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# Precision radiotherapy for brain tumors

## *A 10-year bibliometric analysis*☆

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### Abstract

**OBJECTIVE:** Precision radiotherapy plays an important role in the management of brain tumors. This study aimed to identify global research trends in precision radiotherapy for brain tumors using a bibliometric analysis of the Web of Science.

**DATA RETRIEVAL:** We performed a bibliometric analysis of data retrievals for precision radiotherapy for brain tumors containing the key words cerebral tumor, brain tumor, intensity-modulated radiotherapy, stereotactic body radiation therapy, stereotactic ablative radiotherapy, imaging-guided radiotherapy, dose-guided radiotherapy, stereotactic brachytherapy, and stereotactic radiotherapy using the Web of Science.

**SELECTION CRITERIA:** Inclusion criteria: (a) peer-reviewed articles on precision radiotherapy for brain tumors which were published and indexed in the Web of Science; (b) type of articles: original research articles and reviews; (c) year of publication: 2002–2011. Exclusion criteria: (a) articles that required manual searching or telephone access; (b) Corrected papers or book chapters.

**MAIN OUTCOME MEASURES:** (1) Annual publication output; (2) distribution according to country; (3) distribution according to institution; (4) top cited publications; (5) distribution according to journals; and (6) comparison of study results on precision radiotherapy for brain tumors.

**RESULTS:** The stereotactic radiotherapy, intensity-modulated radiotherapy, and imaging-guided radiotherapy are three major methods of precision radiotherapy for brain tumors. There were 260 research articles addressing precision radiotherapy for brain tumors found within the Web of Science. The USA published the most papers on precision radiotherapy for brain tumors, followed by Germany and France. European Synchrotron Radiation Facility, German Cancer Research Center and Heidelberg University were the most prolific research institutes for publications on precision radiotherapy for brain tumors. Among the top 13 research institutes publishing in this field, seven are in the USA, three are in Germany, two are in France, and there is one institute in India. Research interests including urology and nephrology, clinical neurology, as well as rehabilitation are involved in precision radiotherapy for brain tumors studies.

**CONCLUSION:** Precision radiotherapy for brain tumors remains a highly active area of research and development.

### Key Words

Cerebral tumor; brain tumor; intensity-modulated radiotherapy; stereotactic body radiation therapy; stereotactic ablative radiotherapy; imaging-guided radiotherapy; dose-guided radiotherapy; stereotactic brachytherapy; stereotactic radiotherapy

### Research Highlights

(1) We performed a bibliometric analysis of data retrievals for precision radiotherapy for brain tumors from 2002 to 2011 using the Web of Science.
(2) We analyzed the articles by annual publication output, distribution according to country, distribution according to institution, top cited publications, distribution according to journals, and made a comparison of study results on precision radiotherapy for brain tumors.
(3) We found that precision radiotherapy for brain tumors is still an area of active research in the past 10 years and Chinese radiologists should be encouraged to write more high-quality papers to participate in and enlarge academic exchange worldwide.

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## INTRODUCTION

Radiotherapy plays an increasingly dominant role in the comprehensive multidisciplinary management of cancer. About half of all cancer patients will receive radiotherapy either as a part of the initial treatment with curative intent or as palliative treatment. Methods for improving the therapeutic ratio by increasing the radiation dose to the relevant target and /or decreasing the volume of irradiated normal tissue are therefore desirable. Precision radiotherapy refers to the precise delivery of radiation to targeted areas, such as brain tumors, by combined utilization of radiotherapy, computing and physics[1]. It differs from normal radiation regimes in the following four aspects: (1) the delivery of very high radiation doses to targeted tumors; (2) very little normal tissue is exposed to the radiation; (3) the dose homogeneity and conformity index are used to evaluate plan quality; (4) precision localization of the targeted tumor area and radiation delivery. These four aspects should result in an improved therapeutic ratio, namely, that more patients will be cured with fewer side effects. The best examples of high-precision radiotherapy are intensity-modulated radiotherapy (IMRT), stereotactic radiotherapy and imaging-guided radiotherapy (IGRT). Stereotactic radiotherapy is a way of targeting radiotherapy very precisely at the tumor. The stereotactic radiotherapy treatment is usually divided into between 6 and 25 daily doses called fractions[2]. The objective of IGRT is to take into account the inter- and/or intrafraction anatomic variations (organ motion and deformations) in order to improve treatment accuracy. The IGRT enables direct or indirect tumor visualization during radiation delivery and is realized by different types of devices which can vary in principle as well as in their implementation: from linear accelerators with onboard kV or MV-cone beam computed tomography (CBCT), helical tomotherapy, Cyberknife™ and Novalis® with stereoscopic kV X-ray imaging systems[3-4]. These techniques have led to a more rational choice of planning target volume (PTV). Three dimensional conformal radiation therapy (3D-CRT) is a sophisticated irradiation technique which allows a high dose delivered to the tumor while keeping the dose to the adjacent normal tissues below tolerance. This improves cure rates and decreases chances of treatment related complications. In recent years, 3D-CRT has become quite popular and widely available due to recent advancements in computer technology[5].

