VARIATIONS OF THE ARTERIAL SUPPLY OF THE KIDNEY IN MAN: AN ANATOMICAL AND ANGIOGRAPHIC STUDY

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INTRODUCTION

Classically, each kidney is thought to have a single renal artery; however, numerous published studies describe common variations in renal vascular anatomy in which two or more renal arteries supply a kidney **(Williams et al., 1995; Ali-El-Dein et al., 2003; Bude et al., 2003; Bordei et al., 2004; Khamanarong et al., 2004).** Although frequently described, there is still controversy regarding the naming of these arteries. There were named supplementary by **Anderhuber and Weiglein (1992)**, multiple by **Chevrel (1994)** and **Khamanarong et al. (2004)**, accessory by **Williams et al. (1995)** and **Goscicka et al. (1996)**, additional by **Satyapal et al. (2001)** and aberrant by **Vilhova et al (2002)**. **Bordei et al. (2004)** named the supplementary arteries entering the renal hilum as proper supplementary arteries while those entering the kidney at the upper and lower polar levels were named superior and inferior polar arteries, respectively. On the other hand, **Debatin et al. (1993)** named them supernumerary renal arteries and the hilar supernumerary arteries were classified as co-dominant if they were similar in size to the epsilateral main renal artery.

Multiple renal arteries with an aortic origin represent a frequent vascular variation at kidney level, more common than multiple renal veins in a ratio of 1/8 **(Bordei et al., 2004)**. The frequency of multiple renal arteries ranges between 18-36% and the incidence varies according to the sex and the ethnic origin **(Satyapal et al., 2001)**. Variations in renal vascular anatomy have grown in importance with the increased frequency of renal transplantation, renovascular hypertension and vascular reconstruction for congenital and acquired lesions **(Ali-El-Dein et al., 2003; Makiyama et al., 2003; Khamanarong et al., 2004)**. Recent advances and refinements in urologic surgery as well as radiological interventional procedures have revived interest in renal arterial anatomy because a thorough understanding of such anatomy is essential for the safe and efficient performance of these procedures as well as aids in surgical planning to avoid potential complication **(Smith et al., 1998)**. Renal transplantation is the permanent and safe treatment for patients with chronic renal failure **(Lopes et al., 1998)**. However, the presence of multiple renal arteries increases the complexity of the

transplant procedure and can be challenging for the transplant surgeon because each renal artery is a terminal vessel and its injury may produce segmental ischemia with subsequent hypertension **(Benedetti et al., 1995; Troppmann et al., 2001).** An important component of the evaluation of potential living-related kidney donors is the accurate determination of renal arterial anatomy **(Gourlay et al., 1995)**. Traditionally, conventional or digital-subtraction angiography has been used to outline the number, location and length of the renal arteries **(Flechner et al., 1985).** Recent studies have shown that minimally invasive procedures can be used to achieve a degree of accuracy ranging between 90-97%, in case of using three dimensional magnetic resonance angiography (MRA), and up to 100%, in case of using Three-dimensional computed tomographic (CT) angiography, in depiction of accessory renal arteries **(Smith et al., 1998; Volk et al., 2000; Alvarez-Castells et al., 2001; Mittal et al., 2001; Volk et al., 2001).**

The aim of this work is to determine the incidence of multiple renal arteries and to summarize some of their anatomical characteristics as well as to detect other coexisting renal variations, which could be equally important for surgeons and radiologist, using formalin-preserved human cadavers and angiographies of potential living-kidney donors.

MATERIALS AND METHODS

This study was performed on 54 human formalin-preserved cadavers (15 females and 39 males) and angiographies of 336 potential living-kidney donors (56 females and 280 males) with a total of 780 individual kidneys (142 female and 638 male).

Dissection of human cadavers

A midline abdominal incision was performed, the abdominal viscera was retracted and the peritoneum covering the posterior abdominal wall was dissected to expose the kidneys , renal vessels, ureter, inferior vena cava and abdominal aorta and its branches. The renal artery and any accessory one were dissected and demonstrated with evaluation of the following morphological parameters: the origin of these arteries, their caliber, course, direction, relation to the IVC and renal vein (or veins) as well as the level and the manner of their termination as they approaching the kidney. The origin of the inferior suprarenal artery and the presence of other renal variations coexisting with the double renal arteries on the same or opposite side were also depicted.

Angiographic study

A retrospective study of renal angiographies of 336 potential living-kidney donors attending King Fahd Transplantation Unit- Faculty of Medicine-Cairo University, during the period from August 2000 to April

2004, was done. The subjects were exposed to one or more of the following angiographic techniques:

1. Conventional Digital subtraction angiography (DSA): it was performed via a 5.0-French pigtail catheter placed in the upper abdominal aorta using a standard Seldinger's technique. Digital subtraction filming was used and an oblique and/or selective imaging was performed at the discretion of the angiographer.

2. Three dimensional magnetic resonance angiography (3D MRA): MRA was performed using a three dimensional phase contrast technique with flow encoding in all three directions, 20˚ flip angle, velocity encoding 40 cm/sec, matrix size 192x256, 80% rectangular field of view, partition thickness 1.5 mm, flow compensation, and one sequence average. Images were reconstructed using the maximum intensity pixel.

3. Three-dimensional multislice computed tomographic angiography (3D CTA): the usual scan length at the arterial phase imaging was approximately 25 cm to detect the main and the potential accessory renal arteries. With the use of four-section multi-detector row scanner and 4x1-mm collimation, rotation time of 0.5 sec., a table increment of 6 mm/ rotation and table speed of 12 mm/ sec, this volume was imaged in approximately 21 seconds.

All images were reviewed for the number of renal arteries on each side with evaluation of the above-mentioned parameters.

The following nomenclature was utilized to categorize the renal arteries: hilar artery (HA), an aortic branch that penetrate the kidney in the hilar region; upper polar (UPA), an aortic branch that penetrated the kidney at its superior pole; and lower polar artery (LPA), an aortic branch that penetrated the kidney at its inferior pole. The variations of the renal artery and their incidence and the morphological parameters of the multiple renal arteries were presented in Tables I and II, respectively.

RESULTS

I- Single renal artery (Table I)

A single renal artery was detected in 568/780 cases (72.8%). According to the manner of its termination on approaching the kidney, this artery was categorized into:

*An artery giving terminal branches close to or after penetrating the hilum of the kidney (Type I): it was demonstrated in 465/ 780 cases (60 cadaver specimens and 405 kidneys of living renal donors). This type of

renal artery was associated with normal anatomy of renal pedicle (Fig.1-a) and gave rise to one or two inferior suprarenal arteries (Fig.1-b). However, an epsilateral coexisting vascular variations could be encountered in cases with contralateral renal arterial variations.

