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Study of Anatomical Variations in Renal Arteries and its Branching Pattern Using Computed Tomography Angiography

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Abstract:
Background*: Variations of Renal Artery are common and very important as knowledge of these variations has grown in importance with the increasing numbers of renal transplants, vascular reconstructions, various radiologic and surgical and techniques to avoid vascular injuries.*
Aim of Study*: The present study aimed to describe the frequency of the anatomical variations in renal arteries and their branching pattern among the patients in Aswan University hospitals, using Computed Tomography Angiography.*
Patients and Methods*: In this retrospective cross sectional study 106 patients were included (53 male and 53 female) (212 kidneys) who were referred to the radiology department-Aswan university hospital and underwent abdominal MDCT angiography. The images were analyzed and evaluated for the presence of multiple renal arteries and pre-hilar branching.*
Results*: The incidence of multiple renal arteries was 18.9% of the study participants and 10.8% of the studies kidneys, They arose directly from the abdominal aorta and entered the kidney through the hilum (47.8%), followed by the lower pole (43.5%) then the upper pole (8.7%) in both kidneys). the hilum of the kidney was the most frequent point of entry of the multiple renal arteries. double renal artery pattern occurred in 11.3% in the right kidneys and 8.5% in the left kidneys, the triple renal artery pattern was found only in one left kidney (0.9%). The incidence of multiple renal arteries in females (24.5%) was higher than males (13.2%) and it was statistically significant (P= 0.041). The incidence of pre-hilar branching of the renal arteries (< 2cm) among the study participants was 21.7% and was 11.3% among the studied kidneys. No significant differences were detected between males and females incidence of pre-hilar branching (p= 0.814) but a significant difference between unilateral (91.7%) and bilateral presentation (8.3%) was detected (P= 0.001).*
Conclusion: *Variations in renal arteries are variably prevalent among several populations and this issue seems to have surgical importance. MDCT angiographic imaging assessment of renal vasculature in patients who are candidates of kidney surgeries is very important to reduce the complications, as well as promoting the success, of therapeutic interventions.*
Key Word*: Renal artery – Variations – MDCT – pre-hilar branching- multiple renal arteries.*

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I. INTRODUCTION

Different studies reported great variability in the pattern of renal irrigation **[1].** The detailed knowledge of the anatomical variability of the renal arteries is very important in the new era of renal transplant surgery, uroradiological procedures, renovascular hypertension ,and renal trauma **[2].**The renal artery variations are very common regarding their origin, number ,and branching, There are different renal artery variations reported as early branching into segmental arteries before reaching hilum that occurs within 1cm or 2 cm of the origin of the renal artery from the aorta, Such subjects with those renal artery variations are not ideal candidates for kidney transplantation **[3].** Accessory renal arteries that pass along with normal renal arteries through the hilum and or those aberrant renal arteries, which enter the substance of the kidney through its upper or lower pole **[4]**, these subjects are not suitable to guarantee satisfactory control and anastomosis in renal surgeries **[5].** Imaging of renal arteries and their branching patterns is important before any renal operation. Pre- operative imaging of the

vascular variants facilitates the dissection of these vessels and helps to avoid vascular injuries [6]. The sensitivity and specificity of MDCT angiography for the detection of accessory renal arteries and prehilar renal artery branching were 88% and 98% and 100% or 97%, respectively, MDCTA is considered a promising technique and a road map for vascular anatomy because it enables the radiologist to provide the transplant surgeon with accurate preoperative data about the anatomy of the renal vasculature, to increase the successful outcome [7, 8]. To confirm the effect of social, ethnic, and racial differences on the frequencies of renal artery variations, this study aims to describe the frequency of the anatomical variations in renal arteries and its branching pattern among the patients in Aswan University hospitals, using Computed Tomography Angiography, the knowledge of these variants represents a guide in the treatment of various kidney pathological conditions and allows the anatomist and radiologist to help in providing safety of the surgical procedure and avoid significant complications, thus improve renal surgical outcome results.

II. PATIENTS AND METHODS

1. ***Patients:***

A retrospective cross-sectional study was conducted on 106 patients (53 male and 53 female), who were referred to the radiology department-Aswan university hospital and underwent abdominal MDCT angiography for imaging of the abdominal aorta and its branches for various reasons, from 2018 till 2019. Their ages ranged from (21- 60y) with a mean value was (39.51 ± 10.24). All the cases having normal kidney function with no previous history of allergic reaction to contrast material or history of massive renal trauma, uncontrolled diabetic mellitus, renal tumors, or great renal surgery and pregnant women were not chosen. The study protocol was approved by the local ethics committee of the faculty of medicine at Aswan University. All steps of the test, including the benefits and the risks, were explained to the patients before doing it. No written informed consent was required for retrospective review of imaging examinations.

2. Methods:

2.1. MDCT protocol

MDCT angiography was performed on 212 kidneys, with a 160- slice MDCT scanner (AQUILION PRIME; Toshiba Medical Systems, Tokyo, Japan) by using the same protocol in all patients. Region of interest was placed over the suprarenal abdominal aorta obtained from the single-slice reference image. The patients were injected with 100 mL of nonionic iodinated contrast material (Iopromid; Ultravist 300 mg I/mL, Schering AG, Germany) through an 18 gauge intravenous cannula at a rate of 3–4 mL per second using bolus tracking technique and followed by the delivery of 40 mL saline with an automatic injector.

