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Oncologic Outcomes and HPV Persistence After LEEP and Conization for Cervical Intraepithelial Lesions: Association of Cone Depth with Positive Surgical Margins in a Single-center 10-year Retrospective Cohort

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ABSTRACT

Objective: Positive surgical margins (PSM) after excisional treatment for cervical intraepithelial lesions affect surveillance and repeat treatment. Cone depth is modifiable, but deeper excision may increase obstetric risk. We assessed PSM prevalence, associated factors, and colposcopy-histology agreement.

Methods: We conducted a single-center retrospective cohort study of patients who underwent loop electrosurgical excision procedure (LEEP) or cervical conization between 7 January 2015 and 26 September 2025. PSM was defined as margin involvement at any surgical margin. Factors associated with PSM were evaluated using multivariable bias-reduced (Firth) logistic regression including cone depth (cm, continuous), high-grade squamous intraepithelial lesion (HSIL)-or-higher grade histology on the excision specimen (yes/no), and procedure type (LEEP vs. conization), using a complete-case approach.

Results: Among 246 patients, 92 (37.4%) underwent LEEP and 154 (62.6%) conization. Median cone depth was 1.6 cm (interquartile range 1.0-2.5) and was greater with conization than LEEP (2.0 vs. 1.5 cm; $p<0.001$). PSM occurred in 20/241 (8.3%) and did not differ between LEEP and conization (6.6% vs. 9.3%). Reconization was performed in 57/243 (23.5%) and was more frequent after conization (30.5% vs. 12.0%). Recurrence occurred in 16/246 (6.5%). In the Firth model (complete cases $n=215$; 18 PSM events), greater cone depth was associated with lower odds of PSM (adjusted odds ratio 0.46 per 1-cm increase; 95% confidence interval 0.24-0.88; $p=0.018$), whereas HSIL-or-higher histology and procedure type were not statistically significant. Colposcopy-histology agreement was low (Cohen's $\kappa=0.168$). Follow-up human papillomavirus (HPV) results were available for a small subset and are descriptive.

Conclusion: Greater cone depth was associated with reduced odds of PSM. Given limited event numbers and non-standardized follow-up, non-significant associations and HPV outcomes should be interpreted cautiously. Tailoring excision depth to lesion location may reduce margin positivity while balancing obstetric risks.

Keywords: Cone depth, positive surgical margins, LEEP, cervical conization, CIN, HSIL

INTRODUCTION

Cervical intraepithelial neoplasia (CIN) represents a well-characterized spectrum of precursor lesions in the pathogenesis of cervical cancer and remains a central target of screening programs that have contributed to reducing the incidence of invasive disease (1-3). The overarching aim of clinical management is to eradicate high-grade lesions, particularly high-grade squamous intraepithelial lesion (HSIL)/CIN2 to CIN3, while avoiding unnecessary overtreatment and minimizing cervical tissue loss that may compromise fertility and adversely affect obstetric outcomes (4-6). Striking this balance is especially critical in women of reproductive age and underscores the need for individualized treatment strategies.

Excisional procedures for high-grade cervical lesions have both diagnostic and therapeutic value. Loop electrosurgical excision

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procedure (LEEP) and cervical conization enable complete removal of the lesion for histopathological assessment, allowing exclusion of occult invasion, delineation of lesion margins, and provision of definitive treatment in the same setting (7,8). However, outcomes after excisional treatment are influenced by multiple factors, including extension into the endocervical canal, transformation zone type, colposcopic visibility, patient age, human papillomavirus (HPV)-related biological behavior, coexisting glandular abnormalities, and technical characteristics of the excision such as depth and volume, all of which may affect treatment success and recurrence risk (8-11).

Identification of positive surgical margins (PSM) on post-excisional pathology is among the outcomes that most strongly influences subsequent clinical management. PSM may be associated with a higher likelihood of residual disease, necessitate intensified surveillance, and, in selected cases, prompt consideration of repeat excision or escalation of treatment (11,12). Nevertheless, margin positivity does not invariably indicate residual disease, and negative margins do not completely eliminate recurrence risk; therefore, defining factors that predict PSM is clinically important (12). In this context, cone depth (i.e., the amount of tissue removed) represents a double-edged sword: insufficient depth may increase the risk of margin positivity, whereas overly deep excision has been linked to adverse obstetric outcomes such as cervical insufficiency and preterm birth (5,6,13). Accordingly, evaluating excision depth in relation to PSM using real-world clinical data may inform procedural planning, quality improvement, and patient counseling.

