REVIEW ARTICLES

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Mapping Two Decades of Research on Endoscopic Submucosal Dissection in Esophageal Cancer: A Bibliometric and Visual Analysis

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

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Background: Endoscopic submucosal dissection (ESD) is established as a key minimally invasive, function-preserving technique for early-stage esophageal cancer, valued for its high rate of en bloc resection. This study aims to provide a comprehensive bibliometric and visual analysis of research on ESD in esophageal cancer from 2006 to 2025.

Material/Methods: A systematic literature search was performed in the Web of Science Core Collection. Bibliometric analysis and visualization were conducted using VOSviewer, CiteSpace, and the R package "bibliometrix".

Results: A total of 512 original research articles were included in the analysis. Japan and China collectively contributed over 82% of the total output, with Japanese institutions and authors dominating in productivity and citation impact. Keyword co-occurrence analysis identified 5 thematic clusters: (1) post-ESD complication management; (2) early diagnosis and risk lesion detection; (3) survival analysis and prognostic indicators; (4) adjunctive and supportive therapies; and (5) endoscopic technique and visualization. Recent keyword bursts since 2020 highlighted emerging priorities including "risk factors", "early esophageal cancer", and "prevention".

Conclusions: This bibliometric analysis reveals a clear research trajectory in ESD for esophageal cancer, shifting from foundational technique refinement toward multimodal and personalized management strategies. These findings provide a structured reference for identifying research priorities, fostering international collaboration, and guiding future investigations in this field.

Keywords: Bibliometrics • Endoscopic Mucosal Resection • Esophageal Neoplasms

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Introduction

Esophageal cancer is one of the most aggressive malignancies of the gastrointestinal tract, ranking as the seventh most commonly diagnosed cancer and the sixth leading cause of cancer-related deaths worldwide, with approximately 604 100 new cases and 544 100 deaths reported in 2020 [1]. Histologically, it is classified into squamous cell carcinoma, prevalent in regions like East Asia, and adenocarcinoma, which is more common in Western countries and linked to factors such as gastroesophageal reflux disease and Barrett's esophagus [2,3]. The complex pathogenesis involving genetic alterations, chronic inflammation, and environmental exposures, combined with typically late symptom onset, results in most patients being diagnosed at advanced stages, with limited treatment options and poor prognosis [4].

The introduction and widespread adoption of endoscopic submucosal dissection (ESD) has significantly changed the approach to early-stage esophageal cancer. Compared with traditional esophagectomy, ESD offers notable clinical advantages, including reduced procedural trauma, faster recovery, lower complication rates, and preservation of esophageal structure and function [5]. Consequently, ESD has been increasingly recognized as a preferred therapy for superficial esophageal neoplasia, initially in East Asia and now with growing adoption and expanding indications in the West [6]. In recent years, substantial research efforts have focused on optimizing patient selection, improving procedural safety, and evaluating long-term oncological outcomes associated with ESD. Studies have demonstrated high en bloc and R0 resection rates, as well as favorable survival outcomes for carefully selected patients with mucosal or superficial submucosal involvement [7,8]. Advances in imaging techniques, such as magnifying endoscopy and narrow-band imaging, have further enhanced diagnostic accuracy and lesion characterization, contributing to more precise and effective treatment planning [9,10]. Moreover, ongoing investigations are exploring the integration of ESD with other modalities, including chemoradiotherapy [11] and immune checkpoint inhibitors [12], reflecting a growing trend toward multimodal treatment approaches that may extend the applicability of ESD to more complex or borderline cases.

Although bibliometric studies have examined broader topics, such as endoscopic techniques in gastrointestinal oncology [13], and ESD across all organ indications [14], a dedicated analysis focusing specifically on ESD for esophageal cancer remains absent. For example, Wu et al (2022) [14] conducted a comprehensive bibliometric review of the entire ESD field from 2006 to 2020, yet their broad scope precluded a detailed characterization of disease-specific trends in esophageal cancer. This gap limits understanding of the field's unique developmental trajectory, key intellectual milestones, and emerging frontiers. To address this, we aimed to conduct a bibliometric and visualization analysis of research on ESD for esophageal cancer from 2006 to 2025, employing a multi-tool approach (VOSviewer, CiteSpace, and bibliometrix) to map its evolution, identify key contributors and collaboration networks, and highlight emerging research priorities.

Material and Methods

Literature Search and Selection

A comprehensive literature search was conducted using the Web of Science Core Collection (WoSCC), a widely recognized multidisciplinary database for bibliometric research [15]. The WoSCC was selected as the sole data source for several reasons: it provides standardized citation records essential for co-citation and bibliographic coupling analyses, offers full compatibility with the analytical tools used in this study (VOSviewer and CiteSpace), and minimizes the risk of record duplication that may arise from merging multiple databases [14]. The search was executed on February 20, 2026, covering studies published between January 2006 and December 2025. The start year of 2006 was chosen because it marks the period when ESD for esophageal cancer began to gain significant traction in publications, following its initial development. The analysis was restricted to original articles published in English, as English is the predominant language of international journals indexed in WoSCC, thereby ensuring data consistency, analytical comparability, and compatibility with standardized bibliometric tools. The following topic search terms were used: TS=("endoscopic submucosal dissection") [14] AND TS=("esophageal neoplasm*" OR "esophagus neoplasm*" OR "esophageal cancer*" OR "esophagus cancer*" OR "esophageal tumor*" OR "esophagus tumor*" OR "esophageal carcinoma*" OR "esophagus carcinoma*") [16]. The bibliographic data were exported in both "Full Record and Cited References" and "Plain Text" formats.

Extracted data included article metadata (title, authors, affiliations, journal), citation metrics, geographical distribution, authorship patterns, and keyword occurrences. As this study exclusively analyzed publicly available bibliographic data from an academic database and did not involve human participants, animal experiments, or identifiable personal information, ethical approval was not required. The initial screening of titles and abstracts and the subsequent full-text review were independently conducted by 2 researchers to minimize selection bias; any disagreements were resolved through consensus discussion until full agreement was reached.

Statistical Analysis

To perform a multi-faceted analysis, we used 3 complementary tools. VOSviewer (version 1.6.20) was primarily used for

