

RESEARCH ARTICLE

Narrow band imaging-guided diode laser ablation in recurrent low-grade non-muscle-invasive bladder cancer

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Abstract

Background: Low-grade non-muscle-invasive bladder cancer (NMIBC) is characterized by high recurrence rates, resulting in repeated interventions and intensive surveillance. Office-based transurethral laser ablation (TULA) performed under local anesthesia is a minimally invasive alternative to transurethral resection, and narrow band imaging (NBI) may improve tumor visualization and treatment precision. This study aimed to evaluate the efficacy and safety of NBI-guided office-based diode laser ablation for recurrent low-grade NMIBC and to identify factors associated with recurrence.

Methods: A retrospective review of 71 patients with recurrent Ta low-grade NMIBC was conducted who underwent diode laser ablation in an outpatient clinic. All patients had negative urine cytology prior to treatment. Demographic, clinical, and tumor-related variables were recorded. Recurrence was defined as histologically confirmed tumor reappearance on follow-up cystoscopy. Univariable and multivariable logistic regression analyses were performed to identify predictors of recurrence.

Results: Recurrence occurred in 44 patients (62%). Patients with recurrence were younger (median 52.5 vs. 65 years, $p < 0.001$) and had lower rates of comorbidities (47.7% vs. 74.1%, $p = 0.029$). A higher proportion of patients with more than three original tumors was observed in the recurrent group (40.9% vs. 11.1%, $p = 0.013$). On multivariable analysis, younger age (OR = 0.79, 95% CI: 0.67–0.93, $p = 0.006$), higher number of ablated tumors (OR = 2.5, 95% CI: 1.14–5.85, $p = 0.02$), and presence of comorbidities (OR = 324.8, 95% CI: 2.99–352.0, $p = 0.016$) were independently associated with recurrence.

Conclusion: NBI-guided office-based diode laser ablation is a safe and effective option for managing recurrent low-grade NMIBC.

KEYWORDS

diode laser ablation, low-grade, narrow band imaging (NBI), non-muscle-invasive bladder cancer (NMIBC), recurrence

1 | INTRODUCTION

Non-muscle-invasive bladder cancer (NMIBC) accounts for approximately 70%–75% of all newly diagnosed bladder cancer cases, encompassing a spectrum of urothelial carcinoma (UC) grades from low-grade and high-grade papillary UC to carcinoma in situ (CIS), with low-grade NMIBC constituting roughly 50% of cases^[1]. Tumor grade is a pivotal prognostic factor influencing the likelihood of recurrence and progression^[2]; hence, multiple diagnostic measures are employed to ensure accurate grading and to minimize the risk of missing higher-grade bladder cancer^[3]. Low- and intermediate-grade tumors have a low risk of progression, as they rarely invade the lamina propria or detrusor muscle. However, they carry a high risk of recurrence, reported at 50%–70%. The risk of recurrence is even higher in the presence of multifocal tumors^[4–6]. The high recurrence burden necessitates repeated interventions, prolonged surveillance, and imposes significant costs on health-care systems^[7–9].

Transurethral resection of bladder tumor (TURBT) remains the standard treatment for recurrent NMIBC worldwide^[1]. However, TURBT is associated with peri-operative risks, including bleeding, bladder perforation, and anesthesia-related complications, that are particularly relevant in elderly patients or those with comorbidities^[10–12]. Inpatient endoscopic treatment of bladder lesions is associated with prolonged bed-days, contributing to bladder cancer being among the most expensive malignancies to manage from diagnosis to death^[8,9]. These challenges underscore the need for alternative strategies that maintain oncologic control while reducing morbidity, patient discomfort, and healthcare costs^[6,9,13].

Less invasive outpatient-based approaches, such as fulguration or transurethral laser ablation (TULA) under local anesthesia, have emerged as promising options for small, low-grade recurrent lesions^[5,9,13–16]. Laser technology offers several advantages over electrocautery, including reduced bleeding and absence of electrical stimulation, which may improve patient tolerability^[17]. Previous studies have demonstrated the feasibility and safety of outpatient laser ablation^[6,9,13,18]. The European Association of Urology Guidelines recognize office-based fulguration or laser ablation as potential options for selected cases, although the level of supporting evidence remains low^[1]. Enhancements in tumor detection, such as narrow band imaging (NBI), may further improve outcomes by enabling identification and treatment of small or inconspicuous lesions^[19,20].

