

Imaging in patients with glioblastoma: A national cohort study

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Abstract

Background. Glioblastoma is the most common malignant brain tumor in adults and has a poor prognosis. This cohort of patients is diverse and imaging is vital to formulate treatment plans. Despite this, there is relatively little data on patterns of use of imaging and imaging workload in routine practice.

Methods. We examined imaging patterns for all patients aged 15–99 years resident in England who were diagnosed with a glioblastoma between 1st January 2013 and 31st December 2014. Patients without imaging and death-certificate-only registrations were excluded.

Results. The analytical cohort contained 4,307 patients. There was no significant variation in pre- or postdiagnostic imaging practice by sex or deprivation quintile. Postdiagnostic imaging practice was varied. In the group of patients who were treated most aggressively (surgical debulking and chemoradiation) and were MRI compatible, only 51% had a postoperative MRI within 72 hours of surgery. In patients undergoing surgery who subsequently received radiotherapy, only 61% had a postsurgery and preradiotherapy MRI.

Conclusions. Prediagnostic imaging practice is uniform. Postdiagnostic imaging practice was variable. With increasing evidence and clearer recommendations regarding debulking surgery and planning radiotherapy imaging, the reason for this is unclear and will form the basis of further work.

Keywords

glioblastoma | imaging | outcomes | radiotherapy | surgery

Primary brain tumors are a group of rare, varied tumors, many of which carry a poor prognosis. They have the highest average number of years of life lost, and are the leading cause of cancer death in those under 40 years old.¹ Of these, glioblastoma (WHO grade IV glioma) is the most common malignant brain tumor in adults. The optimal management of glioblastoma typically consists of maximal debulking surgery, concurrent chemoradiation, and adjuvant chemotherapy.^{2,3} Even with this treatment, median

survival is 15 months. More recently, level 1 evidence has shown that adding tumor-treating fields improves outcomes, but cost-effectiveness is still being evaluated.⁴

Imaging is a key component in the management of brain tumors because presentation varies depending on the size and location of the tumor. Symptoms range from stroke mimics and seizures to more nonspecific neurology related to raised intracranial pressure such as headaches.^{5,6} As a result, a CT

head is often one of the earliest investigations. For further characterization, MRI is superior; it offers better soft tissue delineation than CT^{7,8} and improved sensitivity.^{9,10} Advanced MR imaging techniques such as perfusion and permeability imaging, as well as ¹H-magnetic resonance spectroscopy (¹H-MRS), provide additional biological information,^{7,11} which can help to determine tumor grade at presentation, tumor transformation from low to high grade, and whether there are treatment-related effects or true disease progression after treatment.¹²

At presentation, imaging is needed to characterize the tumor in terms of probable type (in particular whether a high grade or low grade) and extent and location of disease. Typical MR sequences would include T_1 -weighted (pre- and post-gadolinium), T_2 -weighted, FLAIR, T_2^* -weighted (or susceptibility-weighted imaging) and diffusion-weighted imaging sequences.¹⁰ Stereotactic sequences are necessary for surgical planning. Additional imaging may be of benefit to assess vasculature or to assist in targeting biopsy sites by determining the regions with the most malignant biological characteristics.¹⁰ In patients undergoing treatment, appropriate use of MRI is part of high-quality care. Early postoperative imaging is recommended for patients undergoing debulking surgery in order to assess the extent of residual disease, both for prognostic purposes and to determine if re-operation is necessary.¹³ Imaging is essential for accurate radiotherapy planning; if the time interval is short enough then this may be the same as the postoperative scan. Radiotherapy planning requires information from both T_1 -weighted and T_2 -weighted sequences.¹⁴ Even if there has been minimal disruption of the tumor architecture at operation due to a limited biopsy, preoperative imaging (typically a T_1 -weighted postcontrast scan) is inadequate for subsequent radiotherapy planning purposes and a postprocedural MRI should be performed before chemoradiation starts.

