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Original Article

Bibliometric analysis of the top-100 most cited articles on the radiosurgical management of cerebral arteriovenous malformation

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ABSTRACT

Background: Radiosurgery is an effective, alternative treatment modality in managing patients with cerebral arteriovenous malformations (AVMs). The present study aims to highlight the scholarly impact of the top-100 most cited articles on the radiosurgical management of AVMs.

Methods: A title-specific search using the keyword "arteriovenous malformation" was conducted in the Scopus database. The outcome of the search was rearranged based on the citations count. Articles were categorized into four entities; clinical, gamma knife radiosurgery, linear accelerator (LINAC) radiosurgery, and proton beam radiosurgery. The exclusion criteria were applied to spinal or non-intracranial AVM, conference papers, non-English articles predominantly discussing the endovascular or microsurgical management.

Results: The top-100 articles on the radiosurgical management of AVM were published between 1972 and 2016. Approximately one-third of the publications were produced between 1995 and 2000. The average citations per year for all papers were seven. The most-studied entity was pertinent to the clinical application of gamma knife radiosurgery in AVM (68%). The United States was the most active country in studying the radiosurgical application in AVM. The Journal of Neurosurgery published approximately one-third of the most-cited articles in the list. The top-3 most contributing authors, publishing 80% of articles in the list, were Lunsford *et al*.

Conclusion: The radiosurgical management of AVMs evolved significantly throughout the years. Identifications of the publication trends facilitate the acquisition of evidence-based articles for authors investigating various radiosurgical techniques in the treatment of AVMs.

Keywords: Arteriovenous malformation, Bibliometric, Citation analysis, Stereotactic radiosurgery

INTRODUCTION

Cerebral arteriovenous malformations (AVMs) are vascular lesions characterized by a pathological connection between the venous and arterial circulation through a nidus.[4] These lesions can be diagnosed in the pediatric and adult populations, with an incidence rate of 1 person per 100,000 and a point prevalence of 18 persons per 100,000.[3]

The treatment option for accessible AVMs is usually achieved by complete surgical resection.[5] On the contrary, inaccessible deep-seated lesions and AVMs situated in eloquent cortices are commonly managed non-surgically.[4,5] One of the alternative and effective methods of managing patients with AVMs is radiosurgery, especially lesions of small and moderate sizes.[4,5,7]

Radiosurgery is defined as "The localized, focused, high-dose, irradiation commonly performed using Gamma knife (Leksell Gamma Knife® Perfexion, Elekta, Stockholm, Sweden), CyberKnife (Accuray Incorporated, 1310 Chesapeake Terrace, Sunnyvale, CA 94089, USA), or linear accelerator (LINAC)."[5] Radiosurgery aims to radiate the lesion by obliterating the abnormal blood vessels of the AVM nidus, without compromising the normal brain parenchyma.[5] The clinical effectiveness of radiosurgery is commonly assessed by measuring the obliteration of the pathological blood vessels on angiography.[5] However, some lesions can become angio-occult that can be apparent only on magnetic resonance imaging. Therefore, angiographic obliteration alone cannot serve to assess the effectiveness of radiosurgery in AVMs.[5] The application of radiosurgery has yielded acceptable and affordable risk-to-benefit in the management of unruptured/partially-resected AVMs, or during staged or partial embolization.[7,8]

Bibliometric analyses serve to address the top-cited articles in a discipline-specific scientific topic.[18] In addition, certain areas of research requiring further development can be identified and addressed accordingly.[18] Bibliometric analyses have been performed in several neurosurgical disciplines, including peripheral, traumatic, oncology, spine, and vascular-related topics.[1,2,6,12,16,18]

Considering the growing field of radiosurgery and its application in the management of AVMs, it is paramount to perform a bibliometric analysis of the most-influential articles in the literature. The main aim of the study is to identify, analyze, and report the current knowledge of the top-100 most-cited articles on the radiosurgical management of cerebral AVMs.

MATERIALS AND METHODS

The identification of the most-cited articles on the radiosurgical management of AVM in the Scopus database was accessed in July 2020. The title-specific search using "arteriovenous malformation" as a search keyword was conducted. The outcome of the search was rearranged based on the article's citations count in descending order. The acquisition of the top-100 articles discussing the radiosurgical management was selected after fulfilling our inclusion and exclusion criteria. Articles discussing the radiosurgical management of cerebral AVM as a primary outcome were included. Spinal or non-intracranial AVM, conference papers, and non-English articles predominantly discussing the endovascular or microsurgical management were excluded from the study.

The examined top-100 most cited articles were categorized into the following four entities: (1) clinical, (2) gamma knife radiosurgery, (3) linear accelerator (LINAC) radiosurgery, and (4) proton beam radiosurgery. In the performance of this bibliometric review, the following citometric relevant parameters were collected; article title, authors, 1st author's specialty, contributing institutions, journals, country of origin, year of publication, citation count (CC), Citation per year (CY), Hirsch index (H-Index), Journal's Source Normalized Impact Per Paper, Journal's SCImago Journal Rank, and Journal Impact Factor.

The present study does not involve human subjects. Therefore, it is exempted from ethical approval, giving the nature of the study being non-interventional.

