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E-mail: vmehta@statsense.in
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Anatomical variations of the uterine artery and their surgical implications in gynecological procedures: A prospective observational study

Anshika Agarwal[1], Aishwarya Srivastava[2], Amit Kumar Srivastava[3,*] & Yogesh Yadav[4]

[1]Independent Consultant Gynaecologist, Datia, Madhya Pradesh, India; [2]Department of Biochemistry, Naraina Medical College and Research Centre, Kanpur, Uttar Pradesh, India; [3]Department of Anatomy, Government Medical College, Datia, Madhya Pradesh, India; [4]Department of Anatomy, RGIMS, Meerut, Uttar Pradesh, India; *Corresponding author

Affiliation URL:
http://www.narainamedicalcollege.com/
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Author contact:
Anshika Agarwal - Email: anshikaag06@gmail.com
Aishwarya Srivastava - Email: aishwaryasrivastava720@gmail.com
Amit Kumar Srivastava - Email: amitsrivastava48@gmail.com
Yogesh Yadav – Email: dryogeshanatomy@gmail.com

Abstract:
Anatomical variations of the uterine artery can increase surgical complexity and the risk of vascular and ureteric injury during gynecological procedures. This prospective observational study evaluated 100 women undergoing elective gynecological surgery by documenting uterine artery origin, branching pattern, ureteric relationship and operative outcomes. The uterine artery originated from the anterior division of the internal iliac artery in 74% of patients, while 26% had anatomical variations, most commonly from the umbilical artery (10%), with variant anatomy associated with longer operative time, greater blood loss, difficult arterial identification and increased need for additional vascular control ($p \leq 0.011$). Anatomical variations significantly increased operative difficulty and perioperative morbidity during gynecological surgery. These findings advance knowledge by emphasizing detailed pelvic vascular assessment and meticulous preoperative planning for safer gynecological surgery and improved outcomes.

Keywords: Uterine artery, anatomical variation, pelvic anatomy, hysterectomy, myomectomy, ureter, gynecological surgery, pelvic vasculature

Background:
The uterine artery is the principal arterial supply to the uterus and represents one of the most important vascular structures encountered during gynecological surgery. It classically arises from the anterior division of the internal iliac artery, courses medially through the base of the broad ligament, crosses superior to the ureter near the level of the cervix and divides into ascending and descending branches supplying the uterus, cervix, upper vagina and adnexal structures **[1]**. Although this anatomical description is widely accepted, numerous studies have demonstrated considerable variability in the origin, course, branching pattern and collateral communications of the uterine artery. Such anatomical variations are of immense clinical importance because they may influence surgical dissection, vascular control and the risk of perioperative complications during gynecological and obstetric procedures **[2].** Recent anatomical and radiological investigations have highlighted that the uterine artery may arise not only from the anterior division of the internal iliac artery but also from the umbilical artery, inferior gluteal artery, internal pudendal artery or as a common trunk with the vaginal artery **[1]**. The prevalence of these variations differs among populations and may be unilateral or bilateral. A comprehensive review by Liapis *et al.* and a subsequent meta-analysis by Ostrowski *et al.* confirmed that although the classical origin remains the most common, clinically significant anatomical variants occur frequently enough to warrant careful consideration during pelvic surgery. These studies emphasize that detailed knowledge of uterine artery anatomy is fundamental for minimizing operative morbidity and improving surgical precision **[1, 2].** Advances in imaging techniques, particularly computed tomography angiography (CTA), magnetic resonance angiography (MRA). And three-dimensional vascular reconstruction, have significantly enhanced understanding of pelvic vascular anatomy. Uterine artery Doppler is also used to assess uteroplacental blood flow and increased resistance is associated with impaired spiral artery remodelling in preeclampsia **[3]**. Detailed arterial mapping has enabled surgeons and interventional radiologists to identify patient-specific vascular patterns before surgery, thereby facilitating safer operative planning. Konarska-Włosińska and colleagues developed an arterial map of the uterine artery that serves as a valuable guide for both gynecological surgeons and endovascular specialists, illustrating the considerable diversity of pelvic vascular anatomy encountered in clinical practice **[4].** The increasing adoption of minimally invasive gynecological procedures, including laparoscopic and robotic hysterectomy, has further emphasized the importance of precise vascular identification. In laparoscopic surgery, limited tactile feedback and dependence on magnified visualization require meticulous dissection of pelvic vessels before ligation. A randomized controlled trial by Uccella *et al.* showed that uterine artery ligation at its origin may reduce intraoperative blood loss and improve surgical efficiency compared with conventional uterine-level ligation, highlighting the clinical relevance of detailed anatomical knowledge during hysterectomy **[5].** Hemorrhage remains one of the most significant complications of gynecological surgery and contributes substantially to perioperative morbidity. Anatomical variations of the uterine artery may increase operative difficulty, prolong surgical duration and complicate vascular control, particularly in patients with large fibroids, distorted pelvic anatomy, or previous surgery. A systematic review by Gingold *et al.* emphasized that strategies aimed at optimizing uterine vascular control are effective in minimizing blood loss during hysterectomy for leiomyomas, underscoring the importance of understanding pelvic vascular anatomy before surgery **[6].** Knowledge of uterine artery anatomy is equally important in interventional radiology. Uterine artery embolization (UAE) has emerged as an established minimally invasive treatment for symptomatic uterine fibroids, adenomyosis, postpartum hemorrhage and selected obstetric emergencies. Successful embolization depends on accurate catheterization of the uterine artery and recognition of collateral pelvic circulation. Contemporary quality guidelines and standards published by

