IA	0.9	0.9	0.0	0.0	0.0	1.7	1.2	1.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	201	B	F	6.5	2.9	1.8	0.7	4.0	1.4	0.7	4.4	53.0	25.0	IB	IA	1.4	1.5	0.0	0.0	2.9	0.0	1.5	1.4	3.1	-1.7	0.0	0.0	0.0	0.0	0.0	0.0
4	258	B	M	7.8	3.3	3.5	0.3	4.1	4.7	0.2	2.9	57.0	69.0	IA	IA	0.9	1.0	0.0	2.2	0.0	0.0	1.2	1.6	1.7	0.6	0.0	0.0	0.0	0.0	0.0	0.0
5	304	B	M	7.9	2.9	3.5	0.5	4.0	3.5	0.8	3.7	66.0	48.0	IB	IB	1.1	0.6	0.0	2.1	0.0	0.0	1.5	1.3	1.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0
6	306	B	M	4.0	1.6	0.5	0.3	3.3	0.5	0.7	2.8	41.0	83.0	IB	III	0.0	0.0	1.2	2.2	0.0	0.0	0.8	1.1	3.4	1.0	2.8	0.0	0.0	0.5	0.0	0.0
7	458	B	M	6.1	3.1	1.8	0.2	4.1	1.8	0.3	4.1	46.0	71.0	IA	IA	0.0	0.0	1.2	1.8	0.0	0.0	1.1	1.0	3.8	2.7	5.0	0.0	0.0	0.0	0.0	0.0
8	465	B	F	3.9	3.0	0.0	0.4	3.5	1.1	0.4	2.4	27.0	59.0	IA	IA	0.8	1.2	0.0	1.9	0.0	0.0	1.1	1.0	2.6	1.5	0.0	0.0	0.0	0.0	0.0	0.0
9	515	B	M	7.7	1.9	3.2	0.3	4.3	2.3	0.9	4.5	29.0	28.0	IA	III	1.6	1.1	0.0	1.5	0.0	0.0	1.2	0.7	2.5	0.5	2.4	0.0	0.0	0.5	0.0	0.0
10	548	I	M	6.8	2.1	1.9	0.5	4.4	2.8	0.3	3.7	52.0	72.0	IA	IB	1.0	1.2	0.0	2.3	0.0	0.0	1.2	1.3	1.9	0.7	0.0	0.0	0.0	0.0	0.0	0.0
11	576	B	M	5.1	2.8	1.7	0.2	3.2	1.5	0.6	3.1	59.0	45.0	IA	IA	0.0	0.0	1.3	0.0	2.1	0.0	1.2	1.1	2.2	-1.1	0.0	0.0	0.0	0.0	0.0	0.0
12	577	B	M	6.7	3.0	2.8	0.7	3.3	3.8	0.2	2.8	57.0	60.0	IA	IA	0.8	1.0	0.0	2.0	0.0	0.0	1.1	1.1	1.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0
13	578	B	M	2.9	3.1	0.0	1.0	1.9	0.0	0.9	2.0	50.0	40.0	IA	IA	0.7	0.8	0.0	0.0	2.0	0.0	1.1	1.3	2.1	-0.9	0.0	0.0	0.0	0.0	0.6	0.0
14	579	B	M	7.4	2.5	3.2	0.7	3.6	2.9	0.8	3.7	57.0	57.0	IA	IA	0.8	1.0	0.0	0.0	0.0	2.1	1.2	1.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	582	B	M	3.7	2.1	0.4	0.8	2.5	1.2	0.2	2.3	62.0	50.0	IB	III	1.1	1.1	0.0	2.2	0.0	0.0	1.3	1.4	3.1	0.4	2.6	0.0	0.0	0.8	0.0	0.0
16	584	B	M	4.0	2.0	1.1	0.9	2.0	0.6	0.5	2.9	52.0	54.0	IA	IB	0.0	0.0	0.8	1.9	0.0	0.0	1.3	1.5	1.9	0.6	0.0	0.0	0.0	0.0	0.0	0.0
17	588	B	M	4.7	2.0	0.4	0.6	3.7	2.0	0.9	1.8	62.0	58.0	IA	IIB	1.2	1.2	0.0	2.4	0.0	0.0	1.4	1.7	2.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
