

# Indispensable for Anesthesia and Intensive Care Units: End-Tidal Carbon Dioxide and Capnography: A Bibliometric Analysis during 1980-2022

## Anestezi ve Yoğun Bakım Ünitelerinin Vazgeçilmezi: End-Tidal Karbon Dioksit ve Kapnografi: 1980-2022 Döneminde Bir Bibliyometrik Analiz

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### ABSTRACT

**Objective:** In this study, we aimed to determine the most cited first 50 publications on end-tidal carbon dioxide (ETCO<sub>2</sub>) and capnography from past to present using various bibliometric citation analysis methods, and to reveal the intellectual structure of the subject through co-citation analysis. Additionally, we aimed to identify the most active authors, institutions, journals, and countries in this field, and to demonstrate global productivity quantitatively.

**Methods:** A total of 2508 publications on ETCO<sub>2</sub> published between 1980 and 2022 were downloaded from the Web of Science database and analyzed using citation and co-citation analyses. VOSviewer (Version 1.6.19) software was utilized to perform citation and co-citation analyses, and bibliometric network visualization maps were created.

**Results:** The top 3 countries with the highest publication productivity in ETCO<sub>2</sub> research were the USA (1008), England (220), and Canada (118). The top 3 journals were Anesthesia and Analgesia (148), Anaesthesia (127), and Anesthesiology (89). The most active institutions were Research Libraries UK (98), Harvard University (80), and The University of California System (71). The top 3 authors were Petak F. (22), Tusman G. (22), and Weil MH. (19). The citation density of the top 50 articles in terms of total citations ranged from 83 to 448, while the average citation density per year ranged from 5.39 to 16.23. Among the top 50 most cited articles, the first two journals with the most publications were Annals of Emergency Medicine (8 articles) and Anesthesia and Analgesia (4 articles).

**Conclusion:** Globally, an increasing trend in publications on ETCO<sub>2</sub> can be observed from the past to the present. Research leadership in the development of ETCO<sub>2</sub> literature is predominantly held by economically strong developed or developing countries. Evaluation of citation and co-citation analyses reveals that the most influential studies on ETCO<sub>2</sub>/capnography focus on sedation, endotracheal intubation, cardiopulmonary resuscitation (CPR)/cardiac arrest, and dead space topics.

**Keywords:** Bibliometric analysis, capnography, end-tidal carbon dioxide, ETCO<sub>2</sub>

### Öz

**Amaç:** Bu çalışmada end-tidal karbondioksit (ETCO<sub>2</sub>) ve kapnografi konusunda geçmişten günümüze çeşitli bibliyometrik atf analiz yöntemleri kullanılarak en çok atf alan ilk 50 yayının belirlenmesi ve ortak atf analizleri ile konunun düşünce yapısının ortaya konulması amaçlanmıştır. Ayrıca bu alanda en aktif yazarları, kurumları, dergileri, ülkeleri belirlemeyi ve küresel verimliliği niceliksel olarak ortaya koymayı amaçladık.

**Yöntem:** Web of Science veri tabanından ETCO<sub>2</sub> ile ilgili 1980 ile 2022 yılları arasında yayınlanan toplam 2508 yayın indirildi ve alıntı ve ortak alıntı analizleri kullanılarak analiz edildi. Atf ve ortak atf analizleri için VOSviewer (Sürüm 1.6.19) yazılımından yararlanılmış ve bibliyometrik ağ görselleştirme haritaları oluşturulmuştur.

**Bulgular:** En yüksek ETCO<sub>2</sub> yayın üretkenliğine sahip ilk 3 ülke ABD (1008), İngiltere (220) ve Kanada'dır (118). İlk 3 dergi Anesthesia and Analgesia (148), Anaesthesia (127) ve Anesthesiology (89) idi. En aktif kurumlar Birleşik Krallık Araştırma Kütüphaneleri (98), Harvard Üniversitesi (80) ve Kaliforniya Üniversitesi (71) idi. İlk 3 yazar Petak F. (22), Tusman G. (22) ve Weil MH idi. (19). Toplam atf bakımından ilk 50 makalenin atf sayısı 83 ile 448 arasında değişirken, yıllık ortalama atf sayısı 5,39 ile 16,23 arasında değişmektedir. En çok atf yapılan ilk 50 makale içerisinde en çok yayına sahip olan ilk iki dergi Annals of Emergency Medicine (8 makale) ve Anesthesia and Analgesia (4 makale) idi.

**Sonuç:** Küresel olarak geçmişten günümüze ETCO<sub>2</sub> ile ilgili yayınlarda artan bir trend gözlemlenmektedir. Literatürde ETCO<sub>2</sub> geliştirilmesindeki araştırma liderliği, ağırlıklı olarak ekonomik açıdan güçlü gelişmiş veya gelişmekte olan ülkeler tarafından yapılmaktadır. Alıntı ve ortak alıntı analizlerinin değerlendirilmesi, ETCO<sub>2</sub>/kapnografi ile ilgili en etkili çalışmaların sedasyon, endotrakeal entübasyon, kardiyopulmoner resüsitasyon (CPR)/kardiyak arrest ve ölü boşluk konularına odaklandığını ortaya koymaktadır.



**Anahtar sözcükler:** Bibliyometrik analiz, kapnografi, end-tidal karbondioksit, ETCO<sub>2</sub>

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## INTRODUCTION

End-tidal carbon dioxide (ETCO<sub>2</sub>) is the maximum CO<sub>2</sub> level measured in respiratory gases at the end of the respiratory cycle (1,2). It is obtained by measuring the expired respiratory gases from the alveoli. The ETCO<sub>2</sub> measurement provides important information in various clinical situations such as the evaluation of respiratory functions, airway monitoring, cardiopulmonary resuscitation (CPR), and sedation monitoring (1). The ETCO<sub>2</sub> measurement help assess the effectiveness of respiration, airway patency, and ventilation-perfusion matching. It also helps in the recognition of respiratory arrest and ETCO<sub>2</sub> measurements are used during CPR (3,4). Monitoring ETCO<sub>2</sub> is employed to assess the efficacy of thoracic compressions and the return of circulation, serving as an indicator for sufficient thoracic compressions and ventilation (4).

End-tidal carbon dioxide measurement is performed using medical technology and capnography, which is a medical device used to monitor and evaluate respiratory functions (2,5). Capnography continuously measures the absorption of CO<sub>2</sub> at a specific wavelength (4.26 μm) using infrared radiation and measurements are displayed as a graph (6,7). Capnography is a primary monitoring system for mechanically ventilated patients (8). Capnography and ETCO<sub>2</sub> measurements are valuable resources widely used in clinical settings, emergency departments, operating rooms, intensive care units, and ambulances (9). The continuous monitoring of respiratory functions enhances patient safety and helps in the early detection of respiratory-related issues (10).

Recent years, have seen great advance in technology and a rapid expansion in the publication of scientific literature. Together with the increasing number of publications, bibliometric studies have been conducted in various medical fields, and bibliometrics has become a widely used quantitative research method for evaluating the literature (11,12). Bibliometrics provides structured information and reveals important insights for future research in a research field or specific topic (13-15). Citation analysis has also become an important tool for evaluating research performance in medical sciences. While the h-index and impact factors are popular bibliometric indicators for performance evaluation, they have certain limitations, in particular that they do not account for significant variations in citation practices across scientific fields (16). More reliable results can be provided by bibliometric indicators that incorporate normalization to account for variations in citation practices between scientific fields or articles (16).

