Original Article

Variations of Renal Vascular Anatomy in a Nigerian Population: A Computerized Tomography Study

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Abstract

Background: A broad spectrum of renal vascular variations has been reported by anatomists and radiologists. The prevalence of these variations is extremely divergent in different populations. Therefore, radiologists and surgeons in different climes must be knowledgeable about the type and prevalence of the variants in their area of practice to avoid diagnostic pitfalls and for optimization of surgical techniques. **Objective:** The objective of this study is to describe the types and prevalence of renal vascular variations among patients undergoing contrast-enhanced computerized tomography (CECT) of the abdomen in a Nigerian population, as well as provide a concise review of literature on the embryological basis and clinical significance of the identified variations. **Materials and Methods:** This study was a retrospective review of 200 CECT of the abdomen to identify variations of arterial (accessory, early branching, and precaval) and venous (multiple, retroaortic, and circumaortic) anatomy of the kidneys. **Results:** We studied 200 patients, 102 (51%) females and 98 (49%) males. Age range is 18–90 years (mean = 53.08 ± 17.01). Prevalence of any renal vascular variations was 50%, arterial variations were 37%, and venous variations were 13%. Variations were significantly more common in males, $P = 0.000075$. The most common arterial variant was the accessory renal artery (23%) seen in 10% (right) and 13.0% (left); early branching was seen in 4.0% (right) and 0.5% (left) as well as precaval right renal artery seen in 4.5%. Venous variants were late confluence 3.0% (right) and 2.5% (left); multiple veins was seen in 2.5% (right) and 2.5% (left) as well as retroaortic left renal vein seen in 2.0%. The inferior polar accessory artery was the most prevalent accessory artery. Early arterial bifurcation was significantly more common on the right ($P = 0.016$) while other vascular variants showed no statistically significant association with laterality. **Conclusion:** Variation of renal vascular anatomy is a frequent finding among Nigerians. Radiologists and surgeons must be aware of these variants for optimization of surgical techniques.

Keywords: *Computerized tomography, kidney, Nigeria, variation, vascular anatomy*

Introduction

The typical renal artery is a lateral branch of the aorta, arising at the level of the second lumbar vertebrae, just inferior to the origin of the superior mesenteric artery. In most individuals, each kidney is supplied by one artery. The longer right renal artery (RRA) travels inferolaterally and posterior to the inferior vena cava (IVC) to reach the right renal hilum, while the left renal artery travels horizontally and

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laterally to reach the left renal hilum. The renal veins are usually anterior to the renal arteries.[1]

However, renal vessels are known for presenting a wide range of variations[1] as illustrated by previous cadaveric and imaging studies.[2,3] These include accessory renal arteries, prehilar branching, and unusual origin of the renal artery which may be proximal to the superior mesenteric artery or even from the iliac arteries. Venous variants include multiple renal veins, late confluence, and on the left, retroaortic and circumaortic renal veins.[1] The presence of one or more additional renal arteries is the most common renal vascular variation. The incidence ranges from 11.3% to 59.5%, and it varies significantly in different racial and geographic locations.[3-6]

Consequently, familiarity with the individual patient's renal vascular anatomy is crucial before surgical interventions involving the abdominal aorta and the renal arteries as well as urological procedures including living donor nephrectomy before kidney transplantation (KT). Such knowledge is, especially, important in kidney donors to ensure the suitability of the donor kidney and optimize surgical techniques.

Discussions on vascular anatomy and its variations were predominantly among surgeons and anatomists until the middle of the nineteenth century.[7] However, following the rapid development of advanced imaging techniques, particularly computerized tomography (CT), radiologists started visualizing and describing variations of vascular anatomy. Computerized tomographic angiography (CTA) is a fast noninvasive imaging modality which enables precise visualization of the normal and variant anatomy of several regions including the renal vasculature with an accuracy approaching that of conventional angiography which is the gold standard in vascular imaging.[1,8]

Although nephrology and urology are well-established specialties in Nigeria, the first KT in Nigeria was performed only in the year 2000.[9] Since then, there has been a fairly sustained growth and improvement in KT practice in the country. For now, only living donation is practiced with kidneys being sourced from genetically or emotionally related donors majorly through open donor nephrectomy.[9] Laparoscopic surgery is still in the early stages in Nigeria, but considering the sustained improvement in KT, laparoscopic donor nephrectomy, which is the preferred technique, will also become routine. Taking into account the increasing number of KT procedures being carried out in our country, it has become imperative for us at this point to determine the pattern of renal vascular anatomy that is peculiar to our population in Southwestern Nigeria. This information is also important in the preoperative assessment of patients for other urological and vascular interventions.

