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Original Research

Association of Uterine Artery Ligation at Its Origin With Reduced Early Postoperative White Blood Cell Count Changes After Robotic Hysterectomy

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Abstract

Background: Uterine artery ligation (UAL) may reduce uterine blood flow and facilitate hemostasis during hysterectomy; however, its association with early postoperative inflammatory changes remains unclear. This study aimed to compare laboratory findings and surgical outcomes based on whether UAL was performed during robotic hysterectomy (RH). **Methods:** We retrospectively reviewed patients who underwent RH using the da Vinci Xi, da Vinci SP, or da Vinci 5 system at Korea University Anam Hospital between January 2022 and July 2025. Patients were divided into a UAL group and a non-UAL group according to whether UAL was performed using Hem-o-Lok® clips (Teleflex Medical) at the uterine artery origin. Postoperative white blood cell (WBC) change was further assessed using the WBC ratio (postoperative day 1 [POD 1] WBC/preoperative WBC), analyzed both as a continuous variable and categorically using an exploratory threshold of 1.3 for logistic regression analysis. Statistical analyses were performed using Student's *t*-test, the chi-square test, and logistic regression analysis. **Results:** Among 354 patients, 146 were classified into the UAL group and 208 into the non-UAL group. Surgical time was significantly longer in the UAL group than in the non-UAL group ($p < 0.001$). However, pericervical bipolar coagulation time and postoperative WBC change were significantly lower in the UAL group ($p = 0.017$ and $p < 0.001$, respectively). On multivariate logistic regression analysis, UAL was independently associated with a reduced risk of greater postoperative WBC change (adjusted odds ratio [OR], 0.25; $p < 0.001$). **Conclusions:** Hem-o-Lok®–assisted UAL during RH was associated with reduced early postoperative WBC elevation and shorter bipolar coagulation time, suggesting a potential benefit in attenuating the early postoperative inflammatory response.

Keywords: robotic hysterectomy; uterine artery ligation; white blood cell; postoperative inflammatory response; minimally invasive surgery; surgical outcomes; Hem-o-Lok® clips

1. Introduction

Hysterectomy is one of the most commonly performed gynecologic surgeries in the United States. According to the 2021 National Health Interview Survey (NHIS), approximately 14.6% of women aged 18 years or older have undergone a hysterectomy, with a higher prevalence observed in older age groups [1]. In Korea, hysterectomy is the second most commonly performed gynecologic surgery following cesarean section. According to data from the National Health Insurance Service, 39,102 hysterectomies were performed in 2023, of which 10,980 were performed in women in their 40s, accounting for the third highest number among all surgical procedures performed in Korea [2]. Hysterectomy can be performed using several approaches, including vaginal, abdominal, and laparoscopic techniques [3]. Since the introduction of laparoscopic hysterectomy, advances in uterine manipulators and energy devices have improved surgical precision and expanded the adoption of minimally invasive practice [4,5].

In 2005, the da Vinci Surgical System received Food and Drug Administration (FDA) approval for gynecologic use [6]. Its subsequent adoption has been substantial: in Denmark, the rate of robotic hysterectomy (RH) rose from 0.7 to 48.8 per 100,000 person-years between 2008 and 2015 [7]. Similarly, in the United States, the proportion of RH increased from 0.5% to 9.5% between 2007 and 2010 [8]. Performing surgery with the da Vinci Surgical System involves substantial costs, including initial system acquisition, disposable instruments, maintenance and servicing of reusable equipment, and training for surgeons and other medical personnel; therefore, RH is generally more expensive than alternative approaches from the patient's perspective [9,10]. Nevertheless, robotic surgery offers several advantages, including stable, surgeon-controlled visualization, high-definition three-dimensional imaging, tremor reduction, and EndoWrist-equipped instruments that enable precise manipulation with reduced surgeon fatigue [11].

However, regardless of whether hysterectomy is performed via a vaginal, abdominal, laparoscopic, or robotic approach, surgeons must remain vigilant for potential complications, including injury to the bladder, ureter, and rectum [12]. Ureter identification is an essential step when performing uterine artery ligation (UAL) at the uterine artery origin. Therefore, UAL may help reduce the risk of ureteral injury and decrease intraoperative hemorrhage during hysterectomy [13]. Based on this rationale, several studies have evaluated the surgical benefits, safety, and feasibility of performing UAL during hysterectomy [14,15,16,17,18,19,20,21]. These previous studies have primarily focused on surgical outcomes, including complications and perioperative hemoglobin (Hb) changes [14,15,16,17,18,19,20,21]. In contrast, perioperative white blood cell (WBC) levels have been rarely investigated. Therefore, this study evaluated surgical and laboratory outcomes, including postoperative changes in WBC levels, according to UAL use in patients undergoing RH.

2. Materials and Methods

2.1 Patient Selection, Surgical Procedure, and Data Collection

We retrospectively reviewed the medical records of 354 patients who underwent RH for benign gynecologic disease at Korea University Anam Hospital between January 2022 and July 2025. All procedures were performed using the da Vinci Xi, da Vinci SP, or da Vinci 5 robotic surgical systems (Intuitive Surgical, Sunnyvale, CA, USA). During the study period, 416 patients underwent RH. Patients were excluded if they had incomplete clinical data, were lost to postoperative follow-up, underwent RH combined with procedures performed by other departments, or had suspected infections unrelated to surgery. After applying these exclusion criteria, 354 patients were included in the final analysis. A flowchart of the participant selection process is presented in Fig. 1.

