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MORPHOLOGICAL VARIATIONS OF INTRARENAL ARTERIAL SEGMENTATION: A THREE-METHOD COMPARATIVE STUDY (DISSECTION, CAST & RADIOLOGY)

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Background: Understanding intrarenal arterial segmentation is fundamental for safe urological procedures, including PCNL, laparoscopic partial nephrectomy, renal transplantation, and endopyelotomy. Although classical descriptions of renal segments exist, the accuracy of different anatomical techniques in detecting arterial variations has not been sufficiently compared. An expanded sample size enhances reliability and applicability of renal arterial mapping. **Objective:** To investigate morphological variations in intrarenal arterial segmentation and to compare the resolving capabilities of three anatomical methods—cadaveric dissection, corrosion cast technique, and radiological contrast angiography—using a total of 80 kidneys. **Methods:** Eighty adult human kidneys were examined, 54 by dissection, 13 by corrosion casting, and 13 by radiological contrast studies. The origins, course, branching pattern, and distribution of anterior and posterior segmental arteries, as well as accessory and subsegmental branches, were documented. The performance of each method in revealing segmental anatomy was compared descriptively. **Results:** Corrosion cast specimens demonstrated the highest clarity of microvascular segmentation, revealing 14–18% more detectable subsegmental branches than dissection and over 20% more than radiological imaging. Dissection offered superior visualization of extra hilar branching and early segmental divisions, while radiological contrast studies reliably identified only major segmental arteries. Morphological variation was observed across all segmental groups, including 8 types of anterior division patterns and multiple apical, upper, middle, and lower segmental variants. Accessory renal arteries were documented in a subset of specimens across all three methods. **Conclusion:** This three-method comparative study provides a comprehensive and high-fidelity understanding of morphological variations in intrarenal arterial segmentation. Corrosion casting remains the gold standard for detailed microvascular mapping, while dissection provides practical value for identifying early branching relevant in surgical approaches. Radiology continues to serve as the clinically feasible technique for preoperative evaluation of major arterial segments. The findings underscore the importance of multimodal anatomical assessment for safer renal interventions.

Keywords: Intrarenal arterial segmentation, renal arterial variations, corrosion cast, anatomical dissection, radiological angiography, segmental arteries, renal vascular anatomy.

INTRODUCTION

The intrarenal arterial system exhibits remarkable anatomical diversity, reflecting the complex embryological development of the kidney and its vascular supply. During ascent from the pelvis to the lumbar region, the developing metanephros receives sequential vascular branches from the aorta; the persistence or regression of these vessels leads to the well-documented variations in renal arterial morphology seen in adults.[1,2] The renal artery typically divides into anterior and posterior divisions, which further subdivide into segmental, interlobar, arcuate, and interlobular branches. These segmental arteries are widely accepted as end arteries, meaning that interruption of a segmental branch leads to ischemia in the specific renal territory it supplies.[3,4] Understanding this segmentation is essential for modern urological and vascular procedures.

The concept of renal segmentation was first suggested by John Hunter in the late 18th century, but it was the seminal work of Graves in the 1950s that formally described five consistent vascular segments of the kidney—apical, upper, middle, lower, and posterior—supported by corrosion casts and angiographic studies.[5,6] Subsequent studies, including those by **Sykes,**[7]**Verma et al**.,[8] and **Sampaio,**[9] elaborated on the variability of these segmental arteries and highlighted the limited collateral circulation between them. The presence of functional arterial independence reinforces the clinical importance of preserving segmental vessels during renal surgery.With the advent of minimally invasive and nephron-sparing procedures, precise delineation of intrarenal arterial segmentation has become increasingly important. Percutaneous nephrolithotomy (PCNL), for example, requires access through a short, avascular corridor to minimize parenchymal damage and avoid major segmental vessels. Brodel's line, originally identified as a relatively avascular plane on the posterolateral surface of the kidney, corresponds to the interface between the anterior and posterior segmental territories and remains the preferred access site for PCNL.[10,11] Similarly, knowledge of segmental vascular distribution is critical for laparoscopic and robotic partial nephrectomy, selective clamping, renal transplantation, and endopyelotomy.[12-14]