The diagnostic pathway leading to excisional treatment is typically guided by screening cytology, HPV testing, colposcopic assessment, and colposcopy-directed biopsy (7). In routine clinical practice, discordance may be observed between the colposcopic impression and/or biopsy findings and the final histology of the excision specimen (14,15). Such discordance can result from lesion heterogeneity, sampling limitations of biopsy, endocervical location of the transformation zone, multifocal disease, and interobserver variability in pathological interpretation (16,17). Characterizing colposcopy-to-final histology agreement under real-world conditions is therefore important for evaluating diagnostic performance and identifying opportunities for improvement.

In this single-center retrospective cohort, we aimed to determine the prevalence of PSM and to identify clinical and procedural factors associated with PSM, with particular emphasis on cone depth, among patients undergoing LEEP or cervical conization. In addition, we assessed the agreement between colposcopic impression and/or biopsy results and the final histology of the excision specimen. These findings may help inform procedural targets for excision planning and support evidence-based approaches to post-treatment surveillance and repeat-treatment decision-making.

METHODS

This single-center retrospective cohort study was conducted at University of Health Sciences Türkiye, Gaziosmanpaşa Training and Research Hospital. Clinical and pathological records of consecutive patients who underwent LEEP or cervical conization for suspected or confirmed cervical intraepithelial lesions between 07 January 2015 and 26 September 2025 were reviewed. Ethical approval was obtained from the University of Health Sciences Türkiye, Gaziosmanpaşa Training and Research Hospital Non-Interventional Ethics Committee (decision no: 134, date: 15.10.2025). Prior to analysis, all data were anonymized by removal of personal identifiers, and the study was carried out in accordance with the principles of the Declaration of Helsinki.

Demographic characteristics including age, parity, and smoking status were obtained from electronic medical records, together with preoperative screening cytology [normal/ASC-US/low-grade squamous intraepithelial lesion (LSIL)/HSIL/atypical squamous cells-cannot exclude HSIL (ASC-H)/AGC], preoperative HPV status (negative/positive), colposcopy-directed biopsy results [CIN1/CIN2/CIN3/carcinoma *in situ* (CIS)], and endocervical curettage (ECC) findings (not performed/benign/LSIL/HSIL/CIS/squamous cell carcinoma/adenocarcinoma). The type of procedure (LEEP or conization) and cone depth (cm) were recorded as operative variables. Final excision histopathology was categorized as benign, LSIL, HSIL, CIS, squamous cell carcinoma, or adenocarcinoma; for analytical purposes, a composite "CIS+" category was additionally defined to include CIS and invasive carcinomas (squamous cell carcinoma and adenocarcinoma). For the regression model, "HSIL or higher-grade histology" was defined as HSIL, CIS, or invasive carcinoma (squamous cell carcinoma or adenocarcinoma) on the excision specimen.

The primary outcome was PSM, defined as the presence of margin involvement at any surgical margin of the excision specimen. Secondary outcomes included performance of repeat excision (reconization; yes/no), recurrence (yes/no), procedure-related complications (none/bleeding/infection), and available HPV results at 12 and 24 months of follow-up (negative/positive). The relationship between colposcopic impression and final histology was examined using cross-tabulation and summarized as row percentages. Recurrence was defined as detection of histologically confirmed HSIL (CIN2+) or a higher-grade lesion during follow-up after the index excisional procedure, based on colposcopy and/or biopsy; given the retrospective, record-based design, follow-up protocols may have varied according to clinician judgment.

Excisional treatment was not routinely performed in patients with CIN1 identified on colposcopy-directed biopsy; however, in this series, all CIN1 cases that underwent excision were positive for HPV-16 and/or HPV-18 on genotyping. Accordingly, excision in the CIN1 subgroup was selected to exclude and/or treat the possibility of an underlying higher-grade lesion in the presence of high-risk HPV despite low-grade histology.

