



Clinical Article

# A bibliometric analysis on the most-cited publications on carotid endarterectomy throughout history

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**Objective:** Carotid endarterectomy (CEA) is the gold standard surgical procedure for managing carotid stenosis due to atherosclerosis and reducing the risk of ischemic stroke. This bibliometric analysis summarizes the most-cited articles on CEA and highlights the contributing articles to today's evidence-based practice.

**Methods:** A title-specific search using the Scopus database was used to perform the search. Pertinent article-based, journal-based, and author-based parameters were obtained for review.

**Results:** A total of 6,824 articles were published between 1970 and 2020. The top 100 most-cited articles accumulated a total of 54,153 citations with an average citation count (CC) of 541, with only a 4.53% self-citation rate for all authors. The publication trends peaked between 1997 and 2010, in which two-third of the highly cited works were published. The most prolific categories with top citations are the clinical, indications, and management, in a descending order. There were 41 published Randomized Controlled Trials (RCT) in the most-cited list.

**Conclusions:** Citation analysis on carotid endarterectomy has witnessed a marked shift in the publication trends from studying the outcome and complications to comparing carotid stenting with endarterectomy. This analysis is a good introductory article to physicians interested in this topic, as it summarizes the highly impactful articles and enlists the most-cited RCT on CEA.

**Keywords** Carotid artery stenosis, Carotid endarterectomy, Stroke, Bibliometric analysis, Citation analysis

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## INTRODUCTION

Carotid endarterectomy (CEA) is a surgical technique where an atheromatous plaque is dissected and removed from the carotid intima-media space, to prevent an ischemic stroke. The first CEA was performed by Raul Carrea in 1951.<sup>7)</sup> The utility of

CEA in preventing stroke was proven by various RCTs and is considered the gold standard in managing extracranial carotid atherosclerotic disease.<sup>4)(11)(14)</sup>

After the proper introduction and definition of bibliometric analysis type studies in 1969, it has gained wide acceptance and popularity by the scientific community.<sup>15)</sup> Bibliometric analysis is a study of the most impactful articles to their respective fields, based on article and journal citometric evaluation. In addition, it summarizes the chronological trends of the most impactful publications to interested readers. Evidence-based studies are carefully reviewed to demonstrate contemporary evidence-based approaches to a disease for physicians in related medical specialties. Many citation analyses were published in neurosurgery; herein, we are presenting the first bibliometric study of the most cited publications on CEA.<sup>3)(5)(6)</sup>

## MATERIALS AND METHODS

The bibliometric based search on the most-cited articles on CEA was performed using the Scopus database in June 2020. A title-specific keyword-based search with no restriction to the time of publication was executed. The search keyword was “Carotid Endarterectomy.” The identified studies were ranked based on their citation

count in descending order and the most-cited 100 articles were selected for further analysis.

Information of interest to bibliometric analysis were obtained which included twelve parameters. The article’s citation count, articles citation count, authors H-index, Journal’s Source Normalized Impact Per Paper (SNIP), Journal’s SCImago Journal Rank (SJR), journal’s Impact Factor (IF), article’s title, contributing authors, specialty of the most contributing authors, contributing journal, corresponding author’s affiliation, and country of contribution. The obtained 100 top studies on CAE were categorized into the following five categories: clinical, clinicoradiological, complications, management, and management indications. Since this study did not incorporate any patients or patient information, an IRB was not required.

## RESULTS

The Scopus bibliometric based search showed that 6,824 articles were published between 1970 and 2020 on CEA. The top 100 most cited articles were published between 1970 and 2016. The top-100 articles received an accumulative citation count of 54,153 and an average citation count of 541 citations per paper (Table 1). The

**Table 1.** The top 100 most-cited articles on CEA

Rank	Authors	Title	Year	Journal	CC	CY
1 <sup>st</sup>	Taylor D.W. et al.	Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis	1991	New England Journal of Medicine	7064	243.58
2 <sup>nd</sup>	Michael D. Walker. et al.	Endarterectomy for asymptomatic carotid artery stenosis	1995	JAMA: The Journal of the American Medical Association	4643	185.72
3 <sup>rd</sup>	Barnett H.J.M. et al.	Benefit of carotid endarterectomy in patients with symptomatic moderate or severe stenosis	1998	New England Journal of Medicine	2692	122.36
4 <sup>th</sup>	Warlow C. et al.	Randomised trial of endarterectomy for recently symptomatic carotid stenosis: Final results of the MRC European Carotid Surgery Trial (ECST)	1998	Lancet	2601	118.22
5 <sup>th</sup>	Yadav J.S. et al.	Protected carotid-artery stenting versus endarterectomy in high-risk patients	2004	New England Journal of Medicine	2348	146.75
6 <sup>th</sup>	Brott T.G. et al.	Stenting versus endarterectomy for treatment of carotid-artery stenosis	2010	New England Journal of Medicine	1931	193.1
7 <sup>th</sup>	Halliday A. et al.	Prevention of disabling and fatal strokes by successful carotid endarterectomy in patients without recent neurological symptoms: Randomised controlled trial	2004	Lancet	1856	116

