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Three-Arm Comparative Analysis of Standard, Traction-Assisted, and Tunnel Endoscopic Submucosal Dissection for Superficial Esophageal Squamous Cell Carcinoma: First Series from the Mediterranean Region

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Abstract

Background

Endoscopic submucosal dissection (ESD) for superficial esophageal squamous cell carcinoma (ESCC) can be performed using standard, traction-assisted, or tunnel techniques; comparative data are limited to pairwise analyses, and evidence from non-Asian populations remains scarce. We compared these three techniques in a Mediterranean ESCC cohort.

Methods

We retrospectively analyzed 73 patients who underwent ESD for superficial ESCC at a Turkish tertiary center (February 2018–February 2026) using standard (n = 15), traction-assisted (n = 19), or tunnel (n = 39) techniques selected by lesion size and circumferential extent. Resection outcomes, stricture, and dissection speed were compared; Firth-penalized logistic regression identified predictors of stricture.

Results

En bloc and R0 resection were achieved in all patients; curative resection in 80.8%, with no difference among techniques (p = 0.069). Post-ESD stricture occurred in 18 patients (24.7%), rising progressively with circumferential involvement: 0%, 4.8%, 42.9%, and 78.6% for < 50%, 50–75%, 75–99%, and 100% (p < 0.001). Circumferential involvement ≥ 75% was the dominant independent predictor (OR 45.1, 95%CI 9.7–440.0; p < 0.001). After adjustment for circumferential extent, tunnel ESD remained an independent predictor of stricture, and traction-assisted ESD conferred lower risk (both p ≤ 0.004). Size-normalized dissection speed did not differ between techniques (p = 0.351).

Conclusions

In this first Mediterranean ESCC ESD series and first three-arm comparison of these techniques, all achieved equivalent oncologic resection. Stricture risk was driven primarily by circumferential extent ≥ 75% and muscularis mucosae invasion. Technique should be tailored to lesion characteristics, and stricture-prevention guided by circumferential involvement.

Trial registration:

Not applicable (retrospective observational study).

Background

Esophageal squamous cell carcinoma (ESCC) is the sixth most common cause of cancer-related death globally and the predominant histologic subtype, with the highest burden in East Asia, East Africa, and Central Asia [1, 2]. Five-year survival is below 20% in advanced disease but 70–85% in early-stage ESCC [3]. Esophagectomy, the historical standard, carries morbidity up to 55%, and endoscopic submucosal dissection (ESD) has become the preferred organ-preserving alternative, enabling en bloc resection regardless of lesion size with oncologic outcomes comparable to surgery in selected superficial lesions [3–5]. ESD is recommended as first-line treatment for most superficial esophageal squamous neoplasms by European and Japanese endoscopy societies [6, 7].

Despite this efficacy, esophageal ESD is limited by post-procedural stricture, driven primarily by circumferential scar contraction within the narrow esophageal lumen. Defects exceeding three-quarters of the circumference carry stricture rates of 70–100%, approaching certainty after entire-circumferential resection [8]. Prophylactic steroids reduce but do not eliminate strictures, which may cause dysphagia and require repeated dilations [9, 10].

Existing comparative studies are limited to pairwise analyses (tunnel vs. conventional, or traction vs. conventional), and whether the ESD technique independently influences stricture risk, beyond established anatomic determinants such as lesion size and circumferential involvement, remains unclear [11–13]. Data from non-Asian populations remain scarce, with no ESCC ESD series reported from Turkey or the Mediterranean region.

This study constitutes, to our knowledge, the first three-way comparison of standard, traction-assisted, and tunnel ESD and the first ESCC ESD series from this region. We report resection outcomes and stricture rates and assessed whether technique was independently associated with stricture after adjustment for lesion size and circumferential extent.

Methods

Study Design and Patient Selection

This retrospective analysis of prospectively collected data included 73 consecutive patients who underwent ESD for ESCC at Koç University Hospital between February 2018 and February 2026, all performed by a single operator (F.A.). Eligible patients had histologically confirmed or highly suspected superficial ESCC confined to the mucosa or with a high likelihood of superficial submucosal invasion without nodal or distant metastasis; those with deep submucosal invasion or advanced disease were referred for surgical or oncologic management and excluded. The study was approved by the Koç University Clinical Research Ethics Committee (approval no. 2024.401.IRB2.180) and conducted in accordance with the Declaration of Helsinki.

Pre-procedural Assessment

All lesions were evaluated with high-definition white-light endoscopy and narrow-band imaging (NBI): the vascular pattern was classified by the intrapapillary capillary loop and Japan Esophageal Society classifications to estimate invasion depth, and morphology by the Paris classification. Endoscopic ultrasound and computed tomography were performed to exclude advanced disease and lymph node involvement.

ESD Procedure

All procedures were performed under deep sedation or general anesthesia with CO_2 insufflation (Olympus Medical Systems, Tokyo, Japan), using a standard single-channel endoscope (GIF-EZ1500 video gastroscope, Olympus Medical Systems, Tokyo, Japan) with a transparent distal cap (D-201-11804, Olympus Medical Systems, Tokyo, Japan). Following Lugol chromoendoscopy, the lateral margins of the lesion were carefully delineated. Circumferential coagulation markings were then placed approximately 2–3 mm outside the unstained area to define the resection boundaries. Submucosal injection used saline (or hydroxyethyl starch) and indigo carmine for lifting. Mucosal incision followed by submucosal dissection was performed for en bloc resection. Hemostatic forceps (Coagrasper, FD-411QR, Olympus Medical Systems, Tokyo, Japan) were used as needed. Procedural time was defined as the interval from initial mucosal incision to complete resection.