The present study aims to evaluate the efficacy and safety of NBI-guided office-based diode laser ablation for the treatment of recurrent low-grade NMIBC under local anesthesia and to identify clinical and pathological factors associated with tumor recurrence following this procedure.

2 | METHODS

2.1 | Study design and setting

This was a single-center retrospective study conducted at the Department of Urology, Hamad Medical Corporation, Doha, Qatar. The study included patients with Ta low-grade NMIBC who underwent office-based transurethral diode laser ablation guided by NBI between September 2020 and September 2024.

Eligible patients were identified through electronic medical records and outpatient cystoscopy logs. All included patients had a prior histological diagnosis of Ta low-grade urothelial carcinoma. The primary objective of the study was to evaluate oncological outcomes, specifically tumor recurrence, following NBI-guided diode laser ablation, and to identify clinical and tumor-related factors associated with recurrence.

2.2 | Population

Our study included all patients with recurrent Ta low-grade urothelial carcinoma of the bladder who underwent NBI-guided office-based diode laser ablation between September 2020 and September 2024. All procedures were performed in the outpatient clinic under local anesthesia. NBI was systematically used during diagnostic cystoscopy and throughout the diode laser ablation procedure in all included patients. All patients had negative urine cytology before the procedure.

2.3 | Inclusion and exclusion criteria

Inclusion criteria were: (1) histologically confirmed Ta low-grade urothelial carcinoma, (2) treatment with diode laser ablation for recurrence, and (3) availability of complete follow-up data. Patients with positive urine cytology, high-grade disease, CIS, or muscle-invasive bladder cancer (MIBC) were excluded.

2.4 | Procedure

All laser ablations were performed in the outpatient clinic setting under local anesthesia, using the biolitec® LEONARDO® diode laser system with a 200 µm fiber. The procedures were carried out under flexible cystoscopic guidance and cold-cup biopsies were performed routinely before every laser ablation. After which, all visible tumors and suspicious areas were completely fulgurated. NBI was systematically employed during cystoscopy to enhance visualization and detection of small or subtle lesions before ablation and during the fulguration of small lesions. Laser settings, fiber handling, and peri-procedural care followed the institutional

protocol for office-based bladder tumor ablation. Post-procedure surveillance cystoscopy was performed according to NMIBC follow-up protocols, generally at 3–6 month intervals.

2.5 | Data collection

Demographic and clinical data were extracted from electronic medical records and procedure notes. Collected variables included age, gender, smoking status, comorbidity profile, original tumor characteristics (number, size, location), and ablated tumor characteristics. Tumor size for both the original and ablated tumors was categorized as <1, 1–3, or >3 cm^[2,21]. Information on prior intravesical therapy with bacillus Calmette-Guérin (BCG) or mitomycin C (MMC) was also recorded.

Recurrence was defined as the reappearance of a bladder tumor confirmed by cystoscopic visualization and histopathological verification on biopsy.

2.6 | Ethical approval statement

Ethical approval was obtained from the Institutional Review Board (IRB) number MRC-01-24-199. A waiver of signed informed consent was granted, as the study involved a retrospective analysis of anonymized patient data, ensuring full protection of participant confidentiality and safety.

2.7 | Statistical analysis

Descriptive statistics were used to summarize baseline clinical and demographic characteristics. Continuous variables were expressed as medians with interquartile ranges (IQR), while categorical variables were presented as frequencies and percentages. Comparisons between recurrence and non-recurrence groups were performed using the Chi-square or Fisher's exact test for categorical variables, and the Mann-Whitney *U* test for continuous non-parametric data. A two-sided *p* value <0.05 was considered statistically significant.

To identify predictors of recurrence following TULA, univariable logistic regression analyses were first conducted for potential clinical and demographic variables, including age, comorbidities, original tumor burden and size, number of tumors, prior intravesical MMC therapy, and follow-up duration. Variables with *p* < 0.10 in univariable analyses or considered clinically important were subsequently entered into a multivariable logistic regression model to determine independent predictors while adjusting for potential confounders. Results were expressed as odds ratios (ORs) with 95% confidence intervals (CIs). Multicollinearity was assessed using the

variance inflation factor (VIF), and model calibration was evaluated using the Hosmer-Lemeshow goodness-of-fit test.