UAL can be classified as ligation at the origin of the uterine artery from the internal iliac artery or at the uterine level. In this study, UAL was defined as ligation at the uterine artery origin following retroperitoneal dissection with ureter identification. Patients were accordingly categorized into the UAL and non-UAL groups. To perform UAL, the peritoneum was entered within the triangle of freedom, formed by the round ligament of the uterus, the infundibulopelvic (IP) ligament, and the external iliac vessels, using robotic monopolar scissors (Intuitive Surgical, Sunnyvale, CA, USA), followed by gentle air insufflation to facilitate retroperitoneal dissection. After entering the lateral pelvic retroperitoneum, the ureter and uterine artery branching from the internal iliac artery were identified, and their crossing relationship was confirmed to ensure safe UAL. Subsequently, 5-mm Hem-o-Lok® clips (Teleflex Medical, Research Triangle Park, NC, USA) were applied to the medial and distal portions of the uterine artery, which was then transected using the robotic vessel sealer (Intuitive Surgical, Sunnyvale, CA, USA) or robotic bipolar forceps (Intuitive Surgical, Sunnyvale, CA, USA) in combination with monopolar scissors. Fig. 2 shows the key anatomical structures and surgical steps using Hem-o-Lok® clips.

All patients initially underwent outpatient ultrasonography. When lesion progression or endometrial (EM) pathology was suspected, additional preoperative imaging, including computed tomography (CT) or magnetic resonance imaging (MRI), was performed. In addition, baseline patient characteristics, including age, weight, height, menopausal status, comorbidities, and history of prior surgery, were obtained from electronic medical records. Comorbidities were categorized as hypertension, diabetes, or others, including dyslipidemia, thyroid disease, and asthma. Surgical outcomes included the type of da Vinci surgical system used, robot docking time, operative time, length of hospital stay, postoperative fever, additional analgesic use beyond routine patient-controlled analgesia (PCA), and the incidence of intraoperative and postoperative complications. Postoperative fever was defined as at least one episode of body temperature ≥38.0 °C during postoperative hospitalization. As all patients routinely received PCA after surgery, additional analgesic use was defined as the administration of any analgesic agent beyond routine PCA at least once during postoperative hospitalization. In addition, pericervical uterine artery bipolar coagulation time was assessed and defined as the total duration of bipolar coagulation applied to the uterine artery and adjacent tissue in the pericervical region during hysterectomy. Robot docking time was defined as the interval between positioning the robotic patient car and completion of docking of all robotic arms to the ports. Surgical time was defined as the duration from initial skin incision to the final skin closure. Patients undergoing RH routinely underwent preoperative laboratory tests, including complete blood count (CBC), blood chemistry tests, and other standard serum examinations. A CBC was routinely performed on postoperative day 1 (POD 1). Changes in Hb and WBC levels were calculated by comparing the POD 1 values with preoperative values, and these changes were compared between the UAL group and the non-UAL group. Furthermore, postoperative WBC changes were further evaluated using the WBC ratio, defined as the POD 1 WBC count divided by the preoperative WBC count. The WBC ratio was initially analyzed as a continuous variable between the two groups. For subsequent multivariable logistic regression analysis, receiver operating characteristic (ROC) curve analysis was performed to identify an exploratory WBC ratio threshold according to UAL status. This analysis yielded an area under the curve (AUC) of 0.758. Based on this analysis, a WBC ratio threshold of 1.3, with a sensitivity of 45.2% and