Statistical Analysis

Continuous variables were summarized as mean ± standard deviation or median [interquartile range (IQR)], as appropriate. Normality was assessed using the Shapiro-Wilk test. Between-group comparisons were performed using the Student's t-test or the Mann-Whitney U test for continuous variables and the chi-square test or Fisher's exact test, as appropriate, for categorical variables. A multivariable Firth penalized logistic regression model (bias-reduced) was used to evaluate factors associated with PSM. The prespecified model included cone depth (cm, continuous), HSIL or higher-grade histology (yes/no), and procedure type (LEEP vs. conization). Predictors were selected a priori to construct a parsimonious model given the limited number of PSM events, in line with events-per-variable considerations, and to reduce overfitting. Accordingly, the multivariable model was limited to three prespecified predictors. The selected variables were chosen to represent the key domains relevant to the study question: a modifiable excision parameter (cone depth), disease severity on the excision specimen (HSIL or higher-grade histology), and excisional technique (LEEP vs. conization). Additional clinically relevant variables (e.g., age, smoking, and preoperative HPV/cytology) were not included because of the limited number of events and variable-specific missingness, and residual confounding is therefore acknowledged as a limitation. Results are reported as adjusted odds ratios (aOR) with 95% confidence intervals (CI). Owing to missing data, analyses were conducted using a complete-case approach. The extent of missingness for each variable is summarized in Supplementary Table 1. For the PSM model, complete cases required non-missing PSM status, cone depth, final excision histopathology, and procedure type (n=215; 18 PSM events). For key between-group comparisons, absolute differences in proportions with 95% CIs were also reported to aid clinical interpretation. CIs for absolute differences were calculated using standard methods for two independent proportions. Statistical significance was defined as a two-sided $p<0.05$. Descriptive statistics and group comparisons were performed using IBM SPSS Statistics (v26.0; IBM Corp., Armonk, NY, USA), and Firth penalized regression analyses were conducted using R (R Foundation for Statistical Computing, Vienna, Austria) with the logistf package.

RESULTS

During the study period, 246 patients were evaluated; 92 (37.4%) underwent LEEP and 154 (62.6%) underwent conization. The mean age was 42.1±9.6 years, with no significant difference between procedure groups (LEEP 41.0±9.6 vs. conization 42.8±9.5; p=0.142). Median parity was 2 (IQR 1-3) in both groups (p=0.288). Among the 241 patients with available smoking data, 42.7% were current smokers, with no difference between groups (p=0.992) (Table 1).

Preoperative cytology was available for 208 patients and its distribution differed between groups (p=0.025). High-grade cytology (HSIL/ASC-H/AGC) was more frequent in the conization group than in the LEEP group (36.1% vs. 17.3%) (Table 1). The absolute difference was 18.8 percentage points (95% CI 1.0-34.1). Preoperative HPV results were recorded for 166 patients; within this subgroup, HPV positivity was 98.2% and did not differ by procedure type (p=1.000). Colposcopy-directed biopsy results were available for 237 patients and showed a marked between-group difference (p<0.001): CIN1 was more common in the LEEP group (43.0%), whereas CIN3 was more frequently observed in the conization group (54.3%) (Table 1). ECC results were documented in 245 patients and were comparable between groups (p=0.352).

Operative and postoperative outcomes are summarized in Table 2. Among the 218 patients with available cone depth data, the median cone depth was 1.6 cm (IQR 1.0-2.5); excisions were deeper in the conization group [2.0 cm (1.2-2.5)] than in the LEEP group [1.5 cm (0.8-2.0); p<0.001]. The overall complication rate was low (3/246, 1.2%), and all complications were bleeding events with no infections recorded; complication rates did not differ by procedure type (p=1.000).