* An artery branched early, 3 cm or more, before reaching the kidney (Type II): it was detected in 103/ 780 cases (16 cadaver specimens and 87 kidneys of living renal donors). The early branches of the main renal artery ended either in the hilum (Fig. 2) or in the upper pole (Figs. 3-a,b). Crossing of these branches to the main artery was demonstrated in 7 cases (Figs.4-a,b) and coexisted other epsilateral uro-vascular variations were encountered.

II- Multiple renal arteries (Tables I & II)

Multiple renal arteries originated from aorta were found in 212/ 780 cases (27.2%), 32 cadaver specimens and 180 kidneys of potential living renal donors, and the incidence was higher in males than in females, 186/638 male specimens (29.2%) and 26/142 female specimens (18.3%). There was a left predominance of the multiple renal arteries, where the left ones were located in 127/212 cases (59.9 %). Bilateral multiple renal arteries were demonstrated in 28/212 cases (13.2%) (Figs.5-a&b). The multiple renal arteries were divided according to their numbers into:

A- Double renal arteries

They were found in 198/780 samples, 32 cadaver specimens and 166 kidneys of living renal donors with a left predominance (117/198 cases). In 52/198 cases, the double arteries had a common aortic origin (Figs.6,7) while in 146/198 cases, they had separate origin from aorta; both originated from lateral side (Figs.8,9) or one from lateral side and the other one arose from anterolateral (Fig. 10-a) or posterolateral (Fig.11) aspect of aorta. The distance between the aortic origins of these double arteries was highly variable ranging between 1-2 mm and 4-6 cm.

The caliber of the double renal arteries was similar in 106 specimens. In 86 cases of them, the two arteries end in the renal hilum (Figs.5-a,b,6,9) while in the other 20 cases, one artery ended in the renal hilum (HA) and the other one ended in the upper pole of the kidney (Figs. 12-a,b,13). The double renal arteries, of the remaining 92 cases, had different calibers where in 61 cases, both arteries ended in the hilum (Fig. 7), and in 31 cases, the artery of the larger caliber terminate in the hilum (main artery) and that of smaller caliber entered the kidney through either the upper, 10 cases, (Fig.14) or the lower pole, 21 cases, (Fig.5-b).

The course of the double renal arteries was variable. In 116/198 specimens, the two arteries was almost parallel to each other from the aorta up to the kidney with possible orientations being oblique or horizontal (Figs. 9, 15-a,b). In 82/198 specimens, the two renal arteries showed different courses; in 40 cases, their courses were convergent (Fig.16), in 30 cases, they were divergent (Fig. 7) and in 12 cases, the two arteries crossed each other (Figs.11,17). The two arteries had either straight or sinuous course (Fig.16) or one was straight and the other one was sinuous (Figs.10-a,b).

As regard their renal approach, in 147/198 cases, the two arteries were HAs. In the other cases (51/198), one artery was a HA and the other one was either an UPA, 30 cases, or a LPA, 21 cases. The polar arteries entered the kidney, as a penetrating branch, most often, on the medial border (Fig. 13) and in 5 cases only, on the anteromedial aspect (Fig.5-b) of the renal pole.

In most cases (116/198), the terminal divisions of the double renal arteries were inside the kidney, while in 53/198 cases, one or the two renal arteries gave branches close to the hilum, when they were hilar (Fig.9), or close to the renal pole, when they were polar (Fig.14). In 29cases of double renal arteries of different caliber, the larger artery (main renal artery) divided early into two branches; either both entered the hilum (21 cases) (Fig.5-b) or one entered the hilum and the other one enter the upper pole of the kidney (8 cases) (Fig. 15-a,b).

B- Triple renal arteries

Triple renal arteries were recorded in 13/780 cases (1.67%), all from potential living renal donor cases, with left predominance (9 cases). They had separate origin from aorta and different calibers; only one case showed similar calibers of the three renal arteries (Fig.18). In all cases, the arteries showed either straight or curved course. In 4 cases, the arteries passed parallel to each other (Fig.18), in 2 cases, they crossed one another (Fig. 19) and in 7 cases, they were convergent (Figs. 20-a,b,c). On approaching the kidney, the three arteries either ended in the hilum (9 cases) (fig.19) or two ended in the hilum and the third one terminated in the upper pole (4 cases) (Fig.18). In 10 cases, the arteries branched inside the kidney and in 3 cases, one or more of these arteries branched close to the kidney (Fig. 20-c). No early branched arteries were detected.

C-Quadruple renal arteries

Only one case (1/780, 0.13%) was recorded in a subject having four renal arteries of variable calibers on the left side with three renal arteries on the right side (Figs.20-a, b,d). The quadruple arteries had separate aortic origin, different calibers and converge towards the kidney. Two arteries

were hilar while the other two arteries were upper and lower polar arteries (fig. 20-d). No prehilar branches were detected.

III Associate anatomical variations

Other urovascular anatomical abnormalities coexisted with the renal artery variations, either on ipsi- or contralateral side, were recorded, only in the dissected specimens (108 cases) as those of angiographies of potential living kidney donors were not reliable.

A-Variations of the origin of the inferior suprarenal artery

*Epsi - or contralateral aortic origin of the inferior supra renal artery in common stem with the middle suprarenal one was recorded in 3 cases. In one case, this was associated with posterior relation of the renal vein to the renal artery, at the renal pedicle, with anterior crossing of the suprarenal vein to the renal artery (Figs. 21).

*One or two inferior suprarenal branches originated from the upper one of the double renal arteries (Figs.9,10-a,b) was recorded in 30 cases.

B- Anatomical variations of the renal vein

They were recorded in epsi- or contralateral side of some cases of double renal arteries, or with those of type II single renal arteries and showed higher incidence on the left side.

*A left renal vein was demonstrated crossing the aorta either obliquely and anteriorly hooking around the renal artery, in 3 cases (Fig.22), horizontally and anteriorly running below and parallel to the renal artery, in 3 cases (Fig.21), or horizontally and posteriorly, in 4 cases, (Fig.8). In all these venous variations, the renal vein entered the hilum posterior to the renal artery (or arteries) or its branches.

*A right renal vein entered the hilum deep to right double renal artery or the prerenal branched one was recorded in 3 dissected specimens (Figs. 4-a,b,9).

*Double left renal veins, one anterior to the other with the renal artery and the renal pelvis between the two veins, was recorded in 2 cases. The two veins united into one stem before crossing superficial to the aorta (Fig.23) to end in the inferior vena cava.

*A left renal vein, crossed both superficially and deeply by double renal arteries and dividing into two parts surrounding the aorta (renal vein collar) before ending separately into the inferior vena cava, was recorded in 2 cases (Figs.10-a,b).