Guidance on posttreatment imaging is variable in terms of frequency and timing. With debulking surgery, there are recommendations that an early postoperative MRI with gadolinium should be performed within 72 hours of the procedure¹³; this aims to minimize the T1 effects of the postoperative blood products that can lead to misinterpretation. Thick linear or nodular enhancement involving the surgical cavity implies a subtotal resection and has a less favorable outcome.^{10,15,16} It has been suggested that patients with a macroscopic resection of >95% have better outcomes.¹⁵ An MRI is also recommended at 3 months following completion of chemoradiotherapy to provide the first treatment response assessment.¹⁰ A 3-month moratorium has been recommended before scanning commences to stop false positive interpretation of disease progression (pseudoprogression).¹³

Much has been written on the use of advanced imaging techniques in patients with glioblastoma^{7,11,12,17} and on how imaging can refine prognosis.¹⁸ Although clinical trials are often held as exemplar practice, less than 10% of all patients are entered in clinical trials and there is little data on current patterns of use of imaging and imaging workload in routine practice. We have previously described the incidence and survival¹⁹ of patients with glioblastoma in a national incident cohort of patients in England, and have shown that neurosurgical care for patients with brain

tumors in England is much more centralized than other countries.²⁰ In this study, using a more detailed dataset and methodology, we present data on the patterns of imaging in patients with glioblastoma in England over a 2-year period.

Methods

We included all patients resident in England who were diagnosed with a WHO grade IV cerebral glioma between 1st January 2013 and 31st December 2014 and who were aged between 15 and 99 years at diagnosis ([Supplementary Appendix 1: inclusion criteria](#)) using international guidance on assigning date of diagnosis.²¹ The National Cancer Registration and Analysis Service (NCRAS) in England holds data on all people diagnosed with cancer in England. We linked these patients to the Diagnostic Imaging Dataset (DID) which holds data on imaging investigations in England from April 2012.²² Identification of a space occupying lesion requires imaging, so we excluded patients who were registered based only on a death certificate (DCO) and those who had no CT or MRI head in the 3 months preceding diagnosis (including the date of diagnosis) in DID ([Supplementary Appendix 2: imaging codes](#)). The remaining patients were the analytical cohort.

We extracted data on demographics, radiotherapy, chemotherapy, surgery, imaging, and death. We categorized patients as having a histological diagnosis or not, and in those with a histological diagnosis, whether they had a biopsy or surgical debulking. We performed simple internal quality assurance on the data by looking at the relationship between histological diagnosis and evidence of biopsy/ surgery. Oncological treatment was defined as one of 4 mutually exclusive options: chemotherapy and radiotherapy, chemotherapy (no radiotherapy), radiotherapy (no chemotherapy), or no oncological treatment (neither chemotherapy nor radiotherapy).

We examined patterns and volume of imaging workload pre- and postdiagnosis. We defined “advanced MRI” as sequences including ¹H-MRS, perfusion and permeability MRI, diffusion tensor MRI, or MRI functional imaging (blood oxygen level dependent) ([Supplementary Appendix 2: advanced imaging codes](#)). We defined the “MRI-diagnosis interval” as the time from each patient’s first MRI in the 3-month (13-week) period before diagnosis to the date of diagnosis (including imaging on the date of diagnosis). We defined the “total prediagnostic workload” as all imaging in the 13 weeks before diagnosis (including date of diagnosis), and the “postdiagnostic workload” as imaging taking place in the year following diagnosis. “Early postoperative imaging” was defined as imaging performed within 72 hours of surgery. We defined the “MRI-radiotherapy interval” as the shortest time interval between an MRI scan and the start of radiotherapy. Because there are a small proportion of patients who are MRI-incompatible (eg, they have metallic implantable devices or intraocular shrapnel), we defined an MRI-compatible patient subgroup, based on patients who had received at least one MRI in the dataset, and calculated all metrics in the analytical group and in the MRI-compatible subgroup. Median survival time was

calculated from the date of diagnosis until either death or 10th February 2016 at which they were censored.

For each measure, we looked for evidence of variation in terms of demographic categories (age, sex, ethnicity, deprivation quintile), variation based on radiological versus histological diagnosis, debulking surgery or biopsy, and the 4 oncological treatment pathways.