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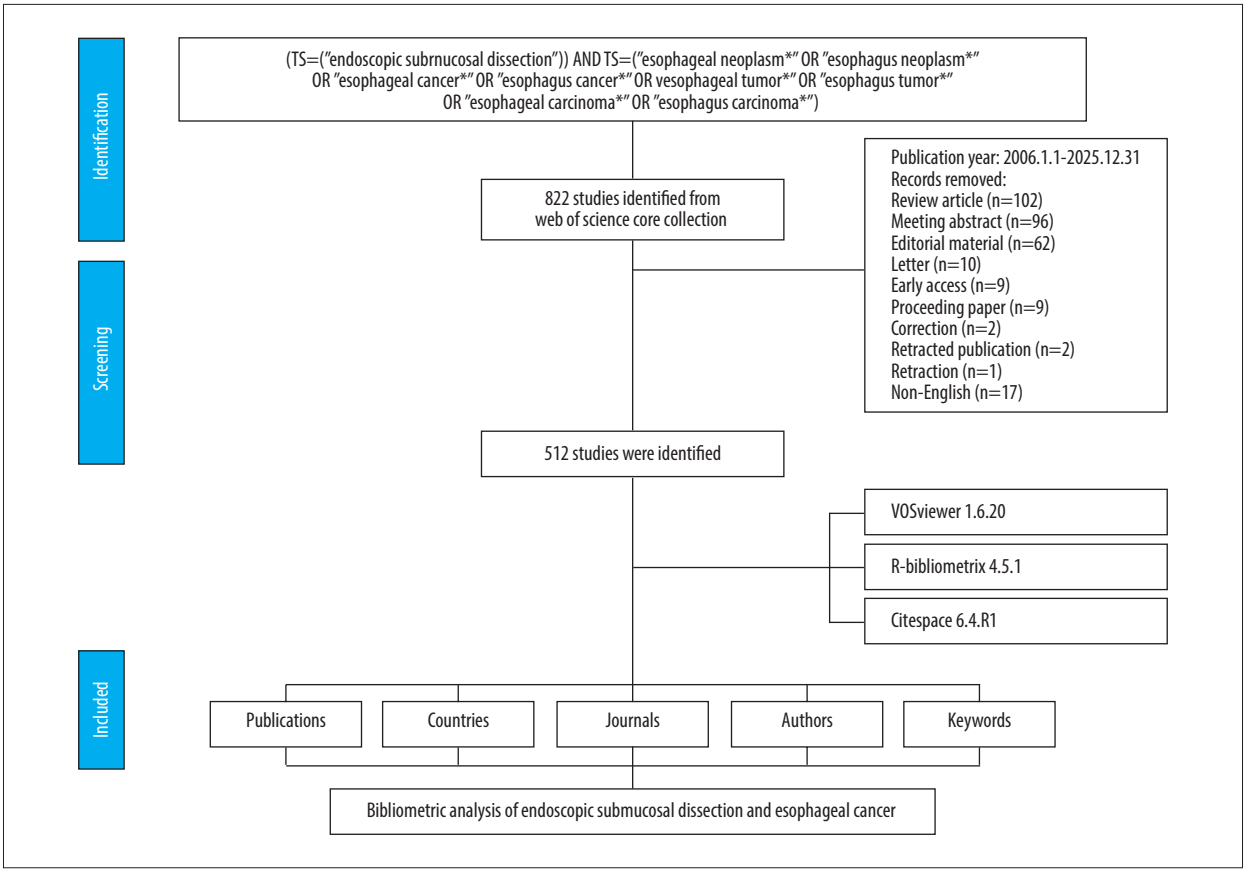

Figure 1. Flowchart of the literature screening process.

constructing and visualizing bibliometric networks, such as collaboration and co-occurrence maps [17]. It was used to map collaborations among countries, institutions, and authors, analyze co-authorship and co-citation networks, and detect keyword co-occurrence patterns. In the resulting visual networks, node size represents the frequency of occurrence (eg, number of publications or citations), line thickness indicates the strength of links (eg, collaboration or co-occurrence), and node color distinguishes different clusters or temporal trends. This allowed for in-depth exploration of interconnections among key contributors, institutions, and thematic areas within the field.

CiteSpace (version 6.4.R1) was specifically applied to detect emerging trends and keyword bursts, highlighting fast-growing research topics [18]. The analysis was configured with the following parameters: time slicing from January 2006 to December 2025 in 1-year intervals, node type set to "keywords", and a top N threshold of 5 keywords per slice to capture the most significant topics while maintaining network clarity. The Pathfinder and merged network pruning methods were used to refine the network structure.

The R package bibliometrix (version 4.4.1) provided a comprehensive framework for quantitative statistical analysis, including productivity assessment and citation analysis [19]. It allows users to import data from major bibliographic databases and perform citation analysis, co-occurrence mapping, productivity assessment, and collaboration network analysis. With its ability to generate informative visualizations and reports, bibliometrix supports a nuanced understanding of research trends and thematic developments.

The h-index, g-index, and m-index were used to evaluate researchers' academic performance [20,21]. It is important to note that the h-index reported here is calculated based only on the 512 articles included in this specific study, not the authors' entire career output. To assess journal quality, we used Journal Impact Factor (IF) and Journal Citation Reports (JCR) quartile rankings.

Results

Overview of Publications

The literature screening process is illustrated in **Figure 1**. Initially, 822 records were retrieved. After excluding non-English articles (n=17), reviews (n=102), meeting abstracts (n=96),

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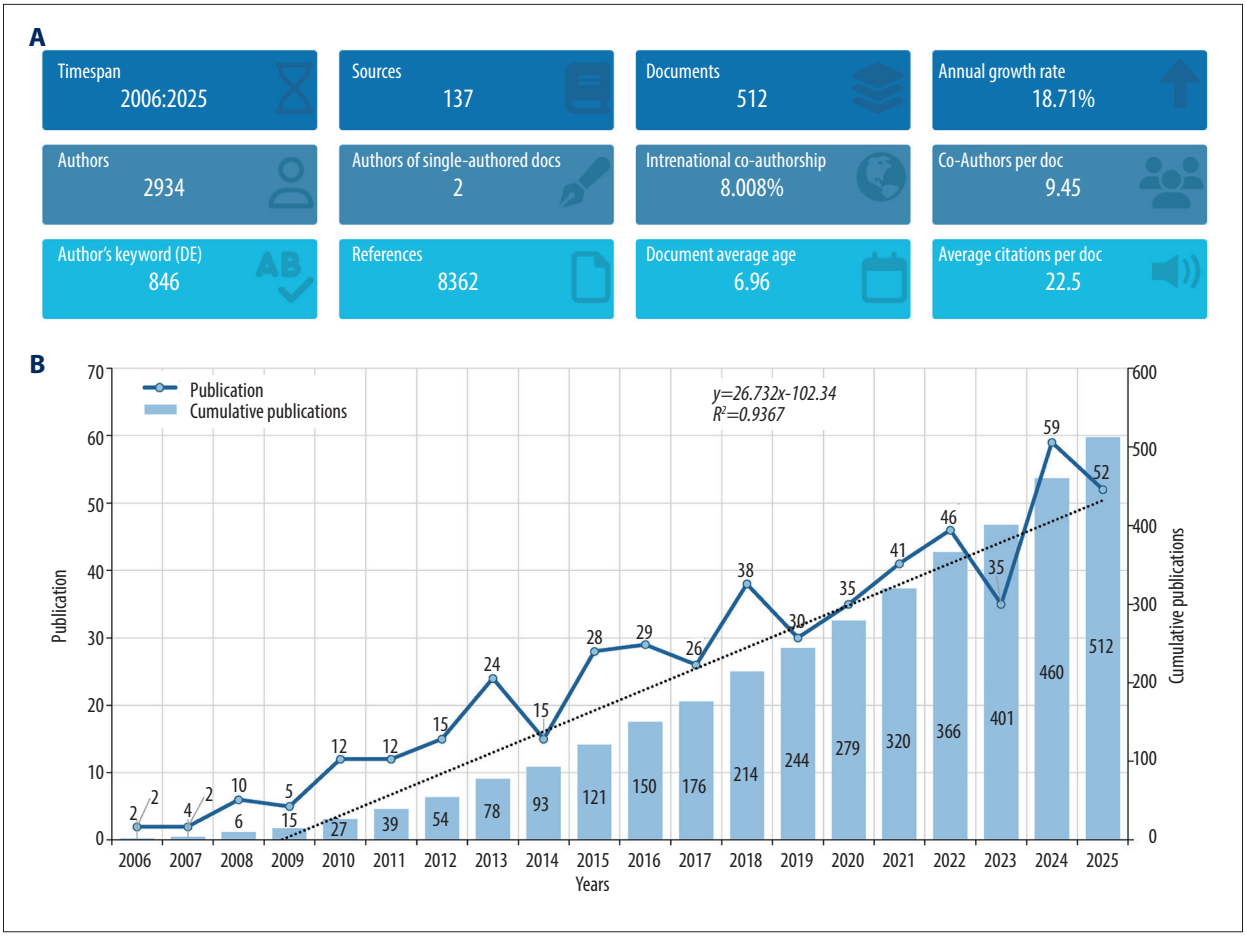

Figure 2. Overview of included studies and publication metrics. (**A**) Summary information of the included studies. (**B**) Annual number of publications and cumulative publication trends from 2006 to 2025.

Table 1. Publication and citation profiles of the top 10 leading countries/regions.