Therefore, the aim of this study is to describe and establish the prevalence of variations in renal vascular anatomy among patients undergoing contrast-enhanced CT (CECT) of the abdomen in our hospital. We will also review the literature for the embryological basis and clinical significance of such variations.

Materials and Methods

This retrospective, descriptive imaging study of the variations in renal vascular anatomy was carried out at the Radiology Department of a tertiary healthcare facility in Southwest Nigeria among patients aged 18 years and above, scanned between 2011 and 2016. We retrospectively studied the images of CTAs of the abdominal aorta and the arterial phase of multiphase abdominopelvic CECT carried out for various indications. Images with artifacts, suboptimal postcontrast arterial opacification, and images of patients with abnormalities which could interfere with optimum evaluation of the renal vessels were excluded from the study.

The images were acquired using a 4-slice CT scanner (Brightspeed, GE Healthcare). Depending on their weight, each patient received a bolus of 80–120 ml of nonionic contrast (Scanlux, Interpharm GmBH) into an antecubital vein through an automatic pressure injector (Medrad Vistron CT injection system). The bolus tracking technique which employs an automated scan triggering software (SmartPrep, GE Healthcare) was used to initiate arterial phase scanning in all CTAs and abdominopelvic CECT studies. Scanning commenced following peak enhancement of 150HU at the region of interest placed within the abdominal aorta at the level of the diaphragm. Contiguous CT slices were acquired from the diaphragm to the iliac crest at 5 mm slice thickness and reconstructed at 2.5 mm.

The CT images were analyzed by two consultant radiologists (OCF and CMA) using a ClearCanvas Workstation version 4.0 (ClearCanvas Inc., Toronto, Canada). Primary axial and multiplanar reconstructed coronal and sagittal views together with maximum intensity projections of the images were assessed for diagnostic image quality and identification of variations in renal arterial and venous anatomy according to the criteria described below.

In this study, we classified the vessels according to what has been described in literature[1,7] as follows:

Hilar artery – Branch of the aorta that enters the kidney close to or at the hilum [Figure 1a].

Superior polar artery – Branch of the aorta that enters the kidney at the upper pole.

Inferior polar artery – Branch of the aorta that enters the kidney at the lower pole [Figure 1b and c].

Early bifurcation – Branch of the aorta that divides <2 cm away from the left (L) lateral margin of the aorta or divides behind the IVC on the right (R) [Figure 2].

Precaval artery – RRA that is anterior to the IVC [Figure 3].

The venous variations studied were classified based on the following criteria:

Number – The number of individual renal veins draining directly into the IVC [Figure 4].

Late confluence – Multiple venous tributaries that join within 1.5 cm of the confluence with the IVC on the right or 1.5 cm of the lateral margin of the abdominal aorta on the left [Figure 5].

Retroaortic – The right renal vein that courses posterior to the abdominal aorta and drains into the lower lumber portion of the IVC [Figure 6a and b].

Circumaortic – The left renal vein which is divided into anterior and posterior limbs that encircle the abdominal aorta.

The patients' age and gender were recorded, and the vessels were classified based on type, frequency, and location (right or left). Statistical analysis was done using IBM SPSS statistical software version 20 (Armonk, NY: IBM Corp) and results were presented using descriptive statistics.

Results

The aortic CTAs and abdominal CECT images of 200 patients were studied, which included 102 (51%) females and 98 (49%) males. Their age range was 18–90 years with a mean age of 53.08 ± 17.01 years. The prevalence of any renal vascular variations, arterial variations only and venous variations only were 50%, 37% and 13% respectively.

Vascular variants were present in 37 females, (36.3 % of all females) and 63 males (64.3% of all males) [Table 1]. Vascular variants were noted to be significantly commoner in males, (P = 0.000075).