The diagnosis and management of brain tumors has been confounded by the challenge of determining the extent of the tumor and elucidation of the function of the surrounding brain tissue. F-18 fluorodeoxyglucose (FDG) positron emission tomography (PET) has been evaluated in the planning of radiation with radiosurgery and IMRT with simultaneous integrated boosts[6]. Popperl *et al* [7] evaluated the value of O-(2-[18F]fluoroethyl)-L-tyrosine PET (FET-PET) for the diagnosis of recurrent glioma. In a group of 63 patients with clinically suspected recurrence after initial therapy, FET-PET was positive in all cases. FET-PET reliably distinguished between post-therapeutic benign lesions and tumor recurrence after initial treatment of low- and high-grade gliomas. Chao *et al* [8] have shown that the sensitivity and specificity of FDG-PET was 75% and 81%, respectively.

## DATA SOURCES AND METHODOLOGY

### Data retrieval

In this study, we used bibliometric methods to quantitatively and qualitatively investigate research trends in studies of precision radiotherapy for brain tumors. Web of Science, a research database of publications and citations that are selected and evaluated by the Institute for Scientific Information in Philadelphia, PA, USA, using the key words cerebral tumor, brain tumor, intensity-modulated radiotherapy, stereotactic body radiation therapy, stereotactic ablative radiotherapy, imaging-guided radiotherapy, dose-guided radiotherapy, stereotactic brachytherapy, and stereotactic radiotherapy. We have limited the period of publication from 2002 to 2011, found 260 results, and downloaded the data on June 02, 2012.

### Inclusion criteria

(a) Peer-reviewed articles on precision radiotherapy for brain tumors which were published and indexed in the Web of Science; (b) type of articles: original research articles and reviews; (c) year of publication: 2002–2011.

### Exclusion criteria

(a) Articles that required manual searching or telephone access; (b) we excluded a number of corrected papers or book chapters from the total number of articles.

The searching results were analyzed by (1) annual publication output; (2) distribution according to country; (3) distribution according to institution; (4) top cited publications; (5) distribution according to journals; and (6) comparison of study results on precision radiotherapy for brain tumors.

## RESULTS

### Search results of publications addressing precision radiotherapy for brain tumors from 2002 to 2011

(Table 1)

Table 1 Number of publications addressing precision radiotherapy for brain tumors included in the Web of Science from 2002 to 2011

| Query formulation | Number of publications |
|---|---|
| ts=("cerebral tumor*" or "brain tumor*") and ts=(intensity-modulated radiotherapy or "IMRT" or stereotactic body radiation therapy or “SBRT” or stereotactic ablative radiotherapy or “SABR” or imaging-guided radiotherapy or "IGRT" or dose-guided radiotherapy or "DGRT" or "Stereotactic brachytherapy" or "stereotactic radiotherapy") | 276 |
| ts=("cerebral tumor*" or "brain tumor*") and ts=(Stereotactic brachytherapy or stereotactic radiotherapy) | 109 |
| ts=("cerebral tumor*" or "brain tumor*") and ts=(“intensity-modulated radiotherapy” or "IMRT") | 80 |
| ts=("cerebral tumor*" or "brain tumor*") and ts=(imaging-guided radiotherapy or "IGRT") | 29 |