Rank	Country	Articles	Freq	SCP	MCP	MCP_ratio	TC	TC_rank	Average citations
1	Japan	251	0.490	239	12	0.048	7309	1	29.1
2	China	172	0.336	165	7	0.041	1931	2	11.2
3	USA	27	0.053	21	6	0.222	506	4	18.7
4	Korea	22	0.043	20	2	0.091	303	5	13.8
5	France	11	0.021	7	4	0.364	154	7	14.0
6	Canada	5	0.010	5	0	0.000	70	8	14.0
7	Germany	4	0.008	2	2	0.500	176	6	44.0
8	Australia	2	0.004	0	2	1.000	27	12	13.5
9	Austria	2	0.004	2	0	0.000	32	10	16.0
10	Belgium	2	0.004	1	1	0.500	20	13	10.0

Articles: publications of corresponding authors only. Freq – frequency of total publications; SCP – single country publications; MCP – multiple country publications; MCP_ratio – proportion of multiple country publications; TC – total citations; TC_rank – rank of total citations; average citations: average number of citations per publication.

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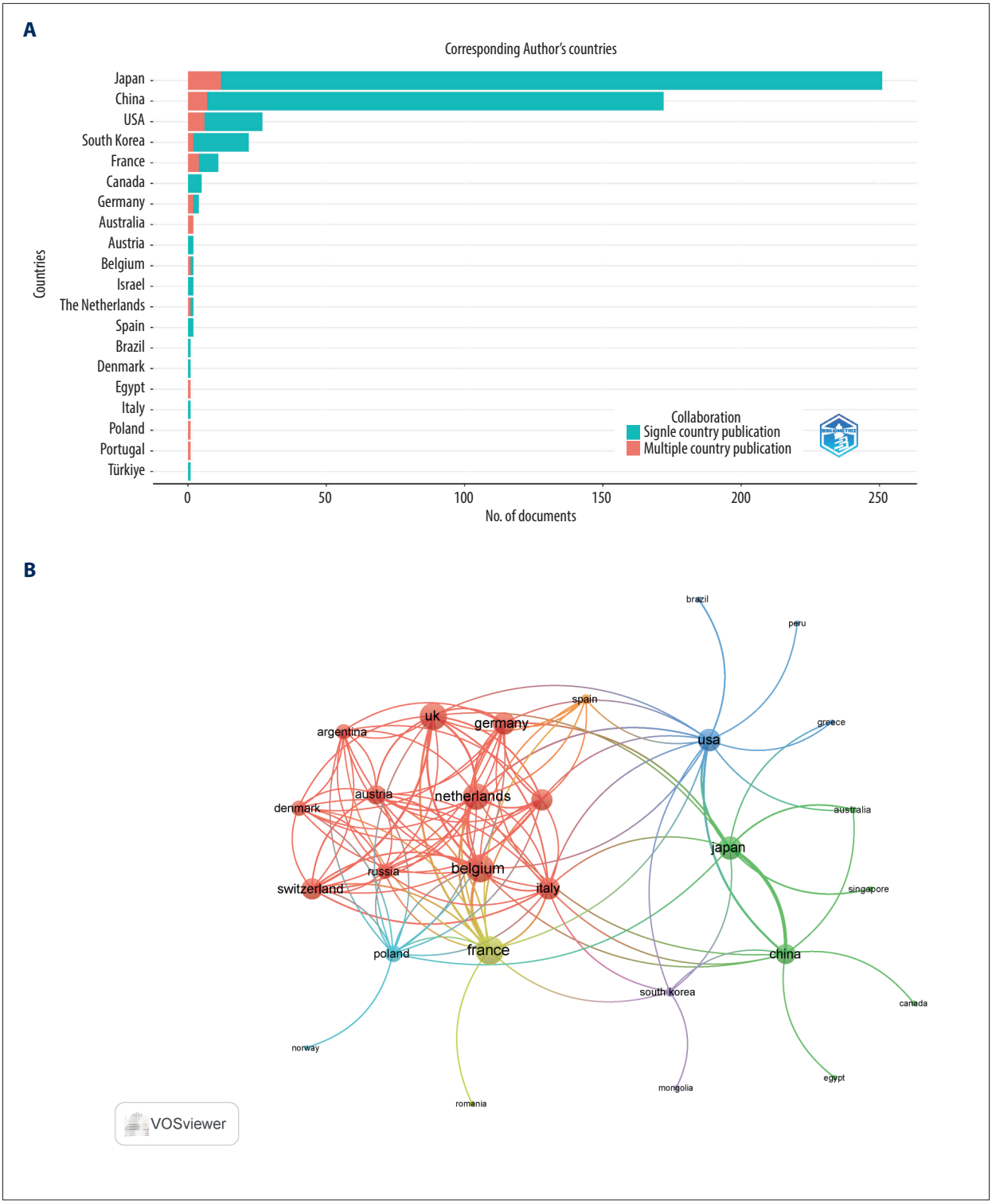

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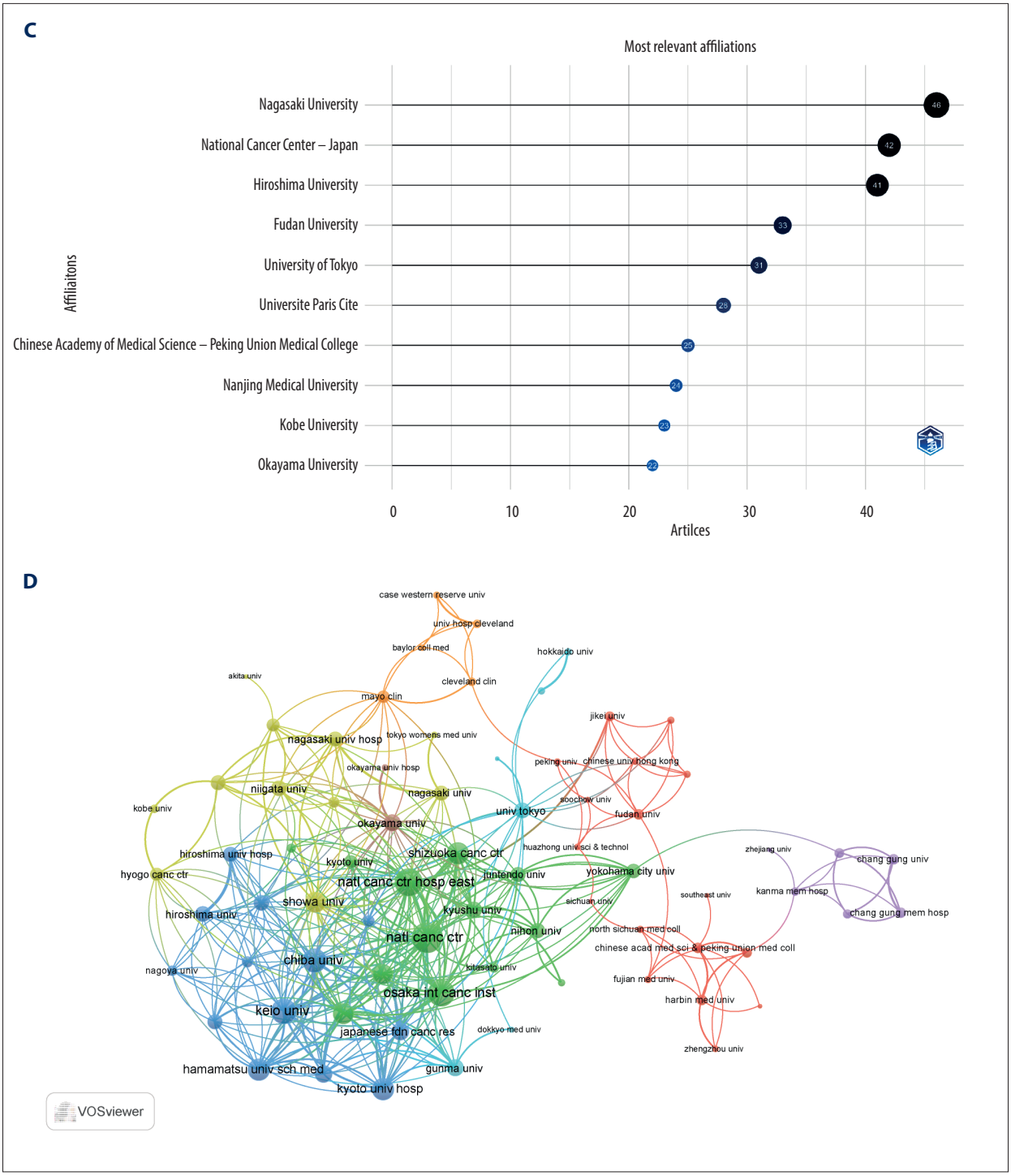