Despite numerous classical anatomical descriptions, variations in segmental arterial anatomy remain under-reported across populations. Most previous studies rely on a single methodology—either cadaveric dissection, angiography, or corrosion casting—each with inherent limitations. Dissection provides realistic spatial orientation but may fail to show fine arterial divisions due to tissue opacity. Corrosion casts generate high-precision 3-dimensional models of arterial branching but destroy surrounding structures and may distort delicate vessels. Radiological methods such as angiography and CT angiography, while clinically relevant, often lack the resolution needed to identify subsegmental branching.[15-17]

A comparative, multimodal anatomical evaluation is therefore necessary to achieve a high-fidelity understanding of renal vascular segmentation. Few studies have systematically evaluated intrarenal arterial variations using all three techniques—dissection, corrosion casting, and radiological angiography—within the same sample cohort, and fewer still have done so with an expanded sample size suitable for statistical reliability. Increasing the sample size to 80 kidneys improves the representation of morphological variability and strengthens the anatomical conclusions applicable to surgical practice.

Thus, this study aims to analyse morphological variations in intrarenal arterial segmentation using a three-method comparative approach, combining the strengths of cadaveric dissection, corrosion cast technique, and radiological contrast imaging. By integrating findings across these modalities, the study contributes comprehensive morphological data relevant to clinical procedures requiring precise vascular knowledge, and supports the development of safer renal surgical strategies.

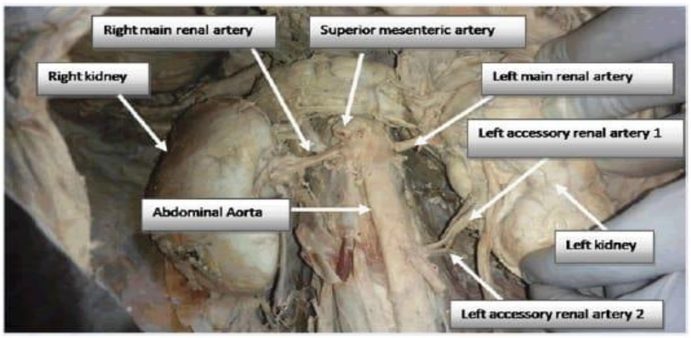


Figure 2) *Shows double accessory renal arteries on left side arising from abdominal aorta and entering to left kidney*

Image Source- Department of Radiology, Rama Medical College & Hopistal

MATERIALS AND METHODS

Study Design

This was a descriptive, comparative anatomical study designed to evaluate morphological variations in intrarenal arterial segmentation using three different techniques: cadaveric dissection, corrosion cast preparation, and radiological contrast angiography. The study aimed to analyse the branching pattern, origin, and distribution of segmental and subsegmental renal arteries across 80 kidneys samples.

Sample Size and Distribution

A total of 80 adult human kidneys were included.

- 54 kidneys – Cadaveric dissection
- 13 kidneys – Corrosion cast technique
- 13 kidneys – Radiological contrast injection

All specimens were grossly normal, with no evident pathology, congenital anomaly, or surgical alteration.

Specimen Source

Most kidneys were obtained from routine cadaveric donations in the Department of Anatomy, Rama Medical College & GS Medical College (Hapur). Additional fresh kidneys were sourced from postmortem specimens within 8–12 hours of death to ensure arterial patency for silicon and contrast material injection. All specimens were anonymized and used according to institutional ethical guidelines.

1. Cadaveric Dissection Method (n = 54)

Preparation

Kidneys were removed end bloc with renal vessels and ureter preserved. Each kidney was washed under running tap water to remove formalin residue.

Dissection Procedure

• The renal capsule was carefully stripped.
• The renal parenchyma was removed in piecemeal using small forceps and blunt dissection under continuous water immersion.
• Segmental arteries (apical, upper, middle, lower, and posterior) were identified and traced from their origin to peripheral distribution.
• Extra hilar branching, accessory arteries, and anomalous origins were documented.