**Annual publication output of precision radiotherapy for brain tumors from 2002 to 2011** (Figure 1)

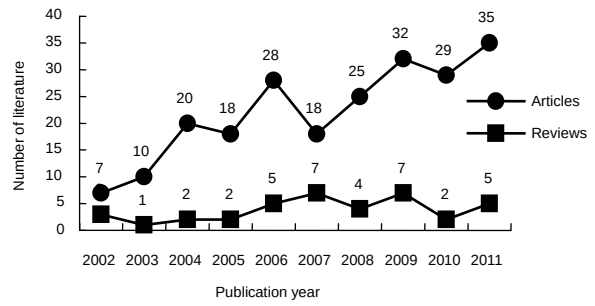


Figure 1 Annual number of publications on precision radiotherapy for brain tumors in the Web of Science from 2002 to 2011.

There were 260 publications on precision radiotherapy for brain tumors in the Web of Science from 2002 to 2011, including 222 articles and 38 reviews. The number of publications on precision radiotherapy for brain tumors has gradually increased over the past 10 years. However, there was a slight decrease in the number of papers published in 2005 and 2007.

**Publication distribution of countries and institutes based on precision radiotherapy for brain tumors from 2002 to 2011** (Tables 2, 3)

The contribution analysis of different countries for publications was based on journal articles in which the address and affiliation of at least one author were provided. The total number of articles analyzed by country and institute publications was 260.

From Table 2, it can be seen that the USA published the most papers on precision radiotherapy for brain tumors. Germany published 51 papers that accounted for 19.62% of the total, which was much higher than the number of publications by other countries. France ranked third with 22 papers that accounted for 8.46%.

Table 2 Top nine countries in terms of number of studies on precision radiotherapy for brain tumors included in the Web of Science from 2002 to 2011

| Country | Number of publications | % of total publications |
|---|---|---|
| USA | 117 | 45.00 |
| Germany | 51 | 19.62 |
| France | 22 | 8.46 |
| Japan | 12 | 4.62 |
| UK | 10 | 3.85 |
| Italy | 18 | 6.92 |
| Canada | 11 | 4.23 |
| Switzerland | 8 | 3.08 |
| India | 8 | 3.08 |

Table 3 Top 13 institutions publishing studies on precision radiotherapy for brain tumors in the Web of Science from 2002 to 2011

| Institution | Number of publications | % of total publications |
|---|---|---|
| European Synchrotron Radiation Facility | 13 | 5.00 |
| German Cancer Research Center | 10 | 4.07 |
| Heidelberg University | 8 | 3.25 |
| Ohio State University | 7 | 2.85 |
| University of Grenoble | 7 | 2.85 |
| Baylor College of Medicine | 6 | 2.44 |
| Emory University | 6 | 2.44 |
| Harvard University | 6 | 2.44 |
| Massachusetts General Hospital | 6 | 2.44 |
| Memorial Sloan-Kettering Cancer Center | 6 | 2.44 |
| St. Jude Children's Research Hospital | 6 | 2.44 |
| Tata Memorial Hospital | 6 | 2.44 |
| Technical University of Munich | 6 | 2.44 |

European Synchrotron Radiation Facility, German Cancer Research Center and Heidelberg University were the most prolific research institutes for publications on precision radiotherapy for brain tumors. Among the top 13 research institutes publishing in this field, seven are in the USA, three are in Germany, two are in France, and there is one institute in India.

The most-cited papers from researchers at European Synchrotron Radiation Facility from 2002 to 2011 were: Prolonged survival of Fischer rats bearing F98 glioma after iodine-enhanced synchrotron stereotactic radiotherapy, by Adam *et al* [9], published in *International Journal of Radiation Oncology Biology Physics*, with 42 citations.