Figure 3. Analysis of countries, regions, and institutions. (**A**) Distribution of corresponding author's publications by country. (**B**) Visualization map depicting collaboration among different countries and regions. Node size indicates publication count, link thickness represents collaboration strength, and colors distinguish research clusters. (**C**) Top 10 institutions by article count. (**D**) Visualization map depicting collaboration among different institutions. Node size indicates publication count, link thickness represents collaboration strength, and colors distinguish research clusters. Total link strength measures the frequency of co-authorship.

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early access articles (n=9), editorials (n=62), proceedings (n=9), letters (n=10), corrections (n=2), retracted publications (n=2), and retractions (n=1), 512 eligible articles were selected for bibliometric analysis. The annual number of publications on ESD in esophageal cancer has shown an overall upward trajectory from 2006 to 2025, despite minor fluctuations in individual years (**Figure 2**). In the early phase (2006-2010), research activity was limited, with annual outputs remaining below 12 publications. A modest increase began around 2010, followed by a more pronounced increase between 2013 and 2016. From 2018 onward, the field entered a phase of accelerated growth, with annual publications consistently exceeding 30 and reaching a peak of 59 articles in 2024. Overall, these trends indicate sustained and accelerating research interest in ESD for esophageal cancer over the past 2 decades.

Analysis of Countries

Analysis of the 30 contributing countries and regions revealed a landscape dominated by East Asia, where esophageal cancer incidence is high. Japan was the most productive country (251 articles, 49.0%), a finding that highlights its pioneering role in developing and refining ESD techniques. China followed with 172 publications (33.6%), reflecting its growing research capacity in response to a significant clinical burden. Together, these 2 nations accounted for over 82% of the total output. In terms of citation impact, Japan's leadership was further solidified with the highest total citations (TC; 7309) and average citations per article (29.1), indicating the foundational influence of its research on the global community (**Table 1, Figure 3A**). In contrast, international collaboration networks were most actively led by European countries, with France (total link strength=29) and Belgium (total link strength=28) serving as key collaborative hubs, suggesting their role in disseminating and validating ESD techniques (**Figure 3B**). In summary, the field is characterized by a dominant East Asian research core led by Japan and China, complemented by an active European collaborative network.

Analysis of Institutions

The institutional analysis mirrored the national trends, with Japanese centers forming a powerful research and training network. Nagasaki University (46 articles), the National Cancer Center Japan (42), and Hiroshima University (41) were the most prolific institutions, underscoring their central role as hubs for ESD innovation and clinical evidence generation (**Figure 3C**). The National Cancer Center's leadership in international collaboration (total link strength=69) further emphasizes its function as a critical node for global knowledge exchange in this field (**Figure 3D**). These findings confirm that a small number of Japanese institutions serve as the primary drivers of research productivity and international collaboration in esophageal ESD.

Analysis of Journals

A total of 137 academic journals published articles on ESD in esophageal cancer. The top 3 journals by h-index were *Gastrointestinal Endoscopy* (h-index=22, IF 2024=7.5, TC=1984), *Surgical Endoscopy and Other Interventional Techniques* (h-index=17, IF 2024=2.7, TC=554), and *Endoscopy* (h-index=14, IF 2024=12.8, TC=1403). In terms of total publications (TP), *Surgical Endoscopy and Other Interventional Techniques* ranked first with 42 articles, followed by *Gastrointestinal Endoscopy* (34) and *Esophagus* (32) (**Table 2**).

In the co-occurrence network analysis of 72 journals with at least 2 instances of co-citation, *Gastrointestinal Endoscopy* (link strength=464), *Endoscopy* (link strength=286), and *Surgical Endoscopy and Other Interventional Techniques* (link strength=284) emerged as the most strongly co-cited journals, highlighting their central influence in this research field (**Figure 4A**). In the journal coupling network, based on 74 journals with at least 2 coupling connections, the top 3 journals were *Surgical Endoscopy and Other Interventional Techniques* (link strength=11 217), *Gastrointestinal Endoscopy* (8974), and *Diseases of the Esophagus* (6469), reflecting a high degree of shared references and intellectual overlap in the literature they publish (**Figure 4B**). Collectively, these analyses identify a core group of endoscopy and gastroenterology journals that dominate both the publication and citation landscape of this field.

Analysis of Authors

Based on the h-index among the top 20 authors, the most influential was Ishihara R (h-index=10), followed by Fujishiro M, Tanaka S, Fujiwara Y, Tanigawa T, Uedo N, and Watanabe T (each h-index=8). In terms of TP, Ishihara R led the field with 16 articles, followed by Tanaka S (14) and both Fujishiro M and Uedo N (13 each). In terms of TC, Ishihara R ranked first with 1279 citations, followed by Fujishiro M (936) and Kato M (855) (**Table 3**). Among the 82 authors who participated in international collaborations and had no fewer than 5 publications, Fujiwara Y exhibited the highest total link strength (88), followed by Ishihara R (74) and Watanabe T (73) (**Figure 4C**). These results highlight a tightly interconnected group of Japanese researchers who have shaped the field's intellectual foundation through sustained productivity and extensive collaboration.

Analysis of Keywords

A total of 64 high-frequency keywords with a minimum of 8 occurrences were identified and categorized into 5 thematic clusters, each reflecting a critical aspect of research (**Figure 5A**). Cluster 1 (red) focused on post-ESD complication management, with commonly used terms such as "stricture", "balloon dilation", "steroid injection", and "triamcinolone injection". Cluster

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Table 2. Bibliometric indicators of the top 20 high-impact journals.

Rank	Journal	h_ index	g_ index	m_ index	IF 2024	JCR 2024	TP	TP_ rank	TC	TC_ rank	PY_ start
1	Gastrointestinal Endoscopy	22	34	1.158	7.5	Q1	34	2	1984	1	2008
2	Surgical Endoscopy and Other Interventional Techniques	17	26	0.810	2.7	Q1	42	1	554	3	2006
3	Endoscopy	14	18	0.824	12.8	Q1	18	7	1403	2	2010
4	Digestive Endoscopy	12	26	0.667	4.7	Q1	26	4	509	4	2009
5	World Journal of Gastroenterology	12	23	0.706	5.4	Q1	23	6	297	7	2010
6	Diseases of the Esophagus	11	21	0.579	2.3	Q3	24	5	354	5	2008
7	Esophagus	8	31	0.471	3.8	Q2	32	3	322	6	2010
8	Journal of Gastroenterology and Hepatology	7	11	0.438	3.4	Q2	11	9	168	8	2011
9	Cancers	5	6	0.556	4.4	Q2	8	10	52	15	2018
10	Digestion	5	6	0.385	3.6	Q2	6	16	75	11	2014
11	Journal of Gastroenterology	5	7	0.417	5.5	Q1	7	13	100	10	2015
12	Radiation Oncology	5	5	0.417	3.2	Q1	5	25	70	12	2015
13	BMC Gastroenterology	4	5	0.400	2.6	Q2	12	8	139	9	2017
14	Experimental and Therapeutic Medicine	4	6	0.250	2.3	Q3	6	17	18	20	2011
15	Gut and Liver	4	6	0.286	3.2	Q2	6	18	47	16	2013
16	Internal Medicine	4	7	0.333	1.1	Q2	7	12	34	18	2015
17	Journal of Gastrointestinal Surgery	4	7	0.333	2.4	Q1	7	14	63	13	2015
18	Medicine	4	7	0.333	1.4	Q2	7	15	63	13	2015
19	Turkish Journal of Gastroenterology	4	5	0.200	1.6	Q3	5	26	19	19	2007
20	United European Gastroenterology Journal	4	4	0.364	6.7	Q1	4	32	35	17	2016

