Citation Measures in Stereotactic Radiosurgery: Publication across a Discipline

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Key Words

Stereotactic radiosurgery • Citations • Publications • Research

Abstract

Objective: It is possible to judge the impact of scientific research by the number of citations a publication has received. We identified the most cited works in the field of stereotactic radiosurgery to study the evolution of this field from the perspective of publication. **Methods:** A Web of Science search was performed for articles that included the word 'radiosurgery' in the title. We studied the reports with >100 citations. **Results:** A total of 5,532 published works were available for study between 1951 and 2010. Eighty-five articles had ≥100 citations, and these were published in 19 separate journals. The majority were published in the *International Journal of Radiation Oncology, Biology and Physics*, the *Journal of Neurosurgery* and *Neurosurgery*. The most common topics included brain metastasis management (n = 20), arteriovenous malformations (n = 17), vestibular schwannomas (n = 9), technologies (n = 9), meningiomas (n = 8) and dose response/radiobiology (n = 6). Fifty-seven percent of the articles were published in the last 10 years. **Conclusions:** The first radiosurgery report by Leksell (1951) initiated the field. The 1980s were a period of new technology development followed in

the 1990s by introductory articles on specific indications that consisted mainly of retrospective case series. More sophisticated higher level evidence reports were published in the last decade. The most significant works in radiosurgery include initial technology descriptions, multicenter studies with large numbers of patients, randomized clinical trials and reports that provide dose prescription guidelines.

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Introduction

Stereotactic radiosurgery has a history spanning 60 years but with increasing use and rapid growth of indications over the last 30. An analysis of published reports over these decades provides insight into what kinds of research have had the most impact and have fostered the scientific direction of the field. The hypothesis was that through an analysis of publication trends and citation evaluations, one could gain a better understanding of the evolution of and valuation of the discipline. This study describes the most highly cited articles in the field of stereotactic radiosurgery. Other similar reports related to Parkinson's disease and neurosurgery in general provided the impetus for this study [1–3].

Methods

A search was performed on the ISI Web of Science Bibliometric Database for articles that included the key word 'radiosurgery' in the title. This search was performed on June 22, 2010, and included all the articles tracked by that database. The search provided 5,532 articles published between 1951 and 2010. The vast majority of these reports were scientific articles (49%) but also included documents related to meetings (35%), abstracts (20%), editorials (10%), review articles (3.7%), letters (2.9%), books (2.3%), case reports (0.94%) and clinical trials (0.38%). Analysis was restricted to those having received ≥ 100 citations. The concept of a 'citation classic' has been noted by others [4], typically associated with >400 citations. However, this applied to only 1 article in the field. For this reason, the analysis was conducted on articles with >100 citations. In this report, numbers in parentheses indicate the rank of the article in order of number of citations (table 1).

Results

One article met the criteria for a 'citation classic' with >400 citations. This was the original article by Lars Leksell, 'The stereotaxic method and radiosurgery of the brain' (Acta Chir Scand 1951;102:316–319). This report had 614 citations. This report from 1951 coined the term 'radiosurgery' and is the first article listed. Interestingly, the second article published with the word 'radiosurgery' in the title was by Gros et al. in 1954, entitled 'Radiosurgery of ovarian cancer,' published in *J Radiol Electrol Arch Elect Medica*. There are only 6 articles with >300 citations, 13 with >200 and 85 with ≥ 100 . The 6 with >300 citations are on the topic of brain metastases (table 1 listings 2, 5, 6), whereas the others are on arteriovenous malformations (table 1 listings 3, 4). Two of the brain metastasis articles with 371 and 311 citations were 1994 and 1995 retrospective series published by the University of Pittsburgh and Harvard University Joint Center, respectively. The 2004 Radiation Therapy Oncology Group randomized trial published in *Lancet* has 310 citations and, due to its more recent publication, might be considered to be the most important article on brain metastasis radiosurgery.

Clinical Topics

Technology Assessments

Nine reports describe radiosurgical systems: modified linear accelerator radiosurgery (n = 4), CyberKnife (n = 2), Gamma Knife (n = 1) and other (n = 2). Most of these works are from the 1980s and 1990s.

Clinical Indications

Sixty-six of the 85 articles dealt with clinical indications such as metastases (n = 20), arteriovenous malformations (n = 17), acoustic neuromas (n = 9), meningiomas (n = 8), trigeminal neuralgia (n = 5), gliomas (n = 2), spinal radiosurgery (n = 2), pain management (n = 1), cavernous malformations (n = 1) and lung cancer (n = 1).