18	626	B	M	5.1	3.5	1.8	0.7	2.6	2.9	0.1	2.1	64.0	64.0	IA	IA	1.4	1.4	0.0	0.0	0.0	2.0	1.1	1.1	1.1	0.0	0.0	0.0	0.0	0.0	0.9	0.0
19	631	B	M	4.2	3.2	1.4	0.8	2.0	1.1	1.0	2.2	59.0	78.0	IA	III	0.9	0.8	0.0	2.2	0.0	0.0	1.5	0.7	2.8	1.5	3.0	0.0	0.0	1.1	0.0	0.0
20	632	B	F	10.4	2.5	3.8	0.4	6.2	5.0	0.5	4.9	72.0	89.0	IB	IA	1.2	1.3	0.0	2.2	0.0	0.0	1.6	1.1	4.7	3.1	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX D

DEMOGRAPHIC AND MORPHOMETRIC DETAILS OF RESIN CASTS OF KIDNEYS (CONTINUED)

SERIES NO.	PM. NO.	RACE	SEX	L-LRV	L-RRV	GV-1	D-GV	GV-IVC	SRV-1	D-SRV	SRV-IVC	L-IRA	R-IRA	L-CL	R-CL	D-LRV-GV	D-LRV-SRV	D-LRV-EQ	D-IVC-R-LW	D-IVC-L-LW	D-IVC-L-R	D-LRV	D-RRV	I-IVC-COM	L-IVC-L=R	L-RRV2	L-RRV3	L-LRV2	D-RRV2	D-RRV3	D-LRV2
21	633	B	F	6.8	2.7	2.2	0.5	4.1	2.4	0.6	3.9	63.0	53.0	IIB	IB	0.0	0.0	1.1	0.0	2.2	0.0	1.1	1.2	1.8	-0.7	0.0	0.0	0.0	0.0	0.0	0.0
22	683	B	F	6.6	2.5	0.6	0.5	5.5	2.0	0.2	4.5	59.0	54.0	IA	IIA	1.3	1.3	0.0	2.4	0.0	0.0	1.3	1.4	2.7	1.4	0.0	0.0	0.0	0.0	0.0	0.0
23	692	W	F	4.2	0.7	0.2	0.8	3.2	1.8	0.4	2.1	42.0	86.0	IIB	IIA	0.9	1.3	0.0	1.8	0.0	0.0	1.4	1.3	2.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0
24	742	B	M	6.1	2.0	1.2	0.8	4.2	3.0	0.2	3.0	46.0	66.0	IA	IB	1.1	1.2	0.0	1.8	0.0	0.0	1.0	1.1	1.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0
25	744	B	M	4.0	3.1	0.2	0.5	3.3	0.1	0.8	3.1	46.0	40.0	IB	IA	1.5	1.0	0.0	0.0	2.4	0.0	1.4	1.2	3.2	-2.0	0.0	0.0	0.0	0.0	0.0	0.0
26	779	B	M	6.4	2.0	2.2	0.3	4.0	2.9	0.5	3.0	53.0	86.0	IA	IA	1.1	1.1	0.0	2.1	0.0	0.0	1.2	1.1	2.8	1.6	0.0	0.0	0.0	0.0	0.0	0.0
27	781	B	M	5.6	3.1	1.5	0.8	3.3	2.7	0.2	2.8	60.0	58.0	IA	IIA	0.9	1.2	0.0	0.0	2.2	0.0	1.0	1.4	2.8	-1.4	0.0	0.0	0.0	0.0	0.0	0.0
28	785	B	M	8.3	2.3	4.8	0.1	3.4	4.0	0.6	3.8	64.0	48.0	IA	IB	1.1	1.1	0.0	0.0	2.0	0.0	1.4	1.4	2.3	-0.9	0.0	0.0	0.0	0.0	0.0	0.0
29	828	B	M	4.9	2.0	1.8	0.1	3.1	0.9	0.8	3.3	49.0	78.0	IA	IA	0.7	1.1	0.0	2.2	0.0	0.0	1.1	1.3	1.9	0.8	0.0	0.0	0.0	0.0	0.0	0.0
30	872	B	M	7.6	2.5	3.2	0.5	4.0	3.4	0.9	3.4	54.0	76.0	IIB	III	1.3	1.4	0.0	2.4	0.0	0.0	1.4	1.1	1.4	0.3	4.6	0.0	0.0	0.7	0.0	0.0