Three ESD techniques were employed according to lesion size, morphology, and circumferential extent: (i) Standard ESD, reserved for lesions < 2 cm, used circumferential mucosal incision followed by submucosal dissection with gravity- and cap-assisted exposure without supplementary traction. (ii) Traction-assisted ESD, used mostly for lesions > 2 cm, employed a clip-and-line or clip-and-snare system deployed at the oral edge after partial and/or circumferential mucosal incision and redirected through the patient's mouth to apply continuous external counter-traction and expose the submucosal plane (Fig. 1A-F). (iii) Tunnel ESD (ESTD), used mostly for lesions > 2 cm: mucosal incisions were performed at the anal and oral margins of the lesion, and a closed submucosal tunnel was created beneath the lesion from the oral to the anal incision, exploiting bilateral mucosal tension and gravity to maintain a continuous dissection plane and orientation. The lateral mucosal margins were then incised and the residual submucosal bridges dissected. Single- or multi-tunnelling was chosen according to the lesion length and diameter [14] (Fig. 2A-F).

For stricture prophylaxis, 80 mg triamcinolone was injected into residual submucosa when the resected area exceeded 50% of circumference; for > 75% involvement, submucosal triamcinolone plus tapered oral prednisolone for eight weeks was preferred. Submucosal fibrosis was graded endoscopically as described as F0 (none), F1 (mild), or F2 (severe) [15].

Histopathological Evaluation

Resected specimens were stretched, pinned, formalin-fixed, and serially sectioned. Histopathological assessment followed the Vienna classification and evaluated depth of invasion, lymphovascular invasion, and resection margins. R0 resection was defined as en bloc resection with histologically negative horizontal and vertical margins; curative resection additionally required mucosa-confined invasion, no lymphovascular invasion, and favorable histology [16]. Invasion depth was staged per the Japan Esophageal Society classification as mucosal (M1, M2, M3) or submucosal (SM1, SM2) [17].

Outcome Measures

Primary outcomes were en bloc, R0, and curative resection rates; secondary outcomes included procedure time, dissection speed (resected area divided by procedure time), and post-ESD stricture.

Dimensions were measured as follows: LLength and LWidth denote the long and short axes of the lesion in millimeters; SLength and SWidth denote the long and short axes of the resected specimen after fixation and pinning. Lesion area (LArea) and resected specimen area (SArea) were calculated using the ellipse formula (Area = π × length/2 × width/2). Post-ESD stricture was defined as dysphagia requiring endoscopic intervention and/or inability of a standard endoscope to pass through the treated segment. Lesion location was the endoscopic distance (cm) from the incisors, with the midpoint assigning each lesion per the American Joint Committee on Cancer (AJCC) classification to cervical (< 20 cm), upper thoracic (20 to < 25 cm), middle thoracic (25 to 30 cm), or lower thoracic (> 30 cm) [18]; cervical and upper thoracic lesions were grouped as upper esophagus.

Follow-up

Patients underwent scheduled endoscopic surveillance, first at 3–6 months after ESD, and annually thereafter, with additional imaging or clinical evaluation when indicated. All patients were followed clinically and endoscopically for at least 12 months, allowing assessment of stricture formation.

Statistical Analysis

All analyses used R version 4.5.3 (R Foundation for Statistical Computing, Vienna, Austria). Continuous variables were reported as mean ± SD or median (range) as appropriate; categorical variables were reported as n (%); between-technique comparisons used the Kruskal-Wallis test and Fisher's exact tests. Predictors of stricture were evaluated by Firth's penalized logistic regression to reduce small-sample bias and address complete or quasi-complete separation arising from zero-event cells. Steroid prophylaxis was excluded because it was confounded by indication. Because 18 stricture events permit only two predictors per model, two-variable models combining technique with either circumferential extent or invasion depth were prespecified as primary analyses; as a sensitivity analysis we fitted every three-variable combination of the candidate predictors (300 models) and report the proportion in which each variable remained significant, interpreting robustness from consistency rather than any single p-value. A two-sided $p < 0.05$ was considered significant.

Use of AI tools. The authors used Claude (Anthropic) for language editing, readability and flow. The authors reviewed and edited the content and take full responsibility for the publication.

Results

Patient and Lesion Characteristics

The 73 patients had a median follow-up of 3 years (range 1–5), a female predominance (52/73, 71.2%), and a mean age of 61.7 years. All lesions were Paris type 0-IIb. Invasion depth was mucosal in 59 and submucosal in 14; circumferential involvement is detailed in Table 1.

Table 1
Baseline patient and lesion characteristics across ESD technique groups (n = 73)

Variable	Standard (n = 15)	Traction (n = 19)	Tunnel (n = 39)	p-value
Demographics				
Age (mean ± SD)	59.2 ± 9.0	64.6 ± 10.0	61.3 ± 12.0	0.197
Female, n (%)	11 (73)	14 (74)	27 (69)	1.000
Comorbidity, n (%)	5 (33)	8 (42)	15 (38)	0.948
Fibrosis (F1/F2), n (%)	1 (7)	3 (16)	4 (10)	0.727
Lesion Characteristics				
Location	3/7/5	4/7/8	5/19/15	0.860
Invasion depth	11/3/1/0/0	9/3/3/3/1	10/8/11/7/3	0.115
Circumferential group	11/4/0/0	5/7/7/0	8/10/7/14	< 0.001
SLength, median (mm)	33 (15–55)	51 (28–99)	64 (26–185)	< 0.001
SWidth, median (mm)	22 (15–36)	36 (18–58)	40 (21–86)	< 0.001
LLength, median (mm)	18 (9–35)	28 (15–77)	41 (12–171)	< 0.001
LWidth, median (mm)	12 (8–23)	17 (10–41)	30 (10–81)	< 0.001
SArea, median (mm²)	584 (177–1357)	1362 (396–3781)	2199 (429–8173)	< 0.001
LArea, median (mm²)	205 (57–632)	393 (118–1932)	1001 (94–6234)	< 0.001
Procedural Outcomes				
Procedure time, median (min)	18 (7–80)	32 (16–146)	51 (12–209)	< 0.001
Dissection Speed (mm²/min)	25.2 (11.6–73.0)	34.4 (10.1–97.3)	33.8 (9.8–80.5)	0.351
LOS, median (days)	2 (0–3)	2 (1–5)	3 (1–11)	< 0.001
Coagulation (mean)	0.33	0.84	1.03	0.158
Steroid use, n (%)	0 (0)	9 (47)	25 (64)	< 0.001
Primary and Secondary Outcomes				