Physics and Radiobiology

Six reports studied the dose-response relationship for brain and cranial nerve tolerance for the radiobiology of a normal brain or brain-tumor responses. Four articles describe physics testing related to specific radiosurgical devices or methods for quality assurance and maintenance of the devices.

Journals

The most frequent journals used to publish radiosurgical articles included the major journals of the neurosurgery or radiation oncology communities. The *International Journal of Radiation Oncology, Biology and Physics* had 23 of the top 85 articles. The *Journal of Neurosurgery* similarly had 23 articles, and *Neurosurgery* had 18. Important works related to brain metastasis management were published in the *Journal of Clinical Oncology* (n = 4) and *Cancer* (n = 2). Initial reports by Lars Leksell on the radiosurgical method were published in *Acta Chirurgica Scandinavica*. Other journals with 1 report each covered a spectrum of different topics. These included the *New England Journal of Medicine*, *Lancet*, *Journal of the National Cancer Institute*, *Journal of Neurology*, *Neurosurgery*, and *Psychiatry*, *JAMA*, *Surgical Neurology*, *Stereotactic and Functional Neurosurgery*, *The British Journal of Radiology*, *Radiotherapy Oncology*, *Neurology*, and also *Thoracic Surgery*, *Acta Neurochirurgica*, and *Physics in Medicine and Biology*.

Articles in general interest high-impact journals, such as the *New England Journal of Medicine* and *Lancet*, included a long-term assessment of acoustic neuroma radiosurgery (table 1 listing 9) and the brain metastasis randomized trial from the Radiation Therapy Oncology Group (table 1 listing 5).

Years of Publication

After the first article had been published in 1951, the first 3 decades of the radiosurgical era were associated with only a small number of reports. Only 2 papers were published in the years 1959, 1963, 1971, 1972, 1973 and 1984. Three each were published in 1967 and 1978, and 4 were published in 1983. At this time only a handful of institutions performed radiosurgery, typically centers that had developed their own technology. The annual number of reports doubled from 7 to 16 in 1987. Rapid publication growth in the field then began in 1989 (n = 41), 1990 (n = 62), 1991 (n = 89), 1992 (n = 114), 1993 (n = 125) and 1994 (n = 155). By 1996, 279 articles were published and by 2000, 330. In the last decade alone, 3,132 articles were published, representing 57% of the total. Thus, the mean number of articles published annually in the 1980s was 9.6, during the 1990s it was 178, and during the 2000s it was 313.

Institutions

Of the 85 reports with >100 citations, 29 were published from the University of Pittsburgh. Other centers in the USA included the Harvard Joint Center (n = 12), University of Florida (n = 4), Stanford University (n = 5) and the University of California at San Francisco (n = 4). Authors from the Karolinska Institute in Stockholm published 5 of these articles. Centers with 2 articles included the University of Wisconsin, Thomas Jefferson University, Vicenza and Henry Ford Hospital (Detroit). The University of Virginia, Mayo Clinic, Montreal Neurological Institute, Northwest Hospital (Seattle), University of California at Berkeley, Tokyo Women's University, University of Munich, Royal Adelaide Hospital, Columbia University, MD Anderson Cancer Center, Hôpital Lariboisière (Paris), Hokkaido University, the University of Heidelberg, and centers in Zurich and Buenos Aires published 1 article each.

Discussion

Stereotactic radiosurgery is a field that impacts on a broad array of topics in neurosurgery, radiation oncology and medical physics. Radiosurgery has had an impact in the management of disorders related to vascular malformations, benign and malignant brain tumors, movement disorders, pain management and psychiatric disease. As a technology-driven field, physics reports and radiobiological

studies serve as the foundation for clinical use. Although conceived and initially developed in the 1950s and 1960s, radiosurgery was a field ahead of its time. Not until high-resolution intraparenchymal imaging with magnetic resonant techniques was available, did radiosurgery truly impact upon high numbers of patients followed by installations at centers in many countries. Indeed radiosurgical practice was limited initially to high-volume academic centers and now is present in many community-based hospitals.