2.2. Image analysis

The data acquired from the MDCT angiography study were transferred to a separate workstation for processing and analysis. A computer program (Radiant Dicom viewer) was used to evaluate and interpret images taken by MDCT, using axial, coronal sections in maximum intensity projections (MIP) and various thicknesses (5-15 mm) 3D images. Decisions were made by the radiologists and anatomists in consensus as:

- The images that measured and evaluated as a single renal artery on each side were considered normal. If more than one renal artery on each side were observed, they were referred to as ‘‘accessory renal artery’’ or ‘‘multiple renal arteries (MRAs)".
- When the kidney had two or more arteries with a separate aortic ostium, the vessel that had the greatest diameter was considered as the main renal artery and the others as accessory renal arteries. The following values were also assessed:

1. The site, level of origin, and frequency of multiple renal arteries.
2. Classification of multiple renal arteries according to the site of entry on the kidney (hilar, superior polar, and inferior polar).
3. Distance of origin between the main renal artery and the multiple renal arteries.
4. pre-hilar branching of the main renal artery (if they arise at a distance less than 2 cm from the aortic origin)
5. Gender variations for all parameters of the study.

Statistical analysis:

Statistical analysis was performed by the Statistical Package for the Social Sciences (SPSS) program (version 23). Frequency tables were done for analysis of the results for categorical variables. The results were presented as mean ± standard deviation for continuous variables. Comparison between the arterial pattern of the right and left kidney will be analyzed using an independent sample t-test and chi-square test. The results were considered significant when the p-value was < 0.05.

III. RESULTS

1.1. Multiple renal arteries:

The incidence of multiple renal arteries in studied individuals was 18.9% (20 individuals out of 106 cases).Out of 212 kidneys, 23 (10.8%) multiple renal arteries were detected (table 1& fig.1), They arose directly from the abdominal aorta and entered the kidney through the hilum (47.8%), followed by the lower pole (43.5%) then the upper pole (8.7%) in both kidneys (Table 2). the hilum of the kidney was the most frequent point of entry of the multiple renal arteries.

1.2. Single and multiple patterns of renal arterial supply:

The single pattern was occurred in 190 kidneys out of 212; 94 on right kidneys (88.4%) and 96 on left kidneys (90.6%) (fig.2), but the double renal artery pattern (one main hilar artery and one accessory artery (fig.3, 4, 5& 6)) occurred in 21/212 kidneys (12 in right kidneys (11.3%) and 9 in left kidneys (8.5%). The triple renal artery pattern (one main hilar and two accessory renal arteries (fig. 7)) was found only in one left kidney (0.9%) and no triple artery pattern was detected on the right side (fig. 8).

1.3. *Distribution of the multiple renal arteries according to gender and laterality:*

This study revealed that 19 multiple variants/212 studied kidneys (83%) were presented unilaterally and 4 variants/212 studied kidneys (17%) were presented bilaterally, with a highly significant difference in between ($p<0.000$). There was no significant difference ($p= 0.09$) between the right side incidence of multiple renal arteries variant (12/23 variants (52.2%) and the left side incidence (11/23 variants (47.8%). A significant difference ($P= 0.041$) in the number and ratio of multiple renal arteries variants in females (13/ 53 individuals (24.5%) in comparison to males (7/ 53 individuals (13.2%) (Table 3).

1.4. The mean diameter of the multiple renal arteries and their level of origin from the abdominal aorta:

The minimum and the maximum diameters of the multiple renal arteries, on the right side were (1.50 mm& 2.00 mm, respectively), whereas, on the left side were (1.30 mm& 2.37 mm, respectively). The mean diameters of the right multiple renal arteries were (1.80± 0.15) and the left were (1.77±.33). The level of origin of these multiple arteries on the right side were extended from the middle third of L1 till the L4 vertebra and that on the left side were extended from the lower third of T12 till L4. The most frequent level of origin on the right and left side was the upper third of L2 (Fig.9).

1.5. *Association between multiple renal arteries and congenital anomalies of the kidney:*

In the present study, two cases were presented with congenital anomalies out of 106 cases; the first case was left ectopic pelvic kidney with multiple renal arteries supplying the upper pole of the kidney and divides into two branches before entering the upper pole (fig.10). The left renal artery of the left pelvic kidney originates at the level of disc between L3-L4.The second case was horseshoe kidney, the fused lower poles are supplied by an accessory renal artery which originated from the bifurcation of the abdominal aorta and bifurcated to enter the lower poles of both fused kidneys (fig.11).

1.6. Frequency of the pre-hilar branching patterns of the main renal artery:

The incidence of pre-hilar branching among the study participants was 21.7% (23 out of 106 individuals) (table 1&fig.1). Out of 212 studied kidneys 24 variants (11.3%) of pre-hilar branching of the renal artery (< 2cm) were detected (fig. 12&13); 17 variants /212 (70.8%), on the left side and 7 variants /212 (29.2%), on the right side, with a high significant difference. A highly significant difference ($P= 0.001$) between the unilateral presentation (22/212 Kidneys & 91.7%) and the bilateral presentation (2/212 kidneys& 8.3%) of the prehilar branching. The pre-hilar branching was found to be present in 12/53 of females, with an incident of (22.6%) and in 11/53 of the males with an incident of (20.8%) with no significant differences in between ($p= 0.814$) (table 3).

1.7. *Both multiple renal arteries and pre-hilar branching among study participants:*

it was found that the number of participants showing variations was 43/106 ; 20 represented with multiple renal arteries and 23 represented with pre-hilar branching, but there were 5 cases that had both multiple renal arteries and pre-hilar branching in the same case so, the real total number of participants having kidney variations was 38/106 cases (35.8%) (fig.14).