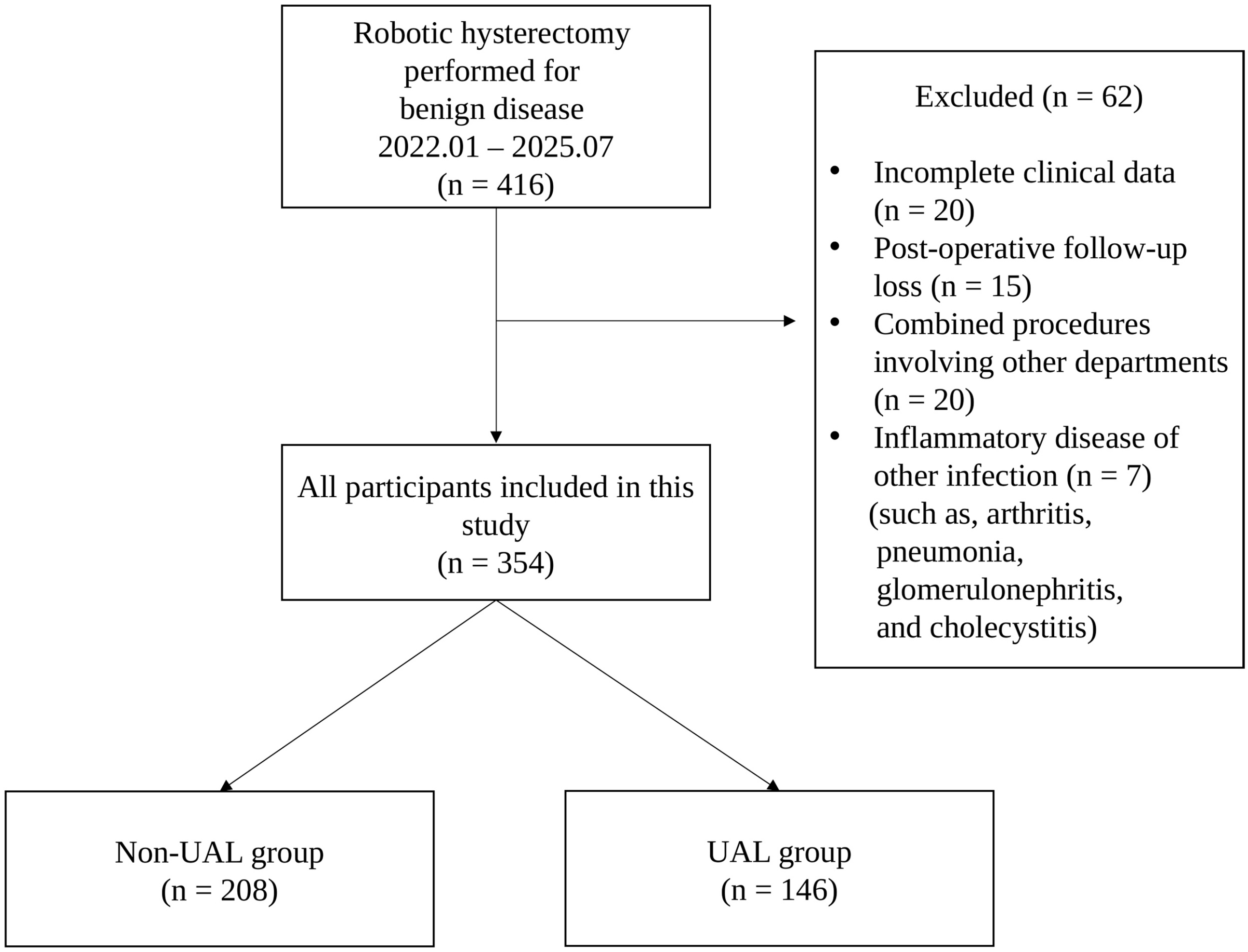

Fig. 1. Flowchart of the study participant selection process. UAL, uterine artery ligation.

a specificity of 82.7%, was used as an exploratory cutoff to define a greater postoperative increase in WBC levels.

2.2 Statistical Analysis

Continuous variables were compared between the UAL group and the non-UAL group using Student's *t*-test, while categorical variables were analyzed using the chi-square test or Fisher's exact test, as appropriate. Univariate and multivariate logistic regression analyses were performed to identify factors associated with greater postoperative WBC change based on the binary WBC ratio classification. Statistical significance was defined as a p-value < 0.05. All analyses were performed using SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA).

3. Results

Of the 354 patients included in the study, 208 were assigned to the non-UAL group and 146 to the UAL group. Patient characteristics are summarized in Table 1. Age ranged from 34 to 69 years, with an overall mean age of 48.68 ± 5.24 years. Mean age was 48.26 ± 5.19 years in the non-UAL group and 49.28 ± 5.69 years in the UAL group, with no statistically significant difference between groups. Mean weight was significantly greater in the non-UAL group than in the UAL group. However, there were no significant differences between the two groups in terms of height, body mass index (BMI), parity, menopausal status, comorbidities, or history of prior abdominal surgery. Indications for RH included leiomyoma, adenomyosis, EM hyperplasia, adenocarcinoma *in situ* (AIS), endometriosis, cervical pathology, pelvic organ prolapse, and others, with no significant between-group differences.

Table 2 summarizes the surgical outcomes. Robotic system type differed significantly between groups: the da Vinci SP system was used more frequently in the UAL group, whereas the da Vinci Xi and da Vinci 5 systems were used more often in the non-UAL group (p = 0.004). No significant between-group differences were observed in robot docking time, uterine weight, or adhesiolysis. Although hospital stay was statistically shorter in the UAL group than in the non-UAL group, the absolute difference was small. However, surgical time was significantly longer in the UAL group (151.85 ± 54.88 minutes) than in the non-UAL group (126.66 ± 56.83 minutes, p < 0.001). In con-