All analysis was carried out in Stata 13.1.

Ethics Approval and Consent to Participate

As this was a retrospective linkage study of routinely treated patients who were subsequently de-identified, ethical approval was not required. No individual personal data are included in this article. The study was performed in accordance with the Declaration of Helsinki.

Results

There were 4,778 patients diagnosed with cerebral glioblastoma over the 2-year period. We excluded 66 patients as they were diagnosed based on a DCO and a further 405 who had no CT or MRI head imaging record in DID in the 3 months preceding diagnosis. This left an analytical cohort of 4,307. Demographic variables for the analytical cohort are presented in [Table 1](#). The median age was 65 years (interquartile range [IQR] 57–73), and 61% were male. Eighty-two percent of patients had a histological diagnosis, of whom 73% (2,557/3,526) underwent debulking surgery (as opposed to biopsy). Seventeen percent of patients (735/4,307) had no record of histology, surgery, or biopsy and were diagnosed based on imaging alone. Twenty-eight patients (0.1% of the cohort) had a record indicating debulking surgery, but with no record of histology. Thirty-five percent (1,522/4,307) of patients underwent chemoradiation, 35% had no oncological treatment, and the remaining 30% had either radiotherapy alone, or chemotherapy alone ([Table 1](#)). Median survival of the 4,307 patients, including the 86% of patients who died during follow-up, was 207 days (IQR 82–434).

Ninety-three percent of the analytical cohort were MRI compatible. Eighty percent of patients had an MRI before diagnosis with 67% having both CT and MRI ([Table 1](#)). The median MRI-diagnosis interval was 11 days (IQR 5–20 days) ([Table 2](#)). Prediagnosis imaging workload showed little variation (7% of patients had > 3 MRI scans in the 13 weeks preceding diagnosis).

The median number of MRI scans in the 12 months postdiagnosis was 1 for the entire cohort, and 2 for those who had any postdiagnosis imaging. However, this varied considerably by treatment pathway. Of the 1,245 patients who underwent surgery and chemoradiation, 99% were MRI compatible and the median imaging workload for this subset in the 12 months after diagnosis was 6 MRI or CT scans (IQR 4–8). In contrast, of the 487 patients who had surgery but no oncological treatment, 89% were MRI compatible and the median workload for this subset was 2 MRI or CT scans (IQR 1–3).

Of the 2,582 patients who had surgery, 96% were MRI compatible ([Table 1](#)). Of those, 45% of patients had an early postoperative MRI (39% within 2 days) ([Table 3](#)). Early postoperative MRI was slightly more common in the 1,245 patients who had surgery and chemoradiation, where 51% had a postoperative MRI within 72 hours following surgery ([Table 3](#)).

Of the 2,519 patients who were MRI compatible, had a histological diagnosis, and underwent radiotherapy (with or without chemotherapy), 51% underwent an MRI after the date of surgery and on or before the start of radiotherapy ([Table 4](#)).

Seven percent of the cohort underwent one or more of the advanced MRI sequences for improved diagnostic capability (dynamic susceptibility contrast and dynamic contrast enhanced and ¹H-MRS). Four percent of patients received an advanced MRI sequence in the 3 months prior to diagnosis, and 2% received one in the 12 months following diagnosis ([Table 5](#)). Less than 1% of the cohort received an image on the list of MRI codes of advanced MRI for surgical planning (diffusion tractography imaging and functional MRI). Less than 1% of the cohort received an image from the list of PET CT for improved diagnostic capability (¹⁸F-choline, ¹¹C-methionine, ¹⁸F-fluoro-D-glucose).

Discussion

We have presented the first study on peridiagnostic imaging workload in a national incident brain tumor cohort. To the best of our knowledge, this work is unique. Recent reports from the United States reporting outcomes in glioblastoma use a partial national cohort^{23,24} and do not report imaging. We excluded 471 patients (10% of our incident cohort) due to DCO registrations and we do not capture patients who have their imaging entirely in the private sector or abroad. Nonetheless, our results are broadly comparable with other datasets in terms of age, sex, and survival distribution. Eighty-two percent of our cohort had a histological diagnosis, which is consistent with other data from the United Kingdom and other countries.²⁵ However, there is clear evidence for low use of postoperative MRI, the low use of preradiotherapy MRI, and the very limited use of “advanced” MRI. Although these data are now somewhat old, they form a useful baseline for further work, and national-level datasets in the United Kingdom currently have a minimum of 18 months delay due to data collection, cleaning, and QA.