*A renal vein situated between the anterior and posterior branches of early divided renal artery was demonstrated in 3 cases on the left side and in 2 cases on the right side (Fig.,24).

C- Other coexisted anatomical variations

*An early-branched right renal artery crossing anterior to the inferior vena cava was demonstrated in 3 specimens. (Figs. 4-a,b).

*Branches of early divided renal artery passing anterior as well posterior to the pelvis of the ureter, was recorded in 6 specimens (Figs. 24,25)

*Coexistence of polycystic kidney was seen in 4 cases (fig.4-a,b).

Table I: Renal artery variations and their incidence

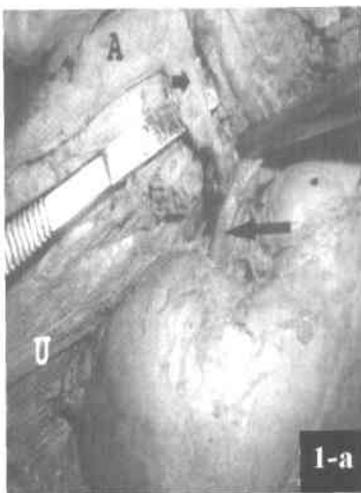| Type	Single renal artery			Multiple renal artery			
	Type I	Type II	total	Double	Triple	Quadruple	Total
No. of cases	465	103	568/780	198	13	1	212/780
Percentage	59.6	13.2	72.8	25.4	1.67	0.13	27.2
Predominant side	Right side (305/568 cases = 53.7%)			Left side (127/212 cases = 59.9%)			

Table II: Morphological parameters of the multiple renal arteries

Type of renal artery	Double No. /198 cases	Triple No./13 cases	Quadruple One case	Total No./212
Aortic origin:				
*Common aortic origin	52	--	--	52
*Separate aortic origin	146	13	1	160
Caliber:				
*Similar calibers	106	--	--	106
*Different calibers	92	13	1	106
Course:				
*Parallel to each other	116	4	--	120
*Convergent towards hilum	40	7	1	48
*Divergent towards hilum	30	--	--	30
*Crossing each other	12	2	--	14
Renal approach:				
* All hilar	147	9	--	156
* Hilar + upper polar	30	4	--	34
*Hilar + lower polar	21	--	--	21
*Hilar + Upper & lower polar	--	--	1	1
Manner of branching:				
* branched inside the kidney	116	10	1	127
*Branched close to kidney	53	3	--	56
*Early branched before kidney	29	--	--	29

Table III: Percentage of multiple renal arteries and geographical zone of the cases studied in the present work and by other workers

Authors	No. of cases	MRA %	Geographical zone
Sampaio and passos (1992)	266	38.2	Brazil
Chugh et al. (1993)	170	21.2	India
Shokeir et al. (1994)	1000	28.1	Egypt
Goscicka et al. (1996)	280	21.3	German
Halpern et al. (1999)	130	25	USA
Satyapal et al. (2001)	472	27.7	South Africa
Makiyama et al. (2003)	393	24.4	Japan
Khamanarong et al. (2004)	534	17.4	Thailand
Bordei et al. (2004)	272	20	Romania
Present work	780	27.2	Egypt

MRA%= the percentage of multiple renal arteries

Figs. (1-a,b): Photographs of dissected abdomens of formalin preserved cadavers showing:
(a): Left kidney with single renal artery (short arrow) and normal renal pedicle. The renal vein (long arrow) is displaced upwards to demonstrate the aortic origin of the renal artery and its course. Note the aorta (A) and the ureter (U).
(b): Two inferior suprarenal branches (*) originate separately from the single renal artery (short arrow) to supply the suprarenal gland (G). Note the renal vein (long arrow) displaced downward.
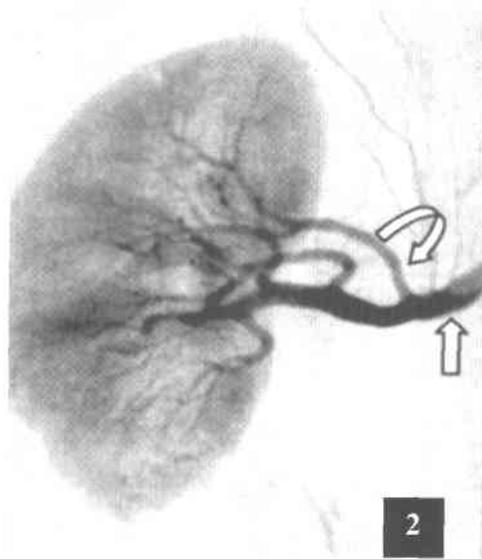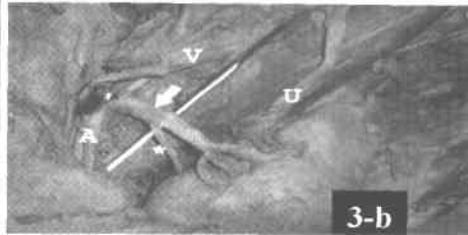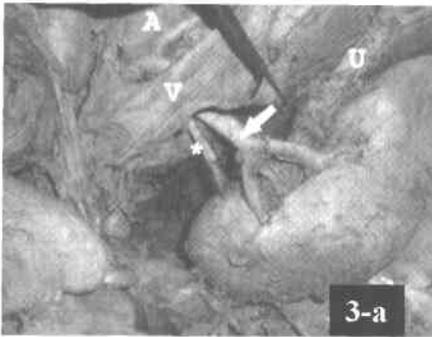
Fig. (2): Conventional DSA of the right kidney showing early division (curved arrow) of the right main renal artery (straight arrow). Note that all branches end in the renal hilum.