RESULTS

The keyword-based literature review resulted in identifying 9939 articles discussing AVM and, of which the top-100 articles according to the inclusion criteria were examined [Table 1].

The top-100 articles on the radiosurgical management of AVM were published between 1972 and 2016 [Figure 1].

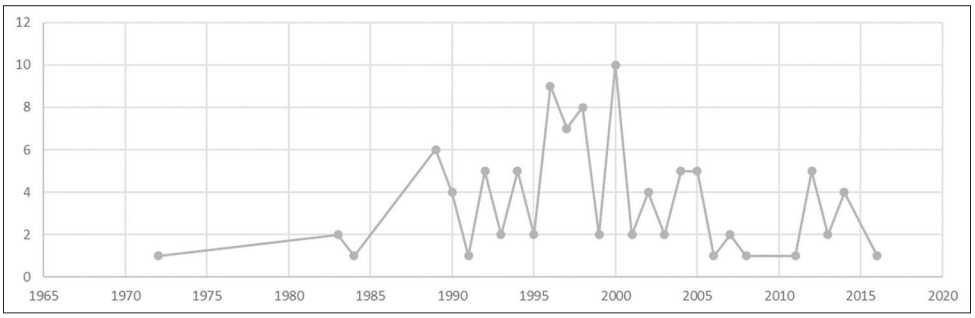

Figure 1: Publication trends for the top-100 most cited articles on the radiosurgical management of arteriovenous malformation (1972–2016).

Table 1: The top-100 most cited articles on the radiosurgical management of arteriovenous malformation.

Rank	Authors	Title	Journal	CC	CY
1st	Lunsford *et al.*, 1991	Stereotactic radiosurgery for arteriovenous malformations of the brain	Journal of Neurosurgery	520	17.9
2nd	Steiner *et al.*, 1992	Clinical outcome of radiosurgery for cerebral arteriovenous malformations	Journal of Neurosurgery	459	16.4
3rd	Kjellberg *et al.*, 1983	Bragg-Peak Proton-Beam Therapy for Arteriovenous Malformations of the Brain	New England Journal of Medicine	388	10.5
4th	Gobin *et al.*, 1996	Treatment of brain arteriovenous malformations by embolization and radiosurgery	Journal of Neurosurgery	299	12.5
5th	Colombo *et al.*, 1994	Linear accelerator radiosurgery of cerebral arteriovenous malformations: an update	Neurosurgery	281	10.8
6th	Pollock, *et al.*, 1998	Factors associated with successful arteriovenous malformation radiosurgery	Neurosurgery	271	12.3
7th	Flickinger, *et al.*, 2000	Development of a model to predict permanent symptomatic post radiosurgery injury for arteriovenous malformation patients	International Journal of Radiation Oncology Biology Physics	251	12.6
8th	Friedman, *et al.*, 1995	Linear accelerator radiosurgery for arteriovenous malformations: the relationship of size to outcome	Journal of Neurosurgery	247	9.9
9th	Flickinger *et al.*, 1996	A dose-response analysis of arteriovenous malformation obliteration after radiosurgery	International Journal of Radiation Oncology Biology Physics	243	10.1
10th	Maruyama *et al.*, 2005	The risk of hemorrhage after radiosurgery for cerebral arteriovenous malformations	New England Journal of Medicine	235	15.7
11th	Schneider *et al.*, 1997	Histopathology of arteriovenous malformations after gamma knife radiosurgery	Journal of Neurosurgery	232	10.1
12th	Pollock and Flickinger, 2002	A proposed radiosurgery-based grading system for arteriovenous malformations	Journal of Neurosurgery	227	12.6
13th	Steinberg *et al.*, 1990	Stereotactic heavy-charged-particle bragg peak radiation for intracranial arteriovenous malformations	New England Journal of Medicine	224	7.5
14th	Pollock *et al.*, 1996	Hemorrhage risk after stereotactic radiosurgery of cerebral arteriovenous malformations	Neurosurgery	218	9.1
15th	Betti *et al.*, 1989	Stereotactic radiosurgery with the linear accelerator: treatment of arteriovenous malformations	Neurosurgery	213	6.9
16th	Karlsson *et al.*, 1997	Prediction of obliteration after gamma knife surgery for cerebral arteriovenous malformations	Neurosurgery	208	9.0
17th	Flickinger *et al.*, 1997	Complications from arteriovenous malformation radiosurgery: multivariate analysis and risk modeling	International Journal of Radiation Oncology Biology Physics	200	8.7
18th	Yamamoto *et al.*, 1996	Gamma knife radiosurgery for arteriovenous malformations: long-term follow-up results focusing on complications occurring more than 5 years after irradiation	Neurosurgery	180	7.5
19th	Steiner, *et al.*, 1972	Stereotaxic radiosurgery for cerebral arteriovenous malformations. Report of a case.	Acta Chirurgica Scandinavica	176	3.7
20th	Flickinger *et al.*, 2002	An analysis of the dose-response for arteriovenous malformation radiosurgery and other factors affecting obliteration	Radiotherapy and Oncology	174	9.7
21st	Friedman *et al.*, 1996	The risk of hemorrhage after radiosurgery for arteriovenous malformations	Journal of Neurosurgery	174	7.3
22nd	Flickinger *et al.*, 1999	A multi-institutional analysis of complication outcomes after arteriovenous malformation radiosurgery	International Journal of Radiation Oncology Biology Physics	158	7.5
23rd	Friedman and Bova, 1992	Linear accelerator radiosurgery for arteriovenous malformations	Journal of Neurosurgery	158	5.6
24th	Pollock *et al.*, 2003	Patient outcomes after arteriovenous malformation radiosurgical management: results based on a 5–14-year follow-up study	Neurosurgery	157	9.2