All the arteries were branches of the abdominal aorta. The arterial variants observed were accessory renal arteries seen on the right in 20 patients (10.0%) and 26 patients (13%) on the left, of these 7 patients (3.5%) had accessory arteries bilaterally. Four of the patients had more than one accessory artery making a total of 60 accessory arteries in 56 patients. Early branching was seen in 4.0% (right) and 0.5% (left) as well as precaval RRA

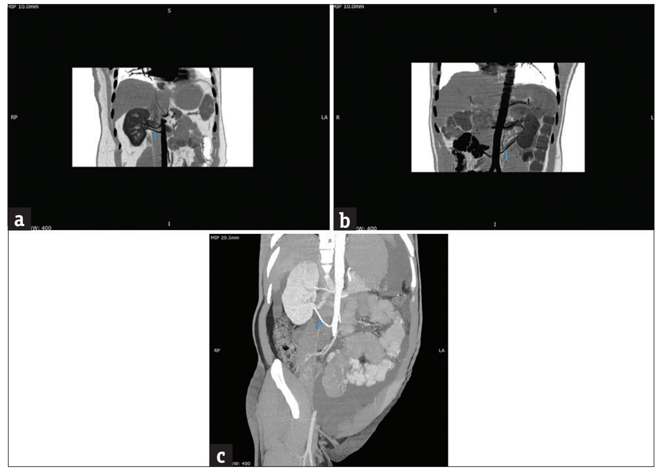

Figure 1: (a) Coronal image (negative) of accessory hilar renal artery on the right (arrow), (b) oblique sagittal image (negative) of inferior polar accessory artery on the left (arrow), (c) oblique sagittal image of an inferior polar accessory artery on the right (arrow)

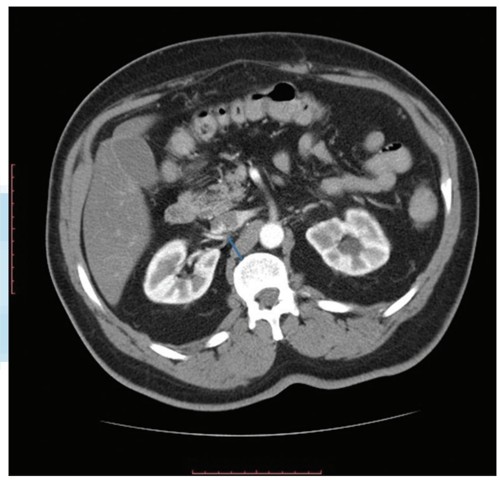

Figure 2: Axial arterial phase image of early branching of R renal artery posterior to the inferior vena cava (arrow)

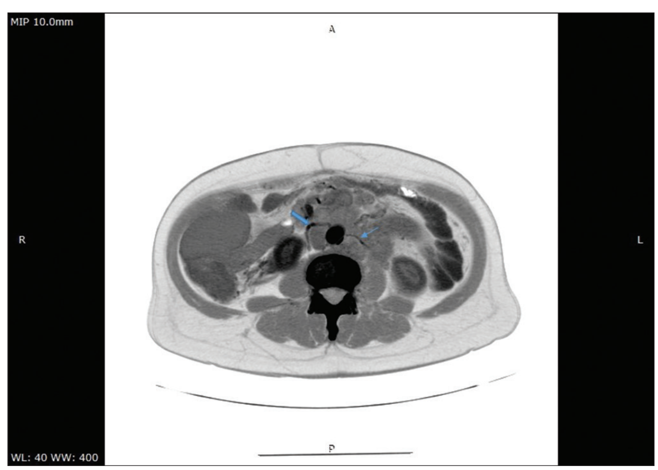

Figure 3: Axial (negative view) of precaval right renal artery supplying the lower pole of the right kidney (block arrow). Note the accessory inferior polar artery on the left (line arrow)