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Rank	Authors	Title	Year	Journal	CC	CY
8 <sup>th</sup>	Mas J.L. et al.	Endarterectomy versus stenting in patients with symptomatic severe carotid stenosis	2006	New England Journal of Medicine	1293	92.35
9 <sup>th</sup>	Ringleb P.A. et al.	30 day results from the SPACE trial of stent-protected angioplasty versus carotid endarterectomy in symptomatic patients: a randomised non-inferiority trial	2006	Lancet	1192	85.14
10 <sup>th</sup>	Rothwell P.M. et al.	Analysis of pooled data from the randomised controlled trials of endarterectomy for symptomatic carotid stenosis	2003	Lancet	1154	67.88
11 <sup>th</sup>	Hobson R.W. et al.	Efficacy of carotid endarterectomy for asymptomatic carotid stenosis	1993	New England Journal of Medicine	1117	41.37
12 <sup>th</sup>	Rothwell P.M. et al.	Endarterectomy for symptomatic carotid stenosis in relation to clinical subgroups and timing of surgery	2004	Lancet	1081	67.56
13 <sup>th</sup>	Ederle J. et al.	Carotid artery stenting compared with endarterectomy in patients with symptomatic carotid stenosis (international carotid stenting study): An interim analysis of a randomised controlled trial	2010	The Lancet	951	95.1
14 <sup>th</sup>	Mayberg M.R. et al.	Carotid endarterectomy and prevention of cerebral ischemia in symptomatic carotid stenosis	1991	JAMA: The Journal of the American Medical Association	765	26.37
15 <sup>th</sup>	Ferguson G.G. et al.	The north american symptomatic carotid endarterectomy trial: Surgical results in 1415 patients	1999	Stroke	764	36.38
16 <sup>th</sup>	Barnett H.J.M.	Original contributions north american symptomatic carotid endarterectomy trial: Methods, patient characteristics, and progress	1991	Stroke	751	25.89
17 <sup>th</sup>	Sundt Jr. T.M. et al.	Correlation of cerebral blood flow and electroencephalographic changes during carotid endarterectomy. With results of surgery and hemodynamics of cerebral ischemia	1981	Mayo Clinic Proceedings	611	15.67
18 <sup>th</sup>	Eckstein H.H. et al.	Results of the Stent-Protected Angioplasty versus Carotid Endarterectomy (SPACE) study to treat symptomatic stenoses at 2 years: A multinational, prospective, randomised trial	2008	The Lancet Neurology	603	50.25
19 <sup>th</sup>	Gurm H.S. et al.	Long-term results of carotid stenting versus endarterectomy in high-risk patients	2008	New England Journal of Medicine	601	50.08
20 <sup>th</sup>	Halliday A. et al.	10-year stroke prevention after successful carotid endarterectomy for asymptomatic stenosis (ACST-1): A multicentre randomised trial	2010	The Lancet	491	49.1
21 <sup>st</sup>	Mas J.L. et al.	Endarterectomy Versus Angioplasty in Patients with Symptomatic Severe Carotid Stenosis (EVA-3S) trial: results up to 4 years from a randomised, multicentre trial	2008	The Lancet Neurology	467	38.916
22 <sup>nd</sup>	Taylor D.W. et al.	Low-dose and high-dose acetylsalicylic acid for patients undergoing carotid endarterectomy: A randomised controlled trial	1999	Lancet	442	21.04
23 <sup>rd</sup>	Spencer M.P. et al.	Detection of middle cerebral artery emboli during carotid endarterectomy using transcranial doppler ultrasonography	1990	Stroke	438	14.6
24 <sup>th</sup>	Naylor A.R. et al.	Randomized study of carotid angioplasty and stenting versus carotid endarterectomy: A stopped trial	1998	Journal of Vascular Surgery	438	19.90

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Rank	Authors	Title	Year	Journal	CC	CY
25 <sup>th</sup>	Wennberg D.E. et al.	Variation in carotid endarterectomy mortality in the medicare population: Trial hospitals, volume, and patient characteristics	1998	Journal of the American Medical Association	430	19.54
26 <sup>th</sup>	Gray-Weale A.C. et al.	Carotid artery atheroma: Comparison of preoperative B-mode ultrasound appearance with carotid endarterectomy specimen pathology	1988	Journal of Cardiovascular Surgery	423	13.21
27 <sup>th</sup>	Biller J. et al.	Guidelines for carotid endarterectomy: A statement for healthcare professionals from a special writing group of the stroke council, american heart association	1998	Circulation	421	19.13
28 <sup>th</sup>	Moore W.S. et al.	Guidelines for carotid endarterectomy: A multidisciplinary consensus statement from the ad hoc committee, american heart association	1995	Stroke	416	16.64
29 <sup>th</sup>	Bonati L.H. et al.	New ischaemic brain lesions on MRI after stenting or endarterectomy for symptomatic carotid stenosis: A substudy of the International Carotid Stenting Study (ICSS)	2010	The Lancet Neurology	410	41
30 <sup>th</sup>	Chaturvedi S. et al.	Carotid endarterectomy - an evidence-based review: Report of the therapeutics and technology assessment subcommittee of the american academy of neurology	2005	Neurology	399	26.6
31 <sup>st</sup>	Moneta G.L. et al.	Correlation of North American Symptomatic Carotid Endarterectomy Trial (NASCET) angiographic definition of 70% to 99% internal carotid artery stenosis with duplex scanning	1993	Journal of Vascular Surgery	379	14.03
32 <sup>nd</sup>	Winslow C.M. et al.	The appropriateness of carotid endarterectomy	1988	New England Journal of Medicine	364	11.375
33 <sup>rd</sup>	Rothwell P.M., Warlow C.P.	Prediction of benefit from carotid endarterectomy in individual patients: A risk-modelling study from (ECST)	1999	Lancet	342	16.28
34 <sup>th</sup>	Brooks W.H. et al.	Carotid angioplasty and stenting versus carotid endarterectomy: Randomized trial in a community hospital	2001	Journal of the American College of Cardiology	341	17.94
35 <sup>th</sup>	Brown M.M.	Short-term outcome after stenting versus endarterectomy for symptomatic carotid stenosis: A preplanned meta-analysis of individual patient data	2010	The Lancet	332	33.2
36 <sup>th</sup>	Sundt Jr. T.M., Sandok B.A., Whisnant J.P.	Carotid endarterectomy. Complications and preoperative assessment of risk	1975	Mayo Clinic Proceedings	314	6.97
37 <sup>th</sup>	Brott T.G. et al.	Long-term results of stenting versus endarterectomy for carotid-artery stenosis	2016	New England Journal of Medicine	302	75.5
38 <sup>th</sup>	Rothwell P.M., Slattery J., Warlow C.P.	Clinical and angiographic predictors of stroke and death from carotid endarterectomy: Systematic review	1997	British Medical Journal	299	13
39 <sup>th</sup>	Sharbrough F.W. et al.	Correlation of continuous electroencephalograms with cerebral blood flow measurements during carotid endarterectomy	1973	Stroke	295	6.27
40 <sup>th</sup>	Rothwell P.M., Slattery J., Warlow C.P.	A systematic review of the risks of stroke and death due to endarterectomy for symptomatic carotid stenosis	1996	Stroke	285	11.87
41 <sup>st</sup>	Piepgras D.G. et al.	Intracerebral hemorrhage after carotid endarterectomy	1988	Journal of Neurosurgery	284	8.87
42 <sup>nd</sup>	Jackson L.A. et al.	Isolation of Chlamydia pneumoniae from a carotid endarterectomy specimen	1997	Journal of Infectious Diseases	282	12.26