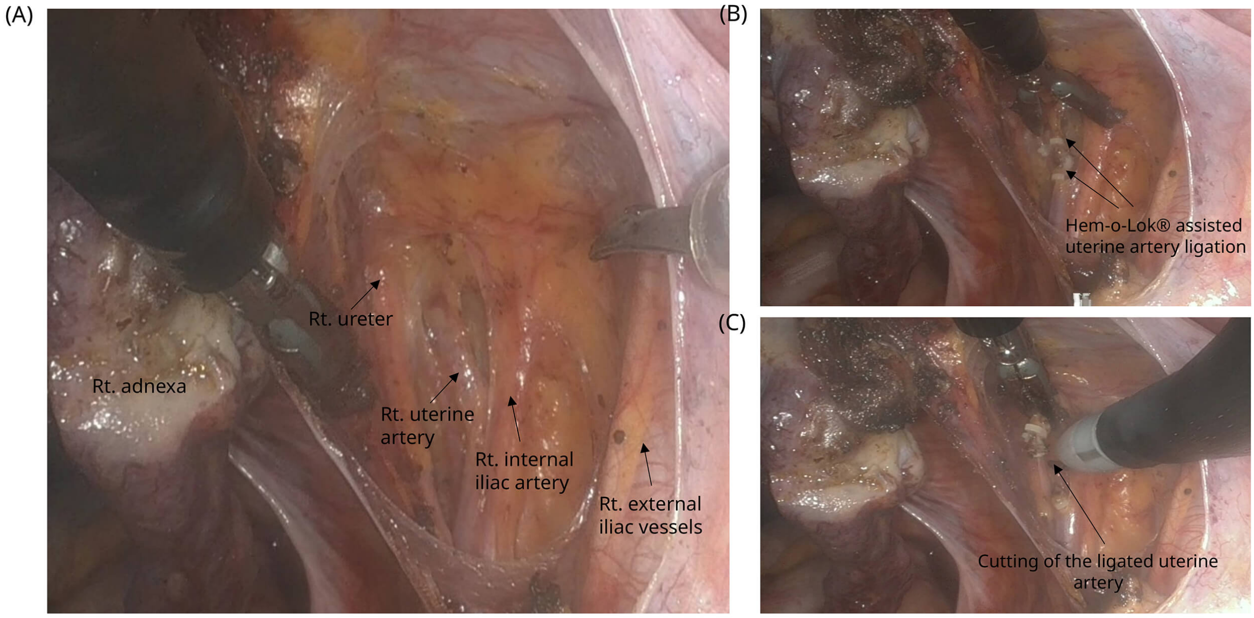

Fig. 2. Stepwise UAL and transection at its origin during RH. (A) Key anatomical structures in the right pelvic retroperitoneum are identified. (B) The uterine artery is securely ligated at its origin using a Hem-o-Lok® clip. (C) Transection of the ligated uterine artery, completing UAL at its origin. RH, robotic hysterectomy; Rt, right.

trast, pericervical uterine artery bipolar coagulation time was significantly shorter in the UAL group (2.42 ± 0.97 minutes) than in the non-UAL group (5.40 ± 2.72 minutes, p = 0.017). No cases of conversion to laparotomy were observed in either group. Regarding laboratory and postoperative recovery-related outcomes, there was no significant difference in postoperative Hb change between the two groups. However, postoperative WBC change was significantly lower in the UAL group ($2.10 \pm 1.26 \times 10^3/\mu L$) than in the non-UAL group ($3.82 \pm 2.08 \times 10^3/\mu L$, $p < 0.001$). The postoperative WBC ratio was also significantly lower in the UAL group than in the non-UAL group (1.36 ± 0.25 vs. 1.71 ± 0.44, $p < 0.001$). The proportion of patients with greater postoperative WBC increase, defined as a WBC ratio ≥1.3, was also lower in the UAL group than in the non-UAL group (64.4% vs. 86.1%, $p < 0.001$). Moreover, postoperative fever occurred significantly less frequently in the UAL group than in the non-UAL group (11.0% vs. 37.5%, $p < 0.001$). However, the frequency of additional analgesic use beyond routine PCA did not differ significantly between the two groups. Intraoperative complications included bowel injury, ureter injury, and bladder injury in the non-UAL group, and vascular injury and bladder injury in the UAL group, with no significant between-group difference. Postoperative complications included skin rash (n = 2), peritonitis (n = 2), and abdominal wound dehiscence (n = 1) in the non-UAL group, and peritonitis (n = 3) and vaginal cuff bleeding (n = 3) in the UAL group, with no significant between-group difference.

Univariate and multivariate logistic regression analyses were performed to identify factors associated with greater postoperative WBC change (WBC ratio ≥1.3) (Table 3). In the univariate regression analysis, menopausal status and performance of UAL during RH were associated with a lower risk of greater postoperative WBC change. The multivariate logistic regression analysis was performed for each variable following adjustment for age, surgical time, BMI, and uterine weight. After adjustment, menopausal status and UAL during RH remained significantly associated with a lower odds ratio (OR) of greater postoperative WBC change (menopausal status: adjusted OR, 0.55; 95% CI, 0.321–0.955; p = 0.034; UAL: adjusted OR, 0.25; 95% CI, 0.146–0.436; $p < 0.001$).

4. Discussion

In this study, most surgical outcomes showed no significant differences between the UAL group and the non-UAL group during RH. However, postoperative WBC change was lower, and pericervical uterine artery bipolar coagulation time was shorter in the UAL group, whereas postoperative Hb change did not differ between groups. Although hospital stay was statistically shorter in the UAL group, the absolute difference was small, and its clinical significance may be limited.

Total laparoscopic hysterectomy (TLH) was first performed in 1989 with coagulation of the uterine artery at its origin via the pelvic retroperitoneal space [22,23]. However, UAL during hysterectomy may also be performed at the uterine level using sutures or energy-based devices [24,25]. Comparative studies of uterine-level and origin-level UAL have reported inconsistent results. Several studies have reported reduced estimated blood loss (EBL) and

Table 1. Baseline characteristics of study participants.

Characteristics	Non-UAL group (n = 208)	UAL group (n = 146)	*p*-value
Age (years)	48.26 ± 5.19	49.28 ± 5.69	0.081
Weight (kg)	62.94 ± 11.02	60.61 ± 10.16	0.044
Height (cm)	160.04 ± 5.37	159.21 ± 4.88	0.136
BMI (kg/m²)	24.57 ± 4.10	23.89 ± 3.72	0.112
Parity, n (%)			0.234
Nulliparous	39 (18.8%)	35 (24.0%)	
Multiparous	169 (81.3%)	111 (76.0%)	
Menopause status, n (%)			0.254
No	162 (77.9%)	106 (72.6%)	
Yes	46 (22.1%)	40 (27.4%)	
Comorbidities, n (%)			0.576
No	156 (75.0%)	104 (71.2%)	
Hypertension	29 (13.9%)	21 (14.4%)	
Diabetes	8 (3.8%)	4 (2.7%)	
Others	15 (7.3%)	17 (11.7%)	
Indications for RH, n (%)			0.454
Leiomyoma	125 (60.1%)	102 (69.9%)	
Adenomyosis	48 (23.1%)	20 (13.7%)	
EM hyperplasia	11 (5.3%)	5 (3.4%)	
AIS	12 (5.8%)	9 (6.2%)	
Endometriosis	4 (1.9%)	3 (2.1%)	
Cervical pathology	3 (1.4%)	3 (2.1%)	
Pelvic prolapse	2 (1.0%)	1 (0.7%)	
Others	3 (1.4%)	3 (2.1%)	
Previous abdominal operation history, n (%)			0.748
No	107 (51.4%)	78 (53.4%)	
Yes	101 (48.6%)	68 (46.6%)	