Bold p-values indicate p < 0.05. Circ group shown as < 50% / 50–75% / 75–99% / 100%; Location as Upper/Mid/Low; Invasion depth as M1/M2/M3/SM1/SM2. Dashes (—) indicate not applicable or no test performed.

Variable	Standard (n = 15)	Traction (n = 19)	Tunnel (n = 39)	p-value
En bloc resection, n (%)	15 (100)	19 (100)	39 (100)	—
R0 resection, n (%)	15 (100)	19 (100)	39 (100)	—
Curative resection, n (%)	15 (100)	15 (79)	29 (74)	0.069
Stricture, n (%)	0 (0)	1 (5.3)	17 (43.6)	**< 0.001**
Dilation sessions (median)	— (n = 0)	1 (n = 1)	1 (1–8)	—
Stent placement, n/stricture patient	0/0	0/1	8/17 (47%)	—

Bold p-values indicate p < 0.05. Circ group shown as < 50% / 50–75% / 75–99% / 100%; Location as Upper/Mid/Low; Invasion depth as M1/M2/M3/SM1/SM2. Dashes (—) indicate not applicable or no test performed.

Technique Comparison and Baseline Characteristics

Three techniques were employed: tunnel (n = 39), traction (n = 19), and standard (n = 15). Demographics and fibrosis were balanced (all p > 0.05), whereas case complexity differed markedly: standard technique was reserved exclusively for smaller, less circumferential lesions (median lesion length 18 vs 28 vs 41 mm for standard, traction, and tunnel; p < 0.001), and no standard case had ≥ 75% circumferential involvement (p < 0.001).

Primary Outcome: Resection Outcomes

En bloc and R0 resection were achieved in all 73 patients (100%). Curative resection was attained in 59 (80.8%); all 14 non-curative cases had submucosal invasion, of whom the four with SM2 were referred for chemoradiotherapy and 10 patients with SM1 managed with surveillance per multidisciplinary board decision. Curative resection rates did not differ among ESD techniques (15/15, 100% standard; 15/19, 78.9% traction; 29/39, 74.4% tunnel; p = 0.069).

Procedure Time and Dissection Speed

Procedure time differed substantially across techniques (median 18 vs 32 vs 51 min for standard, traction, and tunnel; p < 0.001), whereas median dissection speeds were comparable (25.2, 34.4, and 33.8 mm²/min; p = 0.351). In patients with ≥ 75% circumferential involvement, dissection speed was also comparable between traction and tunnel (median 34.4 vs 35.5 mm²/min, p = 0.250).

Post-ESD Stricture and the Role of Circumferential Involvement

Esophageal stricture developed in 18 patients (24.7%), all managed with stepwise endoscopic bougie dilation using Savary-Gilliard dilators (median 1 session, range 1–8). Temporary stents were placed in 8 patients with recurrent stricture and removed after a median of 2 months; thereafter 6 needed no further

intervention, 1 underwent 3 dilations, and 1 performed self-bougienage for 3 months. Dysphagia resolved in all patients without surgery. Stricture rates differed among techniques (0% with standard, 5.3% with traction, and 43.6% with tunnel; $p < 0.001$) and rose progressively with circumferential involvement (0%, 4.8%, 42.9%, and 78.6% for the < 50%, 50–75%, 75–99%, and 100%; $p < 0.001$). Prophylactic steroids were administered to 34 patients (46.6%), exclusively for involvement exceeding 50% (all 28 patients with ≥ 75%; 6 of 21 with 50–75%). All 18 patients who developed a stricture had received steroids; none of the 39 untreated patients did.

Univariate and Multivariable Analysis of Stricture Predictors

On univariate screening, circumferential extent, all four lesion dimension variables, resected and lesion areas, procedure time, technique, and invasion depth were significant predictors (all $p \leq 0.005$) (Table 2). Tunnel technique was associated with stricture (OR = 17.37, $p < 0.001$), whereas Standard (OR = 0.07, $p = 0.008$) and Traction (OR = 0.17, $p = 0.020$) were protective. All circumferential thresholds were significant, ≥ 75% most strongly (OR = 45.14, 95%CI: 9.75–440.0, $p < 0.001$). For invasion depth, M3 vs non-M3 (OR = 7.62, $p < 0.001$) and Deep (M3-SM1-SM2) vs Superficial (M1-M2) (OR = 5.88, $p = 0.001$) were significant, whereas submucosal vs mucosal was not (OR = 1.35, $p = 0.647$); as a five-level factor with M1 as reference, only M3 remained significant (OR = 11.48, 95%CI: 2.79–58.39, $p < 0.001$). After adjustment for circumferential extent ≥ 75%, tunnel technique remained an independent risk factor (OR = 13.98, 95%CI: 2.43–153.95, $p = 0.002$), with consistent effects at the ≥ 50% and 100% thresholds (both $p < 0.05$). Traction was protective at ≥ 50% and ≥ 75% (OR = 0.08, 95% CI: 0.01–0.46, $p = 0.004$ at ≥ 75%) and trended protective at 100%. Standard ESD was not independently associated with stricture after adjustment for circumferential extent or size-related covariates, consistent with its use in smaller lesions. M3 invasion and circumferential involvement ≥ 75% were weakly correlated (Phi = 0.16) and carried largely independent risk. Stricture rates were 0% (non-M3 with < 75%, n = 38), 14% (M3 with < 75%, n = 7), 45% (non-M3 with ≥ 75%, n = 20), and 100% (M3 with ≥ 75%, n = 8). Because all 8 patients with both factors developed stricture, quasi-complete separation prevented all three predictors from being reliably estimated in one multivariable model. Across 300 sensitivity models, circumferential extent ≥ 75% and M3 invasion were significant in 100% of models, Tunnel in 92–100%, and dissection speed in none.