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Rank	Authors	Title	Year	Journal	CC	CY
43 <sup>rd</sup>	Riles T.S. et al.	The cause of perioperative stroke after carotid endarterectomy	1994	Journal of Vascular Surgery	261	10.03
44 <sup>th</sup>	Gasecki A.P. et al.	Long-term prognosis and effect of endarterectomy in patients with symptomatic severe carotid stenosis and contralateral carotid stenosis or occlusion: Results from NASCET	1995	Journal of Neurosurgery	259	10.36
45 <sup>th</sup>	NASCET investigators	Clinical alert: Benefit of carotid endarterectomy for patients with high-grade stenosis of the internal carotid artery. National Institute of Neurological Disorders and Stroke, Stroke and Trauma Division	1991	Stroke	257	8.86
46 <sup>th</sup>	Chambers B.R., Donnan G.A.	Carotid endarterectomy for asymptomatic carotid stenosis.	2005	Cochrane Database of Systematic Reviews (online)	248	16.53
47 <sup>th</sup>	Samra S.K. et al.	Evaluation of a cerebral oximeter as a monitor of cerebral ischemia during carotid endarterectomy	2000	Anesthesiology	248	12.4
48 <sup>th</sup>	Jordan Jr. W.D. et al.	Microemboli detected by transcranial Doppler monitoring in patients during carotid angioplasty versus carotid endarterectomy	1999	Cardiovascular Surgery	239	11.38
49 <sup>th</sup>	Slattery J.	Endarterectomy for moderate symptomatic carotid stenosis: Interim results from the MRC european carotid surgery trial	1996	Lancet	236	9.83
50 <sup>th</sup>	Bonati L.H. et al.	Long-term outcomes after stenting versus endarterectomy for treatment of symptomatic carotid stenosis: The International Carotid Stenting Study (ICSS) randomised trial	2015	The Lancet	236	47.2
51 <sup>st</sup>	Silver F.L. et al.	Safety of stenting and endarterectomy by symptomatic status in the Carotid Revascularization Endarterectomy Versus Stenting Trial (CREST)	2011	Stroke	235	26.11
52 <sup>nd</sup>	Bond R., Rerkasem K., Rothwell P.M.	Systematic review of the risks of carotid endarterectomy in relation to the clinical indication for and timing of surgery	2003	Stroke	234	13.76
53 <sup>rd</sup>	Mantese V.A. et al.	The carotid revascularization endarterectomy versus stenting trial (CREST): Stenting versus carotid endarterectomy for carotid disease	2010	Stroke	226	22.6
54 <sup>th</sup>	Lal B.K. et al.	Restenosis after carotid artery stenting and endarterectomy: A secondary analysis of CREST, a randomised controlled trial	2012	The Lancet Neurology	225	28.125
55 <sup>th</sup>	David O.W. et al.	Results of a randomized controlled trial of carotid endarterectomy for asymptomatic carotid stenosis	1992	Mayo Clinic Proceedings	225	8.03
56 <sup>th</sup>	Thompson J.E., Austin D.J., Patman R.D.	Carotid endarterectomy for cerebrovascular insufficiency: Long-term results in 592 patients followed up to thirteen years	1970	Annals of surgery	220	4.4
57 <sup>th</sup>	Morgenstern L.B. et al.	The risks and benefits of carotid endarterectomy in patients with near occlusion of the carotid artery	1997	Neurology	216	9.39
58 <sup>th</sup>	Toole J.F. et al.	Original contributions study design for randomized prospective trial of carotid endarterectomy for asymptomatic atherosclerosis	1989	Stroke	214	6.90
59 <sup>th</sup>	Coward L.J., Featherstone R.L., Brown M.M.	Safety and efficacy of endovascular treatment of carotid artery stenosis compared with carotid endarterectomy: A cochrane systematic review of the randomized evidence	2005	Stroke	214	14.26
60 <sup>th</sup>	Yadav J.S. et al.	Angioplasty and stenting for restenosis after carotid endarterectomy: Initial experience	1996	Stroke	212	8.83