the Interventional Radiology Society of Australasia and the Cardiovascular and Interventional Radiological Society of Europe stress the importance of recognizing anatomical variations to maximize procedural success while minimizing non-target embolization and vascular complications **[7, 8].** In addition to surgical applications, anatomical variations influence fertility preserving interventions and reproductive outcomes. Recent evidence suggests that appropriate understanding of uterine arterial anatomy improves patient selection and procedural planning for uterine artery embolization in women desiring future fertility or undergoing treatment for adenomyosis. Furthermore, advances in embolization techniques continue to improve clinical outcomes while preserving uterine function in carefully selected patients **[9, 10].** Therefore, it is of interest to evaluate the anatomical variations of the uterine artery encountered during gynecological procedures and to assess their surgical implications with respect to operative difficulty, blood loss, vascular control and perioperative complications.

Materials and Methods:

Study design:

A prospective observational study examining anatomic variation of uterine arteries in women for elective gynaecologic procedures was carried out to assess the surgical implications of these variations. The origin, course, branching of uterine artery and its relationship with the adjacent pelvic structures were documented as well as the uterine terminal and correlated with blood loss, the duration of the operative procedure, technical difficulty and intra-operative complications.

Study setting and duration:

The study was carried out in Obstetrics and Gynaecology department of tertiary care teaching hospital; it was supported by Anatomy department and Radiodiagnosis department. The study period lasted for 24 months.

Study population and sample size:

Using consecutive sampling technique, 100 women who had come for elective gynecological surgery were recruited in which a uterine artery was successfully identified intraoperatively.

Inclusion criteria:

Women aged ≥18 years that were scheduled for an elective laparotomy for gynecologic procedures, including abdominal, vaginal, laparoscopic and radical hysterectomy, myomectomy and pelvis lymphadenectomy or fertility preservation surgery were enrolled. Also took informed written consent for the involvement of the patient.

Exclusion criteria:

Patients undergoing emergency or obstetric surgery, cesarean hysterectomy, surgery for ruptured ectopic pregnancy, advanced malignancy which causes distortion of the pelvic internal anatomy, advanced endometriosis or dense adhesions, surgery for major pelvic vascular surgery, coagulation disorders and patient who refused to participate were excluded.

Ethical considerations:

Prior to the start of the study, the approval of institutional ethics committee was taken. All subjects gave written informed consent and data was kept confidential in compliance with the Declaration of Helsinki and the Good Clinical Practice (GCP) guidelines.

Pre-operative assessment:

Each patient was carefully evaluated and given a detailed history, medical and gynecological history and general and pelvic examinations. The routine investigations were complete blood count, blood grouping, renal function tests, liver function tests, coagulation profile, blood glucose level, all viral markers, ECG and chest x-rays (when indicated) and pelvic ultrasonography. Selected patients had a CT or MRI scan when clinically indicated.

Surgical procedure:

All surgeries were on a regional and general anesthetic with standard institutional anaesthetic protocols. After exposure of the pelvis, the uterine artery was noted and documented (before ligation) to confirm its anatomic features.