There is currently no comprehensive research determining the most influential studies in the literature on ETCO<sub>2</sub> and capnography. The aim of this study was to determine the 50 most effective publications on ETCO<sub>2</sub> and capnography from 1980 to 2022 using various bibliometric citation analysis

methods and to reveal the intellectual structure of the subject through co-citation analyses. It was also aimed to identify the most active authors, institutions, journals, and countries in this field to quantitatively assess global productivity.

## MATERIAL AND METHODS

Since this research article is a bibliometric study, there is no requirement for ethics committee approval.

### Search Strategy

The Web of Science (WoS) database (Clarivate Analytics, Philadelphia, PA, USA) was utilized to access the publications indexed on ETCO<sub>2</sub> and capnography between 1980 and 2022. The search strategy included various keyword combinations that could appear in the titles of publications related to ETCO<sub>2</sub> (endtidal CO<sub>2</sub>, endtidal carbon dioxide, endtidal carbondioxide, end-tidal CO<sub>2</sub>, end-tidal carbon dioxide, end-tidal carbondioxide, ETCO<sub>2</sub>, ET-CO<sub>2</sub>, etc.) and capnogram (capnograms, capnograph, capnography, etc.). The search strategy used in this study was as follows: [(Title = (capnogram) or title = (endtidal CO2) or title = (endtidal carbon dioxide) or title = (endtidal carbondioxide) or title = (end tidal CO2) or title = (end tidal carbon dioxide) or title = (end tidal carbondioxide) or title = (ETCO2) or title = (ET CO2) or title = (ETCO 2) or title = (endtidal CO 2) or title = (end tidal CO 2), and publication time: 1980-2022)] The publication search was performed on June 20, 2023.

### Citation and Co-Citation Analysis

Citation analyses were conducted using the VOSviewer software package (Version 1.6.19, Leiden University), which is a software package used to visualize and create bibliometric networks (17). Citation analysis is a research method used in bibliometrics to measure the impact of scientific studies by determining how many times an article has been cited by other works, thereby assessing the influence of a publication or author. Co-citation analysis provides a method to map the structure of a research field through the pairs of documents that are co-cited (12,17). In citation and co-citation analyses, the normalized citation count of a publication is calculated by dividing the citation count of that publication by the average citation count of all publications published in the same year. Normalization allows correction for the fact that older publications have had more time to accumulate citations than newer publications (17).

## RESULTS

Through the literature search, a total of 2508 publications on ETCO<sub>2</sub> and capnography were identified. Of these publications, 1278 (50.9%) were articles, 608 (24.2%) were meeting

abstracts, 378 (15%) were letters, 103 (4.1%) were proceeding papers, 61 (2.4%) were review articles, and the remainder were classified as other publication types such as editorial materials, notes, book chapters, books, book reviews, and data papers (Figure 1).

Of the total publications, 89.5% (n=2244) were indexed in the Science Citation Index-Expanded (SCI-Expanded), 14.1% (n=353) in the Conference Proceedings Citation Index-Science (CPCI-S), 6.5% (n=164) in the Emerging Sources Citation Index (ESCI), 4.1% (n=103) in the Social Sciences Citation Index (SSCI), 0.9% (n=23) in the Book Citation Index-Science (BKCI-S), and 0.08% (n=2) in the Conference Proceedings Citation Index-Social Science & Humanities (CPCI-SSH). It should be noted that a publication can be indexed in multiple databases simultaneously.

The language of the publications was English in 97.2% (n=2439) and the remainder were in other languages; German (25), Spanish (16), French (15), Portuguese (5), Russian (5), Chinese (1), Malay (1), and Turkish (1). The h-index of the publications was 70, and they received a total of 27,050 citations (19,278 without self-citations) (Table I). In the top 50 most cited articles on ETCO<sub>2</sub>, the citation density ranged from 83 to 448, and the average citation density per year ranged from 5.39 to 16.23.

**Active Research Areas**

The top 10 research areas where the publications are more prominently tagged were as follows: Anesthesiology (Number

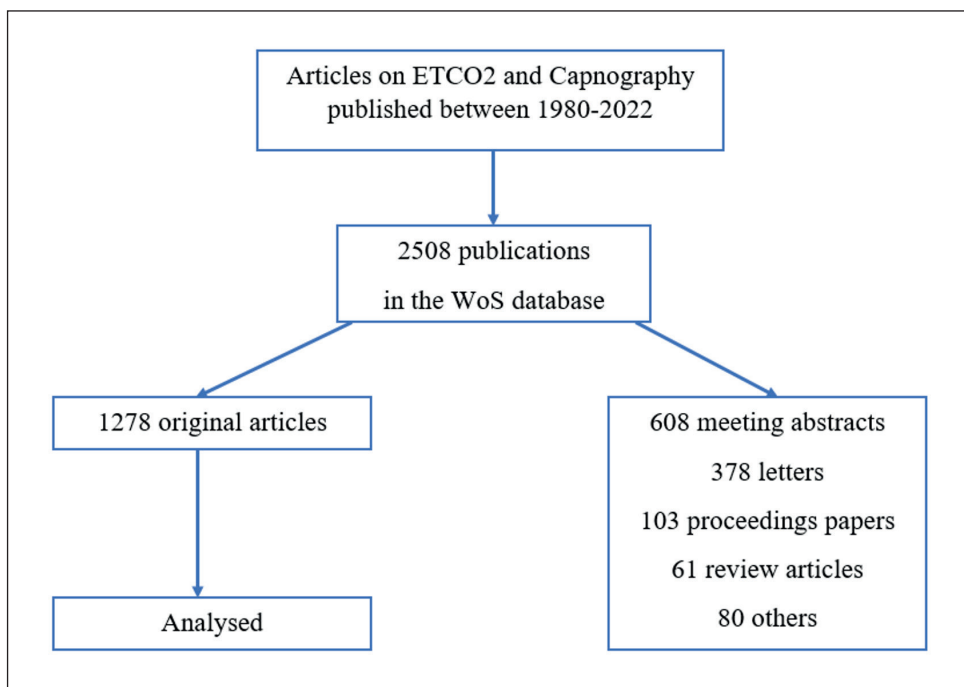
**Table I:** Language Distribution and Citations of Articles on ETCO<sub>2</sub> and Capnography

Language	Number of articles	Total 5323 articles	h- index	70
English	2439			
German	25			
Spanish	16			
French	15			
Portuguese	5			
Russian	5			
Chinese	1			
Malay	1			
Turkish	1			
			Sum of times cited	27050
			Without self-citations	19278

of articles=822, 32.7%), Critical Care Medicine (410, 16.3%), Emergency Medicine (316, 12.6%), Respiratory System (271, 10.8%), Pediatrics (180, 7.1%), Cardiac Cardiovascular Systems (146, 5.8%), Medicine General Internal (119, 4.7%), Peripheral Vascular Disease (95, 3.7%), Surgery (92, 3.6%), and Physiology (65, 2.5%).