Note: Values are presented as mean ± standard deviation (SD) or n (%).
BMI, body mass index; EM, endometrial; AIS, adenocarcinoma *in situ*.

shorter operative time without increased complications with origin-level UAL [16,20,26], and Kale et al. [17] reported similar findings, with no differences in postoperative Hb change or complication rates. In contrast, El-Minawi et al. [14] reported lower EBL but a trend toward longer operative time with origin-level UAL. Herein, EBL could not be evaluated. Operative time was longer with origin-level UAL, whereas postoperative Hb change did not differ between groups, despite previous reports suggesting reduced EBL and postoperative Hb decrease [19,27]. Intraoperative and postoperative complication rates also did not differ significantly between groups. Although vaginal cuff bleeding occurred more frequently in the UAL group, a causal relationship remains unclear. Anatomical variation in vaginal blood supply may affect vaginal cuff healing [28]; however, this remains unproven. Larger prospective studies are warranted to clarify whether origin-level UAL is associated with vaginal cuff complications.

Previous studies evaluating outcomes after hysterectomy have primarily focused on surgical outcomes or postoperative Hb changes, whereas evidence on postoperative WBC dynamics remains limited [14,15,16,17,18,19,20,21]. To date, a single total abdominal hysterectomy (TAH)-based study compared postoperative WBC and other inflammatory markers between UAL using an energy-based vessel sealing system and conventional uterine artery suture ligation and found no significant differences [29]. However, in the present study, postoperative WBC change was significantly lower in the UAL group than in the non-UAL group. Immediately after surgery, WBC levels increased as part of the physiological response to surgical stress. The proposed mechanisms are summarized in Fig. 3. Surgical stress triggers systemic responses characterized by increased stress hormones, such as cortisol, and pro-inflammatory cytokines, including interleukin-6 (IL-6). Tissue injury also releases immune mediators that promote the release of WBC from the bone marrow and inhibit neutrophil apoptosis, leading to leukocytosis [30,31]. Furthermore, surgical bleeding activates monocytes and neutrophils and induces a procoagulant state through the coagulation cascade. Neutrophil extracellular traps (NETs) further enhance thrombin generation and clot formation, and this coagulation-driven inflammatory milieu amplifies immune cell activation through protease-activated receptors

Table 2. Surgical outcomes according to UAL status.

Surgical outcome	Non-UAL group (n = 208)	UAL group (n = 146)	*p*-value
Robotic system type, n (%)			0.004
da Vinci Xi	81 (38.9%)	49 (33.6%)	
da Vinci SP	94 (45.2%)	88 (60.3%)	
da Vinci 5	33 (15.9%)	9 (6.1%)	
Docking time (min)	38.99 ± 45.26	42.06 ± 47.00	0.541
Surgical time (min)	126.66 ± 56.83	151.85 ± 54.88	<0.001
Pericervical uterine artery bipolar coagulation time (min)	5.40 ± 2.72	2.42 ± 0.97	0.017
Uterine weight (g)	432.92 ± 538.78	431.24 ± 332.87	0.973
Conversion to laparotomy, n (%)			NA
No	208 (100.0%)	146 (100.0%)	
Yes	0 (0.0%)	0 (0.0%)	
Adhesiolysis, n (%)			0.176
No	144 (69.2%)	91 (62.3%)	
Yes	64 (30.8%)	55 (37.7%)	
Hospital stay (days)	4.29 ± 1.29	4.03 ± 1.18	0.049
Postoperative Hb change (g/dL)	1.53 ± 1.10	1.56 ± 1.57	0.830
Postoperative WBC change ($\times 10^3/\mu L$)	3.82 ± 2.08	2.10 ± 1.26	<0.001
Postoperative WBC ratio	1.71 ± 0.44	1.36 ± 0.25	<0.001
Greater postoperative WBC increase, n (%)			<0.001
WBC ratio <1.3	29 (13.9%)	52 (35.6%)	
WBC ratio ≥1.3	179 (86.1%)	94 (64.4%)	
Postoperative fever, n (%)			<0.001
No	130 (62.5%)	130 (89.0%)	
Yes	78 (37.5%)	16 (11.0%)	
Additional analgesic use beyond PCA, n (%)			0.467
No	115 (55.3%)	75 (51.4%)	
Yes	93 (44.7%)	71 (48.6%)	
Intraoperative complication, n (%)			0.999
No	205 (98.6%)	144 (98.6%)	
Yes	3 (1.4%)	2 (1.4%)	
Postoperative complication, n (%)			0.329
No	203 (97.6%)	140 (95.9%)	
Yes	5 (2.4%)	6 (4.1%)	
Postoperative transfusion, n (%)			0.407
No	206 (99.0%)	143 (97.9%)	
Yes	2 (1.0%)	3 (2.1%)	

Values are presented as mean ± standard deviation or n (%).

Hb, hemoglobin; WBC, white blood cell; NA, not applicable; PCA, patient-controlled analgesia.