Table 2
Univariate and multivariable logistic regression for stricture prediction (n = 73)

Variable	Univariate OR	Univariate 95% CI	Univariate p	Multivariable OR	Multivariable 95% CI	Multivariable p
Continuous Variables						
SWidth (per mm)	1.11	1.060–1.186	< 0.001	—	—	—
LWidth (per mm)	1.13	1.067–1.205	< 0.001	—	—	—
SLength (per mm)	1.05	1.025–1.084	< 0.001	—	—	—
LLength (per mm)	1.046	1.021–1.078	< 0.001	—	—	—
SArea (per mm²)	1.001	1.001–1.002	< 0.001	—	—	—
LArea (per mm²)	1.001	1.001–1.002	< 0.001	—	—	—
Procedure time (per min)	1.024	1.011–1.042	< 0.001	—	—	—
SSpeed (per mm²/min)	1.012	0.987–1.037	0.342	—	—	—
Invasion Depth (Ref: M1)						
M2 vs M1	1.57	0.236–9.187	0.618	—	—	—
M3 vs M1	11.48	2.789–58.386	< 0.001	—	—	—
SM1 vs M1	3.67	0.653–21.086	0.136	—	—	—
SM2 vs M1	3.37	0.270–29.729	0.307	—	—	—
Technique						
Tunnel vs Non-Tunnel	17.37	3.92–165.14	< 0.001	—	—	—

*Multivariable columns show technique adjusted for circumferential extent ≥ 75%, and the M3 depth contrast adjusted for circumferential extent ≥ 75%. Bold p-values indicate p < 0.05. Dashes (—) indicate variables not entered into a multivariable model. *Steroid use was not entered into multivariable models because steroids were given according to circumferential extent (confounding by indication).*

Variable	Univariate OR	Univariate 95% CI	Univariate p	Multivariable OR	Multivariable 95% CI	Multivariable p
Continuous Variables						
Traction vs Non-Traction	0.174	0.018–0.78	0.020	—	—	—
Standard vs Non-Standard	0.071	0.001–0.58	0.008	—	—	—
Circumferential Extent						
≥ 50% vs < 50%	28.778	3.60–3730.73	< 0.001	—	—	—
≥ 75% vs < 75%	45.145	9.75–439.99	< 0.001	37.47	7.27–391.78	**< 0.001**
100% vs < 100%	23.000	6.073–109.69	< 0.001	—	—	—
Invasion Depth (binary contrasts)						
M3 vs Non-M3	7.62	2.32–27.055	< 0.001	33.001	3.45–4436.42	**< 0.001**
SM vs Mucosal	1.35	0.35–4.54	0.647	—	—	—
Deep vs Superficial	5.88	1.95–19.91	0.001	—	—	—
Non-M1 vs M1	4.27	1.31–17.84	0.015	—	—	—
Steroid Use*						
Steroid vs No Steroid	88.58	10.93–11522.74	< 0.001	—	—	—

*Multivariable columns show technique adjusted for circumferential extent ≥ 75%, and the M3 depth contrast adjusted for circumferential extent ≥ 75%. Bold p-values indicate p < 0.05. Dashes (—) indicate variables not entered into a multivariable model. *Steroid use was not entered into multivariable models because steroids were given according to circumferential extent (confounding by indication).*

Subgroup Analysis: Traction vs Tunnel

Analysis was restricted to the 28 patients with ≥ 75% circumferential involvement (Traction = 7, Tunnel = 21); no standard case met this threshold. Baseline demographics, comorbidities, and invasion depth were comparable, but tunnel ESD was used for more complex lesions: all 14 complete circumference resections were tunnel cases, and lesion width and area were larger in the Tunnel group (Table 3). All 28 received prophylactic steroids. Stricture developed in 1 of 7 Traction patients (14.3%) versus 16 of 21

Tunnel patients (76.2%) (p = 0.007), while procedure time (median 59 vs 76 min, p = 0.791) and dissection speed (p = 0.250) did not differ. Given the residual imbalance in complexity, this comparison is descriptive.