**Number of Studies over Time**

The number of publications on this topic in literature can be seen to have increased over time. The line graph in Figure 2 illustrates the distribution of previously published articles over the years.



**Figure 1:** Diagram of Articles. Others: Editorial material, notes, book chapters, books, book reviews, and data papers.

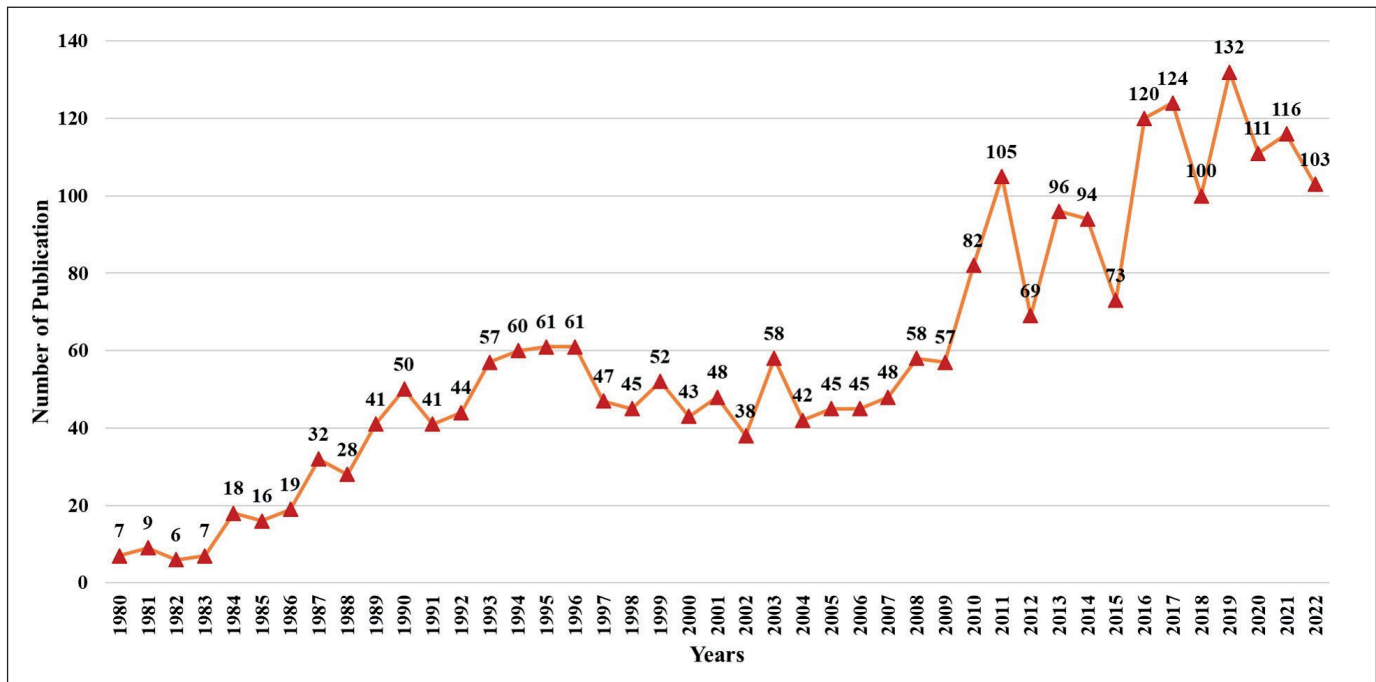


Figure 2: Line graph depicting the trend of the number of publications on ET/CO<sub>2</sub> over the years.

### Active Countries

The top 15 countries contributing to the scientific literature on ET/CO<sub>2</sub>/Capnography, in descending order, were as follows: the United States of America (1008, 40.1%), the United Kingdom (England) (220, 8.7%), Canada (118, 4.7%), Japan (114, 4.5%), France (109, 4.3%), Germany (82, 3.2%), Switzerland (79, 3.1%), India (76, 3%), Spain (67, 2.6%), Australia (60, 2.3%), Italy (53, 2.1%), China (52, 2%), Sweden (52, 2%), the Netherlands (48, 1.9%), and Turkey (45, 1.7%).

### Active Journals

The top 15 journals in terms of contributions to the literature on ET/CO<sub>2</sub>/Capnography were as follows: Anesthesia and Analgesia (148, 5.9%), Anaesthesia (127, 5%), Anesthesiology (89, 3.5%), Critical Care Medicine (85, 3.3%), Resuscitation (72, 2.8%), Annals of Emergency Medicine (69, 2.7%), British Journal of Anaesthesia (66, 2.6%), Circulation (58, 2.3%), European Respiratory Journal (54, 2.1%), American Journal of Emergency Medicine (43, 1.7%), Canadian Journal of Anaesthesia (43, 1.7%), Journal of Clinical Monitoring and Computing (43, 1.7%), American Journal of Respiratory and Critical Care Medicine (42, 1.6%), Intensive Care Medicine (36, 1.4%), and Acta Anaesthesiologica Scandinavica (34, 1.3%). These journals have made significant contributions to the literature on ET/CO<sub>2</sub> and are at the forefront of publishing research related to this topic.

### Active Institutions

The top 15 institutions contributing the most to the literature on ET/CO<sub>2</sub>/Capnography, in descending order, were as follows: Research Libraries UK (98, 3.9%), Harvard University (80, 3.1%), University of California System (71, 2.8%), Udice French Research Universities (56, 2.2%), Pennsylvania Commonwealth System of Higher Education (48, 1.9%), University of Toronto (48, 1.9%), University of Texas System (43, 1.7%), State University System of Florida (42, 1.6%), Assistance Publique Hopitaux Paris (41, 1.6%), University of London (38, 1.5%), University of Pittsburgh (33, 1.3%), Boston Children's Hospital (32, 1.2%), Oregon Health Science University (31, 1.2%), Universite Paris Cite (31, 1.2%), and University of Pennsylvania (31, 1.2%). These institutions have made significant contributions to the literature on ET/CO<sub>2</sub>/Capnography with active involvement in research and publications related to this field.

### Active Authors

The authors who have published 15 or more studies on the topic of ET/CO<sub>2</sub>/Capnography, in descending order, were as follows: Petak F. (22), Tusman G. (22), Weil MH. (19), Daya M. (18), Krauss B. (18), Babik B. (16), Tobias JD. (16), Bohm SH. (15), Fodor GH. (15), Papa L. (15), Russell JK. (15), and Tolnai J. (15). These authors have demonstrated significant productivity in contributing to the literature on ET/CO<sub>2</sub>/Capnography, with a substantial number of publications in this field.

### Citation Analysis

Table II provides information on the top 50 influential studies (with 83 or more citations) among the 2508 publications on ETCO<sub>2</sub>/Capnography. The table includes the total number of citations received by each study and the average number of citations per year. Furthermore, the total number of citations for these publications was divided by the number of years since their publication to calculate the average number of ci-

tations per year, and the studies were re-ranked based on this metric. The results are presented in Table II.

Of the publications presented in Table III, 38 studies were found to have citation relationships, and the citation network map of these studies is presented in Figure 3. The figure reveals four distinct citation clusters (green, red, blue, and yellow) in the field of ETCO<sub>2</sub>/Capnography.