(*Contd...*)

Table 1: (*Continued*)

Rank	Authors	Title	Journal	CC	CY
25th	Andrade-Souza *et al.*, 2007	Embolization before radiosurgery reduces the obliteration rate of arteriovenous malformations	Neurosurgery	153	11.8
26th	Miyawaki *et al.*, 1999	Five year results of LINAC radiosurgery for arteriovenous malformations: outcome for large AVMS	International Journal of Radiation Oncology Biology Physics	148	7.0
27th	Colombo *et al.*, 1989	Linear accelerator radiosurgery of cerebral arteriovenous malformations	Neurosurgery	148	4.8
28th	Starke *et al.*, 2013	A practical grading scale for predicting outcome after radiosurgery for arteriovenous malformations: analysis of 1012 treated patients	Journal of Neurosurgery	144	20.6
29th	Pollock *et al.*, 2008	Modification of the radiosurgery-based arteriovenous malformation grading system	Neurosurgery	143	11.9
30th	Pollock *et al.*, 1996	Repeat stereotactic radiosurgery of arteriovenous malformations: factors associated with incomplete obliteration	Neurosurgery	143	6.0
31st	Pollock *et al.*, 1994	Patient outcomes after stereotactic radiosurgery for "operable" arteriovenous malformations	Neurosurgery	142	5.5
32nd	Schlienger *et al.*, 2000	Linac radiosurgery for cerebral arteriovenous malformations: results in 169 patients	International Journal of Radiation Oncology Biology Physics	132	6.6
33rd	Flickinger *et al.*, 1992	Radiosurgery and brain tolerance: an analysis of neurodiagnostic imaging changes after gamma knife radiosurgery for arteriovenous malformations	International Journal of Radiation Oncology, Biology, Physics	126	4.5
34th	Friedman *et al.*, 2003	Analysis of factors predictive of success or complications in arteriovenous malformation radiosurgery	Neurosurgery	122	7.2
35th	Lewis *et al.*, 1994	Management of tentorial dural arteriovenous malformations: transarterial embolization combined with stereotactic radiation or surgery	Journal of Neurosurgery	120	4.6
36th	Pan *et al.*, 2000	Gamma knife radiosurgery as a single treatment modality for large cerebral arteriovenous malformations	Journal of Neurosurgery	117	5.9
37th	Pollock *et al.*, 2004	Radiosurgery for arteriovenous malformations of the basal ganglia, thalamus, and brainstem	Journal of Neurosurgery	114	7.1
38th	Loeffler *et al.*, 1989	Stereotactic radiosurgery for intracranial arteriovenous malformations using a standard linear accelerator	International Journal of Radiation Oncology, Biology, Physics	114	3.7
39th	Karlsson *et al.*, 2001	Risk for hemorrhage during the 2-year latency period following gamma knife radiosurgery for arteriovenous malformations	International Journal of Radiation Oncology Biology Physics	113	5.9
40th	Fabrikant *et al.*, 1984	Stereotactic heavy-ion Bragg peak radiosurgery for intra-cranial vascular disorders: method for treatment of deep arteriovenous malformations	British Journal of Radiology	113	3.1
41st	Liščák *et al.*, 2007	Arteriovenous malformations after Leksell gamma knife radiosurgery: rate of obliteration and complications	Neurosurgery	111	8.5
42nd	Sirin *et al.*, 2006	Prospective staged volume radiosurgery for large arteriovenous malformations: indications and outcomes in otherwise untreatable patients	Neurosurgery	110	7.9
43rd	Lindqvist *et al.*, 2000	Angiographic long-term follow-up data for arteriovenous malformations previously proven to be obliterated after gamma knife radiosurgery	Neurosurgery	109	5.5
44th	Ellis *et al.*, 1998	Analysis of treatment failure after radiosurgery for arteriovenous malformations	Journal of Neurosurgery	108	4.9
45th	Sasaki *et al.*, 1998	Arteriovenous malformations in the basal ganglia and thalamus: management and results in 101 cases	Journal of Neurosurgery	107	4.9

(*Contd...*)

Table 1: (*Continued*)