Table no 1: Shows incidence of renal artery variations.

	Incidence/ individual	Incidence/ kidney
Multiple renal arteries	20 individual/ 106 (18.9%)	23 / 212 kidney (10.8%)
Pre-hilar branching	23 individual/ 106 (21.7%)	24 /212 kidney (11.3%)

Table no 2: shows point of entry of multiple renal arteries in both kidneys.

Point of entry	No. (%)
Hilum	11 (47.8%)
Lower pole	10 (43.5%)
Upper pole	2 (8.7%)

Table no 3: Distribution of the multiple renal arteries and Pre-hilar branching variants according to gender.

Renal Variations	Multiple renal arteries	Pre-hilar branching
Female (n=53)	13 (24.5%)	12(22.6%)
Male (n=53)	7 (13.2%)	11(20.8)
p-value	0.041	0.814
All (n=106)	20/106 (18.9%)	23/106 (21.7%)

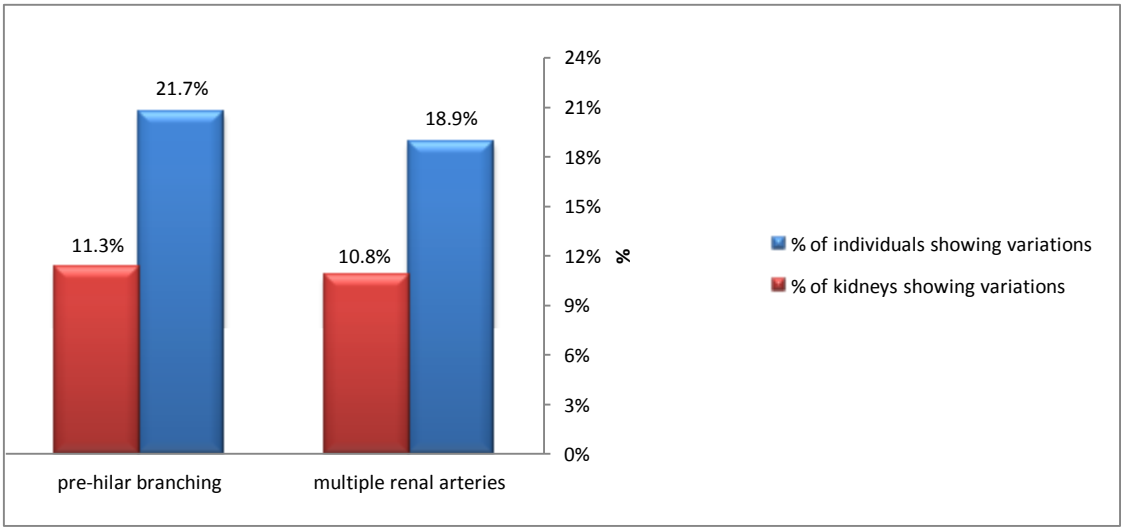

Figure no 1: shows incidence of multiple renal arteries and pre-hilar branching.

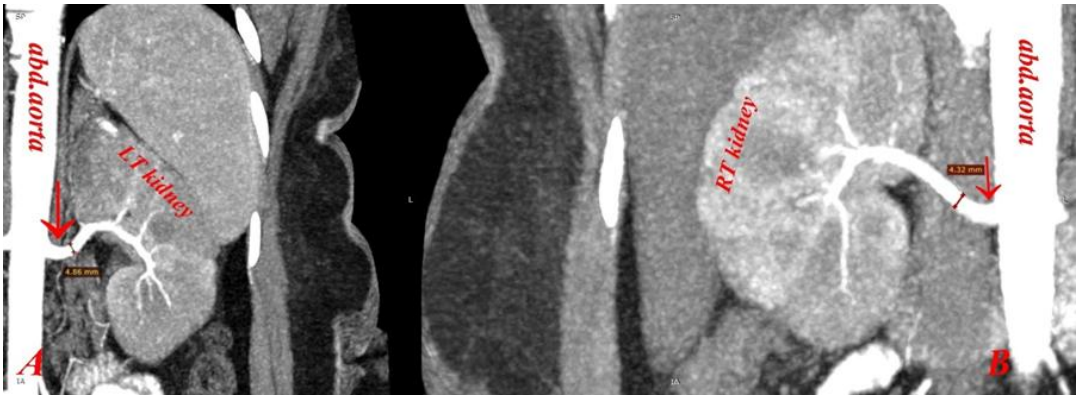

Figure no 2(A& B): Shows 3D MIP images showed the normal pattern of renal arterial supply. Each kidney (RT Kidney, LT kidney) is supplied by a single renal artery (↓), originated from the abdominal aorta, entering the hilum of the corresponding kidney and divided into branches inside the kidney.