Prediagnostic imaging appears uniform; almost all patients will have a scan preoperatively. Details on the quality of this prediagnostic imaging are not available. Further detail on imaging parameters is available in [Supplementary Appendix 3](#). Although there are patients who have repeated imaging episodes in the 13 weeks leading up to diagnosis, these are relatively rare. More patients have CT rather than MRI prediagnosis, consistent with clinical presentation, and there was no significant variation in pre- or postdiagnostic imaging practice by sex or deprivation quintile ([Table 5](#)). Seven percent of the

Table 1. Numbers of Patients and Proportions (out of the analytical cohort) Receiving MRI or CT, MRI Brain, CT Brain, and Both CT Brain and MRI Brain, at Any Point Surrounding Diagnosis, and in the 13 Weeks Before (or on the date of) Diagnosis

| | Imaging at Any Point | | | | | | Imaging in the 13 wk Before Diagnosis (91 d, inclusive, including diagnosis date) | | | | | | | |
|--------------------|--|-----|-----------|----|----------|----|---|----|-----------|----|----------|----|------------------|----|
| | Patients With MRI or CT (=analytical cohort) | | MRI Brain | | CT Brain | | MRI and CT Brain | | MRI Brain | | CT Brain | | MRI and CT Brain | |
| | N | % | N | % | N | % | N | % | N | % | N | % | N | % |
| Total | 4,307 | 100 | 3,999 | 93 | 4,148 | 96 | 3,840 | 89 | 3,428 | 80 | 3,747 | 87 | 2,888 | 67 |
| Sex | | | | | | | | | | | | | | |
| Male | 2,611 | 61 | 2,440 | 93 | 2,524 | 97 | 2,353 | 90 | 2,081 | 80 | 2,276 | 87 | 1,746 | 67 |
| Female | 1,696 | 39 | 1,559 | 92 | 1,624 | 96 | 1,487 | 88 | 1,347 | 79 | 1,471 | 87 | 1,122 | 66 |
| Age groups | | | | | | | | | | | | | | |
| Under 50 | 556 | 13 | 542 | 97 | 534 | 96 | 520 | 94 | 468 | 84 | 439 | 79 | 351 | 63 |
| 50–59 | 813 | 19 | 779 | 96 | 781 | 96 | 747 | 92 | 688 | 85 | 704 | 87 | 579 | 71 |
| 60–69 | 1,449 | 34 | 1,370 | 95 | 1,405 | 97 | 1,326 | 92 | 1,231 | 85 | 1,266 | 87 | 1,048 | 72 |
| 70–79 | 1,107 | 26 | 1,011 | 91 | 1,059 | 96 | 963 | 87 | 855 | 77 | 981 | 89 | 729 | 66 |
| 80+ | 382 | 9 | 297 | 78 | 369 | 97 | 284 | 74 | 186 | 49 | 357 | 93 | 161 | 42 |
| Ethnicity | | | | | | | | | | | | | | |