Figs. (3-a,b): Photographs of a dissected abdomen of a formalin preserved cadaver showing right renal artery (arrow) giving an early branch (*) that ends in the upper pole of the kidney. Note the ureter (U), the aorta (A), and the left displacement of the inferior vena cava (V) in Fig.(3-b).
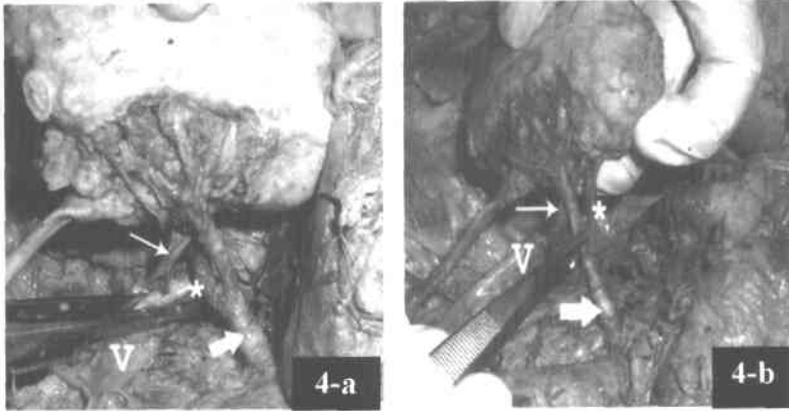
Figs. (4-a, b): Photographs of a dissected abdomen of a formalin pre-
served cadaver showing right polycystic kidney with an early branch arising
(*) from the lower aspect of the main renal artery (thick arrow). Note that
the kidney and the main renal artery are twisted forward (Fig. 4-b), to show
the posterior crossing of the early branch to the main renal artery to reach
the upper pole. Superficial crossing of the renal artery to the inferior vena
cava (V) and the deep position of renal vein (thin arrow) to the main renal
artery at the hilum can be seen.
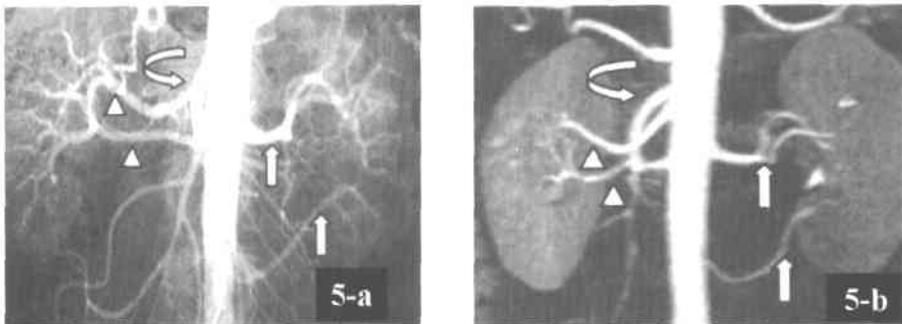
Fig. (5-a,b): Conventional DSA and MRA, respectively, of both kidneys of a
case of bilateral double renal arteries. The right arteries (arrowheads) are
of equal caliber and both are hilar. The left double arteries (arrows) are of
different caliber where the larger one divides early into two branches, both
entering the hilum while the smaller one is seen, in Fig. (5-b), ending in the
anteromedial aspect of lower pole. Note the superior mesenteric artery
(curved arrow).

Fig. (6): A photograph of a dissected abdomen of formalin preserved cadaver showing right double renal arteries (long arrows) of common aortic origin and similar caliber, both ending in the hilum. Note the renal vein (short arrow), the inferior vena cava (V) and the aorta (A).
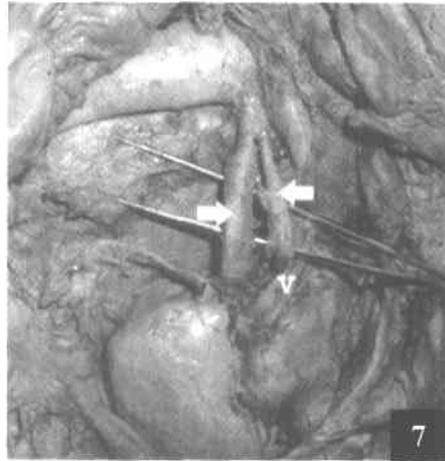
Fig. (7): A photograph of a dissected abdomen of formalin preserved cadaver showing left double renal arteries (arrows) of common aortic origin and different caliber. They have divergent course and both end in the hilum. Note the aorta (A) and the reflected renal vein (v).

Fig. (8): A photograph of a dissected abdomen of a formalin preserved cadaver showing left double renal arteries (short arrows) originated separately from the lateral aspect of the aorta (A) and both ending in the hilum. Note the ureter (U) and the horizontal course of the renal vein (long arrow) crossing the aorta posteriorly to reach the renal hilum deep to the arteries.

Fig. (9): A photograph of a dissected abdomen of a formalin preserved cadaver. The IVC (V) is cut and reflected downward to demonstrate right double renal arteries (arrows) of similar caliber and originating separately from lateral aspect of aorta. The arteries run obliquely and parallel to each other and branch on approaching the hilum. An inferior suprarenal artery (S) arising from the upper renal artery can be seen. Note the cut renal vein (*) located posterior to the arteries at the hilum.

Figs. (10-a,b): Photographs of a dissected abdomen of a formalin-preserved cadaver showing left double renal arteries, one is straight (long arrow) and one is sinuous (short arrow). The upper artery gives two inferior suprarenal branches (*). The renal vein is crossed both superficially and deeply by the double renal arteries, then divides into two parts (crossed arrows) surrounding the aorta before ending separately in the inferior vena cava (V). Note the superficial part of the renal vein is displaced downwards, in Fig. (10-a), to demonstrate the anterolateral aortic origin of the lower renal artery.

Fig. (11): A photograph of a dissected abdomen of a formalin preserved cadaver showing right double renal arteries originated from the lateral (thin arrow) and posterolateral (thick arrows) aspects of the aorta (A) and crossing each other. Note the reflected inferior vena cava (V).
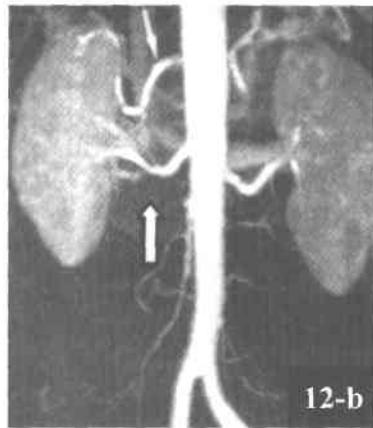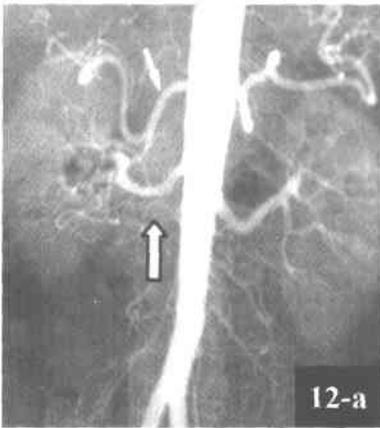

Fig. (12-a,b): Conventional DSA and MRA, respectively, of both kidneys of a case showing right double renal arteries of similar caliber; one is hilar (thick arrow) and one is upper polar (thin arrow).
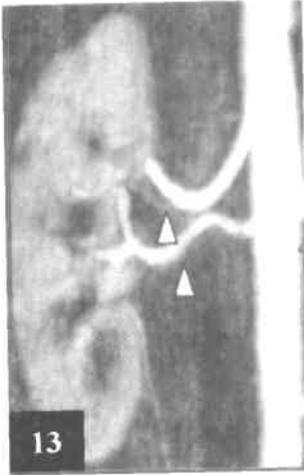
Fig. (13): MRA of the right kidney showing right double renal arteries of similar caliber (arrowheads); one ends in the hilum and one ends in the medial border of the upper pole.