Recurrence-free survival (RFS) was estimated using the Kaplan-Meier method, and survival curves were compared across relevant subgroups (e.g., tumor size, number of tumors) using the log-rank test. Median RFS and corresponding 95% CIs were reported. All statistical analyses were performed using Stata version 17.0 (StataCorp LLC, College Station, TX, USA).

3 | RESULTS

3.1 | Patient characteristics

This retrospective study included 71 patients, of whom 44 (62%) had recurrence after laser ablation and 27 (38%) had no recurrence. The overall median age was 58 years (IQR: 45–66), with patients who developed recurrence significantly younger (median 52.5 years, IQR: 42–61) than patients who did not have recurrence (median 65 years, IQR: 56–71; *p* < 0.001). Males constituted the majority of the cohort (78.9%), with a similar distribution between groups. Comorbidities were present in 57.7% of patients, occurring more frequently among cases with no recurrence (74.1%) compared to cases who developed recurrence (47.7%; *p* = 0.029). Similarly, diabetes mellitus (DM) was less common in the recurrence group (22.7%) than in the no recurrence group (48.1%; *p* = 0.02).

Regarding tumor characteristics, half of the patients (50.7%) initially presented with tumors ≤1 cm, and nearly 46.5% had a single tumor. However, tumor multiplicity showed a significant association with recurrence—patients with more than three tumors were more common in the recurrence group (40.9%) compared to the no recurrence group (11.1%; *p* = 0.01). Tumor size category did not demonstrate a statistically significant difference between groups (*p* = 0.07). The mean follow-up duration was 24.2 ± 14.7 months, significantly longer among patients with recurrence (28.4 ± 13.8 months) than those with no recurrence (17.3 ± 13.8 months; *p* = 0.002). Prior intravesical therapies (BCG or MMC) were used in less than one-third of cases, showing no significant association with recurrence. No patient in the cohort progressed to muscle-invasive disease during follow-up. The procedure was well tolerated, with minimal reported pain and no major complications observed. Patient characteristics are listed in Table 1.

3.2 | Regression analysis

In the univariable analysis, several clinical factors showed significant associations with recurrence

TABLE 1 Patients' characteristics.

Patients' characteristics	No recurrence (<i>n</i> = 27)	Recurrence (<i>n</i> = 44)	Total (<i>n</i> = 71)	<i>p</i> value
Age median (IQR)	65.0 (56–71)	52.5 (42–61)	58.0 (45–66)	< 0.001 ^a
Gender <i>n</i> (%)				0.67
Female	5 (18.5%)	10 (22.7%)	15 (21.1%)	
Male	22 (81.5%)	34 (77.3%)	56 (78.9%)	
Comorbidities				
Yes	20 (74.1%)	21 (47.7%)	41 (57.7%)	0.029 ^a
HTN	17 (63.0%)	18 (40.9%)	35 (49.3%)	0.07
DM	13 (48.1%)	10 (22.7%)	23 (32.4%)	0.02 ^a
Others ^a	8 (29.6%)	5 (11.4%)	13 (18.3%)	0.053
Size category of original tumor				0.07
1 cm	18 (66.7%)	18 (40.9%)	36 (50.7%)	
1–3 cm	7 (25.9%)	16 (36.4%)	23 (32.4%)	
> 3 cm	2 (7.4%)	10 (22.7%)	12 (16.9%)	
Number category of original tumor				0.01 ^a
1	13 (48.1%)	20 (45.5%)	33 (46.5%)	
2–3	10 (37.0%)	6 (13.6%)	16 (22.5%)	
> 3	3 (11.1%)	18 (40.9%)	21 (29.6%)	
BCG before TULA	6 (22.2%)	14 (31.8%)	20 (28.2%)	0.68
MMC before TULA	6 (22.2%)	14 (31.8%)	20 (28.2%)	0.45
Mean size of ablated tumor (SD)	1.0 (1.1)	1.2 (0.9)	1.1 (1.0)	0.58
Size category of ablated tumor				0.18
1 cm	22 (81.5%)	31 (70.5%)	53 (74.6%)	
1–3 cm	4 (14.8%)	13 (29.5%)	17 (23.9%)	
> 3 cm	1 (3.7%)	0 (0.0%)	1 (1.4%)	
Number category of ablated tumor				0.88
1	10 (37.0%)	16 (36.4%)	26 (36.6%)	
2–3	11 (40.7%)	16 (36.4%)	27 (38.0%)	
> 3	6 (22.2%)	12 (27.3%)	18 (25.4%)	
Smoker	9 (33.3%)	17 (38.6%)	26 (36.6%)	0.65
Follow-up duration/months mean (SD)	17.3 (13.8)	28.4 (13.8)	24.2 (14.7)	0.002 ^a

Abbreviations: BCG, bacillus Calmette–Guérin; DM, diabetes mellitus; HTN, hypertension; IQR, interquartile ranges; MMC, mitomycin C; SD, standard deviation; TULA, transurethral laser ablation.