**Table II:** The First 50 High-Impact Articles Based on Average Number of Citations on End-tidal CO<sub>2</sub>/Capnography

No	Article	Author	Journal	PY	TC	AC
1	Evaluation of a humidified nasal high-flow oxygen system, using oxygraphy, capnography and measurement of upper airway pressures	Ritchie JE. et al.	Anaesthesia and Intensive Care	2011	211	16.23
2	Prediction of opioid-induced respiratory depression on inpatient wards using continuous capnography and oximetry: an international prospective, observational trial	Khanna AK. et al.	Anesthesia and Analgesia	2020	61	15.25
3	Nasal high flow oxygen therapy in patients with copd reduces respiratory rate and tissue carbon dioxide while increasing tidal and end-expiratory lung volumes: a randomised crossover trial	Fraser JF. et al.	Thorax	2016	118	14.75
4	Relationship between respiration, end-tidal CO <sub>2</sub> , and bold signals in resting-state fMRI	Chang C. and Glover GH.	Neuroimage	2009	214	14.27
5	Prospective targeting and control of end-tidal CO <sub>2</sub> and O <sub>2</sub> concentrations	Slessarev M. et al.	Journal of Physiology-London	2007	232	13.65
6	Continuous pulse oximetry and capnography monitoring for postoperative respiratory depression and adverse events: a systematic review and meta-analysis	Lam T. et al.	Anesthesia and Analgesia	2017	90	12.86
7	Quantitative relationship between end-tidal carbon dioxide and cpr quality during both in-hospital and out-of-hospital cardiac arrest	Sheak KR. et al.	Resuscitation	2015	113	12.56
8	Capnography during cardiac arrest	Sandroni C. et al.	Resuscitation	2018	69	11.5
9	The use of end-tidal carbon dioxide (ETCO <sub>2</sub> ) measurement to guide management of cardiac arrest: a systematic review	Paiva EF. et al.	Resuscitation	2018	68	11.33
10	Dependency of blood-flow velocity in the middle cerebral-artery on end-tidal carbon-dioxide partial-pressure - a transcranial ultrasound doppler study	Markwalder TM. et al.	Journal of Cerebral Blood Flow and Metabolism	1984	448	11.2
11	End-tidal carbon dioxide and outcome of out-of-hospital cardiac arrest	Levine RL. et al	New England Journal of Medicine	1997	281	10.41
12	Nocturnal monitoring of home non-invasive ventilation: the contribution of simple tools such as pulse oximetry, capnography, built-in ventilator software and autonomic markers of sleep fragmentation	Janssens JP. et al.	Thorax	2011	128	9.85
13	Capnographic monitoring of respiratory activity improves safety of sedation for endoscopic cholangiopancreatography and ultrasonography	Qadeer MA. et al.	Gastroenterology	2009	147	9.8



Table II: Cont.

No	Article	Author	Journal	PY	TC	AC
14	Does end-tidal CO <sub>2</sub> monitoring during emergency department procedural sedation and analgesia with propofol decrease the incidence of hypoxic events? A randomized, controlled trial	Deitch K. et al.	Annals of Emergency Medicine	2010	134	9.57
15	Microstream capnography improves patient monitoring during moderate sedation: a randomized, controlled trial	Lightdale JR. et al.	Pediatrics	2006	171	9.5
16	End-tidal and arterial carbon dioxide measurements correlate across all levels of physiologic dead space	McSwain SD. et al.	Respiratory Care	2010	128	9.14
17	Mapping the end-tidal CO <sub>2</sub> response function in the resting-state bold fmri signal: spatial specificity, test-retest reliability and effect of fmri sampling rate	Golestani AM. et al.	Neuroimage	2015	79	8.78
18	Partial pressure of end-tidal carbon dioxide successful predicts cardiopulmonary resuscitation in the field: a prospective observational study	Kolar M. et al.	Critical Care	2008	140	8.75
19	End-tidal carbon dioxide monitoring during procedural sedation	Miner JR. et al.	Academic Emergency Medicine	2002	192	8.73
20	End-tidal carbon-dioxide concentration during cardiopulmonary resuscitation	Falk JL. et al.	New England Journal of Medicine	1988	296	8.22
21	The effectiveness of out-of-hospital use of continuous end-tidal carbon dioxide monitoring on the rate of unrecognized misplaced intubation within a regional emergency medical services system	Silvestri S. et al.	Annals of Emergency Medicine	2005	155	8.16
22	End-tidal CO <sub>2</sub> : an important parameter for a correct interpretation in functional brain studies using speech tasks	Scholkmann F. et al.	Neuroimage	2013	89	8.09
23	Dynamics of the cerebral blood flow response to step changes in end-tidal P-CO <sub>2</sub> and P-O <sub>2</sub> in humans	Poulin MJ. et al.	Journal of Applied Physiology	1996	221	7.89
24	Capnographic monitoring reduces the incidence of arterial oxygen desaturation and hypoxemia during propofol sedation for colonoscopy: a randomized, controlled study (colocap study)	Beitz A. et al.	American Journal of Gastroenterology	2012	92	7.67
25	Does end-tidal carbon dioxide monitoring detect respiratory events prior to current sedation monitoring practices?	Burton JH. et al.	Academic Emergency Medicine	2006	136	7.56
26	End-tidal carbon dioxide is better than arterial pressure for predicting volume responsiveness by the passive leg raising test	Monnet X. et al.	Intensive Care Medicine	2013	83	7.55
27	A sudden increase in partial pressure end-tidal carbon dioxide (PETCO <sub>2</sub> ) at the moment of return of spontaneous circulation	Pokorna M. et al.	Journal of Emergency Medicine	2010	103	7.36
28	Volumetric capnography: the time has come	Suarez-Sipmann F. et al.	Current Opinion in Critical Care	2014	72	7.2
29	Factors complicating interpretation of capnography during advanced life support in cardiac arrest-a clinical retrospective study in 575 patients	Heradstveit BE. et al.	Resuscitation	2012	86	7.17
30	The prognostic value of end-tidal carbon dioxide during cardiac arrest: a systematic review	Touma O. and Davies M.	Resuscitation	2013	78	7.09
31	Capnography enhances surveillance of respiratory events during procedural sedation: a meta-analysis	Waugh JB. et al.	Journal of Clinical Anesthesia	2011	92	7.08

Table II: Cont.