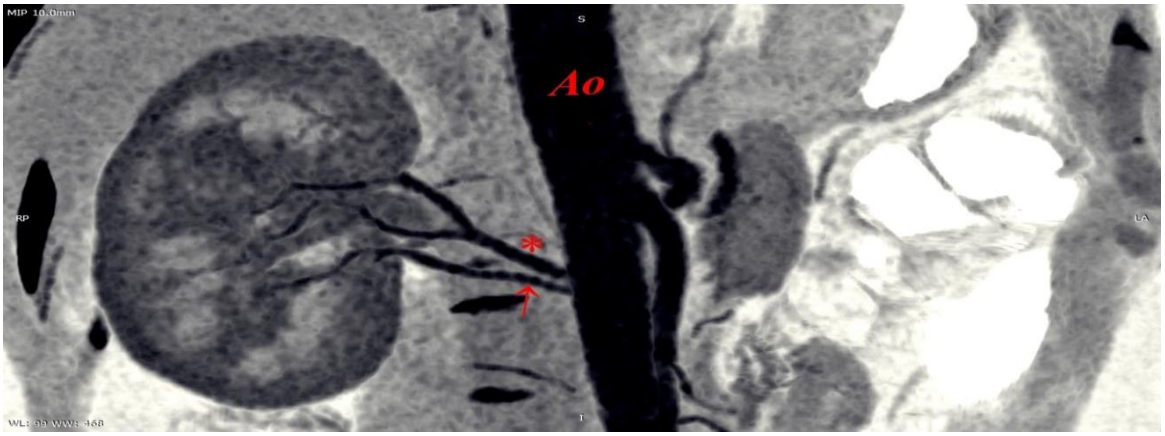

Figure no 3: Shows 3DMIP image of MDCT angiography showed a case of multiple renal vasculature patterns, with double renal arteries (one main (*) and one accessory renal artery (↑)) originating from abdominal aorta (Ao) entering the hilum of the right kidney.

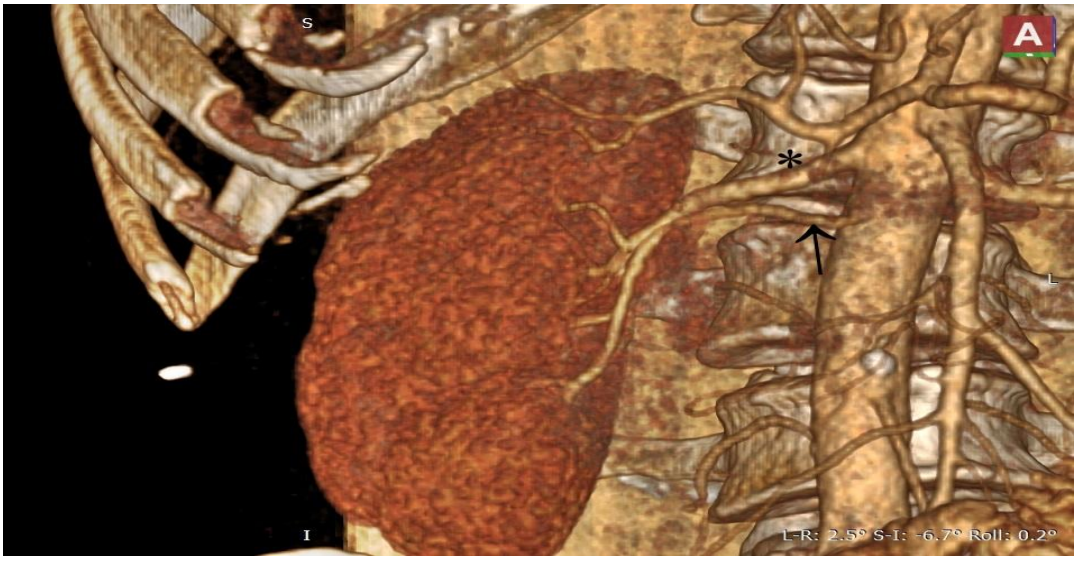

Figure no 4: Shows 3D volume-rendered image showing double renal arteries (one main (*) and one accessory renal artery (↑)) entering the hilum of the right kidney.

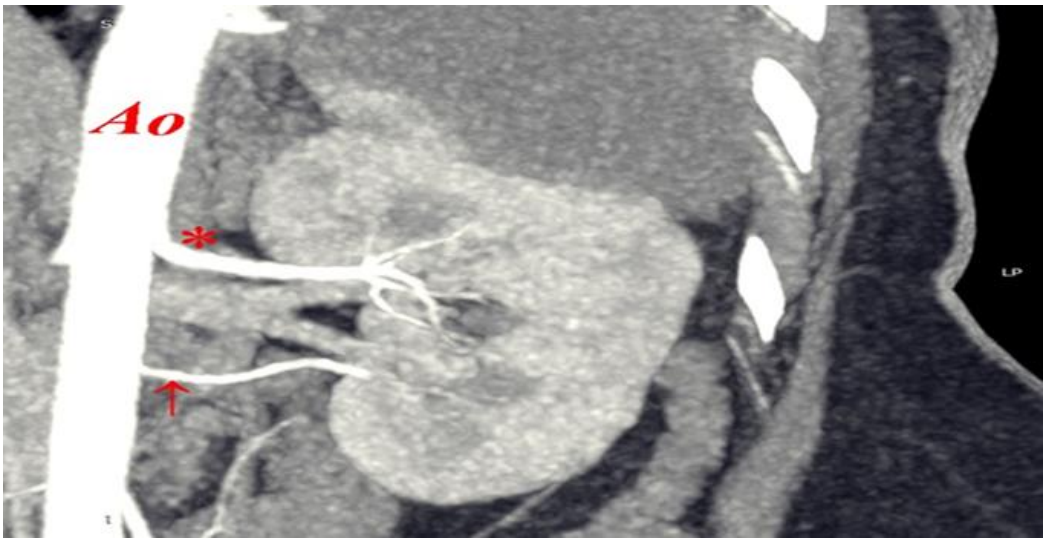

Figure no 5: Shows 3D MIP images of MDCT angiography showed double renal arterial supply, as an additional polar artery (↑), originated from the abdominal aorta (Ao) and entering the lower pole of the left kidney in addition to the main renal hilar artery (*).