^aCoronary artery disease, chronic kidney disease.

following TULA. Younger age was strongly correlated with recurrence (OR = 0.91, $p = 0.001$), indicating that recurrence risk decreased with increasing age. The presence of comorbidities was also associated with recurrence (OR = 0.31, $p = 0.032$), suggesting that patients without comorbid conditions experienced higher recurrence rates. Additionally, longer follow-up duration significantly increased the likelihood of detecting recurrence (OR = 1.05, $p = 0.003$). Other variables, such

as size of original tumor, size category of original tumor, number of original tumors, and prior MMC therapy, did not reach statistical significance in the univariable model, though some approached relevance (e.g., number of original tumors, $p = 0.054$) (Table 2).

In the multivariable analysis, which adjusted for potential confounders, age (OR = 0.79, $p = 0.006$), comorbidities (OR = 324.8, $p = 0.016$), follow-up duration (OR = 1.10, $p = 0.006$), and number of ablated tumors

TABLE 2 Univariable and multivariable regression analysis between recurrence post-TULA and clinical variables.

Variables	Univariable			Multivariable		
	OR	<i>p</i> value	95% CI	OR	<i>p</i> value	95% CI
Age	0.91	0.001 ^a	0.87–0.96	0.79	0.006 ^a	0.67–0.93
Comorbidities (Yes)	0.31	0.032 ^a	0.11–0.90	324.8	0.016 ^a	2.99–352.0
Size of original tumor	1.27	0.14	0.92–1.75	0.05	0.053	0.002–1.03
Size category of original tumor (1–3 cm)	2.28	0.14	0.75–6.88	470.1	0.057	0.82–266
Number category of original tumor (2–3)	0.39	0.13	0.11–1.33	0.01	0.04	0–0.88 ^a
MMC before TULA (Yes)	1.4	0.55	0.45–4.32	16.5	0.063	0.85–32
Follow-up duration	1.05	0.003 ^a	1.01–1.10	1.10	0.006 ^a	1.04–1.25
Number of origin tumor	1.4	0.054	0.99–2.04	12.8	0.09	0.66–251
Number of ablated tumor	1.37	0.11	0.92–2.05	2.50	0.02 ^a	1.14–5.85
Size of ablated tumor	1.16	0.57	0.68–2.00	1.11	0.72	0.61–2.02

Abbreviations: CI, confidence interval; MMC, mitomycin C; OR, odds ratio; TULA, transurethral laser ablation.

^aCoronary artery disease, chronic kidney disease.

(OR = 2.50, $p = 0.02$) remained independent predictors of recurrence. The inverse association with age persisted, confirming that younger patients had a higher risk of recurrence. The markedly elevated odds ratio for comorbidities suggests a strong, possibly exaggerated association that may reflect small subgroup effects. Prolonged follow-up duration was linked to greater recurrence detection, consistent with time-dependent observation bias. The number of ablated tumors also independently predicted recurrence, highlighting the clinical relevance of tumor multiplicity in post-TULA outcomes. Other factors, including tumor burden, tumor size, and MMC use, showed no significant independent associations after adjustment (Table 2).

3.3 | Survival outcomes

This Kaplan–Meier curve shows RFS according to the original tumor size. Patients with tumors larger than 3 cm (green line) had a better long-term RFS compared to those with smaller tumors, particularly after 30 months, where their survival curve declines more slowly. In contrast, patients with tumors between 1 cm and 3 cm (red line) showed the lowest RFS throughout the follow-up, with earlier and more frequent recurrences. Those with tumors of 1 cm (blue line) initially maintained high RFS, but their curve drops more sharply after 25–30 months. So, overall, tumor size appears to influence recurrence patterns over time, with mid-sized tumors (1–3 cm) showing the poorest recurrence-free outcomes, while larger tumors (> 3 cm) surprisingly maintain longer RFS, possibly due to more aggressive initial management or selection bias (Figure 1).