(PARs), thereby contributing to postoperative leukocytosis [32]. In this context, origin-level UAL enables earlier reduction of uterine blood flow, which may decrease intraoperative blood loss and downstream coagulation cascade activation associated with leukocytosis. Reduced bleeding may also improve visualization and limit repeated or excessive use of electrocautery and other energy-based devices. In the present study, pericervical uterine artery bipolar coagulation time was significantly shorter in the UAL group, suggesting that less thermal coagulation may have been required. Given these devices induce tissue injury and activate inflammatory and coagulation pathways, limiting their use may further attenuate leukocytosis [33]. Therefore, origin-level UAL may reduce conditions that promote postoperative leukocytosis, providing a biologically plausible explanation for the observed association between UAL and a smaller postoperative WBC increase in the present study. However, this mechanism should be interpreted as a hypothesis, as exact blood loss, coagulation markers, and additional inflammatory markers were not evaluated in this study. Whether this biochemical difference translates into meaningful patient-centered clinical benefits remains unclear. Because the postoperative WBC ratio is an indirect surrogate marker of inflammation, postoperative fever and additional analgesic use beyond routine PCA were also evaluated. Postoperative fever occurred significantly less

Table 3. Univariate and multivariate logistic regression analyses of factors associated with greater postoperative WBC changes (WBC ratio ≥1.3).

Factors associated with greater postoperative WBC change						
	OR*	95% CI	*p*-value	OR*	95% CI	*p*-value
Age (years)	0.96	(0.919, 1.006)	0.086	0.97	(0.928, 1.020)	0.250
Weight (kg)	1.02	(0.993, 1.043)	0.154	1.02	(0.955, 1.085)	0.578
Height (cm)	1.01	(0.966, 1.063)	0.586	1.01	(0.963, 1.062)	0.643
BMI (kg/m²)	1.04	(0.977, 1.114)	0.208	1.02	(0.955, 1.098)	0.505
Parity						
Nulliparous	1.00	Reference		1.00	Reference	
Multiparous	0.66	(0.344, 1.283)	0.223	0.69	(0.349, 1.345)	0.272
Menopause status						
No	1.00	Reference		1.00	Reference	
Yes	0.55	(0.320, 0.950)	0.032	0.55	(0.321, 0.955)	0.034
Comorbidities						
No	1.00	Reference		1.00	Reference	
Hypertension	1.11	(0.536, 2.298)	0.778	1.06	(0.503, 2.245)	0.873
Diabetes	0.94	(0.247, 3.578)	0.927	0.84	(0.209, 3.350)	0.802
Others	1.96	(0.656, 5.840)	0.229	2.02	(0.672, 6.040)	0.211
Hysterectomy indication						
Leiomyoma	1.00	Reference		1.00	Reference	
Adenomyosis	1.72	(0.823, 3.609)	0.149	1.66	(0.781, 3.534)	0.188
EM hyperplasia	0.65	(0.217, 1.967)	0.449	0.77	(0.247, 2.371)	0.642
AIS	0.95	(0.332, 2.719)	0.925	1.16	(0.383, 3.483)	0.799
Endometriosis	0.40	(0.086, 1.827)	0.235	0.33	(0.069, 1.584)	0.167
Cervical pathology	0.30	(0.058, 1.517)	0.145	0.38	(0.071, 1.998)	0.252
Pelvic prolapse	0.59	(0.053, 6.685)	0.673	1.01	(0.077, 13.321)	0.994
Others	0.59	(0.106, 3.337)	0.554	0.75	(0.124, 4.481)	0.749
Previous abdominal operation history						
No	1.00	Reference		1.00	Reference	
Yes	0.94	(0.572, 1.551)	0.814	0.94	(0.564, 1.554)	0.799
Robotic system type						
da Vinci Xi	1.00	Reference		1.00	Reference	
da Vinci SP	0.58	(0.334, 1.018)	0.058	0.66	(0.370, 1.169)	0.154
da Vinci 5	0.79	(0.332, 1.870)	0.589	0.90	(0.369, 2.213)	0.826
Docking time (min)	1.00	(0.997, 1.009)	0.331	1.00	(0.997, 1.008)	0.420
Surgical time (min)	1.00	(0.997, 1.006)	0.521	1.01	(1.000, 1.010)	0.070
Pericervical uterine artery bipolar coagulation time (min)	0.74	(0.459, 1.202)	0.225	0.80	(0.441, 1.450)	0.462
Uterine weight (g)	1.00	(0.999, 1.001)	0.770	1.00	(0.999, 1.000)	0.526
Conversion to laparotomy						
No	1.00			1.00		
Yes	Not estimable	(no laparotomy cases)	-	Not estimable	(no laparotomy cases)	-
Adhesiolysis						
No	1.00	Reference		1.00	Reference	
Yes	1.27	(0.740, 2.171)	0.388	1.20	(0.683, 2.108)	0.526
UAL status						
No	1.00	Reference		1.00	Reference	
Yes	0.29	(0.174, 0.492)	<0.001	0.25	(0.146, 0.436)	<0.001

Note: OR*, adjusted ORs were calculated for each variable after adjustment for age, surgical time, BMI, and uterine weight; OR, odds ratio; CI, confidence interval; EM, endometrial.

frequently in the UAL group, which may partially support the clinical relevance of the smaller postoperative WBC increase. However, additional analgesic use beyond routine PCA did not differ significantly between the groups. There-