The Most Cited Reports

Our analysis of reports with >100 citations noted that only 1 met the criteria of a citation classic with >400, that being the report that described the radiosurgical method. Five other articles with >300 citations include 3 on the topic of brain metastases and 2 on arteriovenous malformations. The balance between contributions from neurosurgery and radiation oncology is reflected by a similar 23 reports in both the *International Journal of Radiation Oncology, Biology and Physics* and the *Journal of Neurosurgery*. There have been an additional 18 articles that were published in *Neurosurgery* and 6 more in oncology journals. There does remain a significant balance between reports that were submitted and published in these different disciplines.

The Evolution of Radiosurgery Publications

As noted, radiosurgery did not gain much attraction until the late 1980s with general clinical use supported by high-resolution imaging being performed. A significant jump between the mean number of annual articles in the 1980s (9.6) and the 1990s (178) can be explained by several factors. First, the use of imaging allowed a wider number of indications to be evaluated and published (including brain metastasis, meningiomas, pituitary tumors and functional indications); second, the availability of commercially manufactured radiosurgical systems rather than home-grown devices meant that more institutions could purchase radiosurgical systems. Prior to the late 1980s, the manufacturer of the Leksell Gamma Knife had only limited capability to develop their radiosurgical system, and available modified linear accelerator platforms were all built at individual institutions. It was not until the 1990s that commercially available stereotactic LINAC radiosurgical devices were more widely available.

Prior to 1995, formal training in radiosurgical techniques usually consisted of a fellowship which was not widely available to practicing physicians. Dedicated training courses allowed surgeons, radiation oncologists

and medical physicists to learn the nuances of their radiosurgical device and meet institutional requirements before beginning patient care.

Study Limitations

It is difficult for more recent articles, despite their more significant contribution to science, to amass a critical number of citations and be included in this list. However, the 2004 Radiation Therapy Oncology Group randomized trial in *Lancet* with 310 citations helped to substantiate the role of radiosurgery in brain metastasis management and despite the shorter time to collect citations, it already has a place in the top 5. The lack of other more recent articles with a large number of citations may indicate that there have been no reports with similar significant impact during this most recent decade. It will be interesting to track the citations of the recently published guidelines for brain metastasis management in the *Journal of Neuro-Oncology* (2009).

A topic search to identify articles and citations can be conducted in numerous ways. In this report a search was conducted using the term 'radiosurgery'. To test the reliability of this choice, a separate search was conducted using 'gamma knife surgery', which yielded 433 articles, only 2 with >100 citations. One was No. 105 in table 1, and only 1 separate report with 120 citations (Karlsson et al.: Prediction of obliteration after gamma knife surgery for cerebral arteriovenous malformations. *Neurosurgery* 1997;40: 425–430) was found. An additional search on the term 'gamma knife' yielded 2,125 articles, 9 with >100 citations, of which 7 were identified in the original search. The 2 missed reports include the Karlsson article noted above and a report on vascular malformation histopathology.

Finally, it is worthwhile to comment on the wide variety of journals that contain the top 85 articles with >100 citations. As noted, these include neurosurgical, radiation oncology, neurology, physics, oncology and journals of general interest. Some authors have called for a specific journal on the topic of stereotactic radiosurgery. Over a decade ago, the *Journal of Radiosurgery* was created but failed due to lack of submissions and other factors. Another publication, *Radiosurgery*, is the official journal of the International Stereotactic Radiosurgery Society and is published every 2 years with the top peer-reviewed science submitted to the meeting of the International Stereotactic Radiosurgery Society. It is not published often enough for most authors to submit their most important works. The existing array of journals appears to be adequate for radiosurgery articles, each providing their own unique readership but with broad international access.

Table 1. Radiosurgery articles with >100 citations, ranked in order of citations received