Fig. (14): MRA of the left kidney showing left double renal arteries of different caliber (arrows); the larger is hilar and the smaller is upper polar branching close to the renal pole.
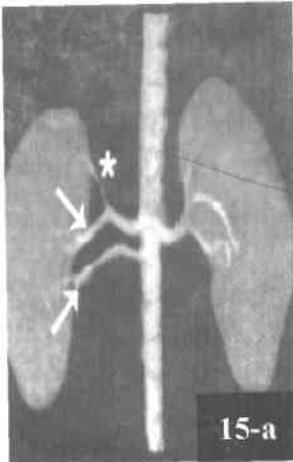

Fig. (15-a,b): 3D CT angiographies of kidneys of two different cases showing:
(a): Right double renal arteries having an oblique parallel course and different caliber (arrows). The two arteries end in the hilum with the larger one giving an early upper polar branch (*).
(b): Left double renal arteries having a horizontal parallel course and different caliber (arrows). Note the larger artery giving an early upper polar branch (*) before entering the renal hilum.
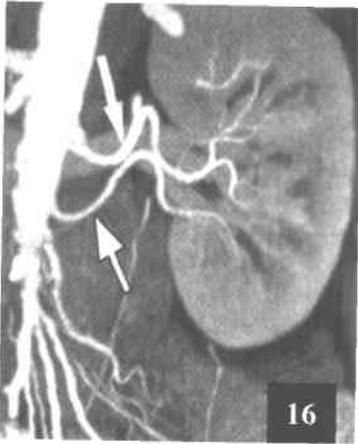
Fig. (16): MRA of the left kidney showing left double renal arteries (arrows) having a sinuous course and converging towards the hilum of the kidney.

Fig. (17): Conventional DSA of the aorta showing right double renal arteries (arrows) crossing each other.
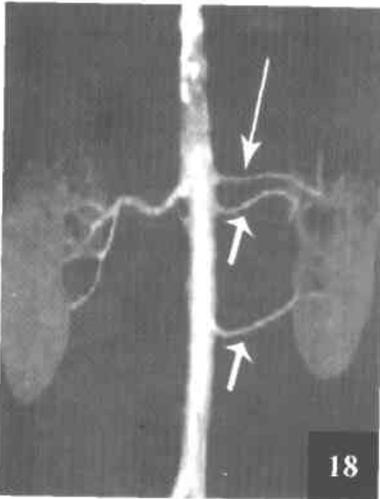

Fig. (18): 3D CT angiography of both kidneys showing left triple renal arteries of similar calibers and parallel course. Two of them end in the hilum (short arrows) and the third one ends in the upper pole (long arrow).

Fig. (19): 3D CT angiography of both kidneys showing left triple renal arteries (arrows) crossing each other and all ending in the hilum.
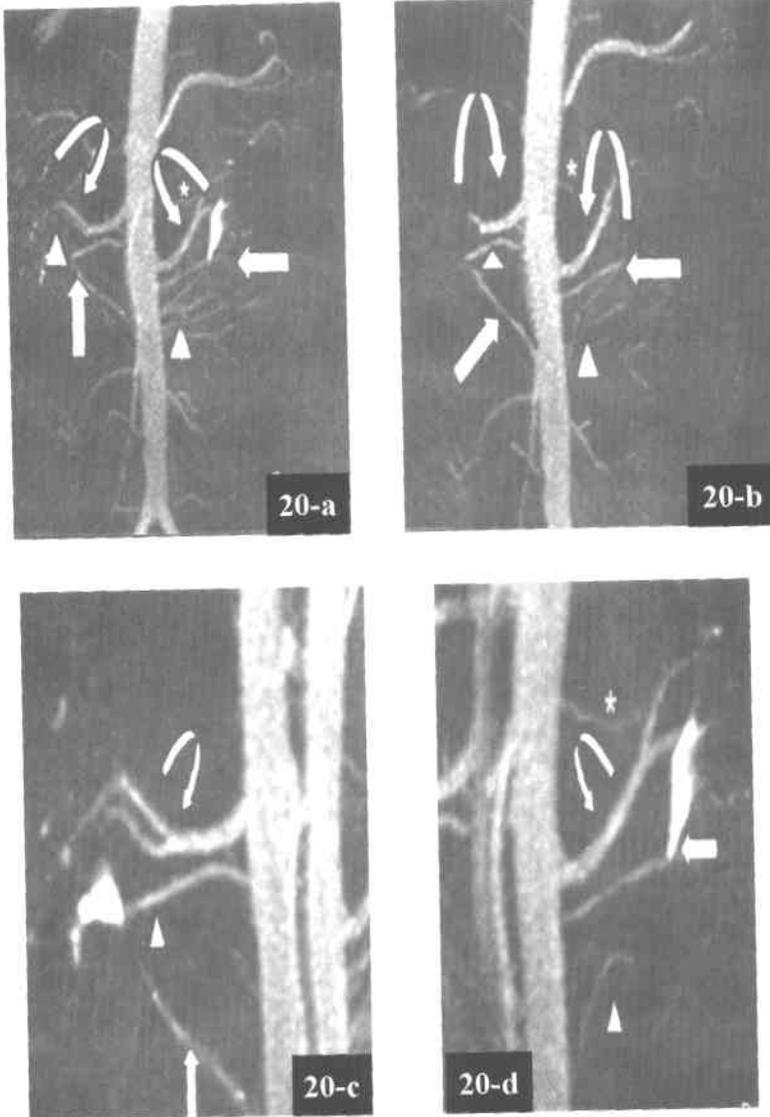
Fig. (20-a,b,c,d): MRA images of the aorta of a case of bilateral multiple renal arteries showing:

(20-a,b,c): Right triple renal arteries (curved arrow, arrowhead and straight arrow) converge towards the kidney. Note the upper larger one (Fig. 20-c) branches close to the kidney.