No	Article	Author	Journal	PY	TC	AC
32	Rationale of dead space measurement by volumetric capnography	Tusman G. et al.	Anesthesia and Analgesia	2012	83	6.92
33	Prevalence of sleep apnoea and capnographic detection of nocturnal hypoventilation in amyotrophic lateral sclerosis	Boentert M. et al.	Journal of Neurology Neurosurgery and Psychiatry	2018	41	6.83
34	Human cerebrovascular and ventilatory CO <sub>2</sub> reactivity to end-tidal, arterial and internal jugular vein P-CO <sub>2</sub>	Peebles K. et al.	Journal of Physiology-London	2007	116	6.82
35	Patient safety during procedural sedation using capnography monitoring: a systematic review and meta-analysis	Saunders R. et al.	BMJ Open	2017	47	6.71
36	Measuring the human ventilatory and cerebral blood flow response to CO <sub>2</sub> : a technical consideration for the end-tidal-to-arterial gas gradient	Tymko MM. et al.	Journal of Applied Physiology	2016	53	6.63
37	End tidal-to-arterial CO <sub>2</sub> and O <sub>2</sub> gas gradients at low- and high-altitude during dynamic end-tidal forcing	Tymko MM. et al.	American Journal of Physiology-Regulatory Integrative And Comparative Physiology	2015	58	6.44
38	Cardiac-output and end-tidal carbon-dioxide	Weil MH. et al.	Critical Care Medicine	1985	248	6.36
39	The CO <sub>2</sub> stimulus for cerebrovascular reactivity: fixing inspired concentrations vs. Targeting end-tidal partial pressures	Fisher Joseph A.	Journal of Cerebral Blood Flow and Metabolism	2016	50	6.25
40	Capnography for procedural sedation and analgesia in the emergency department	Krauss B. and Hess DR.	Annals of Emergency Medicine	2007	105	6.18
41	Efficacy of chest compressions directed by end-tidal CO <sub>2</sub> feedback in a pediatric resuscitation model of basic life support	Hamrick JL. et al.	Journal of The American Heart Association	2014	61	6.1
42	Capnography outside the operating rooms	Kodali BS	Anesthesiology	2013	66	6
43	Multicenter study validating accuracy of a continuous respiratory rate measurement derived from pulse oximetry: a comparison with capnography	Bergese SD. et al.	Anesthesia and Analgesia	2017	42	6
44	Capnographic monitoring of propofol-based sedation during colonoscopy	Friedrich-Rust M. et al.	Endoscopy	2014	58	5.8
45	Capnography accurately detects apnea during monitored anesthesia care	Soto RG. et al.	Anesthesia and Analgesia	2004	115	5.75
46	Dynamic forcing of end-tidal carbon dioxide and oxygen applied to functional magnetic resonance imaging	Wise RG. et al.	Journal of Cerebral Blood Flow and Metabolism	2007	97	5.71
47	End-tidal carbon-dioxide monitoring during cardiopulmonary resuscitation - a prognostic indicator for survival	Sanders AB. et al.	Jama-Journal of The American Medical Association	1989	195	5.57
48	Volumetric capnography: lessons from the past and current clinical applications	Verscheure S. et al.	Critical Care	2016	44	5.5
49	Systematic review and meta-analysis of end-tidal carbon dioxide values associated with return of spontaneous circulation during cardiopulmonary resuscitation	Hartmann SM. et al.	Journal of Intensive Care Medicine	2015	49	5.44
50	Capnography alone is imperfect for endotracheal tube placement confirmation during emergency intubation	Li J	Journal of Emergency Medicine	2001	124	5.39

PY: Publication year, TC: Total citation, AC: Average citations per year.

**Table III:** The First 50 High-Impact Articles Based on the Total Number of Citations on End-tidal CO<sub>2</sub>/Capnography

No	Article	Author	Journal	PY	TC	AC
1	Dependency of blood-flow velocity in the middle cerebral-artery on end-tidal carbon-dioxide partial-pressure - a transcranial ultrasound doppler study	Markwalder TM. et al.	Journal of Cerebral Blood Flow and Metabolism	1984	448	11.2
2	End-tidal carbon-dioxide concentration during cardiopulmonary resuscitation	Falk JL. et al	New England Journal of Medicine	1988	296	8.22
3	End-tidal carbon dioxide and outcome of out-of-hospital cardiac arrest	Levine RL. et al	New England Journal of Medicine	1997	281	10.41
4	Cardiac-output and end-tidal carbon-dioxide	Weil MH. et al.	Critical Care Medicine	1985	248	6.36
5	Prospective targeting and control of end-tidal CO <sub>2</sub> and O <sub>2</sub> concentrations	Slessarev M. et al.	Journal of Physiology-London	2007	232	13.65
6	Dynamics of the cerebral blood flow response to step changes in end-tidal P-CO <sub>2</sub> and P-O <sub>2</sub> in humans	Poulin MJ. et al.	Journal of Applied Physiology	1996	221	7.89
7	Relationship between respiration, end-tidal CO <sub>2</sub> , and BOLD signals in resting-state fmri	Chang C. and Glover GH.	Neuroimage	2009	214	14.27
8	Evaluation of a humidified nasal high-flow oxygen system, using oxygraphy, capnography and measurement of upper airway pressures	Ritchie JE. et al.	Anaesthesia and Intensive Care	2011	211	16.23
9	End-tidal carbon-dioxide monitoring during cardiopulmonary resuscitation - a prognostic indicator for survival	Sanders AB. et al.	Jama-Journal of The American Medical Association	1989	195	5.57
10	End-tidal carbon dioxide monitoring during procedural sedation	Miner JR. et al.	Academic Emergency Medicine	2002	192	8.73
11	Microstream capnography improves patient monitoring during moderate sedation: A randomized, controlled trial	Lightdale JR. et al.	Pediatrics	2006	171	9.5
12	End-tidal carbon-dioxide monitoring during cardiopulmonary-resuscitation	Garnett AR. et al.	Jama-Journal of The American Medical Association	1987	168	4.54
13	The effectiveness of out-of-hospital use of continuous end-tidal carbon dioxide monitoring on the rate of unrecognized misplaced intubation within a regional emergency medical services system	Silvestri S. et al.	Annals of Emergency Medicine	2005	155	8.16
14	Prediction of outcome of cardiopulmonary resuscitation from end-tidal carbon-dioxide concentration	Callaham M. and Barton C.	Critical Care Medicine	1990	154	4.53
15	Capnographic monitoring of respiratory activity improves safety of sedation for endoscopic cholangiopancreatography and ultrasonography	Qadeer MA. et al.	Gastroenterology	2009	147	9.8
16	Partial pressure of end-tidal carbon dioxide successful predicts cardiopulmonary resuscitation in the field: a prospective observational study	Kolar M. et al.	Critical Care	2008	140	8.75
17	Does end-tidal carbon dioxide monitoring detect respiratory events prior to current sedation monitoring practices?	Burton JH. et al.	Academic Emergency Medicine	2006	136	7.56
18	Does end-tidal CO <sub>2</sub> monitoring during emergency department procedural sedation and analgesia with propofol decrease the incidence of hypoxic events? A randomized, controlled trial	Deitch K. et al.	Annals of Emergency Medicine	2010	134	9.57



Table III: Cont.