Figure no 6: Shows 3D MIP images of MDCT angiography showed double renal arterial supply, as an additional polar artery (↑), originated from the abdominal aorta (Ao) and entering the upper pole of the left kidney in addition to the main renal hilar artery (*).

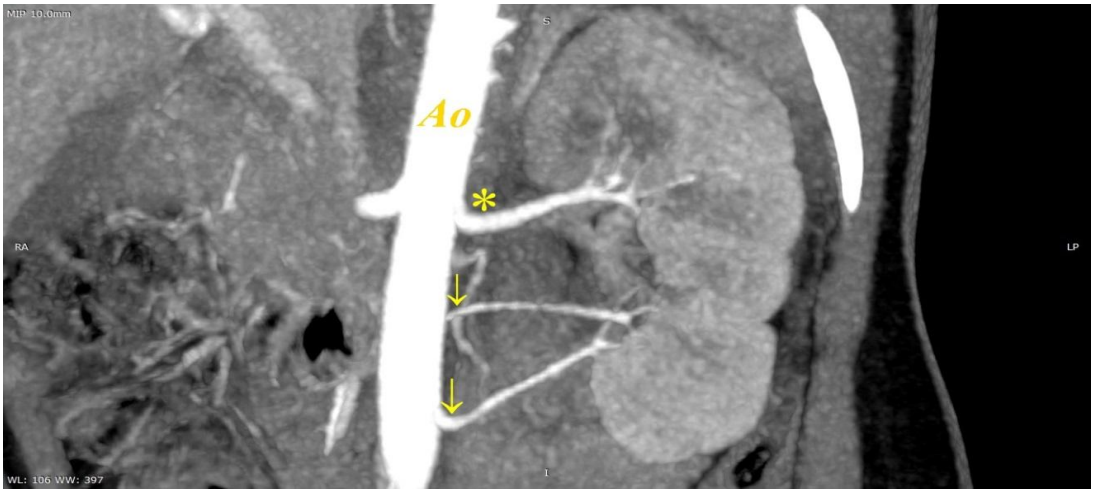

Figure no 7: Shows 3D MIP images of MDCT angiography showed a case of triple renal arterial supply of the left kidney, in which two additional renal arteries (↓), originated from the abdominal aorta (Ao) lower down from the main artery and supplying the kidney with the main renal artery (*).

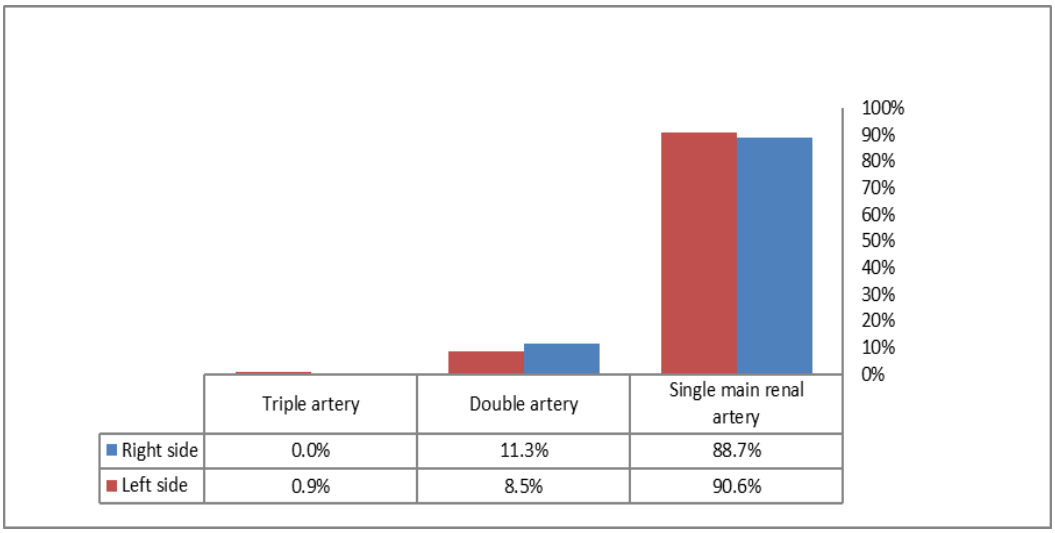

Figure no 8: Shows categories of multiple renal arteries in the right and left kidney.