Rank	Authors	Title	Journal	CC	CY
46th	Kano *et al.*, 2012	Stereotactic radiosurgery for arteriovenous malformations, Part 1: management of Spetzler-Martin Grades I and II arteriovenous malformations: clinical article	Journal of Neurosurgery	103	12.9
47th	Flickinger *et al.*, 1998	Analysis of neurological sequelae from radiosurgery of arteriovenous malformations: how location affects outcome	International Journal of Radiation Oncology Biology Physics	102	4.6
48th	Yamamoto *et al.*, 1992	Long-term results of radiosurgery for arteriovenous malformation: neurodiagnostic imaging and histological studies of angiographically confirmed nidus obliteration	Surgical Neurology	102	3.6
49th	Steinberg *et al.*, 1996	Surgical resection of large incompletely treated intracranial arteriovenous malformations following stereotactic radiosurgery	Journal of Neurosurgery	101	4.2
50th	Wegner *et al.*, 2011	A modified radiosurgery-based arteriovenous malformation grading scale and its correlation with outcomes	International Journal of Radiation Oncology Biology Physics	100	11.1
51st	Ding *et al.*, 2013	Radiosurgery for patients with unruptured intracranial arteriovenous malformations: clinical article	Journal of Neurosurgery	99	14.1
52nd	Kano *et al.*, 2012	Stereotactic radiosurgery for arteriovenous malformations, Part 6: multistaged volumetric management of large arteriovenous malformations: clinical article	Journal of Neurosurgery	99	12.4
53rd	Levy *et al.*, 2000	Radiosurgery for childhood intracranial arteriovenous malformations	Neurosurgery	98	4.9
54th	Karlsson *et al.*, 1997	Factors influencing the risk for complications following Gamma Knife radiosurgery of cerebral arteriovenous malformations	Radiotherapy and Oncology	98	4.3
55th	Engenhart *et al.*, 1994	The role of high-dose, single-fraction irradiation in small and large intracranial arteriovenous malformations	International Journal of Radiation Oncology, Biology, Physics	97	3.7
56th	Shin *et al.*, 2002	Retrospective analysis of a 10-year experience of stereotactic radiosurgery for arteriovenous malformations in children and adolescents	Journal of Neurosurgery	96	5.3
57th	Ogilvy, 1990	Radiation therapy for arteriovenous malformations: a review	Neurosurgery	93	3.1
58th	Izawa *et al.*, 2005	Long-term complications after gamma knife surgery for arteriovenous malformations	Journal of Neurosurgery	92	6.1
59th	Levy *et al.*, 1989	Stereotactic heavy-charged-particle bragg peak radiosurgery for the treatment of intracranial arteriovenous malformations in childhood and adolescence	Neurosurgery	92	3.0
60th	Maruyama *et al.*, 2004	Stereotactic radiosurgery for brainstem arteriovenous malformations: factors affecting outcome	Journal of Neurosurgery	91	5.7
61st	Pollock *et al.*, 2000	The rationale and technique of staged-volume arteriovenous malformation radiosurgery	International Journal of Radiation Oncology Biology Physics	91	4.6
62nd	Lax and Karlsson, 1996	Prediction of complications in gamma knife radiosurgery of arteriovenous malformations	Acta Oncologica	91	3.8
63rd	Mathis *et al.*, 1995	The efficacy of particulate embolization combined with stereotactic radiosurgery for treatment of large arteriovenous malformations of the brain	American Journal of Neuroradiology	90	3.6
64th	Dawson *et al.*, 1990	Treatment of arteriovenous malformations of the brain with combined embolization and stereotactic radiosurgery: results after 1 and 2 years	American Journal of Neuroradiology	90	3.0
65th	Heikkinen *et al.*, 1989	Relief of epilepsy by radiosurgery of cerebral arteriovenous malformations	Stereotactic and Functional Neurosurgery	89	2.9

(*Contd...*)

Table 1: (*Continued*)