h_index – measures both the productivity and citation impact of the publications; g_index – gives more weight to highly-cited articles; m_index – the h-index divided by the number of years since the first published paper; IF – impact factor (2024); JCR – Journal Citation Reports quartile ranking (2024): indicates the journal's ranking relative to others in the same field (Q1: top 25%, Q2: 25-50%, Q3: 50-75%, Q4: bottom 25%); TP – total publications; TP_rank – rank of total publications; TC – total citations; TC_rank – rank of total citations; PY_start – publication year start: indicates the year the first article was published in this dataset.

2 (green) centered on early diagnosis and detection of high-risk lesions, emphasizing keywords such as "Barrett's esophagus", "high-grade dysplasia", and "squamous-cell carcinoma". Cluster 3 (yellow) highlighted survival analysis and prognostic indicators, including terms such as "resection", "efficacy", "management", and "therapy". Cluster 4 (blue) pertained to adjunctive and supportive therapies, featuring terms such as "outcomes", "clinical outcomes", "predictors", and "complications". Cluster 5 (purple) reflected procedural innovation and technical refinement, with frequently occurring keywords such as "submucosal dissection", "surgery", "definitive chemoradiotherapy", and "chemotherapy". Collectively, these 5 clusters map a comprehensive research landscape, evolving from foundational concerns of technical execution and diagnosis to a broader focus on complication management, survival outcomes, and integrated therapies.

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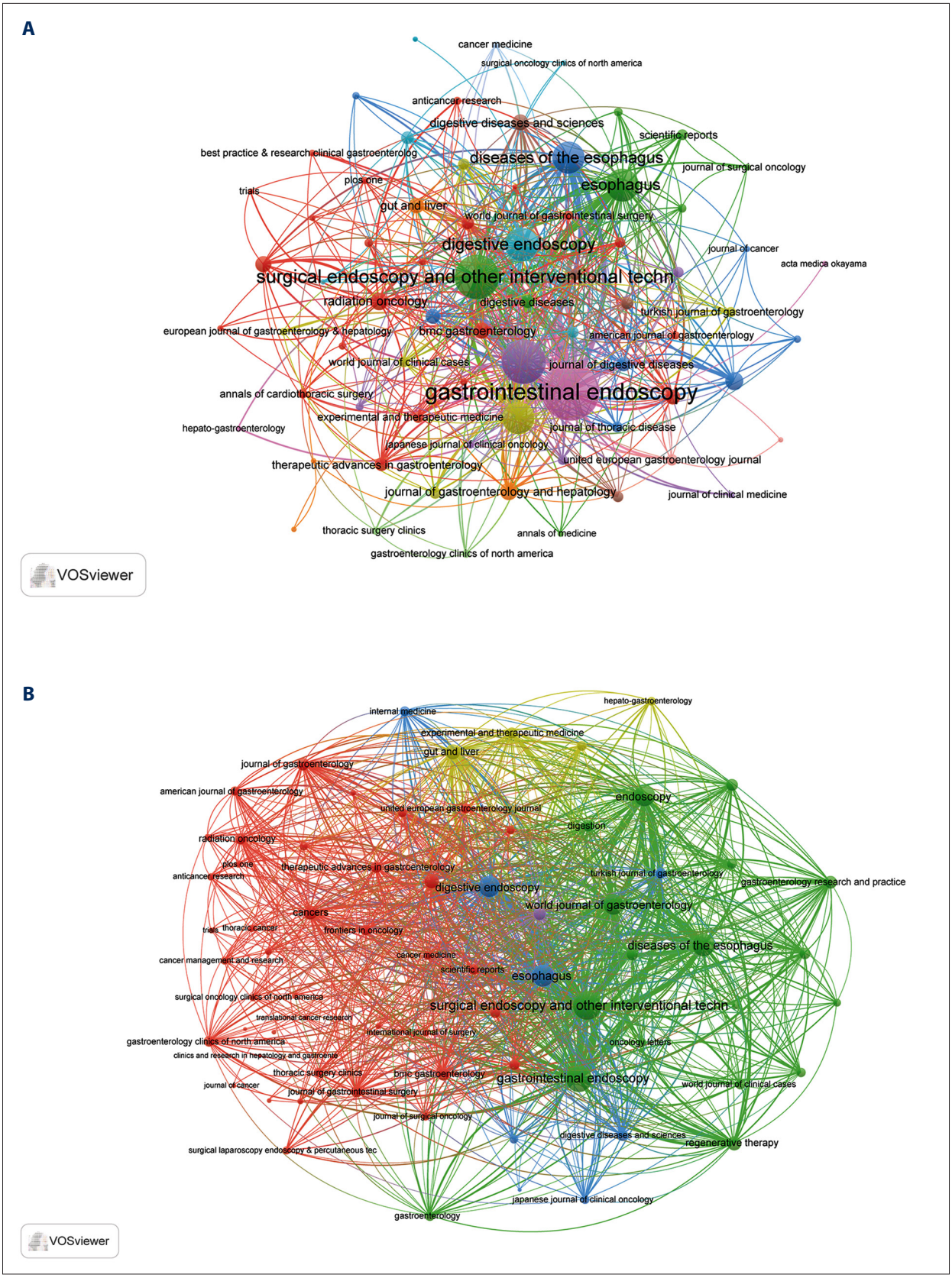

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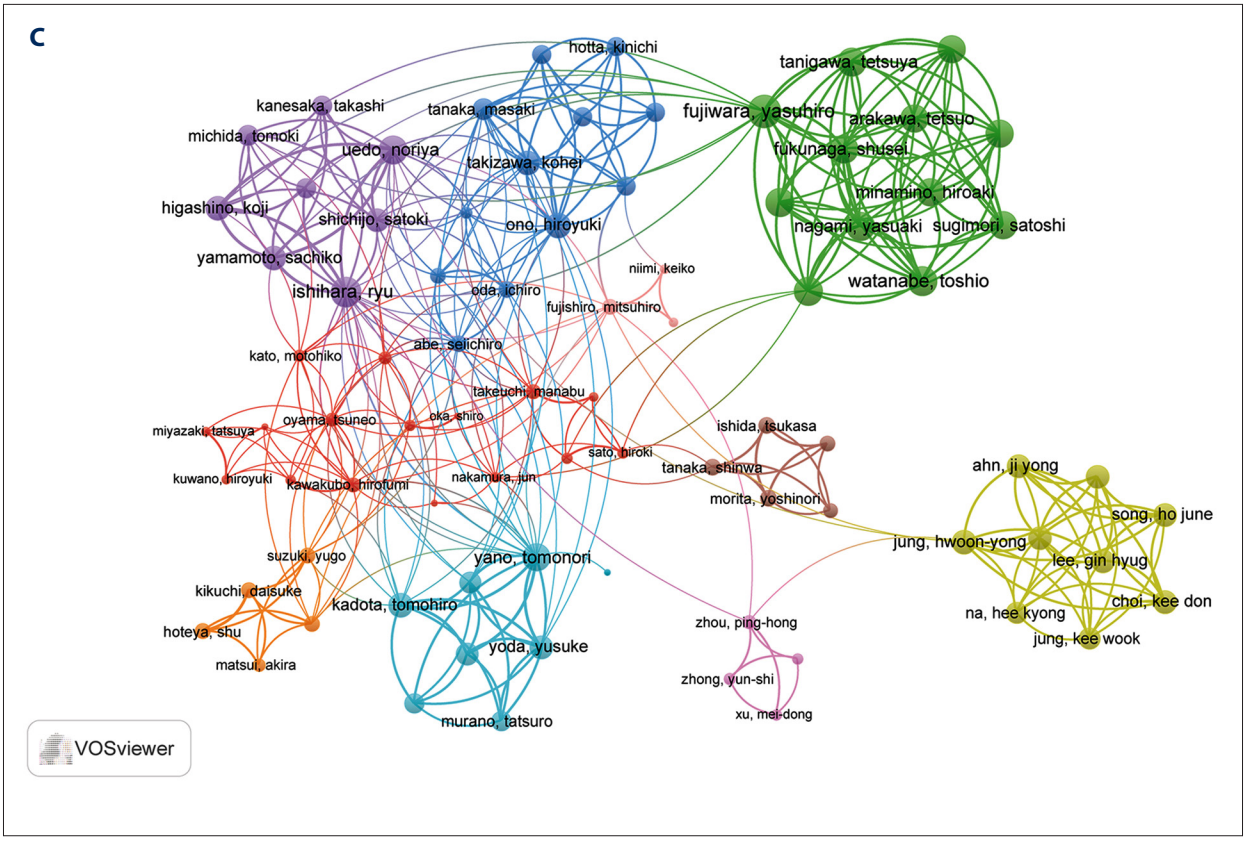