33	1041	B	F	5.3	1.5	1.8	0.3	3.3	1.5	0.4	3.4	44.0	67.0	III	III	0.8	0.8	0.0	0.0	2.1	0.0	0.7	1.2	4.2	-1.5	3.7	0.0	5.9	0.4	0.0	1.0
34	1045	B	M	5.7	1.2	1.8	0.1	3.9	1.1	0.8	3.8	63.0	50.0	IIB	III	0.5	1.2	0.0	2.2	0.0	0.0	1.1	1.2	3.0	1.8	1.4	0.0	0.0	0.5	0.0	0.0
35	1087	B	M	3.8	2.7	0.3	0.1	3.4	1.1	0.8	1.9	54.0	88.0	IA	IIA	1.0	1.4	0.0	2.4	0.0	0.0	1.2	1.3	2.5	1.3	0.0	0.0	0.0	0.0	0.0	0.0
36	1089	B	M	4.3	3.4	0.4	0.3	3.6	1.2	0.2	3.0	20.0	69.0	IA	III	1.3	1.3	0.0	0.0	2.3	0.0	1.2	1.2	2.8	-1.1	1.3	0.0	0.0	0.5	0.0	0.0
37	1151	B	M	5.2	1.5	1.0	0.8	3.4	1.1	0.4	3.7	35.0	88.0	IA	III	1.0	1.2	0.0	2.6	0.0	0.0	1.4	1.0	3.7	1.2	1.0	0.0	0.0	0.9	0.0	0.0
38	1154	B	M	7.0	1.5	2.0	0.8	4.2	2.5	0.7	3.9	40.0	32.0	IB	IB	0.0	0.0	1.2	1.8	0.0	0.0	1.1	1.1	2.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0
39	1224	B	M	7.0	2.8	1.6	0.8	4.6	2.1	0.9	4.0	56.0	50.0	IIB	IB	0.9	1.5	0.0	1.8	0.0	0.0	1.4	1.4	2.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0
40	1227	B	M	6.8	2.9	1.9	0.1	4.8	3.4	0.2	3.2	60.0	40.0	IA	III	1.1	1.2	0.0	2.0	0.0	0.0	1.1	1.0	2.4	0.7	3.0	0.0	0.0	0.7	0.0	0.0

APPENDIX D

DEMOGRAPHIC AND MORPHOMETRIC DETAILS OF RESIN CASTS OF KIDNEYS (CONTINUED)

SERIES NO.	PM. NO.	RACE	SEX	L-LRV	L-RRV	GV-1	D-GV	GV-IVC	SRV-1	D-SRV	SRV-IVC	L-IRA	R-IRA	L-CL	R-CL	D-LRV-GV	D-LRV-SRV	D-LRV-EQ	D-IVC-R-LW	D-IVC-L-LW	D-IVC-L-R	D-LRV	D-RRV	L-IVC-COM.	L-IVC-L=R	L-RRV2	L-RRV3	L-LRV2	D-RRV2	D-RRV3	D-LRV2
41	1263	B	M	2.9	2.9	0.1	0.9	1.9	0.3	0.3	2.4	20.0	43.0	IA	IB	0.9	1.0	0.0	0.0	0.0	2.0	1.3	1.6	1.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0
42	1271	B	M	3.6	1.8	0.1	0.4	3.1	1.4	0.1	2.1	39.0	35.0	IA	IB	0.7	1.1	0.0	0.0	1.9	0.0	1.0	1.0	1.5	-0.5	0.0	0.0	0.0	0.0	0.0	0.0
43	1276	B	M	6.6	2.0	2.5	0.6	3.6	3.1	0.2	3.3	40.0	40.0	IB	IB	1.0	1.2	0.0	2.1	0.0	0.0	1.0	1.3	1.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0
44	1280	W	M	3.8	1.5	0.8	0.1	2.9	0.9	0.5	2.5	36.0	43.0	IA	III	0.8	1.4	0.0	1.9	0.0	0.0	1.3	0.7	4.2	2.9	3.5	0.0	0.0	1.0	0.0	0.0