This Kaplan–Meier curve illustrates RFS across three groups categorized as 1, 2–3, and > 3. At the beginning of the follow-up, all groups show a survival probability of

1.0, indicating no recurrence. Over time, all curves gradually decline, reflecting the occurrence of recurrences. The group labeled “1” (blue line) maintains the highest RFS throughout most of the follow-up period, while the “> 3” group (green line) shows a slightly faster decline in survival probability. The “2–3” group (red line) demonstrates an intermediate pattern between the two. By approximately 40–50 months, all groups converge near a survival probability of zero, indicating that most patients experienced recurrence by the end of the study period. Overall, the plot shows a time-dependent reduction in RFS across all categories, with minor differences in the rate of decline between groups (Figure 2).

The Kaplan–Meier curve displayed represents RFS over a follow-up period of approximately 50 months. At the start of the study, the survival probability was 100%, as expected. Over time, the curve shows a gradual decline, indicating that recurrences began occurring progressively after around 13 months. By approximately 25 months, the recurrence-free probability had fallen to about 50%, suggesting that half of the patients remained free from recurrence at that point (the median RFS). Beyond this point, the curve continues to drop, with a steeper decline after 35–40 months, reflecting an increased rate of recurrence during later follow-up. By the end of the 50-month period, the survival probability approaches zero, indicating that nearly all patients experienced recurrence by the end of observation (Figure 3).

3.4 | Safety

Safety outcomes were assessed for all procedures, including peri-procedural and post-procedural complications, bleeding requiring intervention, urinary retention, infection, unplanned hospital admission, and

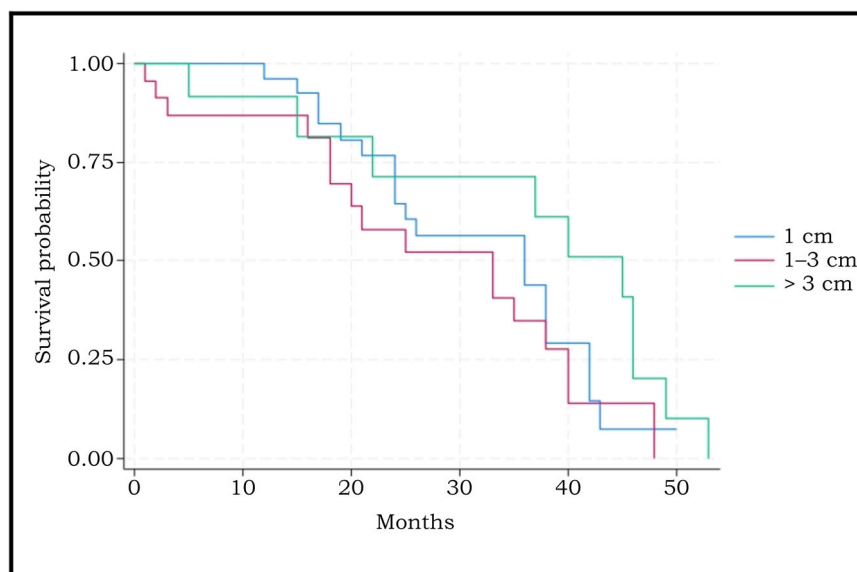


FIGURE 1 Recurrence-free survival (RFS) among tumor size.