Rank	Authors	Title	Journal	CC	CY
66th	Maesawa *et al.*, 2000	Repeated radiosurgery for incompletely obliterated arteriovenous malformations	Journal of Neurosurgery	88	4.4
67th	Shin *et al.*, 2004	Analysis of nidus obliteration rates after gamma knife surgery for arteriovenous malformations based on long-term follow-up data: The University of Tokyo experience	Journal of Neurosurgery	87	5.4
68th	Chang *et al.*, 1997	Stereotactic radiosurgery of arteriovenous malformations: pathologic changes in resected tissue	Clinical Neuropathology	87	3.8
69th	Deruty *et al.*, 1993	The combined management of cerebral arteriovenous malformations experience with 100 cases and review of the literature	Acta Neurochirurgica	87	3.2
70th	Kano *et al.*, 2012	Stereotactic radiosurgery for arteriovenous malformations after embolization: a case–control study. Clinical article.	Journal of Neurosurgery	86	10.8
71st	Kano *et al.*, 2012	Stereotactic radiosurgery for arteriovenous malformations, Part 3: outcome predictors and risks after repeat radiosurgery: clinical article	Journal of Neurosurgery	85	10.6
72nd	Yamamoto *et al.*, 1998	Radiation-related adverse effects observed on neuro-imaging several years after radiosurgery for cerebral arteriovenous malformations	Surgical Neurology	85	3.9
73rd	Smyth *et al.*, 2002	Stereotactic radiosurgery for pediatric intracranial arteriovenous malformations: The University of California at San Francisco experience	Journal of Neurosurgery	82	4.6
74th	Chang *et al.*, 2000	Factors related to complete occlusion of arteriovenous malformations after gamma knife radiosurgery	Journal of Neurosurgery	81	4.1
75th	Gallina *et al.*, 1998	Failure in radiosurgery treatment of cerebral arteriovenous malformations	Neurosurgery	79	3.6
76th	Kihlström *et al.*, 1997	Magnetic resonance imaging of obliterated arteriovenous malformations up to 23 years after radiosurgery	Journal of Neurosurgery	79	3.4
77th	Kurita *et al.*, 2000	Results of radiosurgery for brain stem arteriovenous malformations	Journal of Neurology Neurosurgery and Psychiatry	78	3.9
78th	Karlsson *et al.*, 1998	Gamma knife surgery for previously irradiated arteriovenous malformations	Neurosurgery	78	3.5
79th	Andrade-Souza *et al.*, 2005	Radiosurgery for basal ganglia, internal capsule, and thalamus arteriovenous malformation: clinical outcome	Neurosurgery	77	5.1
80th	Schad *et al.*, 1992	Correction of spatial distortion in magnetic resonance angiography for radiosurgical treatment planning of cerebral arteriovenous malformations	Magnetic Resonance Imaging	77	2.8
81st	Gerszten *et al.*, 1996	Seizure outcome in children treated for arteriovenous malformations using gamma knife radiosurgery	Pediatric Neurosurgery	76	3.2
82nd	Kjellberg *et al.*, 1983	Bragg peak proton beam therapy for arteriovenous malformation of the brain.	Clinical neurosurgery	76	2.1
83rd	Schäuble *et al.*, 2004	Seizure outcomes after stereotactic radiosurgery for cerebral arteriovenous malformations	Neurology	75	4.7
84th	Loeffler *et al.*, 1990	Role of stereotactic radiosurgery with a linear accelerator in treatment of intracranial arteriovenous malformations and tumors in children	Pediatrics	74	2.5
85th	Kano *et al.*, 2012	Stereotactic radiosurgery for arteriovenous malformations, Part 2: management of pediatric patients: clinical article	Journal of Neurosurgery: pediatrics	73	9.1
86th	Hadjipanayis *et al.*, 2001	Stereotactic radiosurgery for motor cortex region arteriovenous malformations	Neurosurgery	73	3.8
87th	Kondziolka *et al.*, 1994	Stereotactic magnetic resonance angiography for targeting in arteriovenous malformation radiosurgery	Neurosurgery	72	2.8
88th	Ding *et al.*, 2014	Radiosurgery for low-grade intracranial arteriovenous malformations	Journal of Neurosurgery	71	11.8

(*Contd...*)

Table 1: (*Continued*)

Rank	Authors	Title	Journal	CC	CY
89th	Ding *et al.*, 2014	Radiosurgery for ruptured intracranial arteriovenous malformations: clinical article	Journal of Neurosurgery	69	11.5
90th	Moosa *et al.*, 2014	Volume-staged versus dose-staged radiosurgery outcomes for large intracranial arteriovenous malformations	Neurosurgical Focus	67	11.2
91st	Andrade-Souza *et al.*, 2005	Testing the radiosurgery-based arteriovenous malformation score and the modified Spetzler-Martin grading system to predict radiosurgical outcome	Journal of Neurosurgery	67	4.5
92nd	Bollet *et al.*, 2004	Efficacy and morbidity of arc-therapy radiosurgery for cerebral arteriovenous malformations: a comparison with the natural history	International Journal of Radiation Oncology Biology Physics	67	4.2
93rd	Kurita *et al.*, 1998	Control of epilepsy associated with cerebral arteriovenous malformations after radiosurgery	Journal of Neurology Neurosurgery and Psychiatry	66	3.0
94th	Ding *et al.*, 2016	Radiosurgery for Cerebral Arteriovenous Malformations in A Randomized Trial of Unruptured Brain Arteriovenous Malformations (ARUBA)-Eligible Patients: a Multicenter Study	Stroke	64	16.0
95th	Chen *et al.*, 2014	Seizure outcomes following radiosurgery for cerebral arteriovenous malformations	Neurosurgical Focus	64	10.7
96th	Chandler *et al.*, 1993	Successful radiosurgical treatment of a dural arteriovenous malformation: case report	Neurosurgery	64	2.4
97th	Hung-Chuan, *et al.*, 2005	Late cyst formation following gamma knife surgery of arteriovenous malformations	Journal of Neurosurgery	63	4.2
98th	Massager *et al.*, 2000	Gamma knife radiosurgery for brainstem arteriovenous malformations: preliminary results	Journal of Neurosurgery	63	3.2
99th	Meder *et al.*, 1997	Cerebral arteriovenous malformations: the value of radiologic parameters in predicting response to radiosurgery	American Journal of Neuroradiology	63	2.7
100th	Altschuler *et al.*, 1989	Gamma knife radiosurgery for intracranial arteriovenous malformations in childhood and adolescence	Pediatric Neuroscience	63	2.0

AVM: Arteriovenous malformation, CC: Citation count, CY: Citation per year, LINAC: Linear accelerator

Approximately one-third of publications were produced between 1995 and 2000. The Top-100 articles have accumulated 11,456 citations and the rate of self-citation accounted for 12.12%. The average CY for all papers was seven. The most-studied entity was pertinent to the clinical application of Gamma knife radiosurgery in AVM (68%) [Figure 2]. The United States was the most active country in studying the radiosurgical application in AVM [Figure 3].