Enhanced survival and cure of F98 glioma-bearing rats following intracerebral delivery of carboplatin in combination with photon irradiation, by Rousseau *et al* [10], published in *Clinical Cancer*

*Research*, with 31 citations.
Gadolinium dose enhancement studies in microbeam radiation therapy, by Prezado *et al* [11], published in *Medical Physics*, with 10 citations.
Intracerebral delivery of 5-iodo-2'-deoxyuridine in combination with synchrotron stereotactic radiation for the therapy of the F98 glioma, by Rousseau *et al* [12], published in *Journal of Synchrotron Radiation*, with 10 citations.
The most-cited papers from researchers at Heidelberg University from 2002 to 2011 were:
Differentiation of radiation necrosis from tumor progression using proton magnetic resonance spectroscopy, by Schlemmer *et al* [13], published in *Neuroradiology*, with 59 citations.
Efficacy of fractionated stereotactic reirradiation in recurrent gliomas: long-term results in 172 patients treated in a single institution, by Combs *et al* [14], published in *Journal of Clinical Oncology*, with 51 citations.
PET and SPECT for detection of tumor progression in irradiated low-grade astrocytoma: a receiver-operating-characteristic analysis, by Henze *et al* [15], published in *Journal of Nuclear Medicine*, with 26 citations.
Follow-up gliomas after radiotherapy: 1H MR spectroscopic imaging for increasing diagnostic accuracy, by Lichy *et al* [16], published in *Neuroradiology*, with 16 citations.
The most-cited papers from researchers at Harvard University from 2002 to 2011 were:
Exciting new advances in neuro-oncology: the avenue to a cure for malignant glioma, by Van Meir *et al* [17], published in *CA-A Cancer Journal for Clinicians*, with 107 citations.
Advantage of protons compared to conventional X-ray or IMRT in the treatment of a pediatric patient with medulloblastoma, by St Clair *et al* [18], published in *International Journal of Radiation Oncology Biology Physics*, with 82 citations.
Stereotactic radiotherapy for localized low-grade gliomas in children: final results of a prospective trial, by Marcus *et al* [19], published in *International Journal of Radiation Oncology Biology Physics*, with 36 citations.

**Most cited articles on precision radiotherapy for brain tumors from 2002 to 2011**

According to bibliometric “law”, the main index for evaluating the quality of an article is the amount of citations it garners. Scientometrics has shown that references are considered as “classical references” once an article is cited four or more times[20]. In our analysis, the top 13 citations are listed in Table 4; therefore, they are classical references in the precision radiotherapy for brain tumors field.

Table 4 Articles with more than six citations average per year on precision radiotherapy for brain tumors in the Web of Science from 2002 to 2011

| Title | Publication year | Average citations per year |
|---|---|---|
| Exciting new advances in neuro-oncology the avenue to a cure for malignant glioma[17] | 2010 | 35.67 |
| Relative cerebral blood volume values to differentiate high-grade glioma recurrence from posttreatment radiation effect: direct correlation between image-guided tissue histopathology and Localized dynamic susceptibility-weighted contrast-enhanced perfusion MR imaging measurements[21] | 2009 | 12.75 |
| Survival and failure patterns of high-grade gliomas after three-dimensional conformal radiotherapy[22] | 2002 | 11.00 |
| Advantage of protons compared to conventional X-ray or IMRT in the treatment of a pediatric patient with medulloblastoma[18] | 2004 | 9.11 |
| Proton radiotherapy for childhood ependymoma: Initial clinical outcomes and dose comparisons[23] | 2008 | 8.00 |
| Assessment of various strategies for (18)F-FET PET-guided delineation of target volumes in high-grade glioma patients[24] | 2009 | 8.00 |
| Correlations between magnetic resonance spectroscopy and image-guided histopathology, with special attention to radiation necrosis[25] | 2002 | 7.73 |
| Stereotactic radiotherapy for treatment of cavernous sinus meningiomas[26] | 2004 | 7.44 |
| Fractionated stereotactic conformal radiotherapy following conservative surgery in the control of craniopharyngiomas[27] | 2007 | 7.17 |
| 3D MRSI for resected high-grade gliomas before RT: Tumor extent according to metabolic activity in relation to MRI[28] | 2004 | 6.67 |
| A comparison of volumetric modulated arc therapy and conventional intensity-modulated radiotherapy for frontal and temporal high-grade gliomas[29] | 2010 | 6.67 |
| Efficacy of fractionated stereotactic reirradiation in recurrent gliomas: Long-term results in 172 patients treated in a single institution[14] | 2005 | 6.38 |
| Radiotherapy of malignant gliomas: Comparison of volumetric single arc technique (RapidArc), dynamic intensity-modulated technique and 3D conformal technique[30] | 2009 | 6.25 |