(20-a,b,d): Left quadruple renal arteries of different caliber and separate aortic origin. They converge towards the kidney. Note that two arteries are hilar (curved and straight arrows) while the other two arteries are upper (*) and lower (arrowhead) polar.
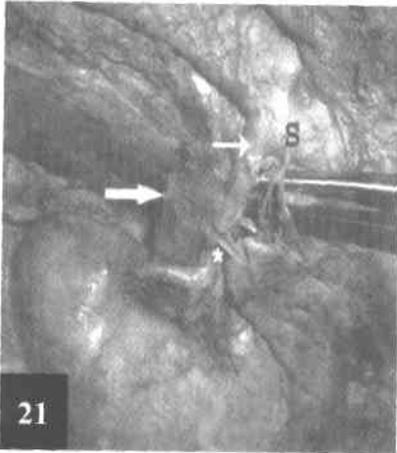
Fig. (21): Photographs of a dissected abdomen of a formalin preserved cadaver showing aortic origin of the left inferior supra renal artery in common stem with the middle suprarenal (S). The left renal vein (thick arrow) passes below and parallel to the renal artery (thin arrow) to enter the renal pedicle deep to the artery. Note the anterior crossing of the suprarenal vein (*) to the renal artery.
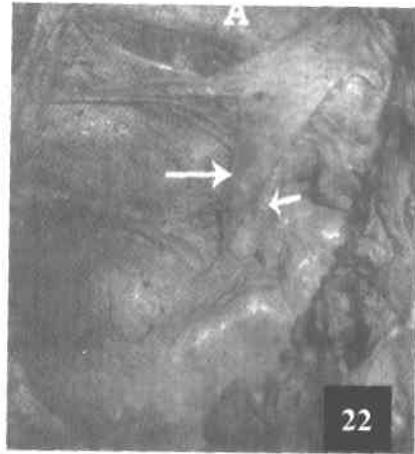

Fig. (22): A photograph of a dissected abdomen of a formalin preserved cadaver showing the left renal vein crossing (long arrow) the aorta (A) obliquely and anteriorly hooking around the renal artery (short arrow) to enter the renal hilum deep to the artery.
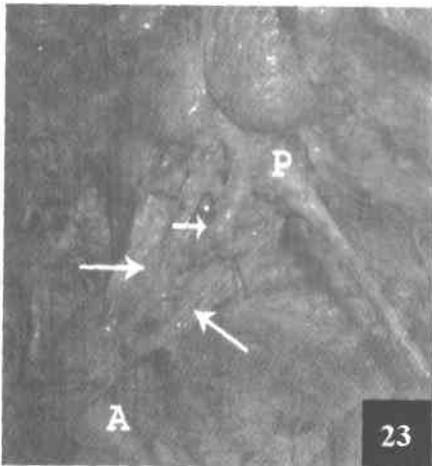

Fig. (23): A photograph of a dissected abdomen of a formalin preserved cadaver showing left double renal vein, one anterior to the other (long arrows) with the renal artery (short arrow) and the renal pelvis (P) between the two veins. Note the union of the two veins into one stem before crossing superficial to the aorta (A).
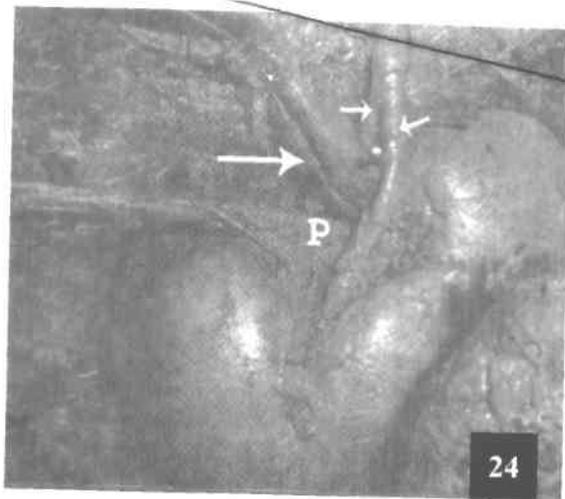
Fig. (24): A photograph of a dissected abdomen of formalin preserved cadaver showing early division of the left renal artery into two branches (short arrows), one anterior to the other, enclosing the renal vein (long arrow) and the pelvis of the ureter (P) between them.
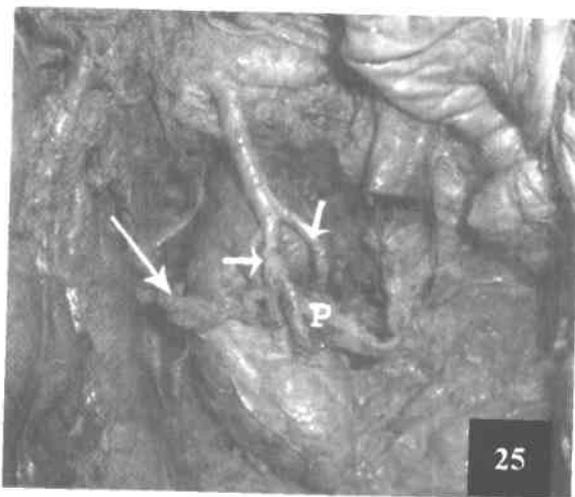

Fig. (25): A photograph of a dissected abdomen of formalin preserved cadaver showing branches (short arrows) of early divided right renal artery passing anterior as well as posterior to the pelvis of the ureter (P). Note the cut renal vein (long arrow).

DISCUSSION

Accessory renal arteries with an aortic origin are a frequent vascular variation and represent the persistence of the embryonic vessels, the fetal branches of the mesonephros, during the renal ascent **(Williams et al., 1995; Langman and Sadler, 1996).** The present work showed that the incidence of multiple renal arteries was 27.2% (212/780 cases). This finding is in perfect correspondence with that of **Shokeir et al. (1994)** and **Satyapal et al. (2001)** who worked on Egyptian and South African cases and reported an incidence of 28.1% and 27.7%, respectively, for the multiple renal arteries. However, the value in the literature varies from 17% to 38% (Table III). The variation in the incidence of multiple renal arteries among those authors who worked on cases of different geographical zones (table III) may be explained by particularities that are racial characters **(Bordei et al., 2004).** Such explanation is strongly supported by the study of **Satyapal et al. (2001)** which demonstrated the incidence of multiple renal arteries, according to the ethnic origin, to be 36.5% in Africans, 35.3% in Caucasians, 19% in Indians, and 18.5% in half-caste population with an average incidence of 27.7%. Furthermore, **Bordei and Antohe (2002)** suggested that in the same geographical area, different environmental factors could be involved, mostly during organogenesis, offering a possible explanation for the differences over time in a population of the same geographical zone. **Satyapal et al. (2001)** also identified significant difference between sexes where the incidence was higher in males (28%) than in females (16.44) and this finding is in full similarity to that deduced from the present work. Likewise, **Makiyama et al. (2003)** stated that their findings implied that men tend to have multiple renal arteries more than women (more prevalent in men than in women). However, **Chugh et al. (1993)** found higher incidence in female than in males. On the other hand, **Pollak and Mozes (1986)** reported that gender did not significantly influence the number of renal arteries. The difference in literature regarding the frequency of double renal arteries may be also attributed to the different techniques used to reveal them **(Halpern et al., 1999; Satyapal et al., 2001; Bordei et al., 2004). Halpern et al. (1999)** compared conventional angiography (CA), computed tomographic (CT) angiography, and magnetic resonance (MR) angiography for the evaluation of accessory renal arteries in the same subjects. They found that CA revealed incidence of 24% of accessory renal arteries and CT angiography revealed incidence of 32% while MRA showed incidence of 20%. Moreover, **Benedetti et al. (1995)** attributed the lower incidence of multiple renal arteries recorded in their series (20%) than most of those reported in the literature to the large number of living related and living unrelated donors used in their program.