Figure 4. Analysis of journals and authors. (**A**) Co-occurrence network of journals. Node size indicates co-citation frequency, link thickness represents co-occurrence strength, and colors distinguish thematic clusters. (**B**) Coupling network of journals. Node size indicates publication count, and link thickness represents the degree of shared references. (**C**) Visualization map depicting collaboration among different authors. Node size indicates publication count, link thickness represents collaboration strength, and colors distinguish research clusters.

The temporal evolution of research themes is visualized in a keyword co-occurrence overlay map (**Figure 5B**). In this map, node color indicates the average publication year, transitioning from blue (early) to yellow (recent). Early research (blue nodes) centered on foundational techniques and diagnosis (eg, "endoscopic submucosal dissection", "high-grade dysplasia"). The focus then shifted to procedural outcomes and safety (green nodes), with keywords such as "complications" and "risk factors" becoming prominent. More recently, the emphasis has moved to long-term prognosis and comprehensive management (yellow nodes), reflected in terms such as "survival" and "predictors". This color-coded timeline demonstrates a clear research trajectory: from initial technical exploration to risk control and, ultimately, the assessment of long-term clinical value.

Analysis of Burst Keywords

The analysis of the top 20 keywords with the strongest citation bursts from 2006 to 2025 reveals the evolving research focus in the field (**Figure 5C**). The keyword with the highest burst strength was "risk factors" (strength=6.81, 2021-2025), followed by "endoscopic mucosal resection" (strength=5.23, 2006-2010) and "efficacy" (strength=4.77, 2018-2020). Earlier bursts (2006-2015) primarily reflected developments in diagnostic and procedural techniques, as evidenced by keywords such as "en bloc resection" (strength=3.99, 2006-2013), "sodium hyaluronate" (strength=3.07, 2006-2010), "local recurrence" (strength=4.04, 2008-2012), and "lesions" (strength=4.18, 2006-2016). Between 2016 and 2020, the focus shifted toward clinical outcomes and safety concerns, indicated by bursts in "perforation" (strength=2.96, 2016-2019), "steroid injection" (strength=3.59, 2017-2021), "efficacy" (strength=4.77, 2018-2020), and "management" (strength=3.13, 2018-2020). Since 2020, citation bursts have concentrated on keywords such as "neoplasms" (strength=3.36, 2020-2023), "esophageal stenosis" (strength=3.03, 2020-2023), "postoperative stricture" (strength=3.32, 2019-2023), "risk factors" (strength=6.81, 2021-2025), "early esophageal cancer" (strength=4.27, 2021-2025), and "prevention" (strength=2.90, 2023-025). These recent bursts underscore a clear shift in research priorities toward risk prediction, complication prevention, and early-stage disease management.

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Table 3. Publication and citation profiles of the top 20 high-impact authors.

Rank	Author	h_index	g_index	m_index	PY_start	TP	TP_frac	TP_rank	TC	TC_rank
1	Ishihara R	10	16	0.526	2008	16	1.99	1	1279	1
2	Fujishiro M	8	13	0.381	2006	13	1.50	3	936	2
3	Fujiwara Y	8	11	0.533	2012	11	0.74	5	238	9
4	Tanaka S	8	14	0.500	2011	14	1.62	2	240	8
5	Tanigawa T	8	8	0.533	2012	8	0.59	13	225	13
6	Uedo N	8	13	0.421	2008	13	0.86	3	697	4
7	Watanabe T	8	9	0.533	2012	9	0.65	11	230	12
8	Arakawa T	7	7	0.467	2012	7	0.52	17	211	15
9	Fukunaga S	7	8	0.636	2016	8	0.52	13	176	19
10	Kato M	7	10	0.368	2008	10	0.81	6	855	3
11	Minamino H	7	7	0.467	2012	7	0.52	17	211	15
12	Nakamura T	7	10	0.412	2010	10	0.86	6	371	5
13	Ominami M	7	8	0.636	2016	8	0.53	13	171	20
14	Ono H	7	9	0.583	2015	9	0.73	11	265	7
15	Sato H	7	10	0.500	2013	10	0.94	6	325	6
16	Sugimori S	7	7	0.467	2012	7	0.52	17	211	15
17	Suzuki S	7	10	0.412	2010	10	0.83	6	233	11
18	Takizawa K	7	8	0.583	2015	8	0.65	13	236	10
19	Tanaka M	7	10	0.583	2015	10	0.93	6	224	14
20	Tominaga K	7	7	0.467	2012	7	0.52	17	211	15

h_index – measures both the productivity and citation impact of the publications. It is important to note that the h-index reported here is calculated based only on the 512 articles included in this specific study, not the authors; entire career output; g_index – gives more weight to highly-cited articles; m_index – the h-index divided by the number of years since the first published paper; PY_start – publication year start; TP – total publications; TP_frac – fractional total publications; TP_rank – rank of total publications; TC – total citations. TC_rank – rank of total citations.

Discussion

This bibliometric and visual analysis systematically mapped the research landscape of ESD in esophageal cancer from 2006 to 2025, based on 512 original articles. The findings demonstrate a steady growth in publication output, highlighting rising global interest and research activity in this domain.

The dominance of Japan and China in this research area is not only due to the high incidence of esophageal cancer [22] but also reflects Japan's pioneering role in developing and disseminating ESD techniques [23]. Top-ranking institutions were predominantly Japanese, underscoring their foundational contributions. Leading journals such as *Surgical Endoscopy*, *Gastrointestinal Endoscopy*, and *Endoscopy* were the leading platforms for publishing high-quality ESD-related studies. Influential authors in this domain included Ishihara R, Fujishiro M, and Tanaka S, who have made substantial contributions to both the clinical practice and academic discourse surrounding ESD. Their work has addressed key issues such as the standardization of procedural guidelines, risk stratification, and the management of complications – particularly postoperative stricture prevention using techniques like triamcinolone injection – as well as factors influencing procedural difficulty and outcomes in esophageal neoplasia [24,25]. Compared with a previous bibliometric study by Wu et al (2022) [14], which analyzed 2131 publications across the entire ESD field, including gastric, colorectal, and esophageal indications, from 2006 to 2020 using CiteSpace as the sole analytical tool, the present study differs in 3 key aspects: (1) a disease-specific focus