Among the 13 articles with more than six citations per year, the article “Exciting new advances in neuro-oncology the avenue to a cure for malignant glioma[17]”, published in 2010, was on average cited 35.67 times per year, which was more over than any other article.

**Journals that published on precision radiotherapy for brain tumors from 2002 to 2011** (Table 5)

Table 5 Top 11 journals that published studies of precision radiotherapy for brain tumors from 2002 to 2011

| Journal | ISSN | Impact factor | Number of papers |
|---|---|---|---|
| *International Journal of Radiation Oncology Biology Physics* | 0360-3016 | 4.105 | 39 |
| *Medical Physics* | 0094-2405 | 2.830 | 12 |
| *Strahlentherapie und Onkologie* | 0179-7158 | 3.561 | 12 |
| *Journal of Neuro-Oncology* | 0167-594X | 3.214 | 11 |
| *Radiotherapy and Oncology* | 0167-8140 | 5.580 | 11 |
| *Radiation Oncology* | 1748-717X | 2.321 | 9 |
| *Journal of Applied Clinical Medical Physics* | 1526-9914 | 1.291 | 8 |
| *European Journal of Nuclear Medicine and Molecular Imaging* | 1619-7070 | 4.991 | 6 |
| *Cancer Radiotherapie* | 1278-3218 | 1.488 | 5 |
| *Journal of Neurosurgery* | 0022-3085 | 2.965 | 5 |
| *Medical Dosimetry* | 0958-3947 | 1.000 | 5 |

In Table 5, it is evident that most papers on precision radiotherapy for brain tumors appeared in journals with a particular focus on oncology research. *International Journal of Radiation Oncology Biology Physics* published 39 papers that accounted for 15.01% of the total number of publications, which was followed by *Medical Physics* which published 12 papers and accounted for 4.62%.

It is disappointing that there are only five papers published by Chinese authors[31-35] though the precision radiotherapy has been widely applied in the treatment of brain tumors. Accordingly, Chinese radiologists should be encouraged to write more high-quality papers to participate in and enlarge academic exchange worldwide.

**Analysis of intensity-modulated radiotherapy, stereotactic radiotherapy and imaging-guided radiotherapy for brain tumors** (Tables 6–8)

Table 6 Studies on intensity-modulated radiotherapy for brain tumors included in the Web of Science from 2002 to 2011