Cita- tions	Reference
614	Leksell, L. (1951). The Stereotaxic method and radiosurgery of the brain. <i>Acta Chirurgica Scandinavica</i> , 102(4), 316–319.
372	Flickinger, J.C., Kondziolka, D., Lunsford, L.D., Coffey, R.J., Goodman, M.L., Shaw, E.G., et al. (1994). A multiinstitutional experience with stereotaxic radiosurgery for solitary brain metastasis. <i>International Journal of Radiation Oncology Biology Physics</i> , 28(4), 797–802.
354	Lunsford, L.D., Kondziolka, D., Flickinger, J.C., Bissonette, D.J., Jungreis, C.A., Maitz, A.H., et al. (1991). Stereotaxic radiosurgery for arteriovenous-malformations of the brain. <i>Journal of Neurosurgery</i> , 75(4), 512–524.
322	Steiner, L., Lindquist, C., Adler, J.R., Torner, J.C., Alves, W., Steiner, M. (1992). Clinical outcome of radiosurgery for cerebral arteriovenous-malformations. <i>Journal of Neurosurgery</i> , 77(1), 1–8.
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312	Alexander, E., Moriarty, T.M., Davis, R.B., Wen, P.Y., Fine, H.A., Black, P.M., et al. (1995). Stereotaxic radiosurgery for the definitive, noninvasive treatment of brain metastases. <i>Journal of the National Cancer Institute</i> , 87(1), 34–40.
292	Lutz, W., Winston, K.R., Maleki, N. (1988). A system for stereotactic radiosurgery with a linear-accelerator. <i>International Journal of Radiation Oncology Biology Physics</i> , 14(2), 373–381.
278	Kondziolka, D., Patel, A., Lunsford, L.D., Kassam, A., Flickinger, J.C. (1999). Stereotactic radiosurgery plus whole brain radiotherapy versus radiotherapy alone for patients with multiple brain metastases. <i>International Journal of Radiation Oncology Biology Physics</i> , 45(2), 427–434.
277	Kondziolka, D., Lunsford, L.D., McLaughlin, M.R., Flickinger, J.C. (1998). Long-term outcomes after radiosurgery for acoustic neuromas. <i>New England Journal of Medicine</i> , 339(20), 1426–1433.
268	Auchter, R.M., Lamond, J.P., Alexander, E., Buatti, J.M., Chappell, R., Friedman, W.A., et al. (1996). A multiinstitutional outcome and prognostic factor analysis of radiosurgery for resectable single brain metastasis. <i>International Journal of Radiation Oncology Biology Physics</i> , 35(1), 27–35.
217	Colombo, F., Pozza, F., Chierago, G., Casentini, L., Deluca, G., Francescon, P., et al. (1994). Linear-accelerator radiosurgery of cerebral arteriovenous-malformations – an update. <i>Neurosurgery</i> , 34(1), 14–21.
212	Betti, O.O., Munari, C., Rosler, R. (1989). Stereotactic radiosurgery with the linear-accelerator – treatment of arteriovenous-malformations. <i>Neurosurgery</i> , 24(3), 311–321.
203	Leksell, L. (1983). Stereotactic radiosurgery. <i>Journal of Neurology Neurosurgery and Psychiatry</i> , 46(9), 797–803.
191	Kondziolka, D., Lunsford, L.D., Flickinger, J.C., Young, R.F., Vermeulen, S., Duma, C.M., et al. (1996). Stereotactic radiosurgery for trigeminal neuralgia: a multiinstitutional study using the gamma unit. <i>Journal of Neurosurgery</i> , 84(6), 940–945.
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183	Duma, C.M., Lunsford, L.D., Kondziolka, D., Harsh, G.R., Flickinger, J.C., Larson, D.A., et al. (1993). Stereotaxic radiosurgery of cavernous sinus meningiomas as an addition or alternative to microsurgery. <i>Neurosurgery</i> , 32(5), 699–705.

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177	Mehta, M.P., Rozental, J.M., Levin, A.B., Mackie, T.R., Kubsad, S.S., Gehring, M.A., et al. (1992). Defining the role of radiosurgery in the management of brain metastases. <i>International Journal of Radiation Oncology Biology Physics</i> , 24(4), 619–625.
176	Kondziolka, D., Lunsford, L.D., Coffey, R.J., Flickinger, J.C. (1991). Stereotaxic radiosurgery of meningiomas. <i>Journal of Neurosurgery</i> , 74(4), 552–559.
176	Flickinger, J.C. (1989). An Integrated logistic formula for prediction of complications from radiosurgery. <i>International Journal of Radiation Oncology Biology Physics</i> , 17(4), 879–885.
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173	Sneed, P.K., Suh, J.H., Goetsch, S.J., Sanghavi, S.N., Chappell, R., Buatti, J.M., et al. (2002). A multi-institutional review of radiosurgery alone vs. radiosurgery with whole brain radiotherapy as the initial management of brain metastases. <i>International Journal of Radiation Oncology Biology Physics</i> , 53(3), 519–526.
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