No	Article	Author	Journal	PY	TC	AC
19	Nocturnal monitoring of home non-invasive ventilation: the contribution of simple tools such as pulse oximetry, capnography, built-in ventilator software and autonomic markers of sleep fragmentation	Janssens JP. et al.	Thorax	2011	128	9.85
20	End-tidal and arterial carbon dioxide measurements correlate across all levels of physiologic dead space	McSwain SD. et al.	Respiratory Care	2010	128	9.14
21	Capnography alone is imperfect for endotracheal tube placement confirmation during emergency intubation	Li J	Journal of Emergency Medicine	2001	124	5.39
22	Can cardiac sonography and capnography be used independently and in combination to predict resuscitation outcomes?	Salen P. et al.	Academic Emergency Medicine	2001	123	5.35
23	Evaluation of an end-tidal CO <sub>2</sub> detector during pediatric cardiopulmonary-resuscitation	Bhende MS and Thompson AE	Pediatrics	1995	121	4.17
24	A single-blind study of combined pulse oximetry and capnography in children	Cote CJ. et al.	Anesthesiology	1991	119	3.61
25	Nasal high flow oxygen therapy in patients with COPD reduces respiratory rate and tissue carbon dioxide while increasing tidal and end-expiratory lung volumes: a randomised crossover trial	Fraser JF. et al.	Thorax	2016	118	14.75
26	Human cerebrovascular and ventilatory CO <sub>2</sub> reactivity to end-tidal, arterial and internal jugular vein P-CO <sub>2</sub>	Peebles K. et al.	Journal of Physiology-London	2007	116	6.82
27	Capnography accurately detects apnea during monitored anesthesia care	Soto RG. et al.	Anesthesia and Analgesia	2004	115	5.75
28	Quantitative relationship between end-tidal carbon dioxide and CPR quality during both in-hospital and out-of-hospital cardiac arrest	Sheak KR. et al.	Resuscitation	2015	113	12.56
29	Capnography for detection of accidental esophageal intubation	Linko K. et al.	Acta Anaesthesiologica Scandinavica	1983	107	2.61
30	Verification of endotracheal-tube placement with colorimetric end-tidal CO <sub>2</sub> detection	Macleod BA. et al.	Annals of Emergency Medicine	1991	106	3.21
31	Capnography for procedural sedation and analgesia in the emergency department	Krauss B. and Hess DR.	Annals of Emergency Medicine	2007	105	6.18
32	A sudden increase in partial pressure end-tidal carbon dioxide (petco <sub>2</sub> ) at the moment of return of spontaneous circulation	Pokorna M. et al.	Journal of Emergency Medicine	2010	103	7.36
33	Expiratory capnography in asthma - evaluation of various shape indexes	You B. et al.	European Respiratory Journal	1994	103	3.43
34	Sublingual capnography - A clinical validation study	Marik PE	Chest	2001	101	4.39
35	Dynamic forcing of end-tidal carbon dioxide and oxygen applied to functional magnetic resonance imaging	Wise RG. et al.	Journal of Cerebral Blood Flow and Metabolism	2007	97	5.71
36	Relationship between cardiac-output and the end-tidal carbon-dioxide tension	Ornato JP. et al.	Annals of Emergency Medicine	1990	97	2.85
37	Multicenter study of a portable, hand-size, colorimetric end-tidal carbon-dioxide detection device	Ornato JP. et al.	Annals of Emergency Medicine	1992	94	2.94

Table III: Cont.

No	Article	Author	Journal	PY	TC	AC
38	End-tidal CO <sub>2</sub> pressure decreases during exercise in cardiac patients - Association with severity of heart failure and cardiac output reserve	Matsumoto A. et al.	Journal of The American College of Cardiology	2000	93	3.88
39	Esophageal detector device versus detection of end-tidal carbon dioxide level in emergency intubation	Bozeman WP. et al.	Annals of Emergency Medicine	1996	93	3.32
40	Capnographic monitoring reduces the incidence of arterial oxygen desaturation and hypoxemia during propofol sedation for colonoscopy: a randomized, controlled study (colocap study)	Beitz A. et al.	American Journal of Gastroenterology	2012	92	7.67
41	Capnography enhances surveillance of respiratory events during procedural sedation: a meta-analysis	Waugh JB. et al.	Journal of Clinical Anesthesia	2011	92	7.08
42	Continuous pulse oximetry and capnography monitoring for postoperative respiratory depression and adverse events: a systematic review and meta-analysis	Lam T. et al.	Anesthesia and Analgesia	2017	90	12.86
43	End-tidal CO <sub>2</sub> : An important parameter for a correct interpretation in functional brain studies using speech tasks	Scholkmann F. et al.	Neuroimage	2013	89	8.09
44	The use of capnography for recognition of esophageal intubation in the neonatal intensive-care unit	Roberts WA. et al.	Pediatric Pulmonology	1995	89	3.07
45	Factors complicating interpretation of capnography during advanced life support in cardiac arrest-A clinical retrospective study in 575 patients	Heradstveit BE. et al.	Resuscitation	2012	86	7.17
46	Noninvasive monitoring of carbon dioxide during respiratory failure in toddlers and infants: End-tidal versus transcutaneous carbon dioxide	Tobias JD and Meyer DJ	Anesthesia and Analgesia	1997	85	3.15
47	Use of end-tidal carbon-dioxide to predict outcome in prehospital cardiac-arrest	Wayne MA. et al.	Annals of Emergency Medicine	1995	85	2.93
48	End-tidal carbon dioxide is better than arterial pressure for predicting volume responsiveness by the passive leg raising test	Monnet X. et al.	Intensive Care Medicine	2013	83	7.55
49	Rationale of dead space measurement by volumetric capnography	Tusman G. et al.	Anesthesia and Analgesia	2012	83	6.92
50	Difference in end-tidal CO <sub>2</sub> between asphyxia cardiac arrest and ventricular fibrillation/pulseless ventricular tachycardia cardiac arrest in the prehospital setting	Grmec S. et al.	Critical Care	2003	83	3.95

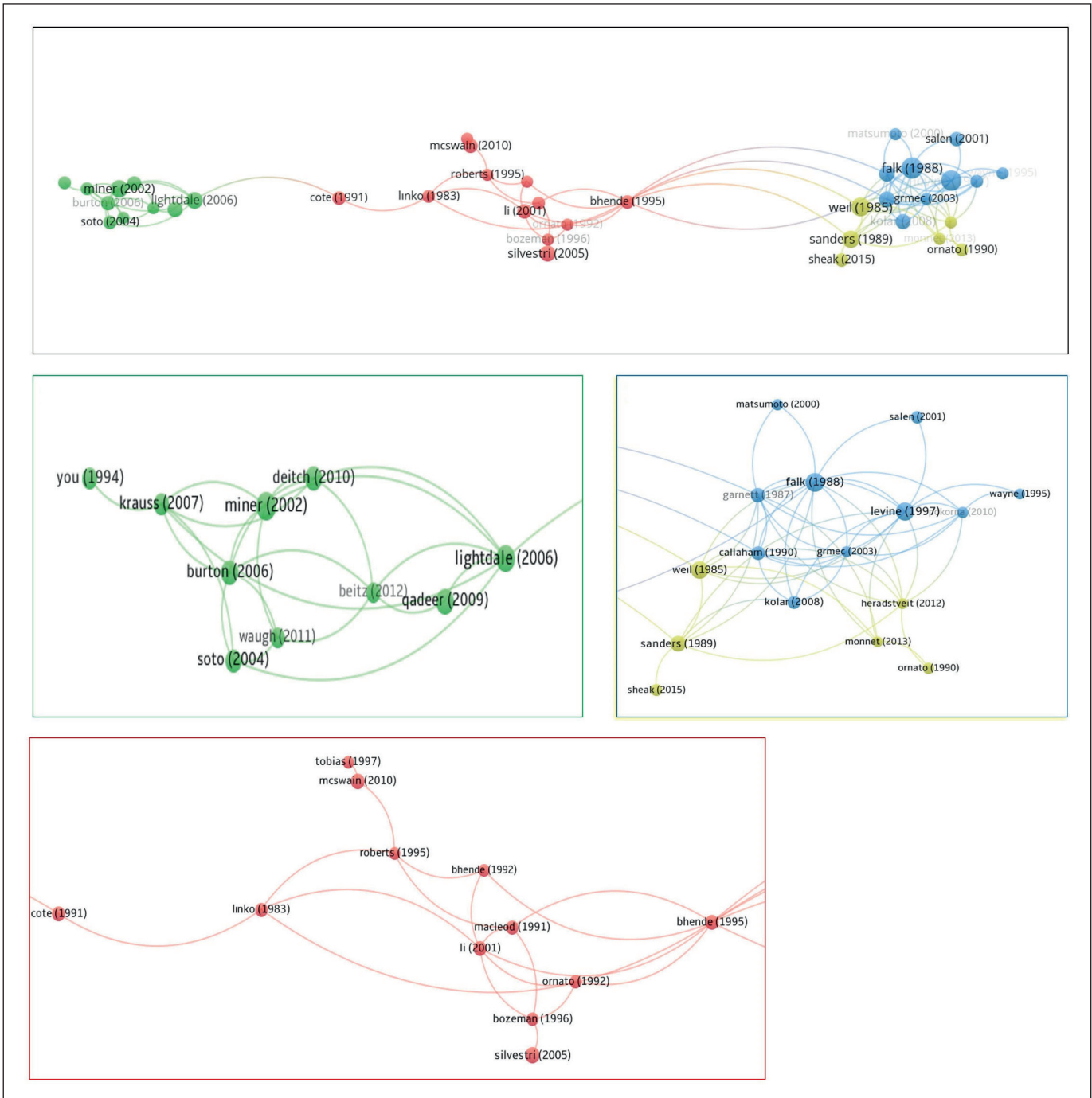
PY: Publication year, TC: Total citation, AC: Average citations per year.