45	1449	B	M	4.5	1.7	1.1	0.2	3.3	1.9	0.1	2.5	33.0	44.0	IA	IA	0.6	1.2	0.0	0.0	0.0	1.7	1.1	1.1	1.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
46	1461	B	M	4.4	1.2	1.2	0.6	2.6	1.4	0.1	2.8	35.0	42.0	IIB	III	0.9	0.8	0.0	1.5	0.0	0.0	1.1	0.7	1.2	0.1	1.3	2.4	0.0	0.7	0.5	0.0
47	1465	B	M	7.5	2.8	2.7	0.1	4.8	2.9	0.7	4.0	40.0	45.0	IA	IA	1.1	1.0	0.0	2.1	0.0	0.0	1.2	1.1	1.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0
48	1519	I	M	7.9	2.3	2.2	1.0	4.8	3.0	0.9	4.1	63.0	65.0	IIA	IA	1.1	1.4	0.0	2.1	0.0	0.0	1.3	1.5	1.9	0.6	0.0	0.0	0.0	0.0	0.0	0.0
49	1639	B	F	5.9	2.6	2.1	0.2	3.6	3.0	0.3	2.6	49.0	61.0	IA	IB	1.2	1.2	0.0	0.0	0.0	1.9	1.0	1.5	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	2384	B	M	7.9	2.5	3.2	0.2	4.5	3.7	0.4	3.8	86.0	86.0	IB	IA	0.8	1.1	0.0	2.4	0.0	0.0	1.4	1.6	1.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0
51	2516	B	M	5.4	3.5	0.0	0.9	4.5	2.2	0.2	3.0	63.0	64.0	IA	III	1.2	1.4	0.0	2.2	0.0	0.0	1.4	1.0	3.2	1.8	3.1	3.3	0.0	1.0	0.8	0.0
52	2602	B	M	5.6	2.4	2.9	0.1	2.7	2.7	0.3	2.6	56.0	78.0	IA	IB	0.8	1.0	0.0	2.1	0.0	0.0	1.1	1.3	1.7	0.6	0.0	0.0	0.0	0.0	0.0	0.0
53	2662	B	M	9.0	4.1	1.7	1.2	6.2	5.2	0.7	3.2	61.0	65.0	IA	IA	1.1	1.3	0.0	0.0	0.0	2.3	1.3	1.4	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	2806	C	M	5.0	1.8	0.8	0.4	3.9	2.0	0.2	2.9	64.0	63.0	IIB	IA	1.3	1.1	0.0	0.0	1.6	0.0	1.0	0.9	1.3	-0.4	0.0	0.0	0.0	0.0	0.0	0.0
55	2974	B	M	6.7	3.6	1.7	0.2	4.8	1.8	0.2	4.8	36.0	78.0	IB	III	1.2	1.1	0.0	0.0	2.2	0.0	1.3	1.1	5.8	-4.6	2.0	2.0	0.0	1.1	0.9	0.0
56	3181	B	F	7.9	2.0	2.2	0.8	4.9	4.4	0.4	3.1	54.0	71.0	IB	IA	1.2	1.2	0.0	0.0	1.9	0.0	1.4	1.1	1.7	-0.6	0.0	0.0	0.0	0.0	0.0	0.0
57	3188	B	M	7.0	2.2	2.4	0.4	4.2	3.1	0.5	3.4	64.0	81.0	IB	IA	1.0	1.1	0.0	0.0	2.4	0.0	1.1	1.1	1.4	-0.2	0.0	0.0	0.0	0.0	0.0	0.0
58	3464	B	M	7.8	1.8	4.0	0.2	3.7	4.9	0.1	2.9	68.0	53.0	IA	IIB	1.0	1.3	0.0	0.0	2.1	0.0	1.5	1.2	1.6	-0.4	0.0	0.0	0.0	0.0	0.0	0.0
59	3557	B	F	7.0	2.0	2.8	0.1	4.1	3.8	0.1	3.1	47.0	80.0	IB	IA	1.1	1.3	0.0	2.1	0.0	0.0	1.0	1.1	3.1	2.1	0.0	0.0	0.0	0.0	0.0	0.0