| White | 3,983 | 92 | 3,715 | 93 | 3,843 | 96 | 3,575 | 90 | 3,191 | 80 | 3,470 | 87 | 2,678 | 67 |
| Non-White | 223 | 5 | 200 | 90 | 213 | 96 | 190 | 85 | 171 | 77 | 191 | 86 | 139 | 62 |
| Unknown | 101 | 2 | 84 | 83 | 92 | 91 | 75 | 74 | 66 | 65 | 86 | 85 | 51 | 50 |
| Deprivation | | | | | | | | | | | | | | |
| 1 (least deprived) | 1,004 | 23 | 929 | 93 | 977 | 97 | 902 | 90 | 803 | 80 | 873 | 87 | 672 | 67 |
| 2 | 1,044 | 24 | 987 | 95 | 994 | 95 | 937 | 90 | 852 | 82 | 894 | 86 | 702 | 67 |
| 3 | 870 | 20 | 804 | 92 | 842 | 97 | 776 | 89 | 697 | 80 | 758 | 87 | 585 | 67 |
| 4 | 792 | 18 | 728 | 92 | 751 | 95 | 687 | 87 | 615 | 78 | 693 | 88 | 516 | 65 |
| 5 (most deprived) | 597 | 14 | 551 | 92 | 584 | 98 | 538 | 90 | 461 | 77 | 529 | 89 | 393 | 66 |
| Histology | | | | | | | | | | | | | | |
| Yes | 3,526 | 82 | 3,353 | 95 | 3,411 | 97 | 3,238 | 92 | 3,058 | 87 | 3,035 | 86 | 2,567 | 73 |
| No | 781 | 18 | 646 | 83 | 737 | 94 | 602 | 77 | 370 | 47 | 712 | 91 | 301 | 39 |
| Surgery | | | | | | | | | | | | | | |
| Yes | 2,582 | 60 | 2,481 | 96 | 2,504 | 97 | 2,403 | 93 | 2,229 | 86 | 2,210 | 86 | 1,857 | 72 |
| No | 1,725 | 40 | 1,518 | 88 | 1,644 | 95 | 1,437 | 83 | 1,199 | 70 | 1,537 | 89 | 1,011 | 59 |
| Biopsy | | | | | | | | | | | | | | |
| Yes | 1,187 | 28 | 1,102 | 93 | 1,150 | 97 | 1,065 | 90 | 1,033 | 87 | 1,046 | 88 | 892 | 75 |
| No | 3,120 | 72 | 2,897 | 93 | 2,998 | 96 | 2,775 | 89 | 2,395 | 77 | 2,701 | 87 | 1,976 | 63 |
| Surgery or biopsy | | | | | | | | | | | | | | |
| Yes | 3,518 | 82 | 3,348 | 95 | 3,407 | 97 | 3,237 | 92 | 3,051 | 87 | 3,031 | 86 | 2,564 | 73 |
| No | 789 | 18 | 651 | 83 | 741 | 94 | 603 | 76 | 377 | 48 | 716 | 91 | 304 | 39 |
| Treatment | | | | | | | | | | | | | | |
| No treatment | 1,506 | 35 | 1,282 | 85 | 1,439 | 96 | 1,215 | 81 | 994 | 66 | 1,364 | 91 | 852 | 57 |
| Chemo and radio | 1,522 | 35 | 1,496 | 98 | 1,471 | 97 | 1,445 | 95 | 1,328 | 87 | 1,261 | 83 | 1,067 | 70 |
| Chemo | 99 | 2 | 95 | 96 | 90 | 91 | 86 | 87 | 91 | 92 | 70 | 71 | 62 | 63 |
| Radio | 1,180 | 27 | 1,126 | 95 | 1,148 | 97 | 1,094 | 93 | 1,015 | 86 | 1,052 | 89 | 887 | 75 |

Table 2. Time Interval (days) Between First MRI, in the 13 Weeks Prior to Diagnosis, and Diagnosis