Table 3
Baseline patient and lesion characteristics among patients with ≥ 75% circumferential involvement (n = 28)

Variable	Traction (n = 7)	Tunnel (n = 21)	p-value
Demographics			
Age (mean ± SD)	64.6 ± 13.3	62.0 ± 11.6	0.507
Female, n (%)	5 (71)	14 (67)	1.000
Comorbidity, n (%)	4 (57)	10 (48)	1.000
Fibrosis (F1/F2), n	3	2	0.082
Lesion Characteristics			
Location	3/2/2	5/10/6	0.667
Invasion depth	2/3/1/1/0	4/4/7/4/2	0.672
Circumferential group	0/0/7/0	0/0/7/14	0.006
SLength, median (mm)	61 (41–99)	79 (40–185)	0.137
SWidth, median (mm)	40 (26–58)	52 (25–86)	0.080
LLength, median (mm)	48 (20–77)	58 (27–171)	0.265
LWidth, median (mm)	25 (10–41)	39 (25–81)	0.017
SArea, median (mm²)	1886 (837–3781)	3039 (785–8173)	0.071
LArea, median (mm²)	805 (267–1932)	1593 (530–6234)	0.027
Procedural Outcomes			
Procedure time, median (min)	59 (29–146)	76 (30–209)	0.791
SSpeed (mm²/min)	34.4 (10.1–52.7)	35.5 (16.7–79.8)	0.250
LOS, median (days)	3 (2–5)	3 (1–11)	0.723
Coagulation (mean)	1.14	1.38	0.557
Steroid use, n (%)	7 (100)	21 (100)	—
Primary and Secondary Outcomes			
En bloc resection, n (%)	7 (100)	21 (100)	—
R0 resection, n (%)	7 (100)	21 (100)	—

Bold p-values indicate p < 0.05. Continuous values shown as median (range). Circ group shown as < 50% / 50–75% / 75–99% / 100%; Location as Upper/Mid/Low; Invasion depth as M1/M2/M3/SM1/SM2. Dashes (—) indicate not applicable or no test performed. n = 28.

Variable	Traction (n = 7)	Tunnel (n = 21)	p-value
Curative resection, n (%)	6 (86)	15 (71)	0.639
Stricture, n (%)	1 (14)	16 (76)	0.007
Dilation sessions (median)	1 (n = 1)	1.5 (1–8)	—
Stent placement, n/stricture patient	0/1 (0%)	8/16 (50%)	—

Bold p-values indicate p < 0.05. Continuous values shown as median (range). Circ group shown as < 50% / 50–75% / 75–99% / 100%; Location as Upper/Mid/Low; Invasion depth as M1/M2/M3/SM1/SM2. Dashes (—) indicate not applicable or no test performed. n = 28.

All Traction and Tunnel Cases

A second analysis included all 58 Traction (n = 19) and Tunnel (n = 39) patients, excluding Standard for a two-arm comparison across the full range of complexity. Demographics were comparable, but Tunnel group had greater circumferential involvement, larger lesions, and longer procedure time and hospital stay (Table 4). Stricture occurred in 1 of 19 Traction patients (5.3%) and 17 of 39 Tunnel patients (43.6%) (p = 0.003). Within this Traction-versus-Tunnel subset, Tunnel technique was a significant risk factor on univariate analysis (Firth's univariate OR = 9.59, 95% CI: 2.08–92.61, p = 0.002) and remained an independent risk factor after adjustment for circumferential extent ≥ 75% (OR = 13.38, 95%CI: 2.24–149.84, p = 0.003), with circumferential ≥ 75% the dominant predictor (OR = 35.98, p < 0.001). Because technique was operator-selected by complexity, this association is hypothesis-generating.

Table 4
Baseline patient and lesion characteristics across Traction and Tunnel techniques (n = 58)

Variable	Traction (n = 19)	Tunnel (n = 39)	p-value
Demographics			
Age (mean ± SD)	64.6 ± 10.0	61.3 ± 12.0	0.281
Female, n (%)	14 (74)	27 (69)	1.000
Comorbidity, n (%)	8 (42)	15 (38)	1.000
Fibrosis (F1/F2), n	3	4	0.438
Lesion Characteristics			
Location	4/7/8	5/19/15	0.562
Invasion depth	9/3/3/3/1	10/8/11/7/3	0.613
Circumferential group	5/7/7/0	8/10/7/14	0.010
SLength, median (mm)	51 (28–99)	64 (26–185)	0.040
SWidth, median (mm)	36 (18–58)	40 (21–86)	0.233
LLength, median (mm)	28 (15–77)	41 (12–171)	0.032
LWidth, median (mm)	17 (10–41)	30 (10–81)	0.028
SArea, median (mm²)	1362 (396–3781)	2199 (429–8173)	0.075
LArea, median (mm²)	393 (118–1932)	1001 (94–6234)	0.020
Procedural Outcomes			
Procedure time, median (min)	32 (16–146)	51 (12–209)	0.039
SSpeed (mm²/min)	34.4 (10.1–97.3)	33.8 (9.8–80.5)	0.987
LOS, median (days)	2 (1–5)	3 (1–11)	0.023
Coagulation (mean)	0.84	1.03	0.935
Steroid use, n (%)	9 (47)	25 (64)	0.265
Primary and Secondary Outcomes			
En bloc resection, n (%)	19 (100)	39 (100)	—
R0 resection, n (%)	19 (100)	39 (100)	—
Curative resection, n (%)	15 (79)	29 (74)	1.000

Bold p-values indicate p < 0.05. Continuous values shown as median (range). Circ group shown as < 50% / 50–75% / 75–99% / 100%; Location as Upper/Mid/Low; Invasion depth as M1/M2/M3/SM1/SM2. Dashes (—) indicate not applicable or no test performed.

Variable	Traction (n = 19)	Tunnel (n = 39)	p-value
Stricture, n (%)	1 (5)	17 (44)	0.003
Dilation sessions (median)	1 (n = 1)	1 (1–8)	—
Stent placement, n/stricture patient	0/1 (0)	8/17 (47%)	—

Bold p-values indicate p < 0.05. Continuous values shown as median (range). Circ group shown as < 50% / 50–75% / 75–99% / 100%; Location as Upper/Mid/Low; Invasion depth as M1/M2/M3/SM1/SM2. Dashes (—) indicate not applicable or no test performed.