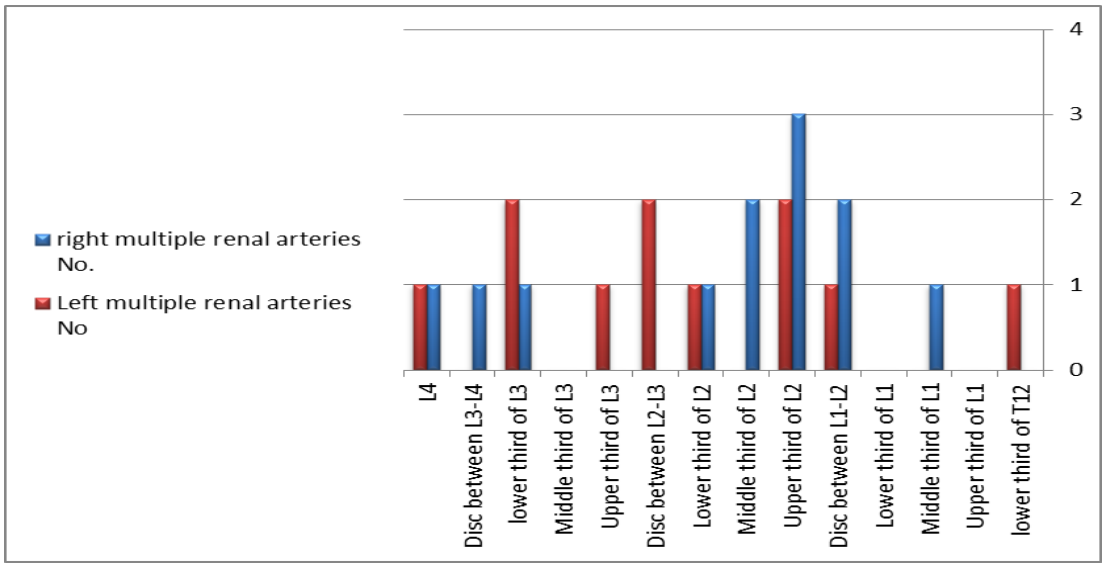

Figure no 9: Shows the distribution of the number (No) of right & left multiple renal arteries according to the level of origin.

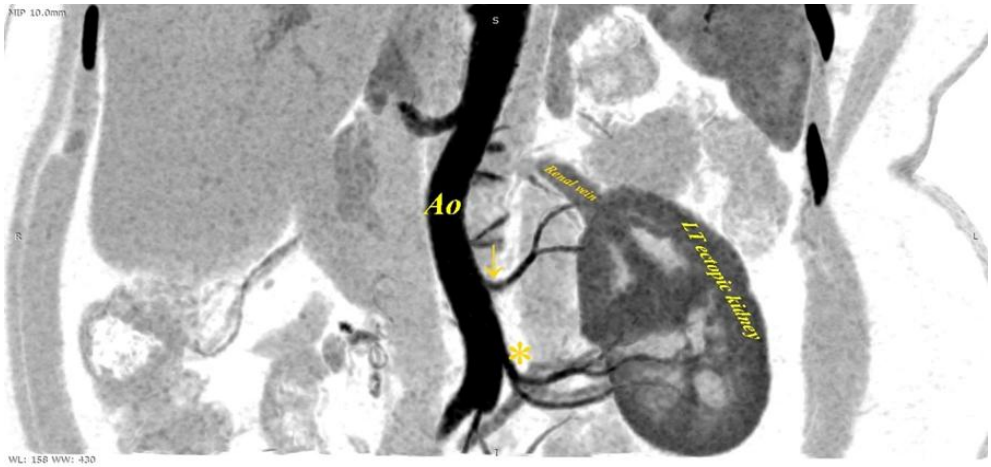

Figure no 10: Shows 3D MIP image of MDCT angiography showed a case of left ectopic pelvic kidney, associated with an additional branched upper polar artery (↓) and early branching of the main renal artery (*), which had a lower origin from the abdominal aorta (Ao) and entered the hilum of the left kidney.

Figure no 11: Shows 3D volume- rendered image of MDCT showed a case of fused kidneys at the lower poles (horseshoe kidney) with an accessory renal artery (↑) originated from the bifurcation of the abdominal aorta (Ao) and bifurcated (↔) to enter the lower poles of both fused kidneys which supplied by right and left renal artery (*).

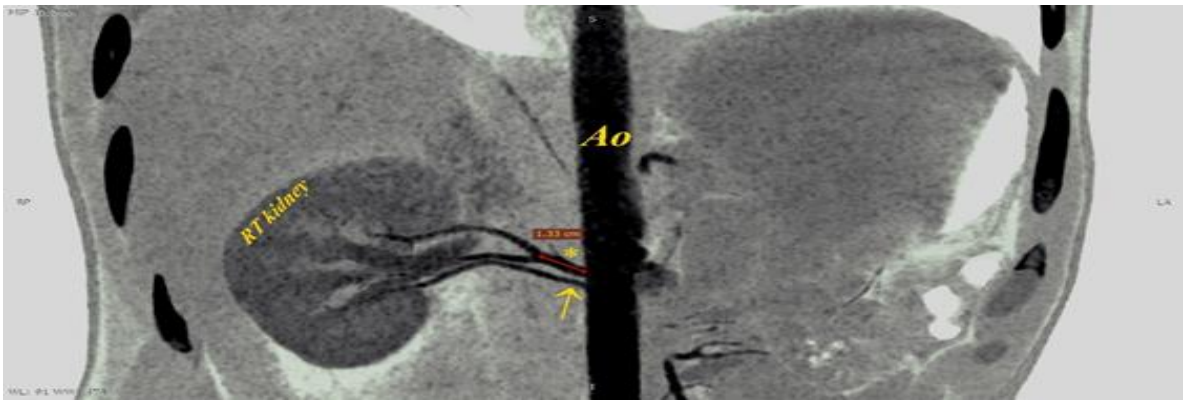

Figure no 12: Shows 3D MIP images of MDCT angiography showed a case of pre-hilar branching of the main right renal artery (*) at the distance less than 1.5 cm from the aortic (Ao) origin. Note the accessory hilar artery (↑) to the right kidney.

Figure no 13: Shows 3D MIP images of MDCT angiography showed a case of a pre-hilar branching of the main left renal artery (*) at the distance less than 1 cm from the aortic (Ao) origin, entering the hilum of the left kidney.