### Co-citation Analysis

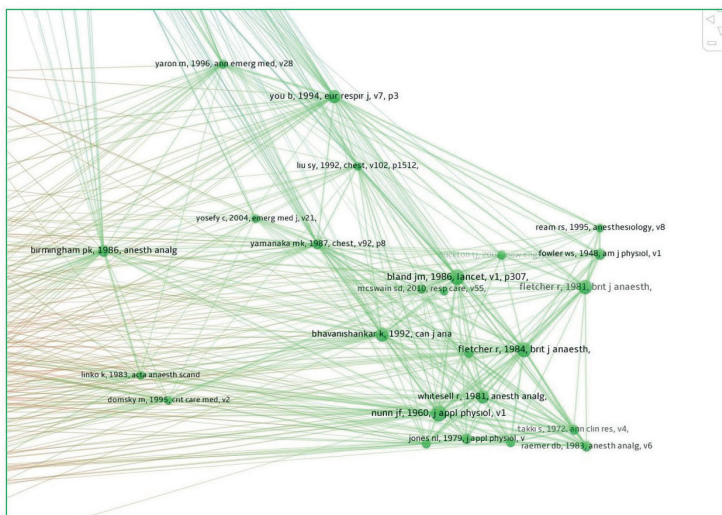
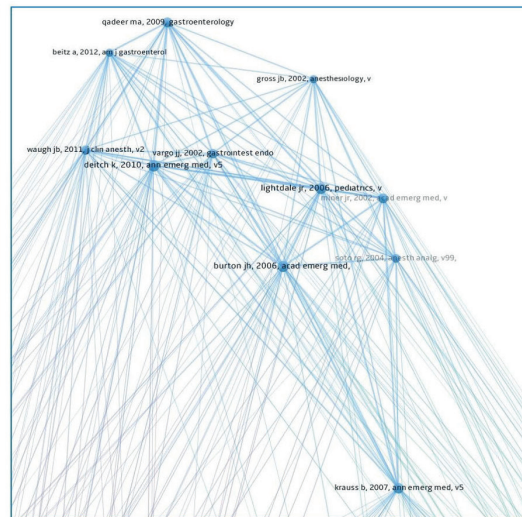
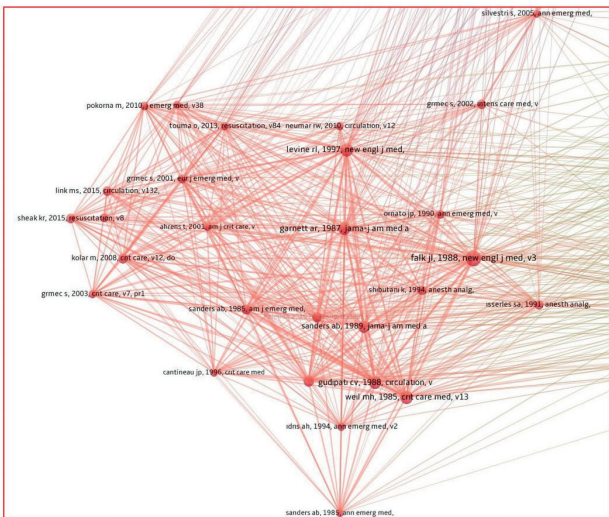
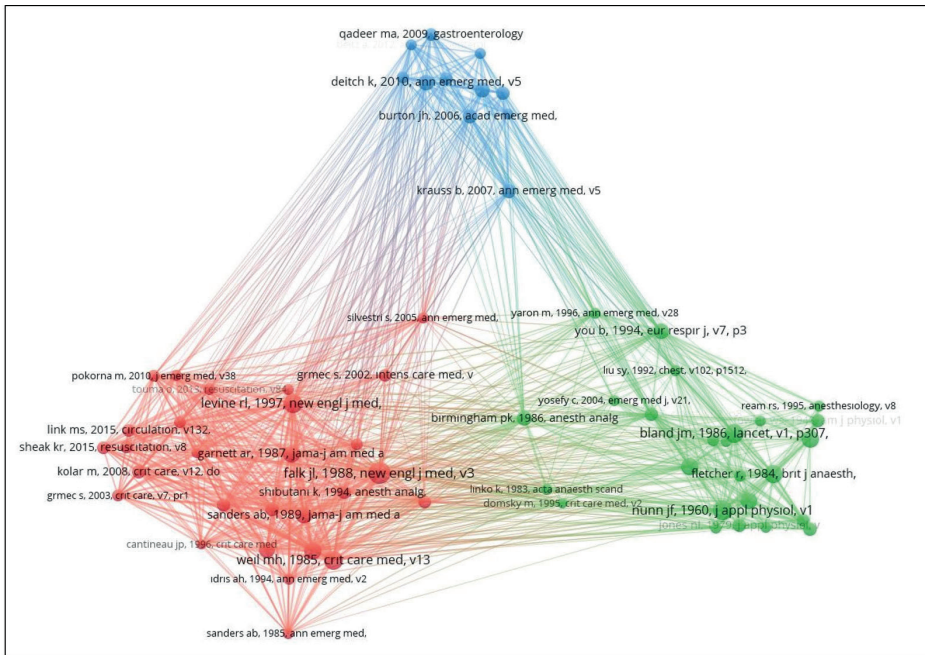
Of the 2508 publications on ETCO<sub>2</sub>/Capnography, a total of 19125 references were cited in their reference sections. For co-citation analysis, a threshold of 30 (minimum number of citations of a cited reference) was selected using the VOSviewer software. This resulted in the identification of 64 studies that were co-cited in at least 30 different articles. The co-citation networks of these studies are presented in Figure 4. The analysis revealed the presence of three distinct co-ci-

tation clusters (red, green, and blue) in the field of ETCO<sub>2</sub>/Capnography.