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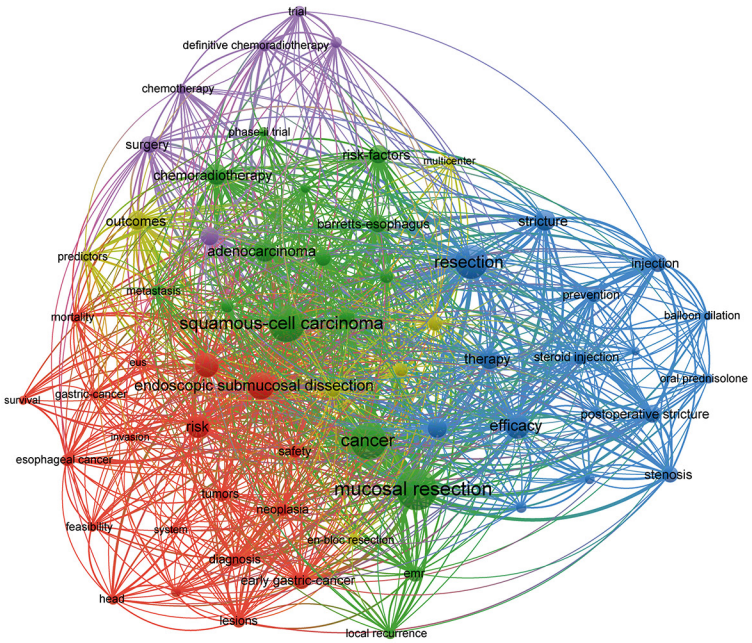
A



VOSviewer

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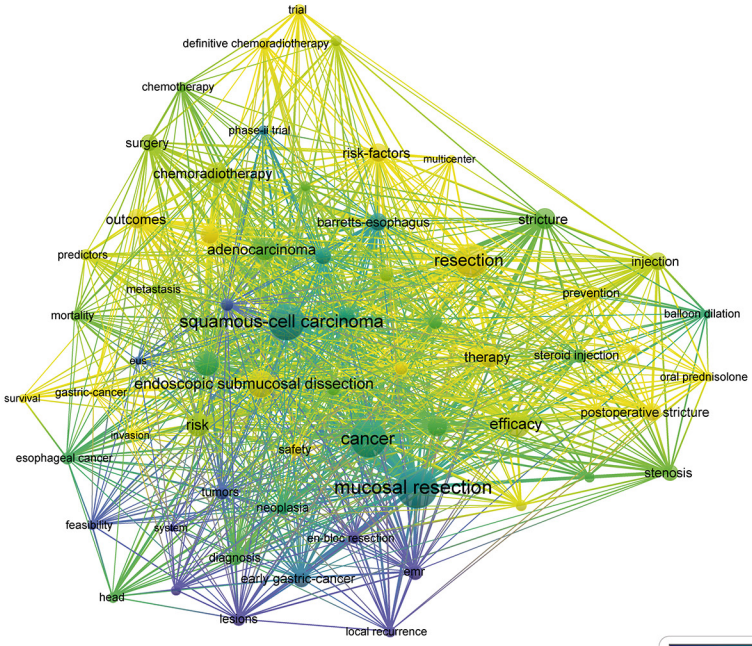

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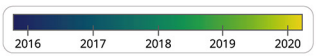

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C

Top 20 keywords with the strongest citation bursts

Keywords	Year	Strength	Begin	End	2006-2025
Endoscopic mucosal resection	2006	5.23	**2006**	2010	
Lesions	2006	4.18	**2006**	2016	
En bloc resection	2006	3.99	**2006**	2013	
Sodium hyaluronate	2006	3.07	**2006**	2010	
Tumors	2006	3.03	**2006**	2014	
Local recurrence	2008	4.04	**2008**	2012	
Mucosal resection	2006	2.93	**2010**	2013	
Japan	2011	2.63	**2011**	2015	
Esophageal perforation	2014	2.48	**2014**	2015	
Perforation	2016	2.96	**2016**	2019	
Steroid injection	2017	3.59	**2017**	2021	
Narrow band imaging	2017	2.81	**2017**	2018	
Efficacy	2014	4.77	**2018**	2020	
Management	2007	3.13	**2018**	2020	
Postoperative stricture	2017	3.32	**2019**	2023	
Neoplasms	2020	3.36	**2020**	2023	
Esophageal stenosis	2006	3.03	**2020**	2023	
Risk factors	2019	6.81	**2021**	2025	
Early esophageal cancer	2008	4.27	**2011**	2025	
Prevention	2011	2.90	**2023**	2025	

Figure 5. Analysis of keywords. (**A**) Keyword co-occurrence network. Node size indicates keyword frequency, link thickness represents co-occurrence strength, and colors distinguish thematic clusters. (**B**) Keyword co-occurrence overlay map illustrating the temporal evolution of research themes. Node color indicates the average publication year, transitioning from blue (early) to yellow (recent), as shown in the color bar. (**C**) Top 20 keywords with the strongest citation bursts. CiteSpace parameters: time slicing from January 2006 to December 2025 in 1-year intervals; node type: keywords; top n=25 per slice; pruning: Pathfinder and merged network.

exclusively on esophageal cancer, (2) an extended time window through 2025 capturing recent trends in risk prediction and multimodal therapy, and (3) multi-tool triangulation combining VOSviewer, CiteSpace, and bibliometrix to provide complementary perspectives on collaboration networks, keyword dynamics, and publication metrics. These distinctions allow for a more targeted characterization of research trends and emerging frontiers specific to esophageal ESD. Furthermore, a comparison with the bibliometric analysis of early gastric cancer ESD by Liu et al (2023) [13] highlights disease-specific research trajectories. While both fields share a common focus on technical refinement, our analysis reveals a pronounced emphasis in esophageal ESD research on managing post-procedural complications, particularly the prevention of esophageal strictures. This is evidenced by the high frequency of keywords such as “stricture”, “steroid injection”, and “balloon dilation”. This distinction underscores the unique clinical challenges associated with esophageal ESD, where extensive circumferential resections frequently lead to a higher risk of stenosis, thus making complication management a central research priority. In contrast, studies on gastric ESD often place greater emphasis on issues such as managing bleeding risk with larger lesions and predicting lymph node metastasis to expand indications. This comparative perspective validates the necessity of disease-specific analyses to uncover nuanced research priorities.

Research Hotspots and Frontiers

The keyword co-occurrence analysis identified 5 major research clusters, each reflecting a distinct thematic area.

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Cluster 1 (Red): Post-ESD Complication Management

This cluster primarily focuses on the management of complications following ESD, with particular emphasis on the prevention and treatment of esophageal strictures, which is one of the most common and clinically significant adverse events after the procedure. A variety of strategies have been investigated to reduce the incidence and severity of post-ESD strictures. Mechanical approaches, such as balloon dilation [26] and stent placement [27], are commonly used to relieve luminal narrowing, while pharmacological interventions aim to inhibit fibrotic responses that lead to stricture formation. Among these, the local injection of triamcinolone has become a widely accepted method due to its anti-inflammatory properties [28]. Additionally, emerging therapies such as botulinum toxin A injection [29] and systemic corticosteroid administration [30] have shown potential in decreasing stricture rates and reducing the need for repeated dilations. The prominence of this cluster, supported by the recent burst of keywords such as "postoperative stricture" (2019-2023) and "esophageal stenosis" (2020-2023), confirms that complication management remains a central and actively evolving research priority.