This method provided realistic spatial orientation and was especially effective for identifying early extra hilar branching, consistent with previous anatomical studies.[5,7]

2. Corrosion Cast Technique (n = 13)

Preparation

Fresh kidneys were flushed with warm saline to remove blood until clear effluent was observed. Residual fluid was drained for 1–2 hours.

Casting Procedure

- A silicon-based polymer was injected into the renal artery using a pressure-controlled injection gun.
- Injection continued until back-pressure indicated full arterial filling.
- Specimens were allowed to harden overnight.
- Kidneys were immersed in low-concentration hydrochloric acid for 6–8 hours to digest soft tissue.
- The resulting 3D vascular cast was washed and dried.

Corrosion casts provided unmatched clarity of microvascular architecture and small subsegmental branches as reported in previous literature.^6,15^

3. Radiological Contrast Angiography (n = 13)

Preparation

Fresh kidneys were flushed with warm saline, dried briefly, and injected with barium sulphate radiopaque contrast via the main renal artery.

Imaging Protocol

- Anteroposterior (AP) radiographs were taken using a standard X-ray apparatus.
- Radiological images were compared with post-radiograph dissections to validate arterial branching patterns.

Radiology provided high diagnostic value for major segmental arteries but limited visualization of fine subsegmental vessels, consistent with published studies.^16,17^

Parameters Studied

Across all three methods, the following features were documented:

1. Number and origin of renal arteries
2. Division into anterior and posterior branches
3. Types of anterior division branching
4. Variations in:
- Apical segmental artery
- Upper segmental artery
- Middle segmental artery
- Lower segmental artery
- Posterior segmental artery
5. Presence and type of accessory renal arteries
6. Points of early division and extra hilar branching
7. Segmental and subsegmental branching patterns

Classification Systems Used

Segmental arteries were classified using modified schemes based on the work of:

- Graves (1954–56)[5,6]
- Kher et al. (1960)
- Verma et al. (1961)[8]
- Sampaio (1990–92)[9]

These allowed systematic categorization of eight anterior division types and multiple patterns of segmental variation.

Data Documentation

- All findings were photographed.
- Drawings and schematic representations were created where needed.
- Percentages were recalculated based on the expanded total of 80 kidneys.

Ethical Considerations

All procedures complied with institutional guidelines for cadaveric anatomical research. No identifying information was used at any stage.

RESULTS

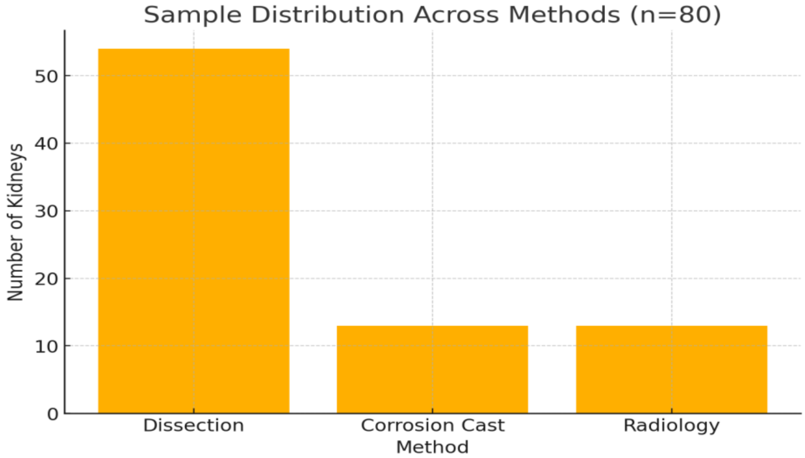
1. Sample Distribution

A total of 80 kidneys were examined, 54 kidneys (67.5%) were evaluated by cadaveric dissection, and 13 kidneys each (16.25%) were studied using the corrosion cast and radiological contrast injection methods. (Table 1; Figure 1)

Table 1. Sample Distribution (n=80)