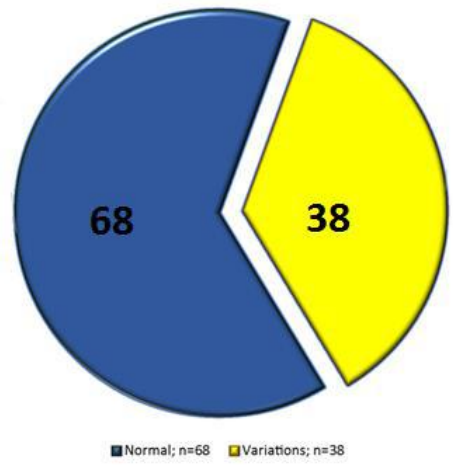

Figure no 14: Shows the percentage of normal (68) and variant patterns (38) of renal arterial supply.

IV. DISCUSSION

The renal vasculature is thought for having a broad spectrum of variants that are reported by anatomists [5]. But after the outburst of imaging techniques, the radiologists started recognizing and describing unconventional renal vascular patterns, which led to a systematic clinical approach to this topic [9]. The low risk and excellent accuracy of MDCT in the detailed evaluation of the normal arterial anatomy and variants of the kidney, make it a practicable alternative to digital angiography in many situations [10], considering the importance

of this anatomy in the treatment planning for various clinical and surgical urological conditions and in the era of transplantation, as well as in minimizing the significant complications [11].

The vast majority of the population has one single renal artery for each kidney arising from the abdominal aorta at the level of the L1 to L2 vertebral bodies [12, 13]. In the present study, this normal (single) pattern of renal arterial supply was detected in 68/ 106 (64.2%) of studied participants, This is in line with Cınar &Türkvatan [14]who detected one renal artery on each side in (68.7%) of the patients and Koplay et al., [15] who reported that (70– 75%) of the people may be expected to have one renal artery on each side.

Multiple renal arteries and early branching of the main renal artery were the common renal arterial variants observed in the present study in Aswan university hospital, Egypt, considered the term multiple is appropriate for any extra arteries supplying the kidney in addition to the main renal artery irrespectively of their origin and the site of penetration. These arteries are end arteries supplying an integral segment of the renal circulation [16]. The present study in Aswan university hospital, Egypt, showed that the incidence of multiple renal arteries was 18.9% (20 out of 106) of studied participants and 10.8% (23 variant out of 212) of total examined kidneys. In line with the present work, Tantawy and Ahmed [17], who detected multiple renal arteries in four (18%) cases of the 22 renal Egyptian donors, also Singh et al. [18] in Singapore, Kok et al. [19] in Dutch, Costa et al. [20] in Brazilian, Chabchoub et al. [21] in Tunisian and Hung et al. [22] in Taiwanese recorded incidence of (18%, 21%, 18.5%, 21.2%, and 17%, respectively).

In this work, this multiplicity was more frequently unilateral than bilateral and showed a statistically significant difference between unilateral distribution and bilateral distribution of multiple renal arteries in the studied patients. About 17% were bilaterally presented while 83% were unilaterally presented. This study also revealed the right-side incidence of multiple renal arteries was higher than the left-sided as multiple renal arteries represented 52.2% on the right, while the left multiple renal arteries represented 47.8 %, with no significant difference. In this field, Natsis et al. [11] emphasized that the multiple renal arteries were found bilaterally in 13% and unilaterally in 87%. In 52.2%, multiple renal arteries were found on the right and in 47.8% on the left side. Prevljak el. [23]observed unilateral accessory renal arteries in 80.7% of patients, while 19.3% of patients registered a bilateral distribution and 52.7% of patients had an accessory renal artery on the right and 47.3% on the left side. Some studies reported left-side predominates of multiple renal arteries[14, 24, 25, 26], while, similar to our result, others indicated the right side predominates [11, 18,27,28,29].

In the present work, the presence of multiple renal arteries on females (13/ 53 females& 24.5%) was higher in comparison to males (7/ 53 males& 13.2%) and the difference was statistically significant. Although, Natsis et al. [11] detected multiple renal arteries presence on females was in preponderance compared to that of males, yet the difference was not statistically significant. Goscicka et al. [30], Vilhova et al. [31] & Aragão et al. [32], observed a higher incidence of multiple renal arteries in females than males. Contradict to our result, Satyapal et al. [33], Singh et al. [18], & Saldarriaga et al. [1] & Prevljak et al. [23] concluded opposite results and observed a higher incidence in males than females. No associations were found between gender and the presence of renal artery variations [14], and no significant difference between frequencies of multiple renal arteries between male and female patients, in both right and left kidneys [26].

In this study, there is one single main renal artery in 94 right kidneys (88.4%) and 96 left kidneys (90.6%). There is double renal artery in 21/212 kidneys (12 right kidneys (11.3%) and 9 left kidneys (8.5%)). There are triple renal arteries only in one left kidney (0.9%). Likely, Natsis et al. [11] reported that the number of multiple renal arteries usually varies from 1–3 however, four, five and seven multiple renal arteries have been documented and they recorded two multiple renal arteries in 13% and three multiple renal arteries in 4.3% in a Greek population. More than one renal artery was observed in (15.5%) patients on the right side and 16.5% of patients on the left side and 4.6% patients, on both sides [29]. Çınar &Türkvatan [14], who found two renal arteries in 22.2%, 7.5% for three renal arteries, 1.4% for four renal arteries, 0.2% for five renal arteries. Ogeng'o et al. [34], found 305 (85.7%) were single; 42 (11.8%) double; 08 (2.2%) triple and 1 (0.3%) quadruple renal arteries.