There were also seen to be six influential studies that have been cited in the references of at least 80 different publications. These studies were as follows, in order: Falk et al. (1988, number of co-citations (NC):114), Nunn and Hill (1960, NC: 94), Bland and Altman (1986, NC: 90), Levine et al. (1997, NC: 86), Weil et al. (1985, NC: 85), and Fletcher and Jonson (1984, NC: 82) (18-23).



**Figure 3:** Network visualization map illustrating the citation analysis on ETCO<sub>2</sub>. **Footnote:** Each circle is labeled with the first author's name and publication year of the article. Colors represent clustering. The color of the circle indicates the cluster with which the article is associated. The size of the circle is determined by the number of citations received by the study. The thickness of the lines between the two articles represents the strength of their common citation relationship.



**Figure 4:** Network visualization map illustrating the co-citation analysis on ETCO2. **Footnote:** Each circle is labeled with the first author's name and publication year of the article. Colors represent clustering. The color of the circle indicates the cluster with which the article is associated. The size of the circle is determined by the number of citations received by the study. The thickness of the lines between the two articles represents the strength of their common citation relationship.



## DISCUSSION

When examining the distribution of publications on ETCO<sub>2</sub>/Capnography from 1980 to 2022, three different periods of publication trends were observed: 1980-1986, 1987-2009, and 2010-2022. During the period of 1980-1986, an average of 12 studies (range: 6-19) per year were published. Starting from 1987, there was an increasing trend in the number of publications, and during the period of 1987-2009, an average of 48 studies (range: 28-61) per year were published. From 2010 onwards, there was a second increase in the number of publications, and during the period of 2010-2022, an average of 102 studies (range: 69-132) per year were published. Based on these past publication trends, it can be said that research on ETCO<sub>2</sub>/Capnography is expected to continue increasing in the future.

When considering citation analysis without taking into account the time factor, the most influential article in terms of total citations among all the articles was "Dependency of blood-flow velocity in the middle cerebral-artery on end-tidal carbon-dioxide partial-pressure - a transcranial ultrasound doppler study" by Markwalder et al. (1984), published in the *Journal of Cerebral Blood Flow and Metabolism* (24). The second most influential study was "End-tidal carbon-dioxide concentration during cardiopulmonary resuscitation" by Falk et al. (1988), published in the *New England Journal of Medicine* (18). The third most influential study was "End-tidal carbon dioxide and outcome of out-of-hospital cardiac arrest" by Levine et al. (1997), also published in the *New England Journal of Medicine* (21). The fourth and fifth most influential studies were by Weil et al. (1985) and Slessarev et al. (2007) (22,25). These articles will be of guidance for authors researching ETCO<sub>2</sub>/Capnography.

When considering citation analysis taking into account the time factor and the average citations per year, the study with the most impact among all the articles was "Evaluation of a humidified nasal high-flow oxygen system, using oxygraphy, capnography and measurement of upper airway pressures" by Ritchie et al. (2011), published in *Anaesthesia and Intensive Care* (26). The second most influential study was "Prediction of opioid-induced respiratory depression on inpatient wards using continuous capnography and oximetry: an international prospective, observational trial" by Khanna et al. (2020), published in *Anesthesia and Analgesia* (27). The third most influential study was "Nasal high flow oxygen therapy in patients with copd reduces respiratory rate and tissue carbon dioxide while increasing tidal and end-expiratory lung volumes: a randomised crossover trial" by Fraser et al. (2016), published in *Thorax* (28). The fourth and fifth most influential studies were by Chang C. and Glover (2009) and Slessarev et al. (2007) (25,29). It can be recommended that these arti-

cles are reviewed before conducting research on the topic of ETCO<sub>2</sub>/Capnography.

According to the co-citation analysis based on the number of common citations among all the analyzed articles, the most influential study was the work by Falk et al. (1988) (18). The second most influential study was "Respiratory dead space and arterial to end-tidal carbon dioxide tension difference in anesthetized man" by Nunn and Hill (1960), published in the *Journal of Applied Physiology* (19). The third most influential study was "Statistical methods for assessing agreement between two methods of clinical measurement" by Bland and Altman (1986), published in *The Lancet* (20). The fourth and fifth most influential studies were by Levine et al. (1997) and Weil et al. (1985) (21,22). It can be recommended that researchers interested in this topic read the influential studies identified through citation and co-citation analyses.

When evaluating the findings of the citation analysis network visualization map, it was observed that the articles with the highest number of citations formed four main clusters based on the total citation count (Figure 3). These clusters were related to ETCO<sub>2</sub> monitoring during sedation/emergency department procedural sedation (green cluster), endotracheal intubation (red cluster), CPR (blue cluster), and cardiac arrest (yellow cluster). When evaluating the co-citation network of the ETCO<sub>2</sub>/Capnography topic, it was observed that it formed three distinct clusters (Figure 3). These clusters were related to CPR and cardiac arrest (red cluster), sedation/emergency department procedural sedation (blue cluster), and dead space (green cluster). Through these citation and co-citation analyses, it is evident that the most influential studies in the field of ETCO<sub>2</sub>/Capnography have focused on sedation, endotracheal intubation, CPR /cardiac arrest, and dead space topics, spanning from the past to the present.

There is no comprehensive study in the literature that specifically focuses on citation and co-citation analyses in the field of ETCO<sub>2</sub>/Capnography. Only one study by Gündüz et al. (2020) was found in the literature search (30). In that study, the authors attempted to identify the most influential publications through altmetric analyses. However, due to the use of incomplete keywords in the literature search, they were unable to access some influential studies such as Markwalder et al. (1984) and Falk et al. (1988) (18,24).

A limitation of this study can be said to be the sole reliance on the WoS database for the literature search. However, citation analyses cannot be performed in the PubMed database. The relative advantages of the WoS and Scopus databases are still under debate, and in recent years, the WoS database has been widely used in previous studies in the literature (11-15).



## CONCLUSION

Citation analyses continue to provide valuable insights for the scientific community in terms of examining the most cited studies and identifying important research directions. In this study, the most influential articles in the field of  $\text{ETCO}_2$ /Capnography were identified through citation and co-citation analyses and the significant contributions of researchers, journals, institutions, and countries to the field were highlighted. Globally, there has been an increasing trend in publications over time. Research leadership in the development of  $\text{ETCO}_2$ /Capnography literature is observed in developed or developing countries with large economies. The current study will serve as a guiding resource for researchers conducting research in the field of  $\text{ETCO}_2$ /Capnography.

## AUTHOR CONTRIBUTIONS

**Conception or design of the work:** ENZ, YO

**Data collection:** YO, ENZ

**Data analysis and interpretation:** YO, ENZ

**Drafting the article:** ENZ, YO

**Critical revision of the article:** ENZ, YO

**Other (study supervision, fundings, materials, etc):** ENZ, YO

The author (ENZ, YO) reviewed the results and approved the final version of the manuscript.

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