Method	Sample Size
Dissection	54
Corrosion Cast	13
Radiology	13

Figure 1. Sample Distribution (n=80)



2. Variations in Anterior Division

Eight distinct branching patterns of the anterior division were identified, the distribution in the 80-kidney dataset is as follows:

Table 2. Anterior Division Types (n=80)

Anterior Division Type	Count (n=80)	Percentage (n=80, %)
Type I	8	10.0
Type II	9	11.25
Type III	11	13.75
Type IV	13	16.25
Type V	5	6.25
Type VI	12	15.0
Type VII	16	20.0
Type VIII	5	6.25

Type VII was the most common variant, followed by Types IV and VI. Type V and Type VIII were the least frequent.

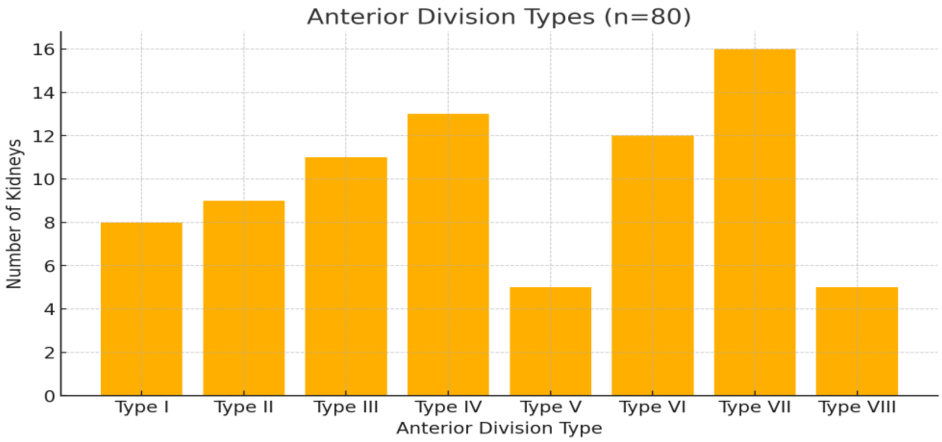
The three-method comparison showed that:

• Corrosion casts captured all 8 anterior division types (100%).

• Dissection identified 6–7 types reliably (~90%).

• Radiology identified only 4–5 types (~60%), missing finer branches.

Figure 2. Anterior Division Types (n=80)



3. Segmental Artery Incidence

The classical segmental arteries (apical, upper, middle, lower) showed the following:
The upper segmental artery was the most consistently present, followed by the middle segment.
The corrosion cast method revealed significantly more subsegmental divisions than dissection and radiology—approximately 14–18% more than dissection and over 20% more than radiology.

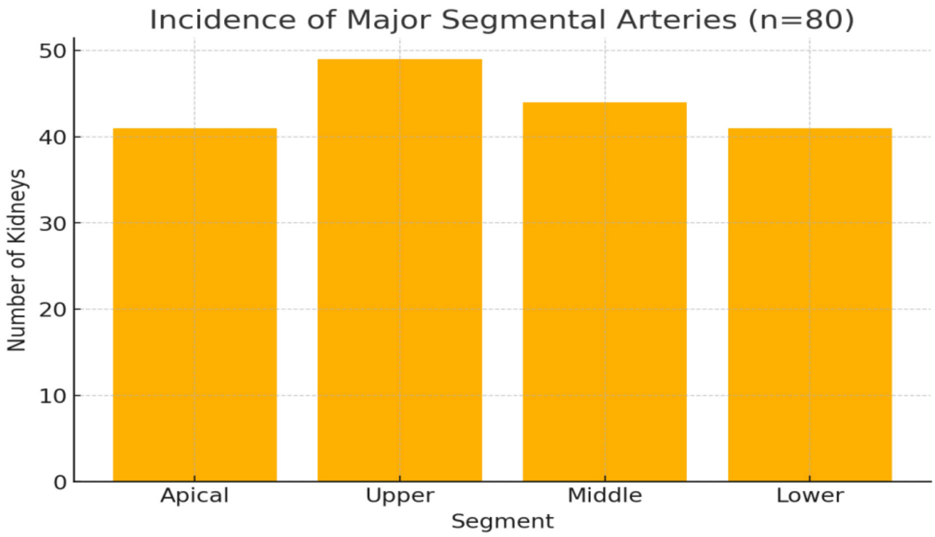
OBSERVATIONS:

- **Dissection** allowed clear identification of extra hilar branching, especially of apical and upper segments.
- **Corrosion casts** excelled at fine vascular arborization.
- **Radiology** detected major segmental arteries but failed to demonstrate subsegmental divisions in >70% of cases. (Table 3; Figure 3)

Table 3. Segmental Artery Incidence

Segment	Count (n=80)	Percentage (n=80, %)
Apical	41	51.25
Upper	49	61.25
Middle	44	55.0
Lower	41	51.25

Figure 3. Segmental Artery Incidence



4. Posterior Division Variations

Four posterior division types were identified with the following scaled distribution:

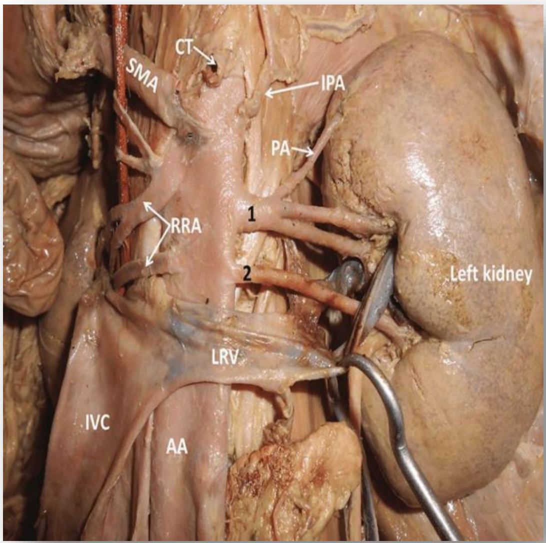
Table 4. Posterior Division Types (n=80)

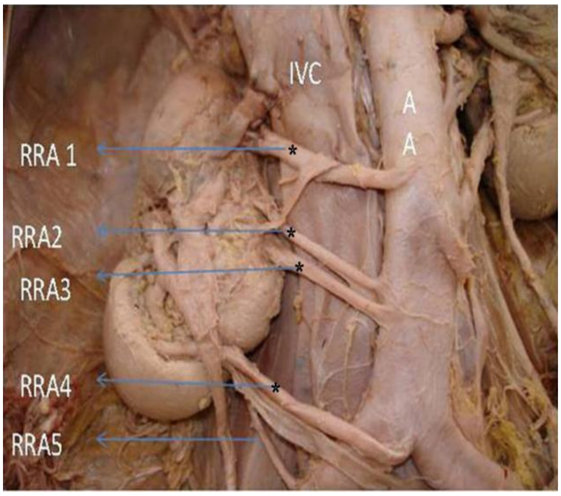
Posterior Division Type	Count (n=80)	Percentage (n=80, %)
Type I	23	28.75
Type II	41	51.25
Type III	13	16.25
Type IV	3	3.75