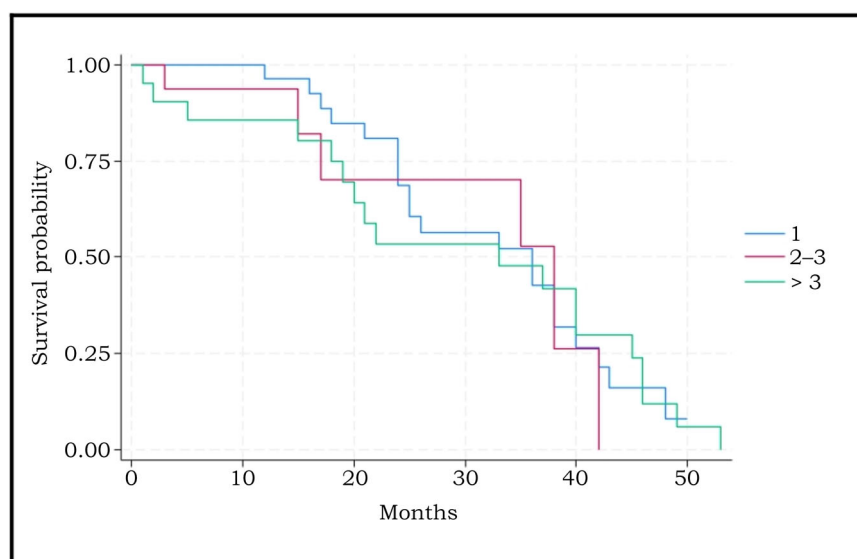


FIGURE 2 Recurrence-free survival (RFS) based on tumor number.

procedure intolerance. No major complications were recorded. There were no cases of bladder perforation, significant hematuria requiring intervention, urinary retention, or hospital admission following diode laser ablation. All procedures were completed successfully in the outpatient setting under local anesthesia, and no procedure was discontinued due to patient discomfort.

4 | DISCUSSION

This study evaluated the efficacy and safety of NBI-guided office-based diode laser ablation for recurrent low-grade NMIBC under local anesthesia. Our results

showed that recurrence occurred in 62% of patients during a mean follow-up of 24.2 ± 14.7 months, with younger age, and higher original tumor burden being significantly associated with increased recurrence risk. Importantly, no patients progressed to muscle-invasive disease, and the procedure was safe, with no major complications reported.

4.1 | Recurrence and oncological outcomes

The recurrence rate in our cohort (62%) is consistent with previous long-term laser ablation studies. Prior

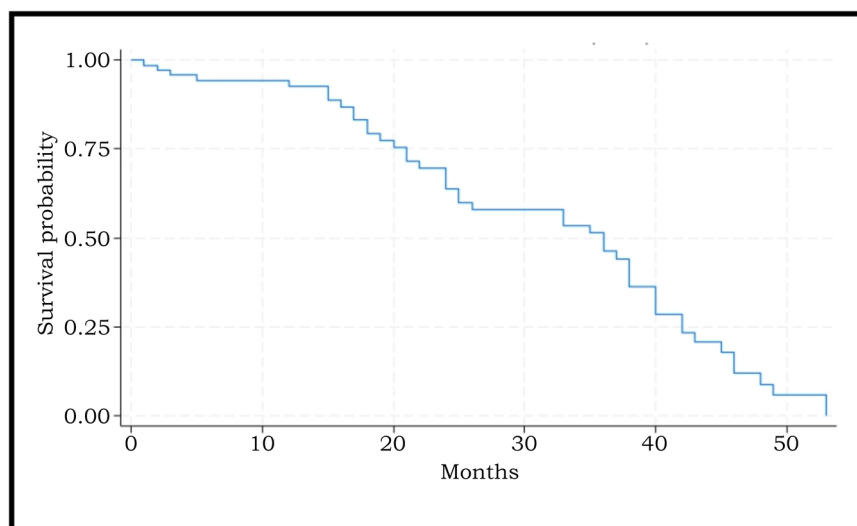


FIGURE 3 Recurrence-free survival (RFS).

reports demonstrated similar recurrence rates, ranging between 56.7% and 73% following laser ablation^[22–24]. Importantly, there was no progression to muscle-invasive disease in our cohort, which is consistent with previous studies that also reported no progression to muscle-invasive or metastatic disease^[22]. Other studies, however, have documented progression rates between 6% and 9%, though these included patients with high-grade or T1 tumors^[23,25]. Furthermore, patients with at least two prior recurrences were associated with higher recurrence rates after diode laser ablation, underscoring the cumulative recurrence risk with each successive episode^[26–29]. Collectively, these findings reinforce that while recurrence remains common, careful patient selection can ensure durable disease control without progression. This is particularly important, as progression to MIBC necessitates more aggressive surgical or multimodal therapeutic approach^[30]. In our study, clinical and pathological predictors played a key role: younger patients had a significantly higher recurrence risk (multivariable OR = 0.79, $p=0.006$), a greater number of ablated tumors was independently associated with increased recurrence risk (OR = 2.5, 95% CI: 1.14–5.85, $p=0.02$). These observations align with previous studies where smaller tumors had lower recurrence risk and recurrence intervals shortened with successive events^[31].