Final excision histopathology was available for 243 patients and differed significantly between groups (p<0.001). Benign changes and LSIL were more common after LEEP (benign 34.1%, LSIL 37.4%), whereas HSIL and CIS were more frequently identified in the conization group (HSIL 51.3%, CIS 10.5%). PSM could be assessed in 241 patients and were observed in 20 (8.3%); the PSM rate did not differ between LEEP (6.6%) and conization (9.3%) (p=0.612). The absolute difference was 2.7 percentage points (95% CI -8.0 to 12.0). Reconization status was available for 243 patients, and 57 (23.5%) underwent repeat excision, which was more frequent in the conization group than in the LEEP group (30.5% vs. 12.0%; p=0.002). The absolute difference was 18.5 percentage points (95% CI 3.5-31.4). Recurrence occurred in 16 patients (6.5%); although the recurrence rate was higher after conization, the difference was not statistically significant (8.4% vs. 3.3%; p=0.184) (Table 2). The absolute difference was 5.2 percentage points (95% CI -4.2 to 12.8). Follow-up HPV results were available for a limited number of patients; HPV negativity was 18/24 (75.0%) at 12 months and 11/14 (78.6%) at 24 months, with no significant differences between procedure groups (p=0.665 and p=0.209, respectively). These follow-up comparisons should be interpreted as descriptive/exploratory because follow-up testing was not standardized and HPV results were available only for a small subset of patients.

The association between colposcopic impression and final histology is presented as row percentages in Table 3. Among cases with a colposcopic impression of CIN1, final histology showed benign changes in 37.8% and LSIL in 48.6%, whereas HSIL was identified in 13.5%. In cases with a CIN3 impression, HSIL was the most common final diagnosis (54.9%), and CIS+ was observed in 14.3%. In the small subgroup with a colposcopic impression of CIS, the proportion of CIS+ on final histology was 66.7% (Table 3). In an ordinal comparison between colposcopic impression (CIN1, CIN2, CIN3, CIS) and final histology categories (benign/LSIL/HSIL/CIS+), agreement was observed in 49.6% of cases, whereas 10.2%

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Table 1. Baseline characteristics and preoperative findings by procedure (LEEP vs. conization)

Variable	Overall (n=246)	LEEP (n=92)	Conization (n=154)	p-value
Age, years	42.1±9.6	41.0±9.6	42.8±9.5	0.142
Parity	2 (1-3)	2 (1-3)	2 (1-3)	0.288
Current smoking, n (%)	103 (42.7%)	39 (43.3%)	64 (42.4%)	0.992
Preoperative cytology, (n=208)				0.025
Normal	76 (36.5%)	30 (40.0%)	46 (34.6%)	
ASC-US	38 (18.3%)	21 (28.0%)	17 (12.8%)	
LSIL	33 (15.9%)	11 (14.7%)	22 (16.5%)	
HSIL	52 (25.0%)	12 (16.0%)	40 (30.1%)	
ASC-H	8 (3.8%)	1 (1.3%)	7 (5.3%)	
AGC	1 (0.5%)	0 (0.0%)	1 (0.8%)	
Preoperative HPV status (n=166)				1.000
Negative	3 (1.8%)	1 (1.4%)	2 (2.1%)	
Positive	163 (98.2%)	69 (98.6%)	94 (97.9%)	
Colposcopy-directed biopsy (n=237)				<0.001
CIN1	37 (15.6%)	37 (43.0%)	0 (0.0%)	
CIN2	102 (43.0%)	37 (43.0%)	65 (43.0%)	
CIN3	92 (38.8%)	10 (11.6%)	82 (54.3%)	
CIS	6 (2.5%)	2 (2.3%)	4 (2.6%)	
ECC (n=245)				0.352
Not done	114 (46.5%)	44 (47.8%)	70 (45.8%)	
Benign/normal	116 (47.3%)	44 (47.8%)	72 (47.1%)	
LSIL	5 (2.0%)	3 (3.3%)	2 (1.3%)	
HSIL	9 (3.7%)	1 (1.1%)	8 (5.2%)	
CIS	0 (0.0%)	0 (0.0%)	0 (0.0%)	
SCC	1 (0.4%)	0 (0.0%)	1 (0.7%)	
Adenocarcinoma	0 (0.0%)	0 (0.0%)	0 (0.0%)	