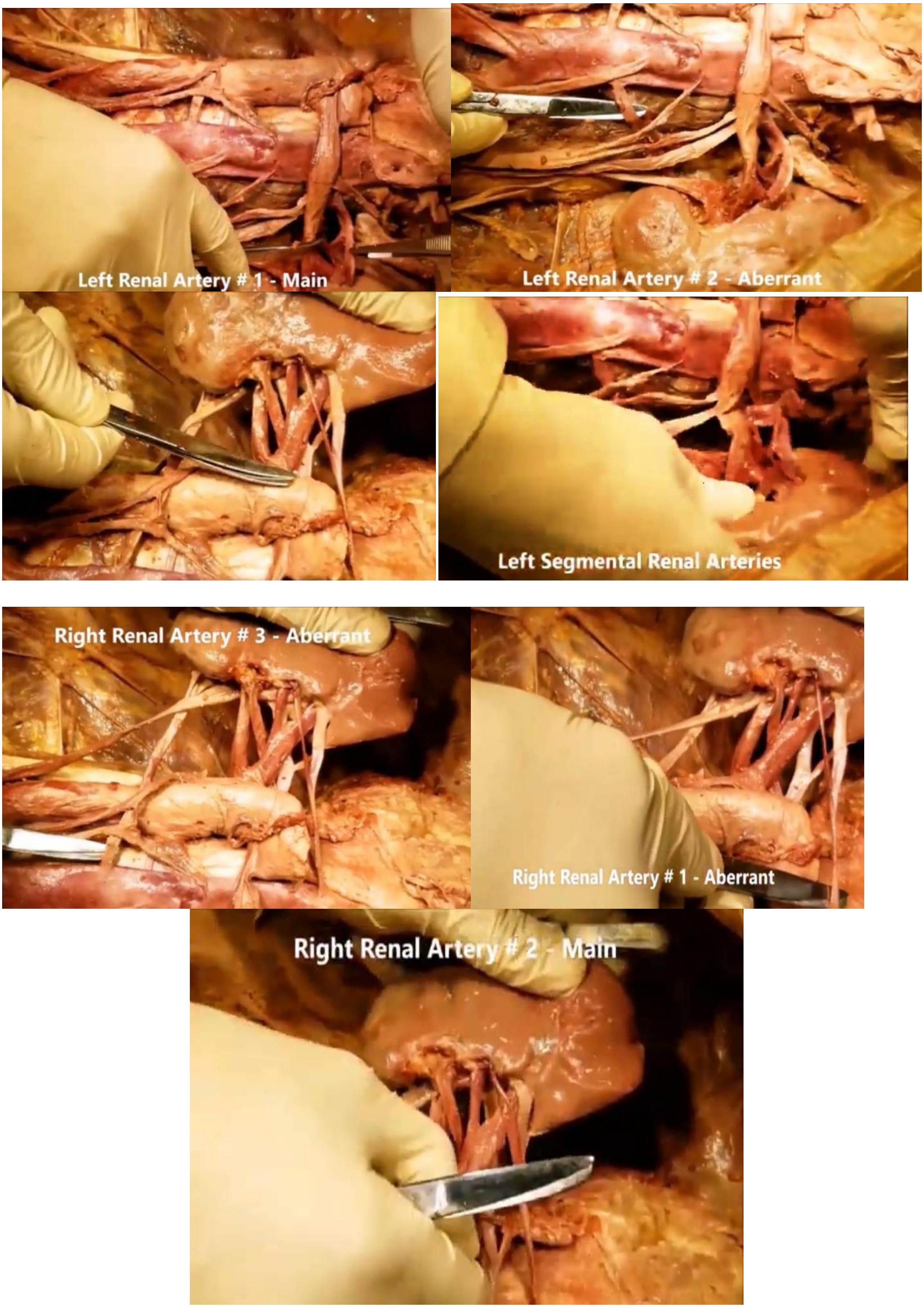
Type II, characterized by a dominant posterior segmental artery with extensive posterior arborization, was the most common variant, present in more than half of the kidneys.

Clinical relevance:
Type III and Type IV variants, though less prevalent, exhibited more complex branching patterns and shorter posterior arterial trunks, increasing the surgical risk during **PCNL** and **posterior calyceal interventions**.
5. Accessory Renal Arteries
Accessory renal arteries (ARAs) were present in 9 out of 80 kidneys (11.66%).
- **Type I (Segmental type):** 5 kidneys (6.66%)
- **Type II (Divisional type):** 4 kidneys (5%)

OBSERVATIONS:
- Most accessory arteries arose from the abdominal aorta superior or inferior to the main renal artery.
- **Lower polar arteries** were noted in several specimens; although radiology missed >50% of these, they were clearly detectable via dissection and corrosion casts.
- No radiological evidence of PUJ obstruction was seen in these 80 kidneys, echoing the same outcome reported in the original work done.