Table 1: Cross tabulation of gender and laterality of renal vascular variants

	Female		Male	
	n	%	*n*	%
Early Branching				
Right	1	12.50	7	87.50
Left	0	0.00	1	100.00
Superior Polar				
Right	4	36.36	7	63.64
Left	2	50.00	2	50.00
Hilar Accessory				
Right	1	20.00	4	80.00
Left	3	60.00	2	40.00
Inferior Polar				
Right	2	18.18	9	81.82
Left	7	35.00	13	65.00
Precaval Right Artery	4	44.44	5	55.56
Total Arterial Malformations	24	32.43	50	67.57
Late Confluence				
Right	2	33.33	4	66.67
Left	3	60.00	2	40.00
Multiple Veins				
Right	2	40.00	3	60.00
Left	3	60.00	2	40.00
Retroaortic Vein				
Right	3	75.00	1	25.00
Left-Sided IVC				
Right	0	0.00	1	100.00
Total Venous Malformations	13	50.00	13	50.00
Total Renal Vascular Malformations	37	37.00	63	63.00

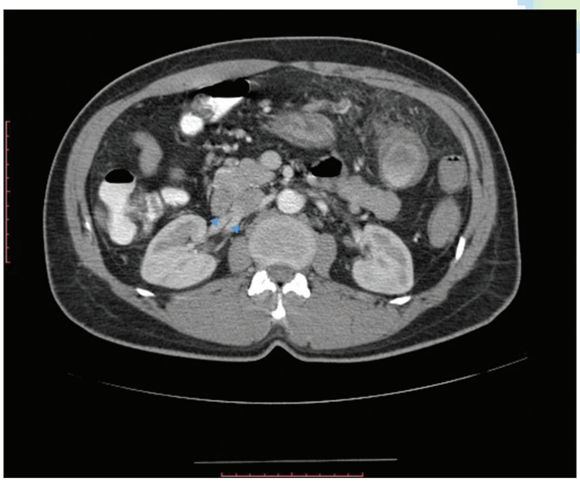

Figure 4: Late arterial phase axial view of multiple renal veins on the right (arrowheads)

Figure 5: Late arterial phase axial view of late confluence of the renal vein on the right (arrowhead)

seen in 4.5%. 7 of the 9 precaval renal arteries (77.8%) were accessory arteries to the right lower pole. Early renal arterial bifurcation was significantly more common on the right side ($P = 0.016$). Of the arterial variants, the inferior polar accessory artery was the most prevalent (15.5%) and was also more commonly seen on the left side.

Venous variants observed were late confluence seen in 3.0% (right) and 2.5% (left); multiple renal veins were seen in 2.5% (right) and 2.5% (left), while retroaortic left renal veins were seen in 2.0% of the cases. One patient (0.5%) had a left-sided IVC that terminated in the left renal vein [Figure 7].

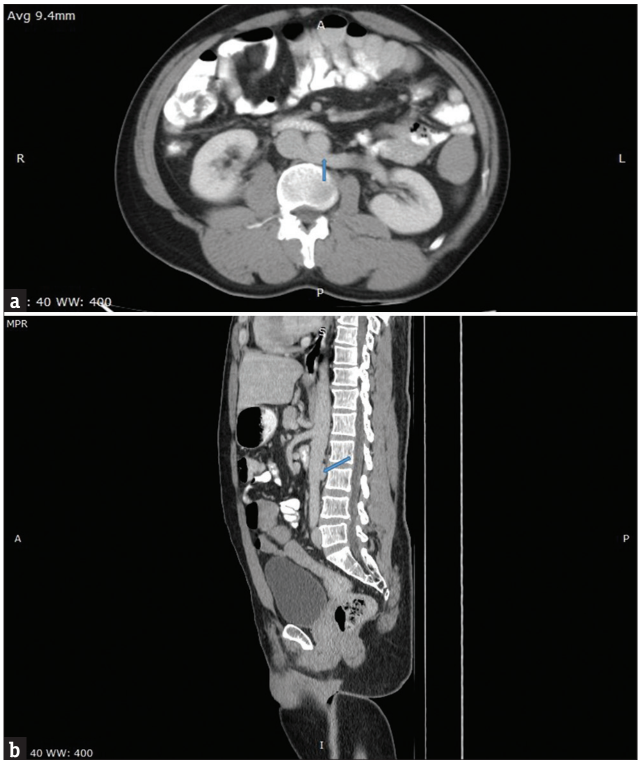

Figure 6: (a) Axial view of retroaortic left renal vein (arrow). (b) Sagittal view of retroaortic renal vein seen as a density projected between and the aorta and the 3rd lumbar vertebral (arrow)