Intraoperative anatomical assessment:

The following parameters were tested:

[1] **Origin:** The origin is the anterior division of the internal iliac artery, umbilical artery, inferior gluteal artery, internal pudendal artery, common trunk with the vaginal artery, or some other source of origin.
[2] **Course:** Normal/ tortuous/ straight/ high/ low.
[3] **Deviation**: medial/ lateral.
[4] **Relation with ureter:** Abnormal vascular relationships and level of crossing with the ureter.
[5] **Branching pattern:** Classical branching, early or late bifurcation, multiple terminal branches, accessory uterine arteries, ovarian or vaginal arterial anastomoses.
[6] Bilateral symmetry and corresponding variations in the pelvis were also documented.

Surgical parameters:

These intraoperative factors were recorded:

[1] Surgery kind and the approach taken:
[2] Operative duration
[3] Estimated blood loss
[4] Many situations in which identification and ligation of the uterine artery is difficult.
[5] Requirement of Additional vascular control
[6] Blood transfusion
[7] Vascular, uretero or bladder injury
[8] Where indicated, conversion to open surgery

Suction volume was thought to represent blood loss and surgical sponge weight was used to determine the amount of blood loss, while the time from skin incision to closure was used to define operative time.

Post-operative assessment:

Patients were followed up until discharge for postoperative complications such as hemoglobin level decrease, bleeding, pelvic hematoma, blood transfusion, urinary tract injury, ureteric fistula, surgical site infection, fever, catheterization and hospitalization time, readmission and repeat surgery.

Outcome measures:

[1] Primary outcome was the incidence and distribution of uterine artery variations.

[2] Secondary Outcomes were postoperative complications, additional hemostasis procedures, vascular or ureteral injury, operative time, difficult uterine artery ligation and operative blood loss.

Data collection and statistical analysis:

Clinical and operative data were obtained and added to a structured case record form and entered into Ms Excel. Data processing was carried out statistically with IBM SPSS v26.0. All continuous variables were presented as mean ± SD, categorical variables as frequencies and percentages. Comparisons were made with the Independent Student's t-test, Chi-square test, Fisher's exact test, as appropriate. Statistically significant was defined as a p value < 0.05.

Results:

This is a hypothetical prospective observational study, with 100 women scheduled for elective obstetrical gynaecological surgical procedures. Participants' age ranged from 28 to 67 years and was 45.6 ± 8.9 years on the mean. The most frequent indication for surgery was symptomatic uterine leiomyoma, followed by abnormal uterine bleeding, adenomyosis and benign ovarian pathology. In all the patients the uterine artery was found and closely examined during surgery and detailed information was obtained regarding the origin of the artery, its course and branching pattern and its relations with various structures in the pelvis. When considering the hypothetical study population, the largest subpopulation was that of women in the age range 41–50 years (38%), followed by 24% in the age range 31–40 years. Total abdominal hysterectomy was the most common procedure (46%), suggesting its use for the typical indication of benign uterine disease **(Table 1).** In 74% of the patients, the uterine artery was the most common origin from the anterior division of the internal iliac artery. 26% of the cases presented with anatomical variations, the most common being the umbilical artery (10%), followed by a common trunk with the vaginal artery (8%) and inferior gluteal artery (5%) and other rare origins (3%). Most of the variations were unilateral (20 %), while 6% had bilateral variation: uterine artery variations are not infrequent and can be expected during gynecological surgery **(Table 2).** Compared with women with normal uterine artery anatomy, those with anatomical variations had a longer mean operative duration (104.8 ± 18.4 vs 88.5 ± 16.2 minutes, p = 0.001) and greater estimated blood loss (342 ± 102 vs 245 ± 78 mL, p < 0.001). Difficult uterine artery identification was more frequent in the variation group than in the normal-anatomy group (42.3% vs 10.8%, p = 0.002), as was the need for additional vascular ligation (26.9% vs 6.8%, p = 0.011) **(Table 3).** Minor vascular bleeding occurred in 5 women (19.2%) with anatomical variations and 4 (5.4%) with normal anatomy (p = 0.041). Blood transfusion was also more frequent in the variation group (4/26, 15.4%) than in the normal-anatomy group (3/74, 4.1%; p = 0.049). Mean postoperative hospital stay was longer in the variation group (5.4 ± 1.6 vs 4.1 ± 1.2 days, p = 0.003). Pelvic haematoma, ureteric injury and surgical-site infection were numerically more frequent in the variation group, but the between-group differences were not statistically significant (p = 0.121, 0.432 and 0.271, respectively) **(Table 4).**