60	3660	B	M	6.5	3.1	0.0	1.2	5.3	2.1	0.1	4.3	48.0	10.0	IA	III	0.7	1.4	0.0	2.1	0.0	0.0	1.6	1.5	3.3	1.7	3.1	0.0	0.0	0.9	0.0	0.0

APPENDIX D

DEMOGRAPHIC AND MORPHOMETRIC DETAILS OF RESIN CASTS OF KIDNEYS (CONTINUED)

SERIES NO.	PM. NO.	RACE	SEX	L-LRV	L-RRV	GV-1	D-GV	GV-IVC	SRV-1	D-SRV	SRV-IVC	L-IRA	R-IRA	L-CL	R-CL	D-LRV-GV	D-LRV-SRV	D-LRV-EQ	D-IVC-R-LW	D-IVC-L-LW	D-IVC-L-R	D-LRV	D-RRV	L-IVC-COM	L-IVC-L=R	L-RRV2	L-RRV3	L-LRV2	D-RRV2	D-RRV3	D-LRV2
61	1000	B	F	4.6	4.0	1.0	0.2	3.4	0.6	0.4	3.6	55.0	63.0	IA	IA	1.0	1.1	0.0	2.1	0.0	0.0	1.4	1.2	1.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0
62	1018	C	M	6.6	2.0	1.5	0.4	4.7	2.5	0.3	3.9	49.0	37.0	IB	III	1.0	1.1	0.0	2.0	0.0	0.0	1.1	0.9	2.7	1.6	3.1	0.0	0.0	0.5	0.0	0.0
63	1023	I	M	5.5	0.9	1.5	0.5	3.5	1.9	0.4	3.2	71.0	90.0	IA	IB	1.0	1.0	0.0	1.7	0.0	0.0	0.9	1.1	1.7	0.8	0.0	0.0	0.0	0.0	0.0	0.0
64	1220	B	M	6.6	2.4	0.6	0.6	5.4	1.8	0.1	4.7	70.0	58.0	IIB	III	0.0	0.0	1.1	2.4	0.0	0.0	1.2	1.1	1.7	0.5	2.8	0.0	0.0	0.9	0.0	0.0
65	1224	B	M	6.4	2.3	2.2	0.4	3.8	3.3	0.4	2.7	54.0	46.0	IB	IA	1.0	1.1	0.0	0.0	0.0	2.2	1.1	1.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
66	1404	B	M	3.8	3.5	1.1	0.2	2.5	2.2	0.6	1.0	43.0	60.0	IB	IA	1.2	0.4	0.0	0.0	2.2	0.0	1.2	1.3	6.7	-5.5	0.0	0.0	0.0	0.0	0.0	0.0
67	1425	W	M	6.0	2.4	0.1	0.8	5.1	1.3	0.2	4.5	55.0	50.0	IB	IIB	1.0	1.4	0.0	0.0	2.2	0.0	1.5	1.6	2.6	-1.1	0.0	0.0	0.0	0.0	0.0	0.0
68	1552	W	M	9.8	4.2	3.5	0.8	5.5	5.1	0.3	4.4	32.0	26.0	IIB	IIB	0.0	0.0	1.2	0.0	2.1	0.0	1.3	1.5	2.2	-0.7	0.0	0.0	0.0	0.0	0.0	0.0
69	1619	B	M	5.0	2.1	1.0	0.3	3.7	2.1	0.4	2.5	52.0	72.0	IB	IB	0.8	1.5	0.0	2.5	0.0	0.0	1.6	1.4	3.1	1.4	0.0	0.0	0.0	0.0	0.0	0.0
70	1620	B	M	6.3	3.3	2.3	0.1	3.9	3.0	0.4	2.9	57.0	88.0	IB	IB	0.0	0.0	0.9	0.0	2.7	0.0	1.1	1.4	2.6	-1.2	0.0	0.0	0.0	0.0	0.0	0.0
71	1624	B	M	8.2	2.6	4.4	0.3	3.5	4.1	0.8	3.3	61.0	82.0	IIB	IA	1.1	1.2	0.0	0.0	2.0	0.0	1.1	1.2	2.6	-1.4	0.0	0.0	0.0	0.0	0.0	0.0
72	1626	W	M	5.7	2.2	0.1	0.7	5.0	0.0	0.7	5.0	84.0	28.0	IB	III	0.0	0.0	1.0	0.0	1.9	0.0	1.5	1.1	4.7	-1.9	3.9	3.1	0.0	0.6	0.4	0.0