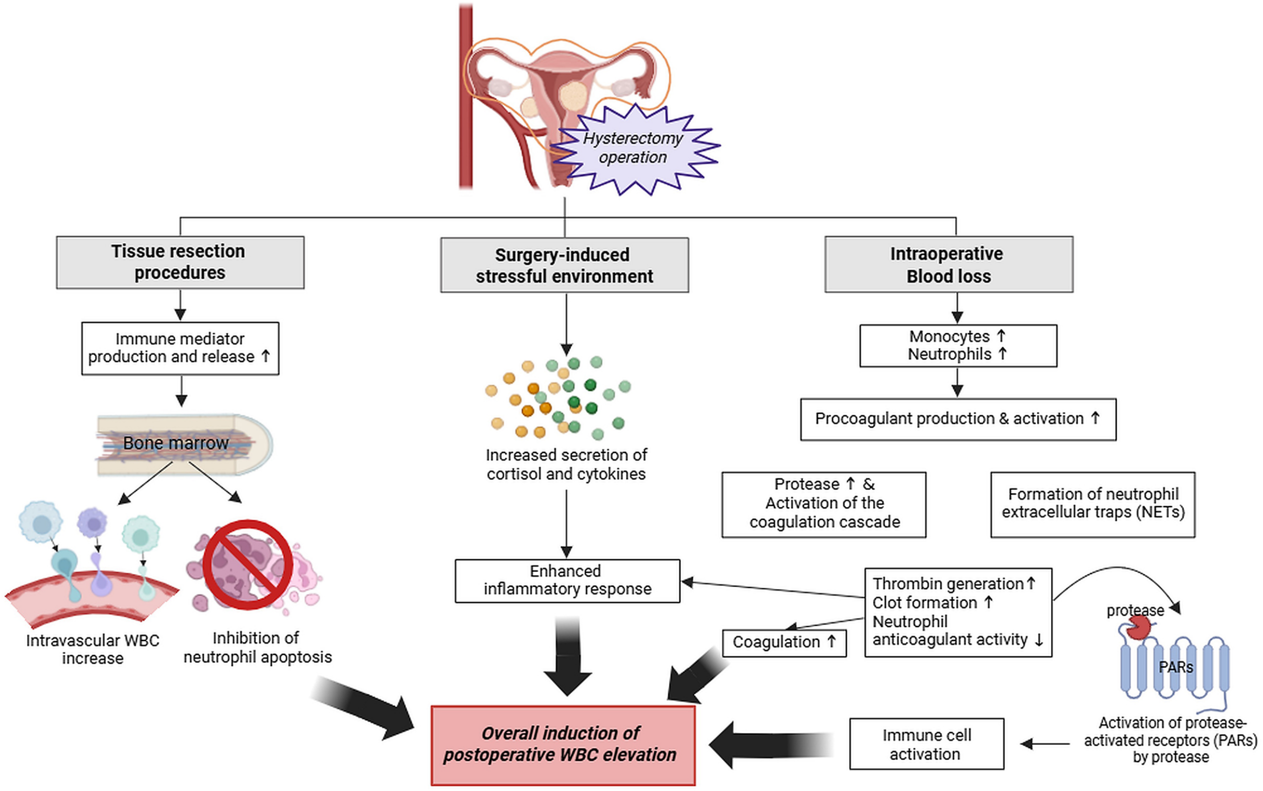

Fig. 3. Mechanistic overview of postoperative WBC elevation following surgery. NETs, neutrophil extracellular traps; PARs, protease-activated receptors. Figure created on BioRender.com.

fore, UAL did not demonstrate consistent benefits across all postoperative recovery-related outcomes, and these findings should be interpreted with caution. In addition, the longer operative time observed in the UAL group should be considered a potential trade-off when interpreting the benefits of origin-level UAL. Further studies are needed to determine whether UAL is associated with meaningful patient-centered benefits, such as reduced postoperative pain, fewer complications, and improved recovery outcomes.

Notably, performing UAL at its origin requires a thorough understanding of pelvic retroperitoneal anatomy and advanced surgical skill. In patients with multiple uterine leiomyomas, large pelvic masses, or severe endometriosis, pelvic anatomy may be distorted, and particular caution is required when performing origin-level UAL [19,34]. In addition, pelvic vascular anatomy is complex and includes collateral pathways. Therefore, ligation of the uterine artery at its origin may reduce the main arterial supply to the uterus but may not fully interrupt uterine or parametrial blood flow, as collateral or reverse flow can occur through adjacent pelvic vascular networks. Small branches related to the ureter or parametrial tissues should also be considered during dissection and ligation. Thus, UAL should be interpreted as a procedure that reduces the main arterial supply to the uterus rather than one that completely interrupts all pelvic collateral circulation. During retroperitoneal dissection, monopolar scissors or other energy-based devices may cause unintended ureteral, bowel, or vascular injuries, potentially resulting in pelvic hematoma, massive bleeding, or reoperation [34,35]. Thus, although origin-level UAL may offer potential benefits, such as reduced bleeding and attenuation of postoperative WBC elevation, it should be performed with careful patient selection and refined surgical technique.