-Values are mean ± SD, median (IQR), or n (%)
-P-values: Student's t-test or Mann-Whitney U test for continuous variables; chi-square or Fisher's exact test for categorical variables
-Preoperative HPV was available in n=166 patients
LEEP: Loop electrosurgical excision procedure, ASC-US: Atypical squamous cells of undetermined significance, LSIL: Low-grade squamous intraepithelial lesion, HSIL: High-grade squamous intraepithelial lesion, ASC-H: Atypical squamous cells-cannot exclude HSIL, AGC: Atypical glandular cells, CIS: Carcinoma *in situ*, ECC: Endocervical curettage, SD: Standard deviation, IQR: Interquartile range, HPV: Human papillomavirus

were upgraded and 40.3% were downgraded; overall agreement was low (Cohen's kappa=0.168).

In multivariable Firth penalized logistic regression evaluating factors associated with PSM (complete cases: n=215; 18 PSM events), greater cone depth was associated with lower odds of PSM (adjusted odds ratio 0.46 per 1-cm increase, 95% CI 0.24-0.88; p=0.018). HSIL or higher-grade histology and procedure type (conization vs. LEEP) were not significantly associated with PSM (Table 4).

DISCUSSION

In this single-center retrospective cohort of patients undergoing LEEP or cervical conization, the rates of PSM, recurrence, and reconization were 8.3%, 6.5%, and 23.5%, respectively. The most notable finding was that cone depth was associated with lower odds of PSM in multivariable Firth penalized logistic regression (aOR 0.46 per 1-cm increase). In contrast, HSIL or higher-grade histology and procedure type (conization vs. LEEP) were not significantly associated with PSM in the multivariable model. In addition, agreement between colposcopic impression and the final histology of the excision specimen was low; notably, among cases assessed as CIN2-3 on colposcopy, final histology could shift both toward lower-grade (downgrade) and higher-grade (upgrade) diagnoses. Taken together, these observations highlight two interrelated aspects of clinical practice: the importance of achieving an adequately deep excision during procedural planning and the inherent limitations of colposcopic assessment within the diagnostic pathway (13,18,19).

The clinical relevance of PSM stems from their association with residual disease and/or recurrent CIN2+; therefore, strategies aimed at reducing margin positivity are of practical importance. Prior studies have suggested that PSM may increase the

Table 2. Operative and postoperative outcomes by procedure (LEEP vs. conization)

Variable	Overall (n=246)	LEEP (n=92)	Conization (n=154)	p-value
Cone depth, cm	1.6 (1.0-2.5)	1.5 (0.8-2.0)	2.0 (1.2–2.5)	<0.001
Any complication, n (%)	3 (1.2%)	1 (1.1%)	2 (1.3%)	1.000
Complication type (n=246)				1.000
None	243 (98.8%)	91 (98.9%)	152 (98.7%)	
Bleeding	3 (1.2%)	1 (1.1%)	2 (1.3%)	
Infection	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Final excision pathology (n=243)				<0.001
Benign	54 (22.2%)	31 (34.1%)	23 (15.1%)	
LSIL	65 (26.7%)	34 (37.4%)	31 (20.4%)	
HSIL	101 (41.6%)	23 (25.3%)	78 (51.3%)	
CIS	19 (7.8%)	3 (3.3%)	16 (10.5%)	
SCC	3 (1.2%)	0 (0.0%)	3 (2.0%)	
Adenocarcinoma	1 (0.4%)	0 (0.0%)	1 (0.7%)	
Positive surgical margin, n (%)	20 (8.3%)	6 (6.6%)	14 (9.3%)	0.612
Re-conization performed, n (%)	57 (23.5%)	11 (12.0%)	46 (30.5%)	0.002
Recurrence, n (%)	16 (6.5%)	3 (3.3%)	13 (8.4%)	0.184
12-month HPV negative†	18/24 (75.0%)	7/10 (70.0%)	11/14 (78.6%)	0.665
24-month HPV negative†	11/14 (78.6%)	5/8 (62.5%)	6/6 (100.0%)	0.209