Discussion

In this three-way comparison of tunnel, traction-assisted, and standard ESD, all approaches achieved equivalent oncologic resection quality across a broad spectrum of lesion complexity, supporting flexible technique selection at experienced centers, while stricture risk was driven by circumferential extent.

Our curative resection rate of 80.8% exceeds comparable Western series: Beaufort et al. reported 52% in 68 patients and Subrahmanyan et al. 55% across 150 patients from 13 North American centers [3, 4]. It is also comparable to high-performing Asian centers; Ono et al. reported 88% complete resection in 84 patients [8]. Non-curative resections resulted from unexpected submucosal invasion rather than technical failure. As a selection bias, patients with strong preoperative suspicion of deep submucosal invasion were referred for surgery and absent from this cohort.

The overall stricture rate and its circumferential dose-response pattern replicate established benchmarks; Ono et al. described an 18% rate and identified circumferential extent as the dominant predictor [8]. In our analysis, circumferential extent ≥ 75% was the principal independent predictor, with M3 invasion adding incremental risk. Crude stricture rates by technique reflect the systematic allocation of progressively more complex lesions to traction and tunnel approaches rather than differential technique safety, leaving residual case-mix differences that adjustment can only partially address. The residual adjusted association between tunnel technique and stricture is therefore best regarded as hypothesis-generating in this single-operator cohort.

While residual confounding by case complexity cannot be excluded, the consistency of the tunnel association across 300 sensitivity models suggests an additional technique-specific contribution that may lie in technique geometry. Tunnel ESD requires the endoscope cap to advance within a narrow submucosal corridor resting against the muscularis propria [19], whereas traction allows greater spatial freedom in choosing the dissection plane. This may produce thinner residual submucosa above the muscle in tunnel cases, exposing the muscularis propria to greater thermal injury, accounting for tunnel's stricture risk and traction's protective effect in adjusted analyses. Muscularis propria injury is the most robust predictor of post-ESD stricture in pooled analysis (OR 5.53) [20], and the recently described "shallow ESD" technique deliberately preserves a thick submucosal layer above the muscle to prevent

stricture [21]. Residual submucosal thickness has not been directly compared between tunnel and traction techniques; prospective histomorphometric studies are needed.

Traction-assisted ESD [22, 23] and tunnel dissection (ESTD) [24] have each been shown to shorten procedure time and improve en bloc resection versus conventional ESD [25, 26]. In our cohort, however, size-normalized dissection speed did not differ across techniques ($p = 0.351$). Two factors may explain this: all procedures were performed by a single highly experienced endoscopist, reducing the incremental benefit of advanced techniques, and traction and tunnel methods were preferentially applied to larger, and more fibrotic lesions, offsetting their expected time-saving effect. The comparable speeds thus indicate similar efficiency despite greater case complexity rather than a lack of efficacy, the longer procedure times reflecting lesion size, consistent with the Yoshida et al. (CONNECT-E trial) and Koike et al. [22, 23].

The progressive risk gradient across circumferential strata provides a framework for patient counseling, surveillance planning, and selecting candidates for prophylactic interventions. The independent contribution of M3 invasion is mechanistically plausible: dissection immediately above the muscularis propria produces broader fibrotic healing irrespective of technique, consistent with Geng et al., who identified muscular injury as an independent risk factor for post-ESD esophageal stenosis in 1,033 patients [27]. Additionally, the complete overlap between stricture and steroid prophylaxis reflects confounding by indication, with steroids targeted toward the higher-risk group.

Although pT1b-SM1 invasion (≤ 200 μm) is not considered definitively curative under current Japan Esophageal Society criteria [16] owing to potential lymph node metastasis, the actual risk appears low absent other adverse histopathological features. Ten patients in our cohort had submucosal invasion limited to ≤ 200 μm; following tumor board evaluation, all underwent surveillance, and no lymph node or distant metastasis occurred over a median of 36 months. This supports growing evidence that surveillance may be reasonable for selected patients with minimal submucosal invasion and otherwise favorable pathology.

Several limitations apply. Technique allocation was non-randomized, with the standard approach reserved for smaller, less complex lesions; we addressed this through multivariable adjustment for circumferential extent and lesion size, two subgroup analyses excluding the standard technique, and 300 sensitivity models. With 73 patients with 18 events, power is limited and widens confidence intervals; so primary analyses were restricted to two predictors. Only 1 stricture occurred among the 34 patients treated without the tunnel technique; the odds ratios for tunnel ESD carry wide confidence intervals, and although the direction and significance of the association are consistent across analyses, its precise magnitude should be interpreted with caution. The 71.2% female predominance is atypical for esophageal SCC globally and may limit generalizability, and non-randomized steroid prophylaxis precludes causal inference regarding its efficacy. External validation in a prospective multicenter cohort is required, and a randomized trial comparing traction and tunnel ESD in patients with ≥ 75% circumferential involvement is the natural next step.

Conclusions

In this first reported Mediterranean ESCC ESD series and first three-arm head-to-head comparison of standard, traction-assisted, and tunnel techniques, all three achieved equivalent oncologic resection and comparable dissection efficiency. Post-procedural stricture risk was driven primarily by ≥ 75% circumferential involvement and M3 invasion. Technique should be tailored to lesion characteristics, and stricture prevention should be guided by circumferential involvement irrespective of technique. Prospective randomized data are needed to define any technique-specific contribution to stricture risk in matched populations.