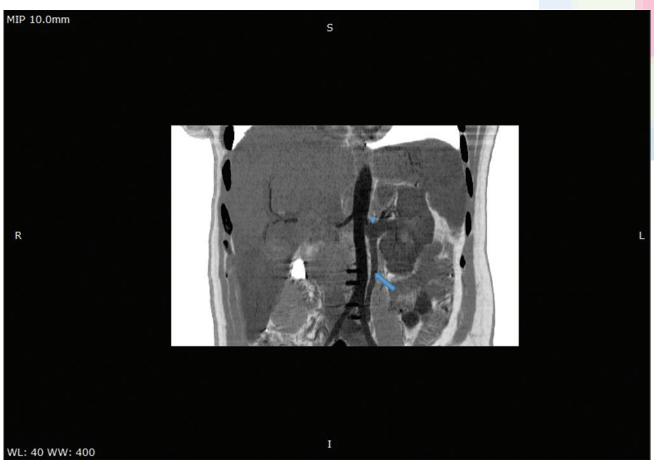

Figure 7: Oblique coronal image of left-sided inferior vena cava (block arrow) showing its confluence (arrowhead) with the left renal vein

Apart from early arterial branching, the vascular variants showed no statistically significant association with laterality. Gender distribution of the observed variants is as shown in Table 1.

Discussion

Variations of renal vascular anatomy occur during embryological development when the kidney, originally in the pelvis, ascends into the abdominal cavity. The immediate precursor of the kidney is the metanephros which is formed from the mesonephric duct and located near the tail of the embryo. The metanephric kidney is supplied by a series of lateral splanchnic arteries arising from the aorta. Growth and increase in the length of the embryo result in an apparent ascent of the kidney to the lumbar region. The "ascending" kidney achieves new and more cranial arterial supply while simultaneously inducing the regression of the more caudal branches. One of these vessels becomes the definitive renal artery. Failure of regression of the other embryonic vessels leads to the formation of accessory renal arteries.[1,7] Meanwhile, three sets of paired embryonic veins, namely, postcardinal, supracardinal, and the subcardinal (in order of appearance) contribute to the formation of the IVC and its tributaries by forming several complex anastomoses. One of such anastomoses is the aortic (renal) collar which gives rise to the renal vein. The dorsal arch of the collar is formed by the intersupracardinal anastomosis while the postsubcardinal and intersupracardinal anastomosis form the ventral arch and the suprasubcardinal anastomosis forms the lateral aspect of the arch. Subsequently, the dorsal arch regresses while the ventral arch remains as the renal vein.[10] Venous variants such as double IVC and circumaortic and retroartic left renal veins occur because the corresponding sections of the embryonic venous network fail to regress.

Detailed knowledge of anatomical variations in any region of the body is essential for correct interpretation of imaging studies. This is also needed to provide preprocedure anatomical information which will guide decisions on optimum techniques before surgical procedures on individual patients. Concerning renal vascular anatomy, such procedures include endovascular aneurysm repair and graft placement, segmental nephrectomy, laparoscopic renal surgery, and renal transplantation.

In our study population, renal vascular variations are significantly more prevalent among men, but a CT study of arterial patterns among Brazilians[3] did not observe any difference between males and females. Although it has been observed that there are differences in normal renal anatomy between genders,[11] and so possibly, differences may also be expected in the variant anatomy too. Moreover, the significant gender difference noted in our study may be explained by ethnic differences. Another congenital renal anatomical aberration that is reportedly more common among men is the horseshoe kidney.[12]

The most common arterial variant in our study is the accessory renal artery. This is similar to the observations from previous studies.[1,7,13] However, there are wide variations in the prevalence observed by these studies ranging from 13.3 to 61.5%.[2-6,8,14] In this study, we observed a prevalence of 24.5% which is within the 23–30% range commonly recorded in literature.[1,7] Such variations have been attributed to racial and ethnic differences, but a recent review by Gulas *et al*.[15] revealed that differences in the presence and number of accessory renal arteries reported in various studies may also be due to the method used to view the anatomy by the authors, especially when CT-based studies were compared with anatomical dissection studies. However, two cadaveric studies from India reported the prevalence of 54.7%[2] and 13.3%,[4] respectively. Further explanation for the divergent figures may be lack of uniformity in the nomenclature employed in many papers published on the subject.[16] Therefore, there is a need for uniform criteria for describing the various anatomical variations.