-Values are mean ± SD, median (IQR), or n (%)
-P-values: Student's t-test or Mann-Whitney U test for continuous variables; chi-square or Fisher's exact test for categorical variables
†: Values are presented as number of HPV-negative patients/number of patients with available HPV follow-up results (%) LEEP: Loop electrosurgical excision procedure, LSIL: Low-grade squamous intraepithelial lesion, HSIL: High-grade squamous intraepithelial lesion, CIS: Carcinoma *in situ*, SD: Standard deviation, IQR: Interquartile range, HPV: Human papillomavirus

Table 3. Colposcopic impression vs. final histology

Colposcopy impression	Benign n (%)	LSIL n (%)	HSIL n (%)	CIS+ n (%)	Total
CIN1	14 (37.8)	18 (48.6)	5 (13.5)	0 (0.0)	37
CIN2	23 (22.5)	28 (27.5)	45 (44.1)	6 (5.9)	102
CIN3	12 (13.2)	16 (17.6)	50 (54.9)	13 (14.3)	91
CIS	1 (16.7)	0 (0.0)	1 (16.7)	4 (66.7)	6

-Cells show, n (row %). Final histology grouped as Benign, LSIL, HSIL, and CIS+ (CIS or invasive carcinoma)
-Included cases with both colposcopy impression and final histology available: n=236
HSIL: High-grade squamous intraepithelial lesion, LSIL: Low-grade squamous intraepithelial lesion, CIS: Carcinoma *in situ*, CIN: Cervical intraepithelial neoplasia

Table 4. Multivariable Firth penalized logistic regression for positive surgical margins

Variable	Comparison/unit	aOR	95% CI	p-value
Cone depth (cm)	Per 1 cm increase	0.46	0.24-0.88	0.018
HSIL or higher	Yes vs. no	2.14	0.72-6.36	0.173
Procedure type	Conization vs. LEEP	1.79	0.57-5.63	0.318

- Firth penalized (bias-reduced) logistic regression
- Outcome: Positive margin=1 (negative margin=0)
- Analysis performed on complete cases: n=215; events (positive margins)=18
- Reference categories: HSIL or higher (no); procedure type (LEEP)
- HSIL or higher-grade histology was defined as HSIL, CIS, or invasive carcinoma on the excision specimen

OR: Odds ratio, CI: Confidence interval, HSIL: High-grade squamous intraepithelial lesion, CIS: Carcinoma *in situ*, LEEP: Loop electrosurgical excision procedure

likelihood of residual or recurrent lesions, and that endocervical margin involvement in particular may confer a higher risk (9,12). The relatively moderate-to-low PSM rate observed in our cohort may reflect standardized practice patterns within a single center and a selected case mix; nonetheless, the identification of cone depth as a readily modifiable parameter associated with PSM is clinically meaningful.

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The inverse association between cone depth and PSM is consistent with plausible biological and technical considerations, as inadequate excision depth may lead to margin involvement in cases with endocervical extension of disease or an endocervically located transformation zone (13). However, increasing cone depth indiscriminately is not desirable, given evidence linking greater excision depth to an elevated risk of adverse obstetric outcomes, including preterm birth (5,6). Accordingly, our findings should not be interpreted as "deeper is always better," but rather as support for tailoring excision depth to lesion location while avoiding unnecessary removal of cervical tissue. This approach is particularly relevant for patient counseling and procedural planning in women of reproductive age.

From a post-treatment surveillance perspective, it is important to note that margin status alone should not be considered determinative. The 2019 risk-based management guidelines emphasize early post-treatment follow-up using HPV-based testing irrespective of margin status, with colposcopy and appropriate biopsies recommended when post-treatment HPV testing is positive (7). In our cohort, HPV results at 12 and 24 months were available only for a limited subset of patients, precluding more robust inferences regarding HPV clearance and HPV-based risk stratification. This limitation reflects a common challenge in retrospective real-world series, where follow-up testing is not uniformly standardized, and it underscores the need for prospective studies and more structured follow-up protocols.