73	1843	B	M	6.6	3.2	3.8	0.1	2.7	2.1	0.4	4.1	42.0	70.0	IA	IB	1.3	1.2	0.0	0.0	2.3	0.0	1.6	1.2	1.8	-0.5	0.0	0.0	0.0	0.0	0.0	0.0
74	1853	B	M	7.6	2.0	3.6	0.3	3.7	4.2	0.4	3.0	63.0	51.0	IIB	IIB	0.0	0.0	1.0	0.0	0.0	1.8	1.0	1.1	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
75	1856	B	M	6.2	1.9	1.4	0.7	4.1	1.0	0.9	4.3	65.0	65.0	IIB	IA	1.2	1.1	0.0	0.0	0.0	2.0	1.5	1.2	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76	2301	B	M	5.8	0.9	2.4	0.5	2.9	3.1	0.3	2.4	53.0	56.0	IB	IIB	1.4	1.3	0.0	0.0	2.2	0.0	1.4	1.1	3.0	-1.9	0.0	0.0	0.0	0.0	0.0	0.0
77	2304	B	M	8.0	2.1	4.1	0.6	3.3	6.2	0.2	1.6	66.0	78.0	IB	IIB	1.3	1.2	0.0	2.1	0.0	0.0	1.6	1.3	2.5	0.9	0.0	0.0	0.0	0.0	0.0	0.0
78	2367	B	F	7.0	2.7	4.0	0.5	2.5	3.5	0.3	3.2	43.0	93.0	IA	IB	0.0	0.0	1.0	2.2	0.0	0.0	1.1	1.3	1.5	0.4	0.0	0.0	0.0	0.0	0.0	0.0
79	2437	B	M	6.5	3.6	2.1	0.5	3.9	3.4	0.4	2.7	65.0	54.0	IIB	IIB	0.6	0.5	0.0	0.0	1.8	0.0	0.7	1.0	1.3	-0.3	0.0	0.0	0.0	0.0	0.0	0.0
80	2553	B	M	5.8	2.9	0.5	0.5	4.8	2.5	0.3	3.0	32.0	86.0	IB	IB	1.2	1.2	0.0	2.0	0.0	0.0	1.1	1.2	2.3	1.2	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX D

DEMOGRAPHIC AND MORPHOMETRIC DETAILS OF RESIN CASTS OF KIDNEYS (CONTINUED)

SERIES NO.	PM. NO.	RACE	SEX	L-LRV	L-RRV	GV-1	D-GV	GV-IVC	SRV-1	D-SRV	SRV-IVC	L-IRA	R-IRA	L-CL	R-CL	D-LRV-GV	D-LRV-SRV	D-LRV-EQ	D-IVC-R-LW	D-IVC-L-LW	D-IVC-L-R	D-LRV	D-RRV	L-IVC-COM	L-IVC-L=R	L-RRV2	L-RRV3	L-LRV2	D-RRV2	D-RRV3	D-LRV2
81	2560	B	M	5.7	2.9	1.0	0.1	4.7	1.6	0.8	3.3	64.0	33.0	III	III	0.0	0.0	1.1	0.0	2.2	0.0	1.1	1.2	1.9	-0.7	3.3	0.0	5.2	0.4	0.0	0.8
82	2580	B	M	4.8	2.6	3.1	0.5	1.2	2.3	0.5	2.0	49.0	48.0	IB	III	0.0	0.0	0.3	0.0	1.6	0.0	0.9	1.1	1.8	-0.5	3.1	0.0	0.0	0.5	0.0	0.0
83	2637	B	M	4.1	2.1	2.3	0.6	1.3	2.0	0.4	1.7	59.0	54.0	IB	IA	1.1	1.3	0.0	0.0	1.7	0.0	1.0	1.0	1.4	-0.5	0.0	0.0	0.0	0.0	0.0	0.0
84	2638	B	F	6.3	3.0	3.3	0.6	2.4	2.7	0.8	2.8	40.0	39.0	IA	III	0.9	0.4	0.0	0.0	1.9	0.0	1.2	1.0	1.4	-0.4	4.2	0.0	0.0	0.5	0.0	0.0
85	2682	B	M	5.3	2.3	4.9	0.4	0.0	3.4	0.6	1.3	25.0	49.0	IB	III	0.2	0.3	0.0	2.0	0.0	0.0	1.0	1.0	2.9	1.6	2.1	0.0	9.0	0.7	0.0	0.0