| Author | Publication year | Method | Result |
|---|---|---|---|
| Piroth *et al* [36] | 2009 | In 16 glioblastoma patients an intensity-modulated radiotherapy technique comprising an integrated boost (IB-IMRT) and a 3D-CRT technique were generated for dosimetric comparison. The integrated boost volume (PTV1) was auto-contoured using a cut-off tumor-to-brain ratio (TBR) of ≥ 1.6 from FET-PET. PTV2 delineation was MRI-based. The total dose was prescribed to 72 and 60 Gy for PTV1 and PTV2, using daily fractions of 2.4 and 2 Gy. | Patients with 3–4 PTV1 subvolumes vs. a single volume revealed a significant decrease in mean dose (67.7 *vs*. 70.6 Gy). From convex to complex shaped PTV1 mean doses decreased from 71.3 Gy to 67.7 Gy. The homogeneity and conformity for PTV1 and PTV2 was significantly improved with IB-IMRT. With the use of IB-IMRT the minimum dose within PTV1 (61.1 *vs*. 57.4 Gy) and PTV2 (51.4 *vs*. 40.9 Gy) increased significantly, and the mean EUD for PTV2 was improved (59.9 *vs*. 55.3 Gy, $P < 0.01$). The EUD for PTV1 was only slightly improved (68.3 *vs*. 67.3 Gy). The EUD for the brain was equal with both planning techniques. |
| Ding *et al* [37] | 2009 | We developed 3 IMRT plans with different multileaf collimators (Novalis m3, Varian MLC-120, and Varian MLC-80) with the same treatment margins, number of beams, and gantry positions as in the 3D-CRT treatment plans. | IMRT significantly improved the target dose homogeneity compared to the 3D-CRT. However, IMRT showed the same radiobiological effect as 3D-CRT. For the brain tumors adjacent to (or partially overlapping with) critical structures, IMRT dramatically spared the volume of the critical structures to be irradiated. In IMRT plans, the smaller collimator leaf width could reduce the volume of critical structures irradiated to the 50% level for those partially overlapping with the brain tumors. |
| Ding *et al* [38] | 2006 | We performed 3D-CRT, DCAT, and IMRT plans for all patients. The margin for the planning target volume (PTV) was 1 mm, and the specific prescription dose was 90% for all plans. | For small tumors (PTV <= 2 $cm^{(3)}$), the three dosimetric parameters had approximate values for both 3D-CRT and DCAT plans. DCAT is suitable for most cases in the treatment of brain tumors. For a small target, 3D-CRT is useful, and IMRT is not recommended. For larger tumors, IMRT is superior to 3D-CRT and very competitive in sparing critical structures, especially for big tumors |
| Chang *et al* [39] | 2008 | Three glioma patients were retrospectively replanned for radiotherapy with additional fMRI information. | Mean dose to the contralateral and ipsilateral PMC was significantly reduced by 66% and 55%, respectively, for I patient. For the other 2 patients, mean dose to contralateral PMC region was lowered by 73% and 69%. In general, IMRT optimization can reduce the RT dose to the PMC regions without compromising the PTV coverage or sparing of other critical organs. It is feasible to incorporate the fMRI information into the RT treatment planning. |
| Nieder *et al* [40] | 2006 | Overall, 56 patients with tumors adjacent to at least one major artery were analyzed by IMRT | The doses to the major arteries should be calculated in IMRT planning for critical tumor locations if a dose gradient >13% within the PTV cannot be avoided because the PTV is large or includes air cavities. |

Table 7 Studies on stereotactic radiotherapy for brain tumors included in the Web of Science from 2002 to 2011

| Author | Publication year | Method | Result |
|---|---|---|---|
| Grosu *et al* [41] | 2003 | The CT and MET-PET investigations were performed using a repositionable mask for head fixation for patients with brain tumors. Fifteen external reference markers that could be identified in CT and MET-PET were applied on the stereotactic localizer frame. | Mean deviation of the intensity-based automatic CT/PET fusion compared with the external marker-based gold standard was 2.4 mm; the standard deviation was 0.5. It is approximately equal to the pixel size of the PET data sets. MET-PET improves target volume definition for stereotactic fractionated radiotherapy of meningiomas and gliomas. |
| Selch *et al* [26] | 2004 | Forty-five patients with benign cavernous sinus meningiomas were treated with SRT. Treatment planning in all patients included CT-MRI image fusion and beam shaping using a micromultileaf collimator. All tumors were treated with a single isocenter plus a margin of normal parenchyma varying from 1 to 5 mm (median, 2.5 mm). The prescribed dose varied from 4 250 to 5 400 cGy (median, 5040 cGy). The prescription isodose varied from 87% to 95% (median, 90%). The maximal tumor dose varied from 5000 to 6000 cGy (median, 5600 cGy). | The actuarial 3-year overall and progression-free survival rate was 100% and 97.4%, respectively. No treatment-induced peritumoral edema, cranial neuropathy, endocrine dysfunction, cognitive decline, or second malignancy occurred. Stereotactic radiotherapy is both safe and effective for patients with cavernous sinus meningiomas. Field shaping using a micromultileaf collimator allows conformal and homogeneous radiation of cavernous sinus meningiomas that may not be amenable to single-fraction stereotactic radiosurgery because of tumor size or location. |
| Marcus *et al* [19] | 2005 | For patients with low-grade gliomas, SRT was delivered using a dedicated 6 MV linear accelerator. CT and MRI fusion was used for treatment planning. The target volume generally included the preoperative tumor plus a 2-mm margin for the planning target volume. The median collimator size was 47.25 mm (range, 30–60 mm). Three to nine arcs were used to deliver a mean total dose of 52.2 Gy in 1.8-Gy daily fractions | With a median follow-up of 6.9 years (range, 0.9–10.2 years), the progression-free survival rate was 82.5% at 5 years and 65% at 8 years. The overall survival was 97.8% at 5 years and 82% at 8 years. Six patients had local progression. Stereotactic radiotherapy provides excellent local control for children with small, localized low-grade glial tumors. |