Table 1: Distribution of patients according to demographic characteristics and surgical procedures

Variable	Number (n=100)	Percentage (%)
Age Group (years)		
21–30	8	8.0
31–40	24	24.0
41–50	38	38.0
51–60	22	22.0
>60	8	8.0
Type of Surgery		
Total Abdominal Hysterectomy	46	46.0
Total Laparoscopic Hysterectomy	24	24.0
Vaginal Hysterectomy	14	14.0
Myomectomy	10	10.0
Radical Hysterectomy	6	6.0

Table 2: Anatomical variations and laterality of the uterine artery (hypothetical data)

Variable	Number (n=100)	Percentage (%)
Origin of Uterine Artery		
Anterior division of internal iliac artery (normal)	74	74.0
Umbilical artery	10	10.0
Common trunk with vaginal artery	8	8.0
Inferior gluteal artery	5	5.0
Other rare origins	3	3.0
Laterality of Variations		
No variation	74	74.0
Unilateral variation	20	20.0
Bilateral variation	6	6.0

Table 3: Comparison of operative parameters according to uterine artery anatomy

Parameter	Normal Anatomy (n=74)	Anatomical Variation (n=26)	p value
Operative duration (minutes)	88.5 ± 16.2	104.8 ± 18.4	0.001
Estimated blood loss (mL)	245 ± 78	342 ± 102	<0.001
Difficult uterine artery identification (%)	8 (10.8%)	11 (42.3%)	0.002
Additional vascular ligation required (%)	5 (6.8%)	7 (26.9%)	0.011

Table 4: Intraoperative and postoperative complications according to uterine artery anatomy

Complication	Normal Anatomy n (%)	Anatomical Variation n (%)	p value
Minor vascular bleeding	4 (5.4%)	5 (19.2%)	0.041
Pelvic hematoma	1 (1.4%)	2 (7.7%)	0.121
Ureteric injury	1 (1.4%)	1 (3.8%)	0.432
Blood transfusion	3 (4.1%)	4 (15.4%)	0.049
Surgical site infection	2 (2.7%)	2 (7.7%)	0.271
Mean hospital stay (days)	4.1 ± 1.2	5.4 ± 1.6	0.003

Discussion:

In the present observational study, checked the anatomical variations of uterine arteries during gynaecological surgery and its effect on surgical outcome were evaluated. These results showed that the anterior division of the internal iliac artery was the most common origin of the uterine artery, yet a significant branch of the other variations was found. Operative time, blood loss and difficulty finding and ligating the uterine artery, in addition to needing further vascular control, were associated with these vascular variations. The observations point to the need for detailed knowledge of the anatomy of the putative vessels in the pelvic region for enhanced surgical safety and reduced perioperative complications. Matsas *et al.* noted that variations in the uterine arteries and ureters may complicate abdominal hysterectomy if they are not recognized, supporting careful pelvic dissection and intraoperative identification of these structures **[11]**. Understanding the anatomy of the uterine arteries is not just important to regular gynecological surgery, but it has actually come into play in a more recently relevant way in minimally invasive treatments and fertility-preserving measures. There is a critical need for accurate knowledge of the uterine arterial anatomy and collateral circulation of the pelvis in the effective application of uterine artery embolization (UAE). according to recent systematic reviews. Embolization techniques resulted in good reproductive outcomes in carefully selected women without compromising uterine function, showing the need for knowledge of each woman's vascular anatomy when planning embolization. Additionally, their systematic review/analysis showed that the proper catheterization of the variants may lead to better procedural success and less complication **[12].** Patients with anatomical variations in the current study had higher amount of operative blood loss when compared with those who had classical vascular anatomy. The same conclusions have been arrived at during comparisons of other uterine-preserving procedures. In the above systematic review and meta-analysis of the efficacy and safety of uterine artery embolization vs myomectomy for uterine fibroids, Peng *et al* concluded that in patient care, a thorough understanding of uterine vascular anatomy is crucial to the successful embolization and to ensure effective hemostasis and reduce intraoperative bleeding and short and long term complications. Embolization and surgery are technically different procedures but both depend on an understanding of uterine arterial branching patterns to achieve procedure success **[13].** Fatima *et al.* found similar results comparing uterine artery embolization and myomectomy in women who presented with uterine fibroids and symptoms. Their study showed that a thorough understanding of the vascular anatomy of the pelvis is an important factor to take into account for a procedural success and impacts postoperative results, recurrence rate and complications. Individualized treatment planning, in relation to the vascular anatomy, should be taken into account as also an important aspect of modern gynecological management was pointed out by the authors **[14].** Since the focus is currently on the evidence for making decisions, several comparative studies of hysterectomy vs. UUE for symptomatic fibroids of the uterus have been conducted. Recently, Chen and You published a systematic review protocol emphasising the value of comparing these treatment options in terms of operative morbidity, blood loss, hospital stay and long-term clinical outcomes in particular. Their work highlights the need for the precise definition of uterine vascular anatomy prior to choosing the best treatment, especially for women who are young and wish to keep their options open for possible future conceptions **[15].** The results of the present study also showed that there was a relationship between the presence of variant anatomy of the uterine artery with the technical difficulty of vascular ligation. This is similar to other recent meta-analyses that have compared UAE against myomectomy. Tzanis *et al.* found that, while both procedures were effective treatments for uterine fibroids, the procedural success is heavily dependent on the knowledge of fine details of the pelvic vascular anatomy and careful vascular management. Identification of the variation of the anatomical structures enables surgeons to prepare for the presence of unusual arterial branches, minimising the operative risks and maximising haemostasis **[16].** Even though the study has been conducted on elective gynecological surgery the findings have implications regarding obstetrics surgery too. The uterine artery ligations are often done to stop severe obstetric bleeding and to save the uterus. A following pregnancy after bilateral uterine artery (BUA) ligation tended to have a good outcome, either of the mother or the child, suggesting that if the procedure is well done, a viable uterus is preserved and bleed is controlled, so no problem. The utero-ovarian ligament is crucial for correct identification prior to ligation **[17].** The results of the same, a team of Chinese researchers led by Lin *et al.*, however, show that early uterine artery control during cesarean deliveries in patients with placenta previa accreta also reduced blood loss in patients without an increased risk of significant complications. They conclude that determination of correct localization of the uterine artery and the knowledge of the anatomic relationships of the artery with its neighbouring structures are still key factors in successful pelvic surgery and are especially important in complex obstetric surgery where the vascular anatomy is altered and haemorrhagic risk is high **[18].** The description of uterine vascular anatomy will continue to improve with the rapid progress in the field of artificial intelligence and computational imaging. Recently, Hosseini-Siyanaki *et al.* have shown the prospects of machine learning algorithms in predicting clinical outcomes after minimally invasive treatment for uterine fibroids. Advanced AI could contribute to preoperative image analysis, allowing for patient-specific vascular patterns to be identified and tailored surgical approaches developed, potentially minimizing complications during the surgery. Advanced imaging combined with predictive computational models could thus be the next step to precision gynecological surgery **[19].** Overall, the findings of this hypothetical study concur with other studies and evidence that anatomical variations of the uterine artery are clinically significant and should not be considered otherwise infrequent anomalies. Some of the imperative prerequisites to limit blood loss, avoid vascular and ureteric injuries and increase surgical successes are: preoperative imaging where appropriate, careful retroperitoneal dissection,

careful anatomical determination of the uterine artery prior to its ligation and ongoing education of anatomy. Advanced imaging modalities and artificial intelligence based vascular mapping should allow for future prospective studies at multiple centres to further deepen the understanding of the vascular anatomy at the pelvis and improve the safety of gynaecologic and obstetric surgery.

Conclusion:

Anatomical variations of the uterine artery were not uncommon and were associated with greater surgical complexity, longer operative time, increased intraoperative blood loss and a higher requirement for supplemental vascular control. Careful identification of the uterine artery, meticulous pelvic dissection and thorough knowledge of pelvic vascular anatomy are essential to minimize vascular and ureteric injuries during gynecological surgery. Thus, data support greater awareness of uterine artery variations and the selective use of pre-operative vascular imaging to improve surgical planning and perioperative outcomes.

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