The precaval accessory RRA observed in 4.5% of our study population is close to findings in previous CT studies in India (5.4%)[17] and the United States (5%)[18] although a cadaveric study in India[19] had a slightly higher prevalence of 8.8% just as a more recent CT study in France[20] also reported a 9.1% prevalence. We also observed that 77.8% of precaval RRA in our study were accessory arteries to the inferior pole in keeping with reports from aforementioned studies that precaval accessory arteries tend to supply the inferior pole.[18]

An unreported accessory renal artery may be ligated during nephrectomy or occluded during stent placement resulting in bleeding and renal infarction, respectively. The accessory inferior polar artery often supplies the upper ureter; therefore, its ligation or occlusion may cause pyeloureteric necrosis with subsequent stenosis or urine leakage.[7]

Transplantation of kidneys with accessory renal arteries requires arterial reconstruction and anastomosis involving arteries with relatively small diameters. This increases the complexity and duration of the surgery with attendant higher probability of arterial thrombosis and bleeding following surgery,[7,21] and these in turn may lead to complications such as acute tubular necrosis, delayed graft function, and rejection. There is also increased risk of urological complications and reduced 1-year survival among such recipients. However, there is no significant detrimental effect on the 5-year survival when compared with recipients of single artery kidneys.[22] Similarly, successful balloon angioplasty and stenting have been carried out in patients with accessory renal arteries.[23]

Prevalence of early arterial branching was 4% in our study, and it was found to be significantly more common on the right. This is different from findings among Brazilians (1%),[3] Kenyans (21.6%),[5] and Indians (13%).[2] On the right, early arterial branching is technically considered to be a double artery.[24] This is because the branching occurs behind the IVC, thereby making dissection difficult due to the possibility of injuring a large vessel. Furthermore, on the left, because at least 1–2 cm of main renal artery is required for easy maneuvers during anastomosis,[7,24] arterial branching <1 cm from the aortic ostium may also need to be treated as double arteries during surgery.

Like in the arteries, variations of renal vein anatomy are usually clinically silent until discovered during imaging, surgery, or at autopsy. The prevalence of multiple renal veins in our study was 5.0% which is considerably lower than 15%–30% generally reported in literature[1,7,24] but closer to 7.1% observed by Hassan *et al*. among Kuwaitis.[25] However, the prevalence of retroaortic renal vein of 2.0% in our study is similar to the 2.1%–4.7% reported in previous studies.[7,10,25] According to Raman *et al*.,[8] multiple, circumaortic, and retroaortic renal veins are major variants because they affected recipient venous anastomosis or altered donor laparoscopic dissection in their study of potential laparoscopic renal donors. Moreover, circumaortic and retroaortic veins may be relative contraindications to donor nephrectomy.[26] The retroaortic vein is associated with hematuria, a manifestation of the so-called posterior nutcracker phenomenon, which is believed to be due to the increased pressure on the vein in its location between the aorta and the vertebral body. Thrombosis, pain, left renal vein hypertension, varicoceles, and splenomegaly have also been associated with retroaortic left renal vein.[27]

This study has obvious limitations. Most of the data used for this study are images from CECT of the abdomen with optimal enhancement of the aorta and renal vessels rather than CTA of the aorta and its branches which is potentially more suitable for answering our research question. The images were acquired with a 4-slice spiral CT scanner, whereas a 16-slice or better still a 64-slice CT scanner which is faster with higher spatial and temporal resolution offers greater precision in CTA evaluation of the origin, size, course, and branching pattern of vessels. Another limitation of this study is its retrospective nature. A larger prospectively designed study using data from CTA of the abdominal aorta and its branches acquired with at least a 16-slice CT scanner is needed to further explore this topic in our population.

Conclusion

This study has shown that variations of the renal arterial and venous anatomy are a frequent finding among

Nigerians. All the variants described have important implications in treatment planning for various surgical procedures. Radiologists and surgeons must apprise themselves of all these possible variants to avoid diagnostic errors and for optimization of surgical techniques to prevent avoidable postsurgical morbidities.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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