The University of Pittsburgh was the most prolific by producing 46 articles in the list [Figure 4]. The Journal of Neurosurgery (JNS) published approximately one-third of the most-cited articles in the list [Figure 5]. Examination of authors showed that Lunsford *et al.* were the top-3 most contributing authors by being involved in 80% of articles in the list with comparable contribution volume [Figure 6].

The top-most cited article based on the citation count was authored by Lunsford *et al.*, published in 1991 by JNS as "Stereotactic radiosurgery for AVMs of the brain," to which it collected 520 citations over the years and was ranked the 2nd most-cited based on the citation per year.

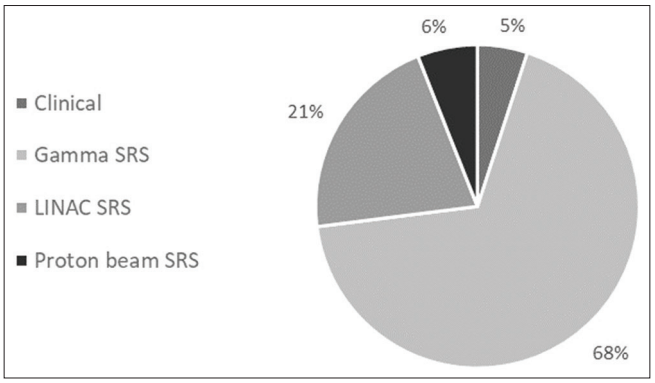

Figure 2: Categorical distribution of the radiosurgical management of arteriovenous malformation in the top-100 cited articles.

The top most cited articles based on the citation per year was authored by Starke *et al.*, published in 2013 by the *JNS* entitled "A practical grading scale for predicting outcome

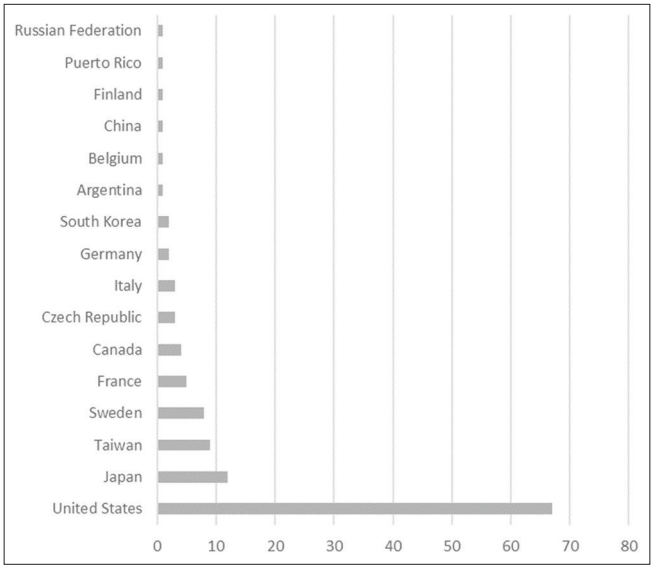

Figure 3: Countries publishing articles on the radiosurgical management of arteriovenous malformation in the top-100 cited articles.

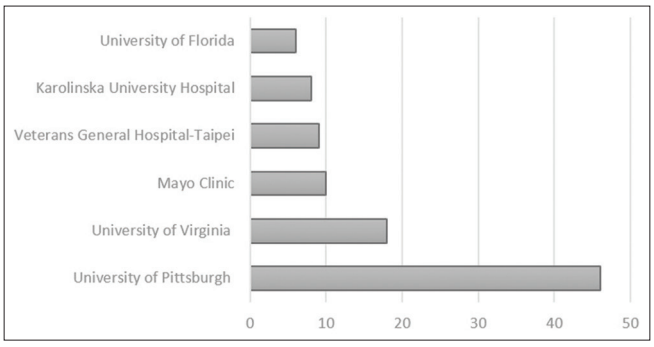

Figure 4: Affiliated institutions contributing to the highest cited articles on the radiosurgical management of arteriovenous malformation.

after radiosurgery for AVMs: analysis of 1012 treated patients" in which it had 20.6 CY and has accumulated 144 citation count over the year.

DISCUSSION

Articles addressing the radiosurgical management of AVMs evolved throughout the decades. Publications commenced by targeting the utilization of stereotactic radiosurgery using Gamma knife in the early 1970s. In the 1980s, as a result of the development and advancement of neuroimaging and proton/photon radiation technology, the publication trends shifted toward proton beam and linear accelerator (LINAC) radiosurgery. In addition, the earliest detailed reports on the utilization of proton beam radiosurgery for AVM with the longest follow-up period were published. In the top-100 list, most articles peaked in the publication in the 1990s,

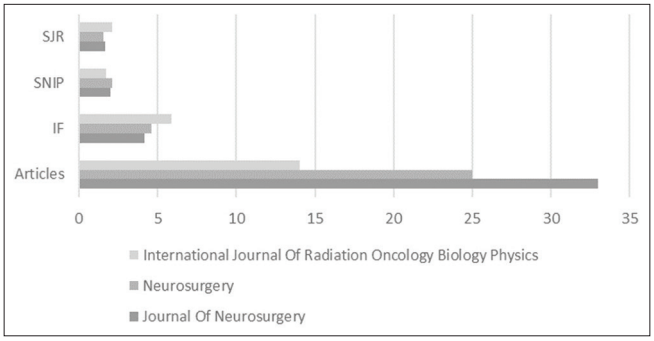

Figure 5: The top journals publishing articles on the radiosurgical management of arteriovenous malformation and their corresponding impact factor, Journal's Source Normalized Impact per Paper, Journal's SCImago Journal Rank.