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Rank	Authors	Title	Year	Journal	CC	CY
61 <sup>st</sup>	Spencer M.P.	Transcranial doppler monitoring and causes of stroke from carotid endarterectomy	1997	Stroke	212	9.21
62 <sup>nd</sup>	McKinlay S.M.	Carotid Revascularization Using Endarterectomy or Stenting Systems (CaRESS) phase I clinical trial: 1-year results	2005	Journal of Vascular Surgery	211	14.06
63 <sup>rd</sup>	Debakey M.E.	Successful carotid endarterectomy for cerebrovascular insufficiency: Nineteen-year follow-up	1975	JAMA: The Journal of the American Medical Association	210	4.66
64 <sup>th</sup>	Naylor A.R. et al.	A systematic review of outcomes following staged and synchronous carotid endarterectomy and coronary artery bypass	2003	European Journal of Vascular and Endovascular Surgery	210	12.35
65 <sup>th</sup>	Schnaudigel S. et al.	New brain lesions after carotid stenting versus carotid endarterectomy: A systematic review of the literature	2008	Stroke	210	17.5
66 <sup>th</sup>	Zierler R.E. et al.	Carotid artery stenosis following endarterectomy	1982	Archives of Surgery	209	5.5
67 <sup>th</sup>	O'donnell T.F. et al.	Correlation of B-mode ultrasound imaging and arteriography with pathologic findings at carotid endarterectomy	1985	Archives of Surgery	207	5.91
68 <sup>th</sup>	Sundt Jr T.M. et al.	Cerebral blood flow measurements and electroencephalograms during carotid endarterectomy	1974	Journal of Neurosurgery	206	4.47
69 <sup>th</sup>	Moritz S. et al.	Accuracy of cerebral monitoring in detecting cerebral ischemia during carotid endarterectomy: A comparison of transcranial Doppler sonography, near-infrared spectroscopy, stump pressure, and somatosensory evoked potentials	2007	Anesthesiology	203	15.61
70 <sup>th</sup>	Ogasawara K. et al.	Intracranial hemorrhage associated with cerebral hyperperfusion syndrome following carotid endarterectomy and carotid artery stenting: Retrospective review of 4494 patients	2007	Journal of Neurosurgery	202	15.5
71 <sup>st</sup>	Brooks W.H. et al.	Carotid angioplasty and stenting versus carotid endarterectomy for treatment of asymptomatic carotid stenosis: A randomized trial in a community hospital	2004	Neurosurgery	198	12.37
72 <sup>nd</sup>	Rothwell P.M. et al.	Treating individuals 3: From subgroups to individuals: General principles and the example of carotid endarterectomy	2005	Lancet	192	12.8
73 <sup>rd</sup>	Featherstone R.L., Brown M.M., Coward L.J.	International Carotid Stenting Study (ICSS): Protocol for a randomised clinical trial comparing carotid stenting with endarterectomy in symptomatic carotid artery stenosis	2004	Cerebrovascular Diseases	191	11.93
74 <sup>th</sup>	Easton J.D., Sherman D.G.	Stroke and mortality rate in carotid endarterectomy: 228 consecutive operations	1977	Stroke	188	4.37
75 <sup>th</sup>	Meyer F.B. et al.	Emergency carotid endarterectomy for patients with acute carotid occlusion and profound neurological deficits	1986	Annals of Surgery	186	5.47
76 <sup>th</sup>	McCrory D.C. et al.	Predicting complications of carotid endarterectomy	1993	Stroke	185	6.8
77 <sup>th</sup>	Cebul R.D. et al.	Indications, outcomes, and provider volumes for carotid endarterectomy	1998	Journal of the American Medical Association	183	8.31
78 <sup>th</sup>	Bonati L.H. et al.	Long-term risk of carotid restenosis in patients randomly assigned to endovascular treatment or endarterectomy in the Carotid and Vertebral Artery Transluminal Angioplasty Study (CAVATAS): Long-term follow-up of a randomised trial	2009	The Lancet Neurology	183	16.63

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Rank	Authors	Title	Year	Journal	CC	CY
79 <sup>th</sup>	Gaunt M.E. et al.	Clinical relevance of intraoperative embolization detected by transcranial Doppler ultrasonography during carotid endarterectomy: A prospective study of 100 patients	1994	British Journal of Surgery	183	7.03
80 <sup>th</sup>	Wade J.G. et al.	Effect of carotid endarterectomy on carotid chemoreceptor and baroreceptor function in man	1970	New England Journal of Medicine	180	3.6
81 <sup>st</sup>	Payne D.A. et al.	Beneficial effects of clopidogrel combined with aspirin in reducing cerebral emboli in patients undergoing carotid endarterectomy	2004	Circulation	180	11.25
82 <sup>nd</sup>	Reigel M.M. et al.	Cerebral hyperperfusion syndrome: A cause of neurologic dysfunction after carotid endarterectomy	1987	Journal of Vascular Surgery	178	5.39
83 <sup>rd</sup>	Hertzer N.R. et al.	A prospective study of vein patch angioplasty during carotid endarterectomy: Three-year results for 801 patients and 917 operations	1987	Annals of Surgery	176	5.33
84 <sup>th</sup>	Hertzer N.R. et al.	Early outcome assessment for 2228 consecutive carotid endarterectomy procedures: The Cleveland clinic experience from 1989 to 1995	1997	Journal of Vascular Surgery	174	7.56
85 <sup>th</sup>	Tu J.V. et al.	The fall and rise of carotid endarterectomy in the United States and Canada	1998	New England Journal of Medicine	174	7.90
86 <sup>th</sup>	Thompson J.E., Patman R.D., Talkington C.M.	Asymptomatic carotid bruit: Long-term outcome of patients having endarterectomy compared with unoperated controls	1978	Annals of Surgery	172	4.09
87 <sup>th</sup>	Ederle J. et al.	Endovascular treatment with angioplasty or stenting versus endarterectomy in patients with carotid artery stenosis in the Carotid and Vertebral Artery Transluminal Angioplasty Study (CAVATAS): Long-term follow-up of a randomised trial	2009	The Lancet Neurology	171	15.54
88 <sup>th</sup>	Levi C.R. et al.	Transcranial Doppler detected cerebral microembolism following carotid endarterectomy. High microembolic signal loads predict postoperative cerebral ischaemia	1997	Brain	170	7.39
89 <sup>th</sup>	Hays R.J., Levinson S.A., Wylie E.J.	Intraoperative measurement of carotid back pressure as a guide to operative management for carotid endarterectomy	1972	Surgery	170	3.54
90 <sup>th</sup>	Bernstein M., Fleming J.F.R., Deck J.H.N.	Cerebral hyperperfusion after carotid endarterectomy: A cause of cerebral hemorrhage	1984	Neurosurgery	168	4.66
91 <sup>st</sup>	McKinlay S. et al.	Carotid Revascularization Using Endarterectomy or Stenting Systems (CARESS): Phase I clinical trial	2003	Journal of Endovascular Therapy	167	9.82
92 <sup>nd</sup>	Ennix C.L. et al.	Improved results of carotid endarterectomy in patients with symptomatic coronary disease: An analysis of 1,546 consecutive carotid operations	1979	Stroke	166	4.04
93 <sup>rd</sup>	Blaser T. et al.	Risk of stroke, transient ischemic attack, and vessel occlusion before endarterectomy in patients with symptomatic severe carotid stenosis	2002	Stroke	166	9.2
94 <sup>th</sup>	Barnett H.J.M., Meldrum H.E., Eliasziw M.	The appropriate use of carotid endarterectomy	2002	CMAJ	166	9.2
95 <sup>th</sup>	Cowan Jr. J.A. et al.	Surgeon volume as an indicator of outcomes after carotid endarterectomy: An effect independent of specialty practice and hospital volume	2002	Journal of the American College of Surgeons	166	9.2
96 <sup>th</sup>	Hannan E.L. et al.	Relationship between provider volume and mortality for carotid endarterectomies in New York State	1998	Stroke	165	7.5