The present results are quite similar to those of **Satyapal et al. (2001)** and **Bordei et al. (2004)** who described the existence of double renal arteries mostly on the left side, but in contradiction with the data of

Goscicka et al. (1996), who worked on human fetuses of different ages and suggested a higher frequency on the right. As regard the appearance of bilateral multiple renal arteries, the present result demonstrated bilateral accessory renal arteries in 28/212 cases (13.2%). This finding is compatible with that reported by **Chugh et al. (1993), Satyapal et al. (2001)** and **Bordei et al. (2004)** who demonstrated it in nearly 11% of cases of multiple renal arteries. Lower incidence was reported by **Shokeir et al. (1994)** who found that 26/281 cases (9.25%) of the multiple renal arteries were presented bilaterally. On the other hand, higher incidence was demonstrated by **Pollak and Mozes (1986)** who reported bilateral multiple renal arteries in 15 % of all cases.

In the current morphological study, the multiple renal arteries that terminate all in the renal hilum (hilar arteries) were reported in 156/212 cases and these hilar arteries were of equal caliber in 86/156 cases (55%). This value was higher than that reported by **Bordei et al. (2004)** who demonstrated hilar arteries of identical caliber in 35% of their cases. They found that these arteries supplied equal-sized renal territories so that they classified both of them as being main renal arteries. The present work showed that the incidence of multiple renal arteries of hilar and upper polar category, 34/212 cases (16%), was higher than those of hilar and lower polar one, 21/212 cases (9.9%). A similar finding was revealed by **Sampaio and Passos (1992), Vilhova et al. (2001 and 2002), Makiyama et al. (2003)** and **Khamanarong et al. (2004).** Although the number of multiple renal arteries reported by the above mentioned authors are nearly similar (93 - 102 cases), the incidences of the upper and lower polar arteries reported by them are quite variable ranging between 7.32% for the upper polar versus 3.56% for the lower polar arteries in the study of **Khamanarong et al. (2004)** and 30.7% for the upper polar versus 14.6% for the lower polar arteries in the study of **Makiyama et al. (2003).** On the contrary, **Bordei et al. (2004)** who worked on adult and fetal specimens demonstrated higher incidence of multiple renal arteries of hilar with lower polar (30%) than those of hilar with upper polar arteries (9%). In addition, **Bordei et al. (2004)** found that in 5 cases out of 19 double hilar arteries of equal caliber, one of the two arteries divided in a prehilar location into two branches one hilar and the other polar. However, the present work demonstrated such early branching by the larger artery (main renal artery) in cases of double arteries of different caliber.

The current work recorded triple renal arteries in 13/780 cases (1.6%) where in 9 cases, the three arteries were hilar and in 4 cases, two arteries were hilar and the third one was upper polar. These findings partially matches those represented by **Khamanarong et al. (2004)** who found triple renal arteries in 1% of their cases (5/534 cases) but they were either 2 hilar and one upper polar (2 cases) or 2 hilar and one lower polar (3 cases) . On the other hand, higher incidence of triple renal arteries of 4.5%,

3% and 4%, was recorded by **Satyapal et al. (2001), Vilhova et al. (2001) and Makiyama et al. (2003)** respectively.

Cases of quadruple renal arteries are very seldom and were demonstrated in 1/780 cases (0.13%) of the present study. Apart from the study of **Pollak and Mozes (1986)**, which revealed quadruple renal arteries in 1% of their cases and up to our knowledge, no further studies in the literature recorded such renal arterial variation.

Bordei et al. (2004) demonstrated multiple variations in the course of double renal arteries such as retroureteral passage, right supplementary passing anterior to the inferior vena cava (IVC) and crossed course of double renal arteries. Similar observation was demonstrated in the present study, in case of double renal arteries or the early-branched ones, with different incidence of occurrence than that reported by previous authors. Associated arterial variations such as genital artery originating from the supplementary renal artery, ipsilateral double testicular arteries and unilateral origin of the inferior phrenic from the accessory renal artery with aberrant suprarenal arteries arising from the upper polar artery were also revealed in the previous works **(Bakheit and Motabagani, 2004; Bordei et al., 2004)**. Coexisting renal vein anomalies or variations, such as posterior relation of the renal vein to the double renal arteries at the renal pedicle, double renal veins, left renal vein collar (around aorta) and retro-aortic left renal vein, were reported in the current as well as in the previous studies **(Satyapal et al., 2001; Bordei et al., 2004; Khamanarong et al. 2004)**. The present work demonstrated the left predominance of the coexisting venous variations. This is confirmed by the findings of **Bordei et al. (2004)**. However, **Satyapal et al. (2001**) recorded these variations on the left side only. In addition, **Bordei et al. (2004)** reported cases of double renal arteries with persistent fetal renal lobulation of the adult kidney; an observation similar to that revealed in the present work. Furthermore, bilateral or unilateral ureter duplication with unilateral multiple renal arteries was reported by **Turgut et al., (2001)** and **Bordei et al. (2004),** respectively.

Khamanarong et al. (2004) attributed the incidence of anomalous renal pedicles to embryological development of the kidneys where they failed to rotate medially when they ascent from the pelvis to the abdomen. The authors added that the awareness of such anomaly is crucial for surgeons performing pyelolithotomy.

The medical and surgical importance of the existence of multiple renal arteries is demonstrated in almost all the scientific papers. The presence of multiple donor renal arteries could be challenging for the transplant surgeon because each renal artery is a terminal vessel and its injury may produce segmental ischemia with subsequent hypertension **(Evan et al., 1996)**. Consequently, **Lechevallier et al. (1995)** concluded that renal arterial anatomy is a selection criterion for the donor and recipient, which must

be taken into account in renal transplantation. **Sampaio and passos (1992)** and **Satyapal et al. (2001)** added that the presence of double renal arteries increases the complexity of the process of renal transplantation itself as these arteries need reconstructive surgery. Other urovascular complications of multiple renal arteries include constriction of the upper portion of the ureter by the lower polar artery leading to hydronephrosis **(Bush et al., 1989)**, injury of the lower polar artery (main nutrition of the ureter) during surgery leading to ureter necrosis **(Desgrandchamps et al., 1998)** and complications developed in suprarenal gland as a result of injury of the upper polar artery that may provide the inferior suprarenal branches **(Sampaio and Passos, 1992)**. Moreover, renovascular hypertension resulted from an isolated accessory renal artery stenosis with patent main renal artery is one of serious sequences of multiplicity of this artery **(Berland et al., 1990)**. **Bude et al. (2003)** emphasized that it is necessary to study accessory arteries when screening the renal arteries for renovascular hypertension, as the prevalence of hemodynamically significant stenosis, isolated to an accessory renal artery, was 1.5% in their study. In addition, **Glodny et al. (2001)** reported that 80% of patients suffering from essential hypertension were proved to have an aberrant renovascular anatomy. They explained that the longer and narrower accessory arteries, than the segmental arteries normally arising from the main renal artery, result in lower levels of blood pressure in the renal segments, thereby increasing rennin secretion.