| | | First MRI to Diagnosis | | |
|--|-----------------|------------------------|---------------|------|
| | | N | Median (days) | IQR |
| Total with brain MRI in 13 wk before diagnosis (91 d, inclusive) | | 3,428 | 11 | 5–20 |
| Sex | Male | 2,081 | 11 | 5–20 |
| | Female | 1,347 | 11 | 5–20 |
| Age groups | Under 50 | 468 | 9 | 4–20 |
| | 50–59 | 688 | 11 | 5–18 |
| | 60–69 | 1,231 | 12 | 6–20 |
| | 70–79 | 855 | 13 | 5–22 |
| | 80+ | 186 | 4 | 0–16 |
| Ethnicity | White | 3,191 | 11 | 5–20 |
| | Non-White | 171 | 8 | 4–21 |
| | Unknown | 66 | 9 | 2–20 |
| Deprivation | 1 (least) | 803 | 11 | 5–20 |
| | 2 | 852 | 12 | 5–20 |
| | 3 | 697 | 11 | 5–21 |
| | 4 | 615 | 11 | 4–19 |
| | 5 (most) | 461 | 11 | 5–20 |
| Histology | Yes | 3,058 | 12 | 6–21 |
| | No | 370 | 1 | 0–10 |
| Surgery | Yes | 2,229 | 12 | 6–20 |
| | No | 1,199 | 10 | 3–20 |
| Biopsy | Yes | 1,033 | 13 | 7–22 |
| | No | 2,395 | 11 | 4–19 |
| Surgery or biopsy | Yes | 3,051 | 12 | 6–21 |
| | No | 377 | 1 | 0–11 |
| Treatment | No treatment | 994 | 10 | 2–21 |
| | Chemo and radio | 1,328 | 11 | 5–18 |
| | Chemo | 91 | 17 | 7–31 |
| | Radio | 1,015 | 12 | 7–21 |

Abbreviation: IQR, interquartile range.

MRI-compatible patients underwent biopsy or surgery without a MRI beforehand; severe presenting features that warranted emergency surgery might explain some of this.

Early postoperative imaging rates in the MRI-compatible cohort were 45%. They were slightly higher in those patients who went on to have chemoradiation (51%) and lower (31%) in those who had no oncological treatment (Table 3), suggesting some degree of postoperative decision-making based on how unwell the patients were. Nonetheless, even in the group who underwent surgical debulking, were MRI compatible, and had postoperative chemoradiation, only 51% of patients had an early postoperative MRI. This suggests that in 49% of the “fittest” group of patients, there was no attempt to objectively assess their extent of resection and it is well recognized that there is significant discordance between surgeon and MRI-based estimates of extent of resection.¹⁶

Similarly, only 51% of patients with a histological diagnosis who had postoperative radiotherapy had an MRI between surgery and radiotherapy. Even among those who have debulking surgery and subsequently receive radiotherapy, only 64% have a MRI performed postsurgery and preradiotherapy. Given the dependence of radiotherapy on accurate target volume definition and recent guidance,^{14,26} this is troubling.

The findings raise significant concerns for neurosurgical, oncological, and radiology practice in England. While we are unable to comment on the reasons for low rates, we do not think that they are due to missing data (patients have evidence of other imaging), sampling bias (we have a near-complete national cohort), MRI compatibility, or patients being unfit for treatment. It is well recognized that England has substantially fewer radiologists and MRI scanners than comparable countries,^{27,28} and our experience suggests that there are practical barriers to implementing early

Table 3. Number of Days Between Surgery and Early Postoperative MRI (within 3 days of surgery), and Total Within 14 days of Surgery