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Rank	Authors	Title	Year	Journal	CC	CY
97 <sup>th</sup>	Goldstein L.B. et al.	Multicenter review of preoperative risk factors for endarterectomy for asymptomatic carotid artery stenosis	1998	Stroke	163	7.40
98 <sup>th</sup>	Solomon R.A. et al.	Incidence and etiology of intracerebral hemorrhage following carotid endarterectomy	1986	Journal of Neurosurgery	163	4.79
99 <sup>th</sup>	Hobson II, R.W.	CREST (Carotid Revascularization Endarterectomy Versus Stent Trial): Background, design, and current status	2000	Seminars in Vascular Surgery	161	8.05
100 <sup>th</sup>	Rothwell, P.M., Slattery, J., Warlow, C.P.	A systematic comparison of the risks of stroke and death due to carotid endarterectomy for symptomatic and asymptomatic stenosis	1996	Stroke	160	6.6

CEA, carotid endarterectomy; CC, citations count; CY, citations per year

identified rate of self-citation among all authors in the top-100 articles; accounted for 4.53% from the overall citation count. The publication trends on CEA were continually active between 1997 and 2010 comprising the time for two-third of the top-cited articles publication time (Fig. 1) Clinical studies and studies on the management indications were the most studied category in approximately two-third of the most-cited articles on CEA (Fig. 2).

The number 1 article on CEA is a RCT authored by Taylor et al., 1991 in *New England Journal* entitled “Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis” in which it received 7064 citations and 243 citations per year. The bibliometric based search has identified 41 clinical trials on carotid endarterectomy. The most prolific author was Barnett, H.J.M a neurologist in which he authored 11 articles in the top 100 list (Fig. 3). The University College London was the most active participating institute by producing 15 articles on the list (Fig. 4). Assessment of

journals showed that *Stroke* was the most active journal by publishing 22 articles in the list (Fig. 5). The United States of America was the source of publication in 56 articles on the list (Fig. 6).

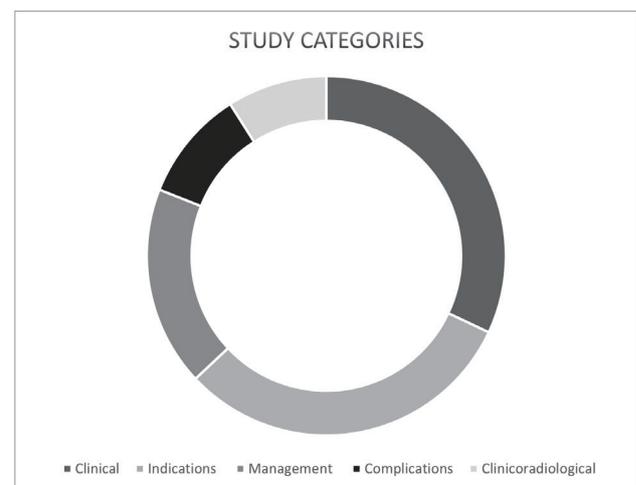


Fig. 2. Pie chart with study categories of publications mostly concentrated on the clinical and indications categories.

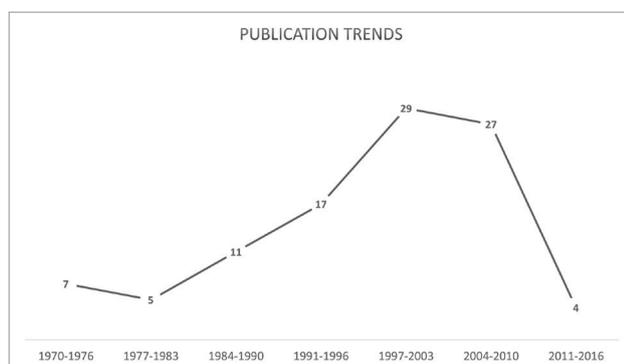


Fig. 1. Line chart demonstrating the chronological trend with the highest publication in the years 1997-2003.