Abbreviations

AJCC
American Joint Committee on Cancer
CI
Confidence interval
Circ
Circumferential involvement group
ESCC
Esophageal squamous cell carcinoma
ESD
Endoscopic submucosal dissection
ESTD
Endoscopic submucosal tunnel dissection
F0/F1/F2
Submucosal fibrosis grades:none/mild/severe
LArea, LLength, LWidth
Lesion area, long axis and short axis
LOS
Length of hospital stay
M1/M2/M3
Invasion limited to the epithelium/lamina propria mucosae/muscularis mucosae
NBI
Narrow-band imaging
OR
Odds ratio
R0
Histologically complete resection with negative margins
SArea, SLength, SWidth
Resected specimen area, long axis and short axis
SD

Standard deviation
SM
Submucosal
SM1/SM2
Submucosal invasion ≤ 200 μm / >200 μm
SSpeed
Dissection speed (resected specimen area divided by procedure time)
TXI
Texture and color enhancement imaging

Declarations

Ethics approval and consent to participate

This study was approved by the Koç University Clinical Research Ethics Committee (approval no. 2024.401.IRB2.180) and was conducted in accordance with the Declaration of Helsinki. Written informed consent for the procedure and for the use of clinical data for research was obtained from all patients.

Consent for publication

Not applicable. The manuscript contains no identifiable individual data; all endoscopic and specimen images are de-identified.

Competing Interests

FA has received honoraria from Olympus and has given lectures on endoscopic suturing for Boston Scientific and Olympus. FA is a board member of the Turkish Gastrointestinal Endoscopy Society and has received speaking and lecture fees. The other authors declare that they have no competing interests.

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Author Contribution

FA conceived and designed the study, performed all ESD procedures and critically revised the manuscript. AH collected the data, performed the statistical analysis and drafted the manuscript. SO contributed to the conception and design of the study, collected the data and helped draft the manuscript. OA collected the data, contributed to the analysis and interpretation of the data and critically revised the manuscript. ABA collected the data and critically revised the manuscript. OCT performed the histopathological evaluation, interpreted the pathology data and critically revised the manuscript. MSS managed sedation

and anesthesia during the procedures, collected the data and critically revised the manuscript. All authors read and approved the final manuscript.

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Data Availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Figures

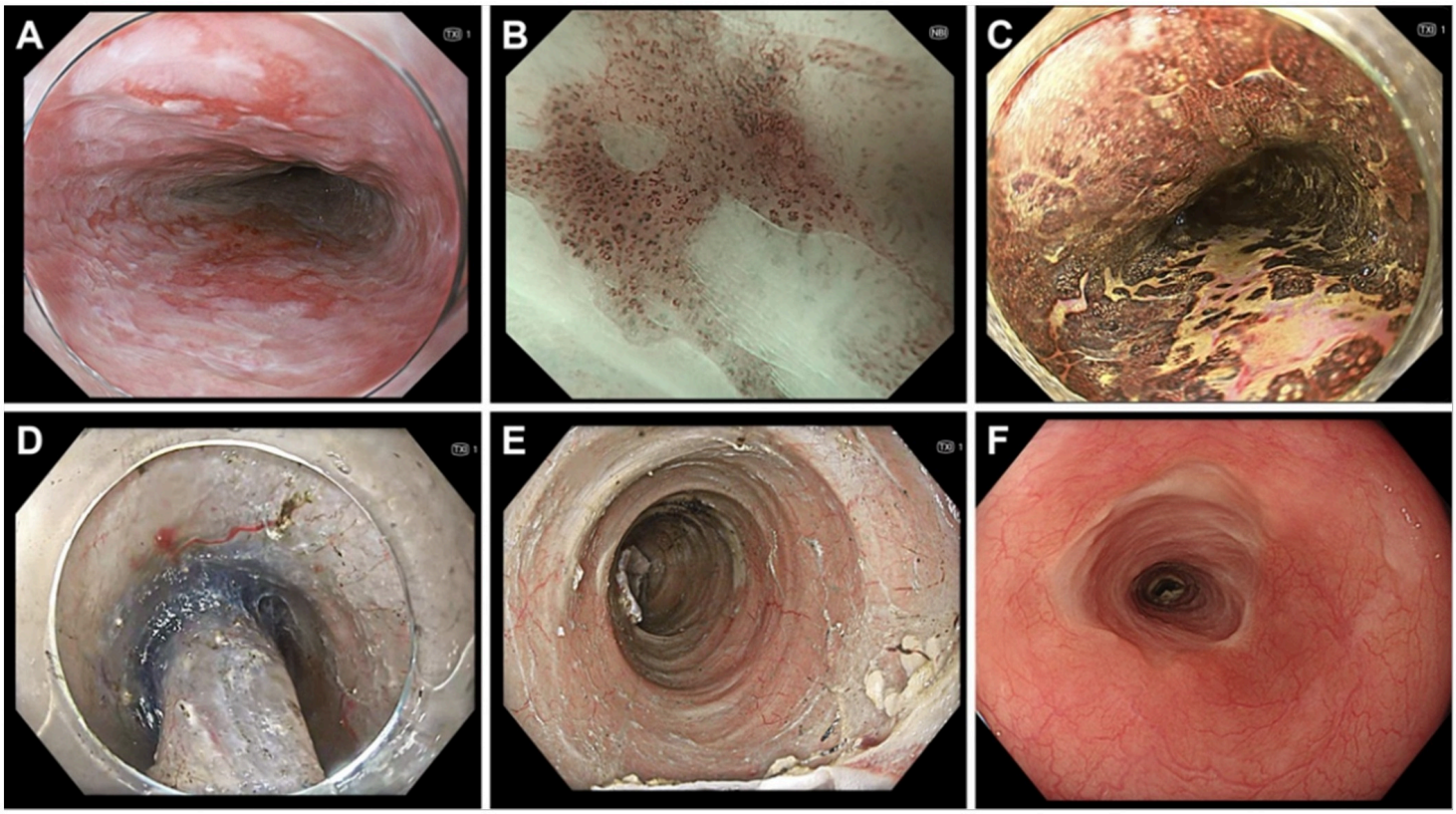

Figure 1

Traction-assisted ESD of two opposing flat superficial esophageal lesions

(A) Endoscopic TXI view demonstrating two opposing flat esophageal lesions.