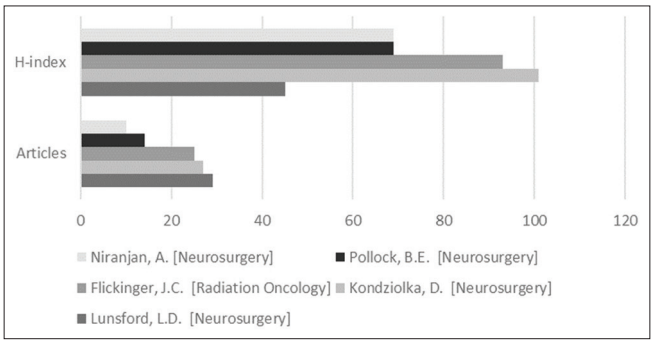

Figure 6: Reputable authors publishing articles on the radiosurgical management of arteriovenous malformation.

comprising 45% of all articles. Those articles were targeting all aspects of the radiosurgical management of AVM including the clinical outcome, Gamma knife, LINAC, and proton beam radiosurgery. In the 21st century, the majority of publications were highlighting the dose-response and clinical outcome predictions, comprising approximately half of the articles in the top-100 list.

The article ranking first in the top-100 list was published in 1991 by Lunsford *et al.* titled "Stereotactic radiosurgery for arteriovenous malformations of the brain" which received a total of 520 CC and 17.9 CY.[15] The authors investigated 227 patients who underwent stereotactic radiosurgery for cerebral AVM.[15] Their 3-year experience demonstrated that radiosurgery is an important technique for AVM obliteration, especially lesions previously rendered inoperable.[15] The success rate and risks of complications were dependent on location and volume of the AVM.[15]

A year later, the second highest cited article was published by Steiner *et al.* titled "Clinical outcome of radiosurgery for cerebral arteriovenous malformations" to which it received 459 CC and 16.4 CY.[21] The authors described the long-term neurological outcomes for 247 consecutive patients with AVM treated with Gamma knife.[21] In their cohort,

radiosurgery has proven to obliterate AVMs as evident by angiography, with few side effects. They suggested that complete protection against rebleeding in AVM occurs only after total obliteration of the lesion.[21]

Gamma knife radiosurgery

Articles predominantly discussing the application of gamma knife radiosurgery peaked in terms of publication from 1972 to 2016. Operable and non-operable AVMs, deep-seated lesions, staging, and the risk of hemorrhage were the areas of interest to authors investigating the radiosurgical aspect of AVM. Gamma knife radiosurgery populated the majority of publications in the top 100 most cited articles on the radiosurgical management of AVM, comprising around two thirds of the articles. In the category of gamma knife radiosurgery, the first utilization of radiosurgery in obliterating AVM was discussed in the literature. Gobin *et al*. published an article (ranked 4th) titled "Treatment of brain AVMs by embolization and radiosurgery" to which it received 299 CC and 12.5 CY.[11] The authors investigated a cohort of 125 patients who underwent embolization before radiosurgery.[11] The patients were included in the study as they were either refusing surgery or were labeled poor surgical candidates.[11] They concluded that embolization before radiosurgery serves to facilitate irradiation of large-sized AVMs.[11] In addition, they demonstrated that the hemorrhagic risk of the residual nidus is similar to the natural history of AVMs of the same size.[11] Pollock *et al*. published an article (ranked 6th) titled "Factors associated with successful arteriovenous malformation radiosurgery" to which it received 271 CC and 12.3 CY.[17] The authors proposed a new method to report the clinical outcome of radiosurgery in AVM.[17] It comprised the incorporation of the postoperative neurological deficits and angiographic obliteration results of the AVM. Their multivariate analysis proved that younger age, location, AVM volume, and the number of draining veins were associated with a better obliteration rate after radiosurgical treatment in AVMs.[17]

LINAC radiosurgery

Articles in addressing LINAC radiosurgery had a publication peak between 1989 and 2007. Around one-fifth of the articles in the top-100 most cited publications on the radiosurgical management of AVM were investigating the usage of LINAC radiosurgery. In addition, the earliest reports on the usage of LINAC radiosurgery were published in the late 80s. Around 61% of articles addressing LINAC radiosurgery peaked in publication in the 90s. In the early years of the 21st century, articles have carried out what has been previously published in the literature, with a relatively larger number of cohorts. Colombo *et al*. published an article (ranked 5th) titled "Linear accelerator radiosurgery of cerebral AVMs: an update" to which it received 281 CC and 10.8 CY.[14] The authors aimed to report the risk of bleeding and evaluate their clinical experience in 153 patients with irradiated AVMs.[14] In patients with totally-radiated AVMs, the risk of bleeding decreased from 4.8% to 0% after radiosurgery.[14] In contrast, the risk of bleeding in partially-radiated AVMs increased from 4% to 10%.[14] Friedman *et al*. published an article (ranked 8th) titled "Linear accelerator radiosurgery for arteriovenous malformations: the relationship of size to outcome" to which it received 247 CC and 9.9 CY.[10] The authors investigated the association between the size of AVM and clinical outcome in a cohort of 158 patients.[10] Their study findings demonstrated that AVMs of volumes larger than 10 cc could be successfully managed using LINAC radiosurgery.[10]