4.2 | Safety and tolerability

Our safety findings are consistent with those reported in earlier studies. Previous reports observed no cases of bladder perforation, urinary retention, or hospital admission, even when treating frail elderly patients under local anesthesia. Other series reported no major

complications, with only minor, self-limiting events such as hematuria or transient dysuria^[9,17,25,32–34]. These results underline the excellent safety profile of laser ablation in the outpatient setting. Our study adds further evidence that diode laser ablation under local anesthesia is well tolerated, even without the need for complex anesthetic techniques.

4.3 | Cost-effectiveness

Although we did not conduct a formal economic analysis, our findings align with the cost-effectiveness rationale demonstrated in previous studies. Wong et al. reported, using a Markov model, that outpatient laser ablation was significantly less costly than inpatient TURBT, with potential National Health Service (NHS) savings exceeding 1.2 million pounds annually if 10% of procedures were shifted to the outpatient setting^[9]. Similar cost advantages have also been reported in Holmium:YAG laser series^[34–37]. These savings can largely be attributed to the outpatient setting, the elimination of hospital admission, and the avoidance of general anesthesia, all of which substantially reduce healthcare costs.

4.4 | Role of enhanced imaging

Our study is the first to evaluate diode laser ablation guided by NBI in this context. NBI may play an important role in reducing the likelihood of missed tumors. Wong et al. demonstrated that the use of photodynamic diagnosis (PDD) with hexaminolevulinate acid instillation and blue-light cystoscopy identified additional tumors in 21% of patients^[9] which is similar to findings

reported in the published literature^[38]. Since missed lesions remain a major driver of recurrence^[26,27], integrating NBI could improve oncological outcomes by enhancing tumor detection^[19,39].

4.5 | Limitation

This study has several limitations that should be acknowledged. Its retrospective design introduces an inherent risk of selection bias and limits the ability to infer causality. The relatively small sample size, drawn from a single institution, may restrict the generalizability of the findings. Although recurrence was confirmed by cystoscopy and histopathological examination, variability in follow-up duration between patients could have influenced recurrence detection, with longer follow-up in the recurrent group potentially inflating recurrence rates. The large magnitude of the odds ratio in multi-variable analysis may reflect sample size limitations and model sensitivity to covariate distribution and therefore warrants cautious interpretation. The absence of a comparator group managed with TURBT or other modalities precludes direct evaluation of relative efficacy and safety. While NBI was systematically used to improve lesion detection, the study did not include a formal comparison with white-light cystoscopy, limiting conclusions regarding its added diagnostic value. Finally, unmeasured confounding factors, such as variations in tumor biology or adherence to surveillance protocols, may have impacted the outcomes.

5 | CONCLUSION

NBI-guided office-based diode laser ablation is a safe and well-tolerated treatment option for recurrent low-grade NMIBC, offering effective local tumor control without the need for general anesthesia or hospitalization. The procedure demonstrated favorable oncological outcomes in the outpatient setting, with recurrence influenced by patient age, comorbidity status, and ablated tumor multiplicity. These findings support the role of NBI-guided diode laser ablation as a minimally invasive alternative to conventional approaches, particularly in selected patients, while highlighting the need for prospective, controlled studies to validate these results and further refine patient selection criteria.

AUTHOR CONTRIBUTIONS

Ibrahim A. Khalil contributed to conceptualization, methodology, data curation, formal analysis, and drafting as well as final writing of the manuscript. Ahmed B. Altayeb contributed to data collection, data validation, and drafting of the manuscript. Majd AlKabbani contributed to literature review, drafting of the manuscript, and critical revision.

Nagy Younes contributed to methodology, supervision, and critical revision for important intellectual content. Alaeddin Badawi contributed to data curation, data management, and validation. Ahmad R. Al-Qudimat contributed to formal analysis, interpretation of data, manuscript writing, and critical revision. Khalid AlRumaih contributed to supervision and project administration. All authors have read and approved the final version of the manuscript.

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The authors have nothing to report.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data generated in this study have been included in the article, and further inquiries can be directed to the corresponding author or the first author.

ETHICS STATEMENT

This study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was obtained from the Institutional Review Board (IRB) of Hamad Medical Corporation, Qatar (approval number: MRC-01-24-199). A waiver of signed informed consent was granted, as the study involved a retrospective analysis of anonymized patient data. All data were handled with strict confidentiality, ensuring full protection of participant privacy and safety.

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