Limitations

This study has several limitations. First, its retrospective design did not permit longitudinal follow-up. Second, because EBL was recorded as $<$300 mL or $\geq$300 mL rather than as an exact volume, objective comparisons of EBL between groups were not possible. Third, the postoperative WBC ratio and postoperative fever assessed in this study may reflect the early postoperative inflammatory response and recovery. However, these variables are nonspecific and should be interpreted with caution. Postoperative WBC elevation and fever can be influenced by multiple perioperative factors, including fluid administration, steroid use, systemic stress response, atelectasis, and infection risk. Therefore, although UAL was associated with a smaller postoperative WBC increase and a lower frequency of postoperative fever, these findings do not necessarily confirm a definitive reduction in postoperative inflammation or a patient-centered clinical benefit. In addition, this study did not evaluate other inflammatory markers, such as C-reactive protein, neutrophil-to-lymphocyte ratio, or IL-6. Further prospective studies incorporating validated inflammatory markers and clinical recovery outcomes are needed to clarify the clinical significance of these findings. Fourth, postoperative WBC change was evaluated using both the absolute WBC change and the WBC ratio, which reflects the relative increase in POD 1 WBC compared with the preoperative WBC level. For multivariable logistic regression analysis, a greater postoperative WBC increase required categorization. Therefore, a WBC ratio threshold of 1.3 was used as an exploratory cutoff, based on ROC curve analysis of the WBC ratio distribution according to UAL status. However, this threshold has not been externally validated as a clinical cutoff. In addition, dichotomizing the continuous WBC ratio may reduce statistical sensitivity and may lead to information loss or misclassification bias. Therefore, the cutoff-based logistic regression results using a WBC ratio threshold of 1.3 should be interpreted cautiously. Future studies using external cohorts are needed to determine whether this threshold can reliably identify greater postoperative WBC increase and whether it is meaningfully associated with patient-centered recovery outcomes, including postoperative fever. Fifth, as this was a retrospective, nonrandomized study, selection bias may have influenced the results. The decision to perform UAL was based on the operating surgeon's judgment and may have been influenced by surgeon preference, pelvic anatomy, anticipated surgical difficulty, anticipated bleeding risk, robot platform, and calendar period. In addition, UAL can be considered a technical modification rather than a fully standardized protocol. Therefore, differences in surgeon experience, case complexity, and hemostatic strategies may have influenced postoperative WBC changes. To partially account for differences in bipolar energy use near the cervix, pericervical uterine artery bipolar coagulation time was evaluated, and was significantly shorter in the UAL group. However, this variable alone cannot fully explain all differences in surgical technique. Furthermore, residual confounding from unmeasured intraoperative factors, such as tissue handling, ischemia time, and the surgeon's learning curve, may also persist despite adjustment. Accordingly, the findings should be interpreted as an association between UAL use during RH and postoperative WBC change rather than evidence of a direct causal relationship. Sixth, the use of multiple robotic platforms may have introduced heterogeneity. Although inclusion of the da Vinci Xi, da Vinci SP, and da Vinci 5 Surgical Systems reflects current clinical practice, these platforms may differ in visualization, instrument handling, energy delivery, and ergonomics. Such differences may have affected operative time, tissue trauma, and postoperative WBC changes. Therefore, the influence of platform-related heterogeneity could not be fully excluded. Future studies using a single robotic platform or platform-stratified analyses are needed to better evaluate the association between UAL and postoperative outcomes, including postoperative WBC changes, while minimizing the impact of platform-related heterogeneity. Seventh, this was a single-center study with a relatively small sample size, limiting generalizability. Nevertheless, a key strength of this study is that it is the first to objectively evaluate postoperative WBC changes according to the performance of origin-level UAL in patients undergoing RH. Using quantitative data, these findings demonstrate an association between origin-level UAL and a smaller early postoperative WBC increase. Future multicenter prospective studies with larger sample sizes are warranted to validate and generalize these findings.

5. Conclusions

In this study, origin-level UAL during RH was associated with a smaller early postoperative WBC change and a reduced OR for a greater postoperative WBC increase after adjustment. In addition, the shorter pericervical bipolar coagulation time observed in the UAL group suggests that UAL may reduce the need for thermal coagulation around the cervix. Overall, these findings support a potential technical advantage of origin-level UAL during RH. However, future prospective studies using validated inflammatory markers are warranted to clarify their clinical significance.

Abbreviations

UAL, uterine artery ligation; WBC, white blood cell; OR, odds ratio; NHIS, National Health Interview Survey; FDA, Food and Drug Administration; RH, robotic hysterectomy; Hb, hemoglobin; CT, computed tomography; MRI, magnetic resonance imaging; CBC, complete blood count; POD 1, postoperative day 1; ROC, receiver operating characteristic; AUC, area under the curve; IRB, institutional review board; BMI, body mass index; AIS, adenocarcinoma *in situ*; CI, confidence interval; EBL, estimated blood loss; NETs, neutrophil extracellular traps; PARs, protease-activated receptors; TLH, total laparoscopic hysterectomy; TAH, total abdominal hysterectomy.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions

S-ML contributed to conceptualization, data curation, formal analysis, writing—original draft, and writing—review & editing. HS contributed to conceptualization and data curation. SK contributed to formal analysis. K-JM contributed to formal analysis. SL contributed to data interpretation and writing—review & editing. J-HH contributed to visualization. J-YS contributed to conceptualization, study design, supervision, and writing—review & editing. J-KL contributed to visualization. N-WL contributed to visualization. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study was conducted in accordance with the Declaration of Helsinki. The research protocol was approved by the Ethics Committee of the Korea University Anam Hospital (2026AN0006). The need for informed consent was waived due to the retrospective nature of this study.

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Conflicts of Interest

The authors declare no conflicts of interest.

Declaration of AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used ChatGPT-Pro only for language editing and grammar checking. The authors reviewed and edited all AI-assisted outputs and take full responsibility for the final content of the manuscript.

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