Proton beam radiosurgery

In the "proton beam radiosurgery" entity, articles peaked in the publication from 1983 to 1990. During this period, the earliest, most detailed, and longest follow-up data on the application of proton beam radiosurgery were published. In addition, authors discussed the technicality of proton beam radiosurgery, treatment protocols, and the approach to the selection criteria of patients who were rendered fit to undergo such therapy. Kjellberg *et al*. published an article (ranked 3rd) titled "Bragg-Peak Proton-Beam Therapy for Arteriovenous Malformations of the Brain" to which it received 388 CC ad 10.5 CY.[13] The authors investigated the outcome of such a treatment option in patients with AVM.[13] They concluded that proton beam radiosurgery appears to be a useful and alternative treatment of choice for patients harboring cranial AVMs not suitable to other treatment modalities.[13] Steinberg *et al*. published an article (ranked 13th) titled "Stereotactic heavy-charged-particle bragg-peak radiation for intracranial arteriovenous malformations" to which it received 224 CC and 7.5 CY.[20] The authors presented their experience in terms of the clinical and radiological outcome in a cohort of 86 patients with inaccessible AVMs, and they concluded that heavy-charged particles proved to be effective treatment for inaccessible AVM.[20] However, they highlighted two disadvantages of that time technique; small risk of neurological complications and the long time interval of complete obliteration.[20]

Clinical articles

Articles addressing the clinical entity of the radiosurgical management of AVM were published between 1990 and 2014. During the specified period, articles predominantly investigated predictors of successful obliteration of AVM utilizing radiosurgery. Furthermore, articles comprehensively investigated and compared dose-staged versus volume-staged radiosurgical treatment of AVM in terms of outcome and

complications. Friedman *et al*. published an article (ranked 34th) titled "Analysis of factors predictive of success or complications in arteriovenous malformation radiosurgery" with 122 CC and 7.2 CY.[9] The authors reviewed the clinical and radiological data in 269 consecutive patients.[9] Their multivariate analysis proved that eloquent location of AVMs and 12-Gy volume was associated with radiation-induced sequelae in radiosurgery.[9] However, radiological success was associated with a lower grade (Spetzler-Martin) and steeper/higher dose gradients.[9] Steinberg *et al*. published an article (ranked 49th) titled "Surgical resection of large incompletely treated intracranial arteriovenous malformations following stereotactic radiosurgery" with 122 CC and 7.2 CY.[19] They concluded that adjunct pretreatment with radiosurgery, few years before open surgery, serves to treat large-sized AVMs.[19]

The present bibliometric analysis on the radiosurgical management of AVM highlights the following clinical key aspects to practitioners in the field: (1) radiosurgery remains an important technique in managing patients with inoperable AVMs. (2) Complete obliteration of the lesion can be achieved by radiosurgery. (3) The obliteration rate of AVM following radiosurgery can be predicted by several factors including; age, location, volume, and the number of draining veins. (4) Prior embolization of the lesion facilitates the radiosurgical management of large-sized AVMs. (5) LINAC radiosurgery can successfully treat AVMs of relatively larger volumes (>10 cc). (6) Proton beam radiosurgery, in the form of heavy-charged particles, can be utilized to treat inaccessible AVMs. (7) Radiosurgery, before microsurgical resection, may be of use to treat large-sized and complex AVMs.

Limitations

In the current bibliometric analysis, few obstacles need to be acknowledged which may limit the generalizability of the findings. First, the rate of self-citations was encountered in more than one-tenth of the articles. Therefore, self-citations might falsely increase the CC for all published articles. However, this might be caused by the small society of radiosurgery and the limited number of institutions performing such advanced technology early in the history of radiation treatment (1970s). Second, a title-based search in a keyword-fashion might miss some articles published in the literature, and hence, not included in the analysis. Third, as the CC was considered to rank the articles in a descending order, older articles were likely to accumulate a higher number of citations throughout the years. However, the CY was calculated for all articles to balance this limitation. Fourth, only one database was utilized to conduct this bibliometric analysis. Fifth, due to the time; the relatively newer technology (i.e., CyberKnife) did not appear in our list. However, we expect an increasing number of publications relevant to this topic in the near future. Although bibliometric analyses assess the intellectual scholarly work from a quantitative perspective, the present study identified key and influential articles within this relatively growing field in the management of AVM.

CONCLUSION

The radiosurgical management of AVMs evolved significantly throughout the years. Articles addressing the application of Gamma knife radiosurgery were the most frequently published category by neurosurgeons in the field. The top-two most cited articles in the list were both published in the JNS. Identifications of the publication trends serves as a benchmark for gaining evidence-based knowledge for authors investigating various radiosurgical techniques in AVMs.

Declaration of patient consent

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Conflicts of interest

There are no conflicts of interest.

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