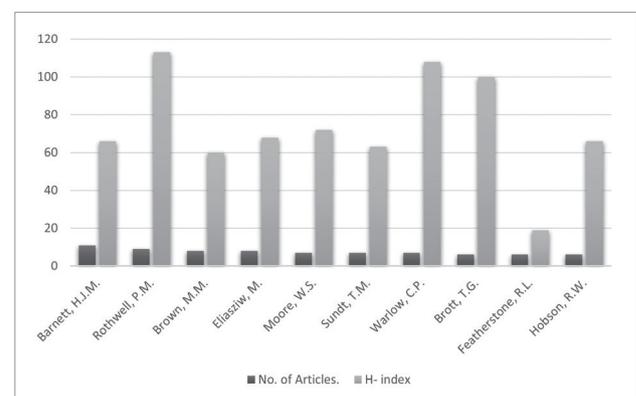


Fig. 3. Bar chart of the most contributing authors in carotid endarterectomy.

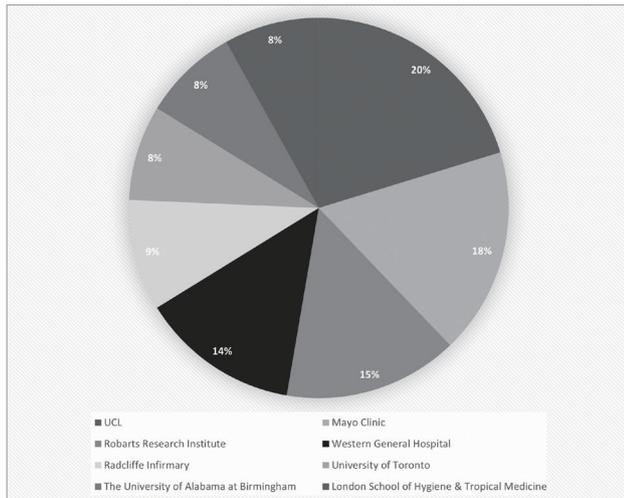


Fig. 4. Pie chart demonstrating the top contributing institutions in carotid endarterectomy.

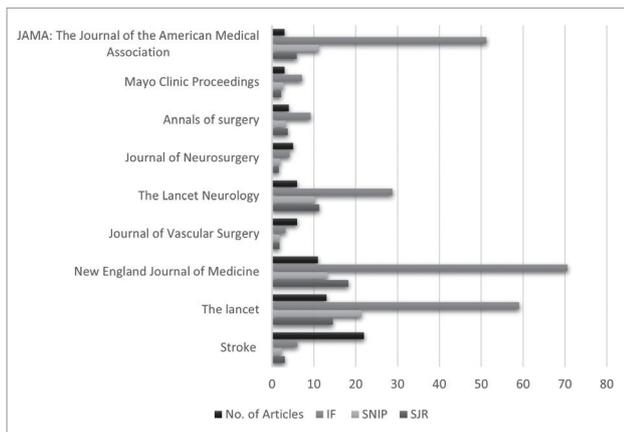


Fig. 5. Bar chart demonstrating the top contributing journals in publishing articles of carotid endarterectomy.

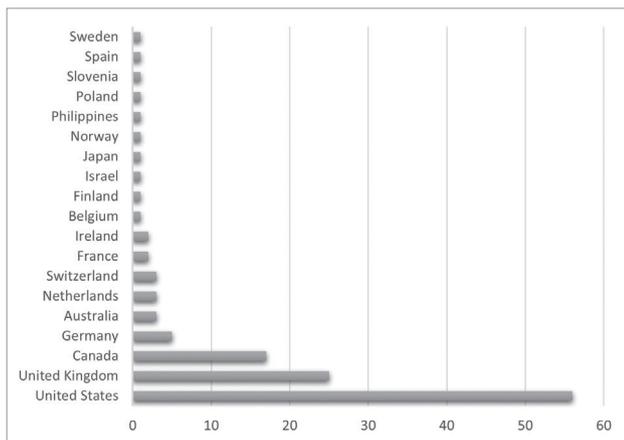


Fig. 6. Bar chart demonstrating the most contributing countries in publishing carotid endarterectomy studies.

## DISCUSSION

During the 1970s, publications were mainly focused on the short and long-term outcomes of CEA, complications of the procedure, and the usefulness of CEA in patients with asymptomatic carotid atherosclerosis. In the 1980s, more publications were focused on the short and long-term complications of CEA, especially cerebral hyperperfusion with the ensuing intracerebral hemorrhage, and the recurrence of carotid atherosclerosis post CEA. In addition, some articles studied the efficacy and outcome of emergency CEA. The 1990s witnessed a major shift geared by the production of major RCT, primarily analyzing the indications and outcomes of CEA in symptomatic and asymptomatic carotid atherosclerosis. In contrast, the 21<sup>st</sup> century was flourishing with more RCTs that compared the outcomes and complications between CEA and carotid stenting. Various systematic review and meta-analyses studies were published in the 21<sup>st</sup> century, comparing the efficacy of CEA to medical management, and comparing CEA to endovascular treatment.

The highest cited article in the top 100 list, and the indications category, is an RCT with 7064 Citations Count (CC) and 243 Citations per Year (CY) is “Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis” by the North American Symptomatic Carotid Endarterectomy Trial Collaborators in 1991 published by the *New England Journal of Medicine*. The trial resulted in significant findings that most vascular surgeons and neurosurgeons adopted the results. The aggregate risk of any ipsilateral stroke at two years was 9% in patients who underwent CEA, and 26% in patients who received best medical management; the absolute risk reduction was 17±3.5% (p-value= < 0.001). The overall risk of fatal or major ipsilateral was 13.1% in medically treated patients and 2.5% in patients who underwent CEA; the absolute risk reduction was 10.6±2.6% (p-value= < 0.001).<sup>12)</sup>

The second highest cited article, and the second highest in the indications category, with 4643 CC and 185 CY is “Endarterectomy for Asymptomatic Carotid Artery