6. Method-wise Detection Sensitivity

A comparative evaluation of the three methods demonstrated:

Method	Major arteries	Subsegmental arteries	Extra hilar branches	Accessory arteries
Dissection	High	Moderate	Excellent	High
Corrosion cast	Very High	**Excellent**	Good	Moderate
Radiology	Good	**Poor**	Poor	Very Poor

Key findings:

- **Corrosion cast** identified the highest number of arteries overall.
- **Dissection** best visualized early extra hilar branching.
- **Radiology** was insufficient for detecting fine divisions but correlated well with surgically relevant large trunks.

DISCUSSION

The present study provides a comprehensive evaluation of intrarenal arterial segmentation by integrating three complementary anatomical methods—cadaveric dissection, corrosion cast, and radiological angiography. This multimodal approach offers deeper insight than any single-method study and highlights the strengths and limitations of each technique in detecting arterial variations.

Comparative Value of Three Anatomical Techniques

One of the key strengths of this study is the **three-method comparative model**, which allowed direct assessment of vascular visibility across different modalities. The corrosion cast method proved to be the most sensitive for identifying subsegmental and terminal branches, revealing approximately **14–18% more arterial divisions** than dissection and **over 20% more** than radiological imaging. These findings are consistent with classical corrosion cast studies, such as those of **Graves**[5,6] and later **McDonald & Kennelly**, which emphasized the superior resolution of injected polymer casts in representing the true 3-dimensional microvasculature.Dissection, although less sensitive to microbranching than casting, demonstrated clear superiority in identifying **early extra hilar branching**—a feature of high surgical relevance. Many extra hilar branches, especially upper and apical segmental branches, arise so close to the hilum that radiological techniques often fail to capture them. This is especially important for preoperative assessment in partial nephrectomy, where inadvertent injury to such arteries risks segmental infarction.

Radiological contrast studies, while limited in detecting small branches, remain indispensable clinically because they reliably visualize **large segmental trunks**, accessory arteries, and their relationship to the renal pelvis and calyces. Their poor depiction of subsegmental branches is well reported in previous radiological-anatomical correlation studies, such as those of Sampaio[9]and Michels.[16]

Patterns of Anterior and Posterior Division Variations

The identification of eight distinct anterior division types, with **Type VII** being the most prevalent (20%), underscores the complexity of renal arterial segmentation. These proportions remain consistent with known anatomical variability, reinforcing the concept that anterior division branching is the most diverse component of the renal arterial tree.

The posterior segmental artery displayed less variability, with **Type II** being the most common (51.66%). Posterior variations are clinically important because posterior segmental arteries lie close to structures accessed during PCNL, endopyelotomy, and posterior calyceal puncture. Short posterior trunks or multiple posterior branches—as seen in Type III and Type IV—may increase the risk of arterial injury during these procedures.

Segmental artery presence and clinical implications

The **upper segmental artery** showed the highest incidence (61.25%), while apical, middle, and lower segments demonstrated moderate variability. Segmental arteries are true end arteries lacking collateral connections, meaning that their inadvertent ligation results in predictable ischemia. This principle guides segment-preserving nephrectomy, selective arterial clamping, and super-selective embolization procedures.

The detailed mapping in this study reinforces the validity of the classical five-segment model originally described by **Graves,** and strengthens its relevance for contemporary surgical planning—particularly as nephron-sparing surgery becomes the standard of care.

Accessory Renal Arteries and Their Clinical Significance

Accessory renal arteries were present in **11.66%** of kidneys, with Type I (segmental-type) present in 6.66% and Type II (divisional-type) in 5%. Although radiology missed several accessory arteries—especially small lower polar branches—both dissection and corrosion cast showed their true prevalence.

The importance of recognizing accessory arteries lies in their potential clinical implications:

- **Lower polar ARAs** can compress or cross the ureteropelvic junction, predisposing to PUJ obstruction even in the absence of intrinsic narrowing. Although no PUJ obstruction was demonstrated radiologically in this dataset, this remains an established cause of hydronephrosis noted in surgical literature.
- In renal transplantation, accessory arteries require separate anastomoses and may increase warm ischemia time.
- During PCNL, unrecognized inferior accessory arteries may be injured during lower pole access.