| | | | Number of Days Between Surgery and MRI | | | | Total Within 14 d | Total in Cohort |
|-------------|-----------------|---|--|-----|-----|-----|-------------------|-----------------|
| | | | 0 (same day) | 1 | 2 | 3 | | |
| Total | | N | 268 | 426 | 308 | 151 | 1,292 | 2,582 |
| | | % | 10 | 16 | 12 | 6 | 50 | |
| Sex | Male | N | 158 | 268 | 184 | 94 | 788 | 1,589 |
| | | % | 10 | 17 | 12 | 6 | 50 | |
| | Female | N | 110 | 158 | 124 | 57 | 504 | 993 |
| | | % | 11 | 16 | 12 | 6 | 51 | |
| Age groups | Under 50 | N | 71 | 78 | 60 | 23 | 262 | 446 |
| | | % | 16 | 17 | 13 | 5 | 59 | |
| | 50–59 | N | 57 | 108 | 59 | 44 | 299 | 582 |
| | | % | 10 | 19 | 10 | 8 | 51 | |
| | 60–69 | N | 89 | 156 | 114 | 54 | 468 | 953 |
| | | % | 9 | 16 | 12 | 6 | 49 | |
| | 70–79 | N | 49 | 76 | 69 | 25 | 237 | 550 |
| | | % | 9 | 14 | 13 | 5 | 43 | |
| | 80+ | N | 2 | 8 | 6 | 5 | 26 | 51 |
| | | % | 4 | 16 | 12 | 10 | 51 | |
| Ethnicity | White | N | 242 | 402 | 286 | 136 | 1,195 | 2,409 |
| | | % | 10 | 17 | 12 | 6 | 50 | |
| | Non-White | N | 18 | 18 | 19 | 9 | 72 | 131 |
| | | % | 14 | 14 | 15 | 7 | 55 | |
| | Unknown | N | 8 | 6 | 3 | 6 | 25 | 42 |
| | | % | 19 | 14 | 7 | 14 | 60 | |
| Deprivation | 1 | N | 65 | 99 | 52 | 36 | 284 | 618 |
| | | % | 11 | 16 | 8 | 6 | 46 | |
| | 2 | N | 61 | 113 | 78 | 44 | 327 | 623 |
| | | % | 10 | 18 | 13 | 7 | 52 | |
| | 3 | N | 43 | 99 | 73 | 22 | 261 | 518 |
| | | % | 8 | 19 | 14 | 4 | 50 | |
| | 4 | N | 57 | 71 | 49 | 28 | 229 | 463 |
| | | % | 12 | 15 | 11 | 6 | 49 | |
| | 5 | N | 42 | 44 | 56 | 21 | 191 | 360 |
| | | % | 12 | 12 | 16 | 6 | 53 | |
| Histology | Yes | N | 265 | 423 | 307 | 148 | 1,280 | 2,557 |
| | | % | 10 | 17 | 12 | 6 | 50 | |
| Biopsy | Yes | N | 15 | 22 | 8 | 4 | 59 | 251 |
| | | % | 6 | 9 | 3 | 2 | 24 | |
| Surgery | Yes | N | 268 | 426 | 308 | 151 | 1,292 | 2,582 |
| | | % | 10 | 16 | 12 | 6 | 50 | |
| Treatment | No treatment | N | 46 | 54 | 41 | 16 | 174 | 487 |
| | | % | 9 | 11 | 8 | 3 | 36 | |
| | Chemo and radio | N | 137 | 255 | 158 | 82 | 710 | 1,245 |
| | | % | 11 | 20 | 13 | 7 | 57 | |
| | Chemo | N | 3 | 8 | 5 | 1 | 19 | 64 |
| | | % | 5 | 13 | 8 | 2 | 30 | |
| | Radio | N | 82 | 109 | 104 | 52 | 389 | 786 |
| | | % | 10 | 14 | 13 | 7 | 49 | |

Table 4. Number and Proportions of Patients Receiving a Postdiagnostic MRI in the 3 Months Prior to Starting Radiotherapy

| | | | Total Receiving MRI Before Radiotherapy (% of those with MRI and radiotherapy) | Total of Those With Radiotherapy (of the MRI-compatible population) |
|-------------|-----------|---|--|---|
| Total | Total | N | 1,599 | 2,622 |
| | | % | 61 | |
| Sex | Male | N | 998 | 1,655 |
| | | % | 60 | |
| | Female | N | 601 | 967 |
| | | % | 62 | |
| Age groups | Under 50 | N | 305 | 433 |
| | | % | 70 | |
| | 50–59 | N | 380 | 611 |
| | | % | 62 | |
| | 60–69 | N | 581 | 990 |
| | | % | 59 | |
| | 70–79 | N | 297 | 533 |
| | | % | 56 | |
| | 80+ | N | 36 | 55 |
| | | % | 65 | |
| Ethnicity | White | N | 1,487 | 2,445 |
| | | % | 61 | |
| | Non-White | N | 82 | 129 |
| | | % | 64 | |
| | Unknown | N | 30 | 48 |
| | | % | 63 | |
| Deprivation | 1 | N | 356 | 624 |
| | | % | 57 | |
| | 2 | N | 397 | 656 |
| | | % | 61 | |
| | 3 | N | 313 | 519 |
| | | % | 60 | |
| | 4 | N | 292 | 459 |
| | | % | 64 | |
| | 5 | N | 241 | 364 |
| | | % | 66 | |
| Histology | Yes | N | 1,535 | 2,519 |
| | | % | 61 | |
| | No | N | 64 | 103 |
| | | % | 62 | |
| Surgery | Yes | N | 1,373 | 1,988 |
| | | % | 69 | |
| | No | N | 226 | 634 |
| | | % | 36 | |
| Biopsy | Yes | N | 243 | 682 |
| | | % | 36 | |
| | No | N | 1,356 | 1,940 |
| | | % | 70 | |