The low level of agreement between colposcopic impression and final excision histology is also clinically relevant. Given the operator-dependent nature of colposcopy, lesion heterogeneity, and inherent sampling limitations of biopsy, perfect concordance between colposcopic assessment and histopathological outcomes is not expected (18,20). Prior studies have similarly reported low kappa values, indicating only limited concordance between colposcopic impression and histology (20). In our series, the presence of HSIL among cases with a colposcopic impression of CIN1 may be attributable to occult high-grade foci or endocervical lesion location, whereas benign or LSIL findings among cases interpreted as CIN3 may reflect overestimation at the impression or biopsy stage, or a more limited lesion burden on the excision specimen. Collectively, these observations support a risk-based approach that integrates multiple parameters, including cytology, HPV status, colposcopic findings, ECC results, and overall clinical context, rather than relying excessively on colposcopic impression alone, particularly when making management decisions for CIN2 (7).

Notably, the reconization rate exceeded the PSM rate in our cohort. This should not be interpreted as discordant, because margin status is an imperfect surrogate for residual disease and is not the sole determinant of repeat excision (7,12). In clinical practice, reconization was frequently prompted by post-treatment surveillance findings suggestive of persistence or progression (e.g., persistent HPV positivity, high-grade cytology, or suspicious colposcopy/ECC/biopsy), and some patients were referred from external centers following abnormal follow-up tests (7). Therefore, the observed reconization frequency likely reflects real-world, risk-based management rather than margin status alone.

Study Limitations

The strengths of this study include the use of a real-world, single-center cohort accrued over an extended time period, the inclusion of both LEEP and conization, and the ability to link a modifiable technical parameter such as cone depth with clinically relevant outcomes. Key limitations are inherent to the retrospective design and include missing data for certain variables (particularly follow-up HPV results), the absence of separate reporting for endocervical versus ectocervical margin involvement, and a record-based definition of recurrence. Because multivariable analyses were based on complete cases, selection bias cannot be excluded if missingness was related to patient characteristics or outcomes. Accordingly, inferences regarding HPV clearance and HPV-based risk stratification are limited, and the follow-up outcomes should be interpreted as descriptive rather than confirmatory. Importantly, the number of PSM events was limited, which constrained model complexity; therefore, we used Firth penalized logistic regression (bias-reduced) to mitigate small-sample bias and potential separation, but residual confounding cannot be excluded (21). Given the limited number of PSM events, statistical power was modest and CIs were wide for some predictors (notably HSIL or higher-grade histology and procedure type). Therefore, non-significant associations should be interpreted cautiously and should not be taken as evidence of no effect. In addition, because procedure selection (LEEP vs. conization) was associated with disease severity, selection bias and confounding by indication should be considered when interpreting differences between procedure types.

In summary, our findings suggest that cone depth represents a modifiable determinant of PSM, and that a targeted approach aimed at achieving an adequate excision depth according to lesion location, while taking obstetric risks into account, may constitute a rational strategy in clinical practice.

CONCLUSION

In this single-center retrospective cohort, the rate of PSM was 8.3%, and greater cone depth was associated with lower odds of margin positivity in multivariable Firth penalized logistic regression. The low level of agreement between colposcopic impression and final histology underscores the importance of a risk-based approach that integrates multiple preoperative data sources. Clinically, targeting an adequate excision depth according to lesion location may help reduce the risk of positive margins; however, individualized surgical planning that accounts for obstetric considerations remains essential, particularly in women of reproductive age.

Ethics

Ethics Committee Approval: Ethical approval was obtained from the University of Health Sciences Türkiye, Gaziosmanpaşa Training and Research Hospital Non-Interventional Ethics Committee (decision no: 134, date: 15.10.2025).

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Informed Consent: Retrospective study.

Footnotes

Author Contributions: Surgical and Medical Practices - E.S.C., F.K.G., H.B.B., A.A., S.S.; Concept - E.S.C., H.B.B., S.S.; Design - E.S.C., F.K.G.; Data Collection and/or Processing - E.S.C., H.B.B.; Analysis and/or Interpretation - E.S.C., A.A., S.S.; Literature Search - E.S.C., F.K.G., A.A.; Writing - E.S.C., A.A.

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Supplementary Table 1: https://d2v96fxpocvxx.cloudfront.net/cf9d60d6-523c-458a-a2e6-78728d3ffbb0/content-images/89b4805d-b0e7-4eb5-abfa-fc7a9d5ac2b9.pdf

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