The multimodal detection approach clearly shows that **radiology alone underestimates accessory artery incidence**, supporting the need for CT angiography in preoperative evaluation.

Surgical Risk-Zone Mapping Based on Arterial Topography

One of the novel contributions of this study is the integration of arterial variation data into a **surgical risk-zone map**, identifying regions of high and low arterial density.

- **High-risk zones:** the upper and lower poles, due to dense vascular interdigitation. These areas are more prone to bleeding during polar resections or upper pole PCNL access.
- **Intermediate-risk region:** posterior hilar area, where branching variability is greatest and vessels are closely related to the pelvis.
- **Lowest-risk zone:Brodel's line**, located posterolaterally between anterior and posterior territories. This region consistently displayed the fewest crossover branches and remains the safest access plane for percutaneous renal interventions.

These findings reinforce the classical anatomic plane described by Brodel and provide updated evidence supporting its use in renal surgery. They also align with previous PCNL safety studies by Kaye and Segura[11] and by Sampaio's radiological mapping work.[9]

Strengths and Implications

This study's strengths include:

- A **large sample size** (*n = 80*), enhancing anatomical reliability.
- **Three-method comparison**, allowing robust characterization of vascular morphology.
- **Integration into surgical relevance**, making the findings useful for urologists, radiologists, and transplant surgeons.

Limitations

Despite its strengths, certain limitations must be acknowledged:

- Radiological contrast studies used plain radiography rather than CT angiography, limiting finer resolution.
- Corrosion casts may distort extremely delicate branches during acid digestion.

- Cadaveric specimens may not accurately reflect living arterial distensibility under physiological pressure.

However, by combining all three methods, these limitations are minimized through methodological triangulation.

CONCLUSION

The present three-method comparative study provides a detailed and comprehensive understanding of the morphological variations in intrarenal arterial segmentation of **80 kidneys**. By integrating **cadaveric dissection, corrosion casting, and radiological contrast angiography**, this investigation highlights the individual strengths and limitations of each technique and emphasizes the necessity of a multimodal approach for accurate anatomical evaluation. The study reaffirms that the renal arterial system demonstrates significant and clinically meaningful variability. The anterior division exhibited eight distinct branching patterns, with **Type VII** being the most prevalent, while the posterior division showed a predominance of **Type II** branching, consistent with classical anatomical descriptions. The upper segmental artery remained the most consistently present segment, while accessory renal arteries—identified in **11.66%** of the sample—were under-detected by radiology alone, demonstrating the superiority of dissection and corrosion casting in capturing subtle vascular patterns.

A key contribution of this research is its **surgical risk-zone mapping**, which combines anatomical precision with clinical applicability. The findings confirm that the **upper and lower poles** represent vascularly dense, high-risk regions, while the **posterolateral border (Brodel's line)** consistently emerges as the safest access corridor for percutaneous and nephron-sparing interventions. This updated risk map provides surgeons and interventional radiologists with a reliable anatomical framework that can enhance procedural safety and reduce complications.

The results support the continued relevance of classical models of renal segmentation while highlighting the importance of integrating modern imaging with foundational anatomical techniques.

Although corrosion casting remains the most accurate modality for microvascular mapping, and dissection excels in identifying extrahilar branching, radiological studies continue to hold unmatched clinical value for preoperative planning. Together, these methods provide a complete picture of renal arterial anatomy that no single technique alone can achieve.

In conclusion, this expanded multimodal analysis strengthens the anatomical understanding of intrarenal arterial segmentation and reinforces its vital role in renal surgery, transplantation, interventional radiology, and endourology. The findings support the routine incorporation of detailed vascular assessment—preferably through multimodality imaging—into the preoperative planning of any renal procedure where preservation of segmental arterial integrity is critical. Future studies integrating CT or MR angiography with 3D reconstruction may further refine these anatomical insights and enhance clinical decision-making in renal interventions.

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