86	2702	B	M	3.9	1.8	0.9	0.1	2.9	0.4	0.1	3.4	49.0	62.0	IB	III	0.9	1.1	0.0	0.0	2.2	0.0	1.1	1.1	2.6	-0.8	1.5	0.0	0.0	0.8	0.0	0.0
87	2752	B	F	6.5	2.1	3.0	0.3	3.2	4.3	0.2	2.1	45.0	75.0	IIB	IB	1.2	1.2	0.0	2.3	0.0	0.0	1.4	0.9	2.4	1.1	0.0	0.0	0.0	0.0	0.0	0.0
88	2757	B	M	4.1	1.5	3.1	0.5	0.5	1.9	0.5	1.7	30.0	49.0	IIB	III	0.0	0.0	0.8	1.9	0.0	0.0	1.0	1.1	2.8	1.3	3.0	0.0	0.0	0.3	0.0	0.0
89	2811	B	M	5.5	1.2	3.2	0.6	1.7	3.0	0.3	2.2	60.0	40.0	IB	IIB	0.8	1.1	0.0	2.0	0.0	0.0	1.2	1.2	3.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0
90	2887	B	M	4.0	2.3	3.7	0.3	0.0	2.0	0.5	1.5	30.0	43.0	IB	III	0.8	0.7	0.0	0.0	2.5	0.0	1.0	1.4	2.6	-1.5	0.6	0.0	0.0	0.5	0.0	0.0
91	2897	B	M	5.8	1.9	4.5	0.2	1.1	3.2	0.5	2.1	53.0	20.0	IIB	IIB	0.6	1.4	0.0	1.7	0.0	0.0	1.3	1.1	1.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0
92	2898	B	M	5.8	3.5	3.4	0.5	1.9	3.2	0.3	2.3	22.0	40.0	IA	III	1.2	1.3	0.0	0.0	0.0	1.1	1.2	0.8	1.7	0.0	0.9	0.0	0.0	0.6	0.0	0.0
93	2912	B	M	4.0	2.2	2.5	0.5	1.0	2.2	0.4	1.4	38.0	35.0	IA	IIB	1.2	1.3	0.0	0.0	1.8	0.0	1.4	1.5	2.2	-0.7	0.0	0.0	0.0	0.0	0.0	0.0
94	2974	B	M	4.0	2.5	3.6	0.4	0.0	3.5	0.5	0.0	38.0	50.0	IB	III	0.6	1.1	0.0	2.1	0.0	0.0	1.0	0.9	2.4	0.8	1.1	0.0	0.0	0.8	0.0	0.0
95	2977	B	M	7.2	1.9	2.3	1.0	3.9	3.4	0.7	3.1	49.0	50.0	IB	III	1.0	1.0	0.0	0.0	1.9	0.0	1.2	0.8	2.1	-1.3	1.9	0.0	0.0	1.0	0.0	0.0
96	2983	B	M	6.2	1.2	3.7	0.7	1.8	1.7	0.5	4.0	48.0	41.0	IIB	IA	0.0	0.0	1.1	0.0	1.8	0.0	1.3	1.1	2.3	-1.1	0.0	0.0	0.0	0.0	0.0	0.0
97	2988	B	F	5.6	2.2	1.9	0.4	3.3	2.0	0.4	3.2	40.0	50.0	IB	IA	1.0	1.3	0.0	0.0	0.0	1.9	1.4	1.4	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
98	3170	B	M	7.0	1.9	3.9	0.2	2.9	3.0	0.1	3.9	37.0	79.0	IB	IA	1.1	1.4	0.0	2.3	0.0	0.0	1.2	1.1	1.6	-0.5	0.0	0.0	0.0	0.0	0.0	0.0
99	3188	C	M	4.0	2.7	2.8	0.7	0.5	1.5	0.6	1.9	54.0	60.0	IA	III	0.8	1.3	0.0	1.8	0.0	0.0	1.1	0.7	3.1	1.4	0.6	1.2	0.0	0.7	0.7	0.0
100	2585	B	M	5.7	2.3	2.7	0.2	2.8	1.3	0.2	4.2	55.0	64.0	IA	III	1.1	1.3	0.0	0.0	1.5	0.0	1.4	1.5	2.4	-0.9	2.5	0.0	0.0	0.5	0.0	0.0