Cluster 2 (Green): Early Diagnosis and Detection of High-Risk Lesions

This cluster focuses on strategies for the early identification of high-risk lesions that are amenable to ESD, such as Barrett's esophagus with high-grade dysplasia and squamous intraepithelial neoplasia. Accurate detection of these precancerous changes is essential for enabling timely, minimally invasive interventions. A range of endoscopic techniques has been investigated to enhance diagnostic precision. For example, a randomized controlled trial demonstrated that computed virtual chromoendoscopy is as effective as conventional acetic acid chromoendoscopy in detecting high-grade intraepithelial neoplasia and early cancer in patients with Barrett's esophagus, supporting its role as a non-dye alternative for surveillance [31]. Similarly, another randomized crossover study compared high-resolution endoscopy combined with either indigo carmine chromoendoscopy or narrow-band imaging, finding both techniques to be effective adjuncts for identifying high-grade dysplasia or early cancer, with comparable sensitivity [32]. These imaging enhancements, alongside tools like confocal laser endomicroscopy [33,34], help improve lesion characterization and guide appropriate use of ESD for curative treatment in early-stage esophageal cancer while minimizing procedural morbidity.

Cluster 3 (Yellow): Survival Analysis and Prognostic Indicators

This cluster centers on identifying prognostic factors that inform treatment decisions and help tailor ESD strategies to individual patient risk profiles. Several studies have demonstrated that combining EMR with chemoradiotherapy can improve survival in patients with clinical stage I esophageal cancer [35], while factors such as submucosal invasion and smoking have been linked to worse outcomes due to increased fibrosis and recurrence risk [36]. In addition, prognostic tools such as the Charlson Comorbidity Index and the Prognostic Nutritional Index have been validated as independent predictors of overall survival, supporting more precise risk stratification and patient selection for ESD [37].

Cluster 4 (Blue): Adjunctive and Supportive Therapies

This cluster focuses on optimizing post-ESD management through risk-adapted strategies and evidence from clinical interventions. For instance, adjuvant radiotherapy following ESD has been shown to enhance locoregional control in patients with T1a-MM or T1b-SM1 lesions [38], while tumor location has emerged as a significant predictor of stenosis risk after salvage radiotherapy [39]. In the context of procedural support, propofol demonstrated superior performance over midazolam in maintaining continuous sedation during ESD, improving procedural efficiency and patient safety [40]. Together, these studies underscore the importance of comprehensive supportive strategies throughout the treatment continuum in improving ESD outcomes and patient quality of life.

Cluster 5 (Purple): Procedural Innovation and Technical Refinement

This cluster focuses on advances in ESD techniques and instrumentation aimed at improving resection quality and minimizing recurrence. Studies demonstrated that the ITknife nano reduced dissection time without increasing complications [41], and robot-assisted ESD enhanced control and visibility, especially for esophageal lesions [42]. Lugol's chromoendoscopy-guided confocal laser endomicroscopy showed higher diagnostic accuracy for superficial neoplasia than did biopsy [43], while narrow band imaging was more efficient than iodine staining for margin delineation, with fewer adverse effects [44]. These innovations collectively contribute to safer, faster, and more accurate ESD procedures, reinforcing its role as a frontline modality for early esophageal cancer.

An interpretive analysis of keyword citation bursts reveals the field's maturation, tracing a trajectory from procedural establishment to personalized and multimodal management approaches. In the initial phase (approximately 2006-2015), the research emphasis was on foundational techniques and diagnostic accuracy. This is evidenced by a focus on achieving complete en bloc resection and refining visualization with tools such as chromoendoscopy and magnifying endoscopy, which were critical for establishing ESD's viability and indications [45,46].

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Subsequently, as the technique became more widespread, the research agenda shifted toward safety and managing adverse events (approximately 2016-2020). This is reflected in the increased attention to complications such as perforation and to the development of preventive strategies, most notably the use of steroid injections to mitigate post-ESD strictures [47,48].

More recently, the field has entered a new phase focused on predictive analytics and personalization, reflecting a transition from reactive management to proactive, risk-stratified care. A primary focus has been the prediction of post-ESD esophageal stricture. In this context, considerable attention has been directed toward predicting post-ESD esophageal stricture, leading to the development of numerous nomograms and scoring systems incorporating diverse predictors, ranging from endoscopic features such as lesion circumference to novel biomarkers [49]. A recent systematic review and meta-analysis not only confirmed the proliferation of these models but also identified muscularis propria injury as a highly reliable predictor, solidifying the evidence base for these clinical tools [50].

This data-driven approach extends beyond strictures. Predictive models are now being developed for other critical endpoints, such as forecasting technical difficulty during the procedure itself and predicting postoperative bleeding risk [51]. This trend is increasingly powered by machine learning techniques, which are being applied to enhance diagnostic and therapeutic precision in esophageal disorders [52,53]. Looking ahead, the research frontier is expanding toward the integration of novel technologies and multimodal therapies. Robotic-assisted ESD is emerging as a platform to enhance procedural stability and precision [54], while the synergy between ESD and systemic treatments such as immunotherapy is being actively explored, opening new avenues for comprehensive patient management [55]. It should be noted that these observations reflect trends in research activity as captured by bibliometric indicators, rather than direct evidence of clinical efficacy or guideline adoption.

Clinical Relevance

Beyond a historical overview, this analysis provides a practical roadmap for clinicians and researchers in the field of esophageal ESD. For clinicians, our findings underscore that the management of post-procedural complications, particularly esophageal strictures, remains a core competency and a major focus of clinical research. More importantly, the recent trends identified since 2020 signal a significant evolution in research direction. The emergence of validated risk-prediction models for outcomes such as strictures suggests a growing interest in data-driven, individualized patient management, moving beyond generalized protocols [56,57]. Clinicians should also be aware of the increasing research attention on novel technologies such as robotic-assisted ESD, which may enhance procedural precision, and the integration of multimodal treatments, such as combining ESD with immunotherapy, which may inform future care pathways for selected patients [12].

For researchers, the present study maps the intellectual structure of the field, clearly delineating mature research areas from emerging frontiers. The trajectory from optimizing resection techniques toward developing predictive analytics and exploring synergistic therapies highlights critical gaps and opportunities for future investigation. These insights can help guide the allocation of research funding, inform the design of future clinical trials, and facilitate international collaboration aimed at advancing evidence-based management of esophageal cancer.

Strengths and Limitations

This bibliometric analysis offers a comprehensive evaluation of research trends in ESD for esophageal cancer. By employing VOSviewer, CiteSpace, and the R package bibliometrix, the study systematically maps key contributors, international collaborations, core journals, and thematic evolutions over 2 decades. The identification of 5 distinct keyword clusters and recent citation burst trends provides valuable insights into shifting research priorities – from technical innovation to personalized risk assessment and multimodal treatment strategies.

However, several limitations should be noted. First, this study relies on citation-based metrics, which may not fully capture the clinical applicability, innovation, or methodological rigor of individual studies. Second, the analysis was limited to English-language publications indexed in the WoSCC, potentially omitting influential work published in other languages or indexed in other databases such as Scopus, PubMed, or region-specific databases (eg, CNKI for Chinese-language literature and J-STAGE for Japanese-language literature). This restriction may lead to an underrepresentation of clinically relevant studies from non-English-speaking regions, particularly in East Asia where the disease burden and research output are substantial. Accordingly, the findings should be interpreted as reflecting the English-language, WoSCC-indexed literature rather than the entirety of research on this topic. Third, as a descriptive and exploratory analysis, this study did not employ formal statistical validation methods, such as cross-validation or consistency checks, to assess the robustness of the identified trends. Fourth, bibliometric tools emphasize quantitative relationships and may not reflect nuanced clinical practices or guideline-driven decision-making. Future research should address these gaps by incorporating broader data sources and validating bibliometric findings against clinical outcomes and guideline updates.

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Conclusions

This bibliometric and visual analysis mapped the development of research on ESD in esophageal cancer over the past 2 decades. Recent trends strongly indicate a shift from procedural refinement toward a holistic approach that combines ESD with adjunctive therapies and refines post-procedural care based on personalized risk assessment. The growing emphasis on individualized management and data-driven decision-making, as evidenced by recent keyword bursts in risk prediction and complication prevention, highlights key directions for future research and international collaboration in optimizing outcomes for early esophageal cancer.

Declaration of Figures' Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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