On conclusion, multiplicity of renal artery is a common variant with expectation of coexistence of other urovascular anomalies. An awareness of the incidence of these variants is equally important for surgeons and radiologists and should be considered in preparation for urosurgical interventions. This necessitates preoperative renal angiography for the appropriate consideration of operative techniques.

SUMMARY

The aim of this work was to determine the incidence of multiple renal arteries and to summarize some of their anatomical characteristics, which could be equally important for surgeons and radiologists. The study was performed on 54 human formalin-preserved cadavers and renal angiographies of 336 potential living-kidney donors with 780 individual kidneys (142 female and 638 male). The formalin-preserved cadavers were dissected to expose the renal artery and any accessory one with evaluation of the following: the origin of these arteries, their caliber, the course and the manner of their termination as well as other coexisting urovascular variations on the same or opposite side. A retrospective study of renal angiographies of 336 potential living-kidney donors was done. The subjects were exposed to one or more of the following angiographic techniques: conventional digital subtraction, three-dimensional multislice computed tomography and three-dimensional magnetic resonance. The renal arteries in all images were evaluated in the same way as mentioned above.

The study revealed that the renal artery of 568/780 cases (72.8%) was a single artery and in 103/568 cases, this artery showed early branches. On the other hand, the renal arteries of 212/780 cases (27.2) were multiple with left predominance. Bilateral multiple renal arteries were located in 28/212 cases (13.2%). They were double in 198 cases (25.4%), triple in 13 cases (1.67%) and quadruple in one case (0.13%). The multiple renal arteries of common aortic origin were seen in 52 cases and those of similar caliber were recorded in 106 cases. The courses of the multiple arteries were either parallel to each other (120 cases), convergent (48 cases) or divergent (30 cases) towards the kidney or crossing each other (14 cases). As regard the mode of their termination, they were all hilar arteries in 156 cases, hilar and upper polar in 34 cases, hilar and lower polar in 21 cases and hilar with upper and lower polar in one case. In 29cases of double renal arteries of different caliber, the main renal artery divided early into two branches; either both entered the hilum (21 cases) or one entered the hilum and the other one enter the upper pole of the kidney (8 cases). A co-existence of other urovascular variations on the same or opposite side, such as right renal artery passing anterior to the inferior vena cava, double renal vein, renal vein collar around aorta, polycystic kidney and aberrant inferior suprarenal artery, were also encountered.

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الملخص العربى

تنوّعات الإمداد الشرياتي للكلية في الإنسان:
دراسة تشريحية و أشعيّة للشرايين

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الهدف من هذا العمل هو تحديد مدى حدوث الشرايين الكلوية المتعددة وكذلك تلخيص بعض خواصهم التشريحية التي قد تكون ذو أهمية متساوية للجراحيين والراديولوجيين.

وقد أجريت هذه الدراسة على ٥٤ جثة أدمية محفوظة بالفرمالين وروسومات أشعة للشرايين الكلوية لـ ٣٣٦ من الأحياء الممكن تبرعهم بالكلية، باجمالي ٧٨٠ كلية فردية (١٤٢ انثى و ٦٣٨ ذكر) . وقد تم تشريح الجثث المحفوظة بالفرمالين لكشف الشريان الكلوي و أي شريان اضافي مع تقييم الأتي: منبت هذه الشرايين وقطرها ومسارها وأسلوب نهايتها وكذلك أي اختلافات وعائية كلوية أخرى مصاحبة على نفس الجانب أو الجانب الأخر. وكذلك تمت دراسة استرجاعية لرسومات أشعة الشرايين الكلوية للأحياء الممكن تبرعهم بالكلية. وقد تعرض هؤلاء الأشخاص لواحدة أو أكثر من الطرق الأتية للرسم الأشعي للشرايين: الطرح الرقمي التقليدي والأشعة المقطعية متعددة المقاطع ثلاثية الأبعاد والرنين المغناطيسي ثلاثي الأبعاد. وقد تم تقييم الشرايين الكلوية في كل صور الأشعة بالطريقة السابق ذكرها.

وقد كشفت الدراسة أن الشريان الكلوي كان شريانا فرديا في ٧٨٠/٥٦٨ حالة (٧٢,٨%) وأظهر ١٠٣ شريان منهم تفروعات مبكرة. وعلى الجانب الاخر، كانت الشرايين الكلوية متعددة في ٧٨٠/٢١٢ حالة (٢٧,٢%) مع غلبة الجانب الأيسر. وكانت هذه الشريين ثنائية في ١٩٨ حالة (٢٥,٤%) وُثلاثية في ١٣ حالة (١,٦٧%) ورباعية في حالة واحدة (٠,١٣%). وقد شوهدت شرايين كلوية متعددة ذات منبت أورطي مشترك في ٥٢ حالة وشرايين متعددة ذات أقطار متماثلة في ١٠٦ حالة. وكانت مسارات الشرايين المتعدّدة إما موازية لبعضها البعض (١٢٠ حالة) أو متقاربة

(٤٨ حالة) أومتباعدة (٣٠ حالة) عن بعضها في اتجاه الكلية أومتقاطعة مـــع بعـــضها البعض (١٤ حالة). وبالنسبة لأسلوب انتهائها، كانت الشرايين كلها سُرَية (تنتهي بـــسُرة الكلى) في ١٥٦ حالة وسرَية وقطبية علوية في ٣٤ حالة وسُرَية وقطبية سفلية في ٢١ حالة وسُرَية وقطبية علوية وسفلية في حالة واحدة. وكذلك تصادف وجـــود اختلافـــات وعائية كلوية أخرى مصاحبة على نفس الجانب أوالجانب الآخر مثل مسـار الـشريان الكلوي الأيمن أمام الوريد الأجوف السفلي ووريد كلوي ثناني وطوق من الوريد الكلوي حول الأورطى وكلى متعددة الكيسات وشريان فوق كلوي سفلي شاذ.