(B) Magnifying narrow-band imaging (NBI) view of the lesions, showing detailed mucosal and microvascular patterns.

(C) TXI view following Lugol chromoendoscopy, clearly delineating the unstained neoplastic areas.

(D) Traction-assisted endoscopic submucosal dissection using a snare traction system. The submucosal plane is widely exposed, providing improved visualization and dissection access.

(E) Circumferential post-ESD defect demonstrating a broad and well-preserved residual submucosal layer overlying the muscularis propria throughout the resection bed.

(F) Endoscopic follow-up at 6 months demonstrating complete healing of the resection site without evidence of symptomatic or endoscopic stricture.

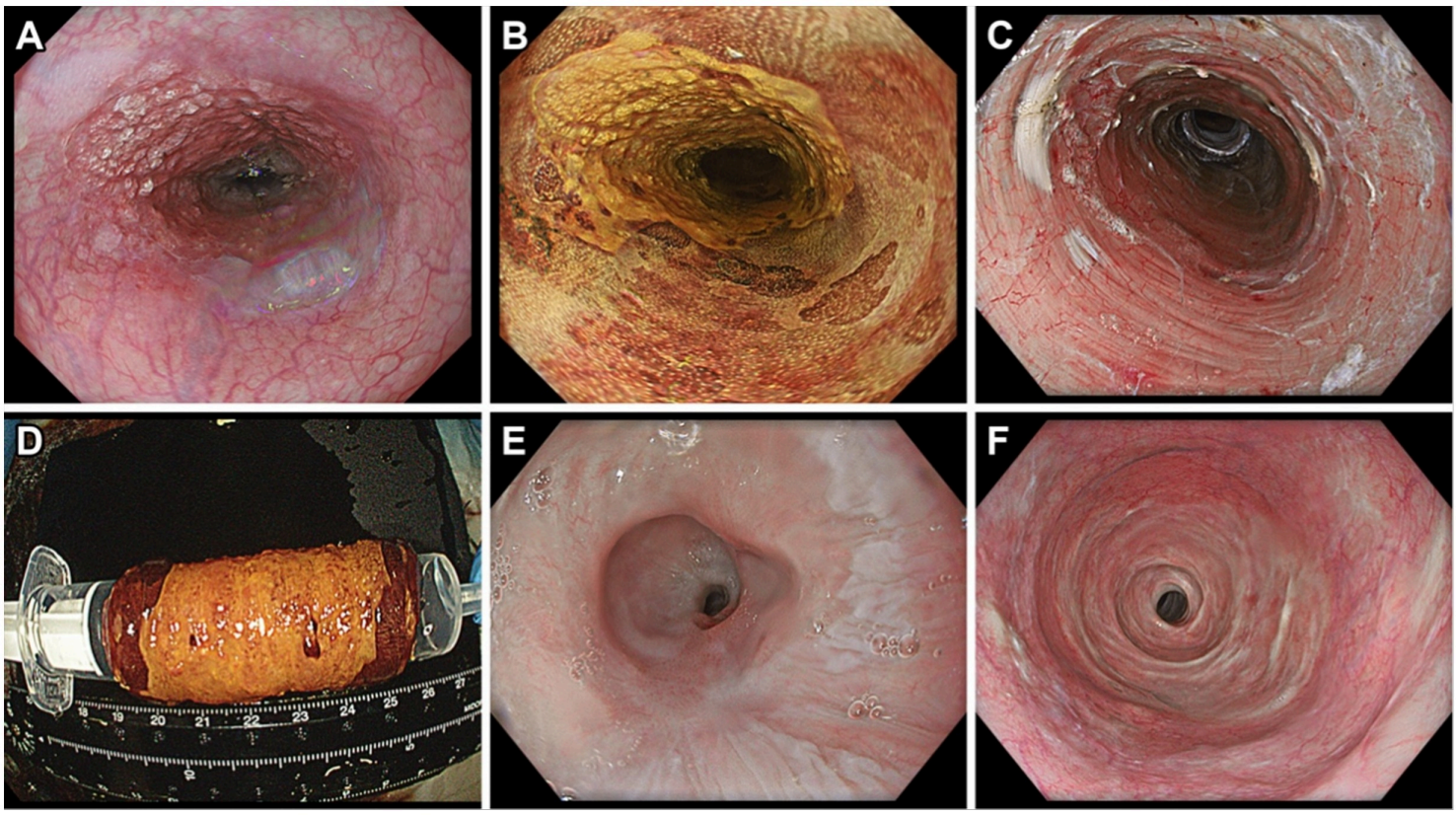

Figure 2

Multi-tunnel ESD of a circumferential esophageal lesion complicated by stricture

(A) Endoscopic TXI view of a circumferential esophageal lesion.

(B) Endoscopic TXI view following Lugol chromoendoscopy, clearly delineating the unstained neoplastic area.

(C) Endoscopic TXI view of the post-ESD defect. A multi-tunnel technique was used during dissection. The muscularis propria fibers are clearly visible throughout the resection bed, with only a thin residual submucosal layer remaining.

(D) Macroscopic appearance of the circumferentially resected specimen following Lugol staining.

(E) Symptomatic esophageal stricture observed 10 weeks after ESD. A standard gastroscope (9.9 mm) could not be advanced beyond the stenotic segment. Endoscopic bougie dilation was subsequently performed.

(F) Endoscopic appearance after serial bougie dilation therapy, demonstrating a healed scar with restoration of luminal patency and easy passage of the endoscope.