In the present study 47.8% of multiple renal arteries were hilar 43.5% were lower polar and 8.7% were upper polar. On the right side, 50% of multiple renal arteries enter the hilum and 50% enter the lower pole. On the left side, 45.4 % of multiple renal arteries enter the hilum, 36.4% enter the lower pole and 18.2% enter the upper pole of the kidney. The hilum was the most frequent point of termination of the multiple renal arteries. It is very important to make a good evaluation of the inferior polar artery as Lipshutz and Hoffmanin [35], reported that accessory inferior polar renal artery originating from the aorta may compress the renal pelvis and may produce attacks of high obstruction of the urinary tract and lead to hydronephrosis. In this line, Cınar& Türkvatan [14] detected higher hilar arteries than polar arteries in their studies. Swarna, et al. [25] reported 58.5% hilar arteries, and 41.5% polar arteries out of the right accessory renal arteries and 61.8% hilar arteries and

38.2% polar arteries on the left side. Contradict to this study; Pérez et al. [5] stated that the most frequent accessory artery was a polar supplying the inferior renal pole, while the second most frequent supplementary artery irrigated the small segmented upper pole. Animaw et al. [36] reported that out of 10 accessory renal arteries, 8 (80%) of them enter the inferior pole of the kidney while 2 (20%) of them enter through the hilum of the kidney. Mohiuddin et al. [37] found that superior polar arteries were present in 14.9% of kidneys and inferior polar arteries in 1.3 % kidneys. Lama and Pradhan et al. [38] found all additional arteries enter the upper pole, hilum, and the lower pole with the same percentage of incidence 33.33%. The surgical importance of upper polar arteries was presented by Harraz et al, [39] who found that transplantation of a kidney with an upper polar artery must be done very carefully and with great attention as it may lead to delayed graft function.

In the present work, all multiple renal arteries were shown to be originated from different levels along the abdominal aorta. The level of origin on the right side extended from the middle third of L1 till the L4 vertebra and that on the left side extended from the lower third of T12 till L4. Inconsistent with our result, the accessory renal arteries were found to be originated from the abdominal aorta [9, 11, 23, 25, 40, 41] and rarely they may arise from the lower thoracic aorta, as well as from the common iliac arteries, lumbar and mesenteric arteries, middle sacral artery or main hilar renal artery [11, 15, 23, 42, 43]. Gümüş et al. [29] found that the external renal arteries commonly originated between the upper margin of L1 and the lower margin of L2 vertebrae; also their level of origin can extend between T12 till L3-L4.

In this work; the minimum diameter of the right multiple renal arteries was 1.5mm and the maximum was 2.00mm.The minimum diameter of the left multiple renal arteries was 1.30mm and the maximum was 2.37mm. There is a statistically significant difference between the mean diameter of the right multiple renal arteries (1.80±0.15mm) and the mean diameter of the left multiple renal arteries (1.77±0.33mm) p-value (< 0.000). with these results; Harraz et al. [39] in Egypt described that the mean diameter of hilar multiple renal arteries was 2 ± 0.6mm, lower polar arteries was 2 ± 0.8mm and the mean value of upper polar arteries was 1.4 ± 0.9 mm. Swarna et al. [25] in a CT study found that the minimum right accessory renal artery diameter was 1.9 mm, the maximum diameter was 3.4 mm and the average diameter was 2.4 mm. The minimum left accessory renal artery diameter was 1.8 mm, the maximum diameter was 4 mm and the average diameter was 2.6 mm. small multiple renal arteries with a diameter of 2 mm or less may be cut or thrombosed, producing a graft infarction. In some cases, the surgeon may clamp a polar artery to see the amount of parenchyma it provides before deciding to chop the artery [33].

In the present study; there were two cases of congenital anomalies of the kidney one was a horseshoe and the other was pelvic kidney and both are associated with multiple renal arteries in CT angiography, which was in the line with Sasikala & Singh [44] who found Three cases in CT angiograms showed accessory renal artery with horseshoe kidney with three accessory renal arteries, pelvic kidney with an accessory renal artery on the right side, and the third case had hypoplastic kidney with an accessory renal artery on the right side.

In the present work; the pre-hilar branching of the main renal artery was observed in 21.7% of individuals and 11.3% of examined kidneys; 29.2% on the right and 70.8% on the left. Our result emphasized that incidence of the prehilar branching variant was higher (21.7%), versus (18.9%) of multiple renal arteries in studied participants and more presented unilaterally (91.7 %) than bilaterally (8.3%) and more in females (22.6%) than males (20.8%) but there were no significant differences between females and males p-value (0.814). Close similar to those results; In Korea Chai et al. [45] found early branching of a renal artery was (12%) kidneys. Ardalan et al. [46] found the early division of the main renal artery was 9.4% kidneys in Iran. Higher incidence values were observed by Lama and Pradhan et al. [38] in Nepal found the early division of main renal arteries was16.66 % on both sides. In India, Bhandari et al. [47] found that pre-hilar branching was 19.38% kidneys. In Austria Schönherr et al. [48] observed that the main artery was shorter than 2 cm; in 43 cases (34.1%).

V.CONCLUSION

- Variations of the renal arteries are common in the Egyptian population. The most important variations are the presence of multiple renal arteries and early-branching patterns.

-MDCT angiographic imaging is recommended in the assessment of renal vasculature in patients who are candidates for kidney surgeries to reduce the complications, as well as promoting the success, of therapeutic interventions**.**

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