Table 8 Studies on imaging-guided radiotherapy for brain tumors included in the Web of Science from 2002 to 2011

| Author | Publication year | Method | Result |
|---|---|---|---|
| Bogaards *et al* [42] | 2004 | An intracranial VX2 tumor in a preclinical rabbit model was selected and a fluorescence imaging/spectroscopy system, exciting and detecting the fluorescence of protoporphyrin IX (PpIX) induced endogenously by administering 5-aminolevulinic acid (ALA) at 4 hours before surgery. | Using FGR in addition to WLR significantly increased resection completeness by a factor 1.4 from 68 +/- 38 to 98 +/- 3.5%, and decreased the amount of residual tumor post-resection by a factor 16 from 32 +/- 38 to 2.0 +/- 3.5% of the initial tumor volume |
| Kim *et al* [43] | 2011 | Median total dose given was 2 500 cGy in 500 cGy fractions for recurrent high grade gliomas. | The median planning target volume was 69.5 $cm^{(3)}$. Acute Radiation Therapy Oncology Group (RTOG) toxicity scores measured zero in all patients with only one patient requiring a reoperation following treatment. |
| Kim *et al* [44] | 2011 | A stereo camera system consisting of two CCD cameras was mounted on the inferior wall of treatment room. The stereo camera system was calibrated to reconstruct 3D coordinates of multiple markers with respect to the isocenter using the direct linear transform (DLT) algorithm. | The calibration accuracy of the system was in submillimeter (0.33 mm +/- 0.27 mm), which was comparable to others. The mean distance between each of marker positions of optical images and planning CT images was 0.50 mm +/- 0.67 mm. The maximum deviations of 6-DOF registration were less than 1 mm and 1 degree for the couch translation and rotation, respectively. |

## DISCUSSION

Based on our bibliometric results from the Web of Science, we found the following research trends in studies on precision radiotherapy for brain tumors over the past 10 years. There were 260 research articles addressing precision radiotherapy for brain tumors included in the Web of Science.

The USA published the most papers on precision radiotherapy for brain tumors, followed by Germany and France. European Synchrotron Radiation Facility, German Cancer Research Center and Heidelberg University were the most prolific research institutes for publications on precision radiotherapy for brain tumors. Among the top 13 research institutes publishing in this

field, seven are in USA, three are in Germany, two are in France, and there is one institute in India. Research interests including urology and nephrology, clinical neurology, as well as rehabilitation are involved in precision radiotherapy for brain tumors studies. Most researchers are focused on stereotactic radiotherapy and intensity-modulated radiotherapy in brain tumors, and fewer on image-guided radiotherapy. Though precision radiotherapy has resulted in major advances in brain tumor treatment in China, there are only five articles by Chinese authors that can be found in the Web of Science. This suggests that Chinese investigators should improve their writing and communication skills as well as increase the number of publications and preferred conference abstracts in order to contribute to and enlarge worldwide academic exchange in the field of precision radiotherapy for brain tumors.

**Author contributions:** Ying Yan conceived and designed the study. Zhanwen Guo and Haibo Zhang, retrieved the references, extracted the data, and provided technical support. Ning Wang wrote the manuscript. Ying Xu revised the manuscript.
**Conflicts of interest:** None declared.

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