Stenosis. Executive Committee for the Asymptomatic Carotid Atherosclerosis Study” by Walker et al., 1995 in the *Journal of the American Medical Association*. The trial randomized patients into an aspirin-treated group with medical risk factor management, and a CEA-treated group. Risk reduction of the cumulative 5-year risk of ipsilateral stroke and any perioperative stroke and death was noted to be 5.1% for the CEA group, and 11% for the medical management group (aggregate risk reduction of 53%). The authors concluded that CEA is indicated for patients  $\leq 75$  years, with asymptomatic carotid atherosclerosis who have a  $\geq 60\%$  stenosis and  $\leq 3\%$  risk of perioperative morbidity and mortality will have a lower 5-year aggregate risk of ipsilateral stroke.<sup>21)</sup>

### Clinical category

The clinical category has the highest number of publications, with multiple RCTs. From 1970-2010s, studies were mainly reviewing and assessing the outcome and complications of CEA, relative to medical management and carotid stenting. The highest article in the category (ranked 20<sup>th</sup> overall), with 491 CC and 49.1 CY, is “10-year stroke prevention after successful carotid endarterectomy for asymptomatic stenosis (ACST-1): A multicentre randomised trial” by Halliday et al., 2010 in *Lancet*. The study incorporated asymptomatic patients with carotid atherosclerosis and were randomized to immediate CEA group and deferral CEA group. The stroke risk at 5-years was 4.1% in the immediate CEA group, and 10% in the deferred CEA group; the 10-year stroke risk was 10.8% and 16.9% in the immediate and deferred CEA groups, respectively. Ratio of the stroke incidence rate was 0.54 (95% CI: 0.43 – 0.68; p-value= < 0.0001).<sup>10)</sup>

The second highest article in the category (ranked 25<sup>th</sup> overall), with 430 CC and 19 CY, is “Variation in carotid endarterectomy mortality in the medicare population: Trial hospitals, volume, and patient characteristics” by Wennberg et al., 1998 in the *Journal of the American Medical Association*. The authors reviewed the 30-day perioperative mortality rate in the North American Symptomatic Carotid Endarterectomy Trial (NASCET) and the Asymptomatic Carotid Atherosclerosis Study

(ACAS), compared to Medicare-insured patients treated in hospitals that did and didn't participate in the trial. They demonstrated a mortality rate of 1.4% at trial hospitals, 1.7% in non-trial high volume hospitals, 1.9% in non-trial average volume hospitals, and 2.5% in non-trial low volume hospitals. The authors concluded that Medicare-insured patients had a higher mortality rate, even in hospitals who participated in NASCET and ACAS. Therefore, they advised caution in inferring trial's mortality rate to the general everyday practice hospitals.<sup>22)</sup>

### Indications category

The indications category has the highest number of RCTs, with the main goal of comparing CEA and carotid stenting. The third highest cited article in the category (ranked 3<sup>rd</sup> overall), with 2692 CC and 122 CY, is “Benefit of carotid endarterectomy in patients with symptomatic moderate or severe stenosis” by Barnett et al., 1998 in the *New England Journal of Medicine*. Patients were categorized into mild (< 50%) and moderate (50-69%) carotid stenosis and were divided into CEA-treated group and medical management alone group. Patients with moderate stenosis had a 15.7% 5-year risk of any ipsilateral stroke, versus 22.2% in patients with medical management alone (p-value=0.045). Conversely, patients with mild stenosis didn't have a notable difference between the CEA group (14.9%) and the medical management group (18.7%; p-value= < 0.16). Hence, a moderate benefit of CEA is seen in patients with moderate stenosis.<sup>1)</sup>

The fourth highest cited article in this category (ranked 4<sup>th</sup> overall), with 2601 CC and 118 CY, is “Randomised trial of endarterectomy for recently symptomatic carotid stenosis: Final results of the MRC European Carotid Surgery Trial (ECST)” by Warlow et al., 1998 in *Lancet*. The authors randomized patients with carotid stenosis to CEA-treated group and control group with delay of CEA. The 3-year risk of major stroke or mortality was 26.5% for the control group, and 14.9% for the CEA group. The conclusion of the study was that CEA is indicated for patients with >80% stenosis, as the morbidity of non-operation is higher than the risk of surgery; with taking consideration to the age and gender of the patient.<sup>9)</sup>

The fifth highest cited article in the indication category (ranked 5<sup>th</sup> overall), with 2348 CC and 146 CY, is “Protected carotid-artery stenting versus endarterectomy in high-risk patients” by Yadav et al., 2004 in the *New England Journal of Medicine*. Patients were randomized to CEA-treated group and stent with an emboli protection device group. Results showed non-inferiority of carotid stenting with emboli protection device (cumulative incidence of 12.2%), compared to CEA-treated group (cumulative incidence of 20.1%; non-inferiority p-value =0.004).<sup>23)</sup>

### Management category

The management first started with publications in the correlation of electroencephalogram (EEG) and cerebral blood flow intraoperatively in detecting intraoperative cerebral ischemia. Later, studies focused on the use of intraoperative doppler ultrasound in identifying cerebral ischemia. Many authors focused on medication use with CEA to reduce stroke risk, such as the use of high vs. low dose aspirin, or the combination of aspirin and clopidogrel. Some studies reviewed the association of mortality and surgeon's volume. The highest cited article in the category (ranked 17<sup>th</sup> overall), with 611 CC and 15 CY, is “Correlation of cerebral blood flow and electroencephalographic changes during carotid endarterectomy: with results of surgery and hemodynamics of cerebral ischemia” by Sundt et al., 1981 in *Mayo Clinic Proceedings*. The study found that EEG had a positive correlation with cerebral blood flow, and the authors concluded a good prediction of postoperative outcome based on intraoperative EEG fluctuations.<sup>19)</sup>

The second highest cited article in the category (ranked 22<sup>nd</sup> overall), with 442 CC and 21 CY, is “Low-dose and high-dose acetylsalicylic acid for patients undergoing carotid endarterectomy: A randomized controlled trial” by Taylor et al., 1999 in *Lancet*. The authors found that low dose aspirin (81 and 325 mg) was associated with a lower risk of myocardial infarction, stroke, and mortality within 30 days and 3 months of CEA than high dose group (650 mg and 1300 mg).<sup>20)</sup>

The highest cited article in the 21<sup>st</sup> century (ranked

47<sup>th</sup> overall), with 248 CC and 12 CY, is “Evaluation of a cerebral oximeter as a monitor of cerebral ischemia during carotid endarterectomy” by Samra et al., 2000 in *Anesthesiology*. The authors measured regional cerebral oxygen saturation in patients who developed neurological deficits compared to those with no neurological deficits during carotid occlusion in CEA. There was a noticeable 20% reduction threshold in oxygen saturation before developing neurological symptoms (p=.0002).<sup>17)</sup>

### Complications category

The complications category assessed the association of cerebral hyperperfusion to intracerebral hemorrhage. The highest cited article (ranked 36<sup>th</sup> overall), with 314 CC and 6.9 CY, is “Carotid endarterectomy. Complications and preoperative assessment of risk” by Sundt et al., 1975 in *Mayo Clinic Proceedings*. The authors divided the preoperative risk of myocardial infarction and residual mild to severe stroke based on neurological status, with medical and angiographic. Group 1 (1% risk) are patients with no neurological deficits and no medical or angiographic risk factors. Group 2 (2%) are patients with no neurological deficits and no medical risk factors, but with angiographic risk factors. Group 3 (7%) are patients with no neurological deficits; however, they have medical risk factors, with or without angiographic risk factors. Group 4 (10%) are patients who have neurological deficits.<sup>16)</sup>

The second highest cited article in the category (ranked 40<sup>th</sup> overall), with 285 CC and 11 CY, is “A systematic review of the risks of stroke and death due to endarterectomy for symptomatic carotid stenosis” by Rothwell et al., 1996 in *Stroke*. The finding of this systematic review demonstrated a 1.62% mortality and 5.64% of stroke or mortality.<sup>16)</sup>

The highest cited article in the 21<sup>st</sup> century (ranked 70<sup>th</sup> overall), with 202 CC and 15 CY, is “Intracranial hemorrhage associated with cerebral hyperperfusion syndrome following carotid endarterectomy and carotid artery stenting: Retrospective review of 4494 patients” by Ogasawara et al., 2007 in the *Journal of Neurosurgery*. All patients who underwent CEA and carotid artery

stenting (CAS) who developed intracranial hemorrhage (ICH) were collected and studied. ICH developed at a rapid setting in the CAS group (12 hours) compared to the CEA group (6 days). Interestingly, inadequate blood pressure control was found to be significantly associated with ICH in CEA ( $P=.016$ ) compared to CAS.<sup>13)</sup>

### Clinicoradiological category

Multiple articles were published in this category which have correlated the pathological finding in carotid atherosclerosis using ultrasound and angiogram. In addition, there were multiple RCTs that studied the utility of ultrasound in predicting the degree of stenosis calculated on angiography. The highest cited article in the category (ranked 23<sup>rd</sup> overall), with 438 CC and 14 CY, is “Detection of middle cerebral artery emboli during carotid endarterectomy using transcranial doppler ultrasonography” by Spencer et al., 1990 in *Stroke*. Transcranial ultrasound of the middle cerebral artery proved to be efficacious in detecting emboli from the carotid artery, when correlated with the postoperative neurological status.<sup>18)</sup>

The second highest cited article in this category (ranked 26<sup>th</sup> overall), with 423 CC and 13 CY, is “Carotid artery atheroma: Comparison of preoperative B-mode ultrasound appearance with carotid endarterectomy specimen pathology” by Gray-Weale et al., 1988 in *Journal of Cardiovascular Surgery*. The authors demonstrated the correlation between ultrasound detection of heterogeneous signals and intraplaque hemorrhage and ulceration on pathological specimens ( $p\text{-value} < 0.001$ ).<sup>8)</sup>

The highest cited article in the 21<sup>st</sup> century (ranked 29<sup>th</sup> overall), with 410 CC and 41 CY, is “New ischaemic brain lesions on MRI after stenting or endarterectomy for symptomatic carotid stenosis: a substudy of the International Carotid Stenting Study (ICSS)” by Bonati et al., 2010 in *Lancet Neurology*. Patients who underwent CAS were found to have a higher likelihood of ischemic changes on MRI at 1 day ( $p < .0001$ ) and 1 month ( $p=.0003$ ) post-stenting compared to CEA, and thus, confirms the notion that ischemic stroke is associated with CAS.<sup>2)</sup>

### LIMITATIONS

Bibliometric review is a purely quantitative measure of the scientific community’s recognition rather than the reflection of the article’s impact in its respective field. Therefore, the usage of bibliometric in conjunction with peer reviewed articles provides a comprehensive overview on a certain topic. Inherited limitations exist in bibliometric studies which includes the citation accumulation overtime for old studies which can be counteracted by the use of the citation per year. Another limitation is the self-citation by authors which was minimal in our citation analysis on CEA (4.53%). Articles published after 2010 are focused on the comparison of CAS to CEA, hence, contemporary studies on CEA is lacking. Lastly, the coverage of the Scopus databases have an extensive citation tracking for articles published between 1970 and 2020 in which articles published prior to that might be underrepresented.

### CONCLUSIONS

The CEA chronological trends have witnessed an initial surge in the short and long-term outcomes, and complications following CEA. Then multiple RCTs emerged in studying the indications of CEA in symptomatic and asymptomatic carotid atherosclerosis. The latest articles and RCTs focused on comparing CEA and carotid stenting. The topic of carotid atherosclerosis contains various RCTs that define the current evidence-based approach to this disease. The temporal trends and the most-cited articles and the published RCT are highlighted in this rich evidence-based guide article for today’s clinicians.

### Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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