Table 4. Continued

| | | | Total Receiving MRI Before Radiotherapy (% of those with MRI and radiotherapy) | Total of Those With Radiotherapy (of the MRI-compatible population) |
|-------------------|-----------------|---|--|---|
| Surgery or biopsy | Yes | N | 1,544 | 2,523 |
| | | % | 61 | |
| | No | N | 55 | 99 |
| | | % | 56 | |
| Treatment | Chemo and Radio | N | 1,007 | 1,496 |
| | | % | 67 | |
| | Radio | N | 592 | 1,126 |
| | | % | 53 | |

Table 5. Count of MRI Imaging in the 12 Months After Diagnosis Among Those With the Image in the 12 Months After Diagnosis (excluding the date of diagnosis), by Sociodemographic and Treatment Variables

| | | | Median MRI Count |
|-------------------|--------------------|--|------------------|
| Total | | | 2 |
| Sex | Male | | 2 |
| | Female | | 2 |
| Age groups | Under 50 | | 4 |
| | 50–59 | | 3 |
| | 60–69 | | 2 |
| | 70–79 | | 1 |
| | 80+ | | 1 |
| Ethnicity | White | | 2 |
| | Non-White | | 1 |
| | Unknown | | 1 |
| Deprivation | 1 (least deprived) | | 2 |
| | 2 | | 2 |
| | 3 | | 2 |
| | 4 | | 2 |
| | 5 (most deprived) | | 2 |
| Histology | Yes | | 2 |
| | No | | 1 |
| Surgery | Yes | | 3 |
| | No | | 1 |
| Biopsy | Yes | | 1 |
| | No | | 2 |
| Surgery or biopsy | Yes | | 2 |
| | No | | 1 |
| Treatment | No treatment | | 0 |
| | Chemo and radio | | 4 |
| | Chemo | | 2 |
| | Radio | | 2 |

postoperative and radiotherapy planning MRI²⁹. Studies such as ours, which use linked individual patient data, demonstrate the power of clinically informed detailed analyses of patterns of care; one of the strengths of our study is that we report imaging rates in clinically relevant patient populations (ie, those who are well enough to go on and receive postoperative chemoradiation). However, because of this, they are inevitably retrospective. Data QA, linkage, and analysis take time, and so we report data from 7 years ago, and we expect practice to have changed over time. Repeating such analyses should now be substantially quicker as the analytical approach has now been developed.

We have reported national peridiagnostic patterns of imaging in a national incident cohort of patients with glioblastoma. Prediagnostic imaging is expected and appropriate, but postdiagnostic imaging is variable. There appears to be a significant under use of early postoperative MRI. Furthermore, only 64% of MRI-compatible patients who underwent chemoradiation had a postoperative radiotherapy planning MRI, which seems unacceptably low and raises significant questions about national patterns of practice. Reasons for low imaging rates are not available from our data, and will form the basis of further research, as will updated analysis of more recent data.

This work uses data provided by patients and collected by the NHS as part of their care and support.

Supplementary Material

Supplementary material is available at *Neuro-Oncology Practice* online.

Funding

M.W. receives funding for his time from the Imperial/NIHR BRC, the Imperial CRUK Centre and Brain Tumour Research Campaign.

Acknowledgments

Data for this study are based on patient-level information collected by the NHS as part of the care and support of cancer patients. The data are collated, maintained, and quality assured by the National Cancer Registration and Analysis Service, which is part of Public Health England (PHE). This study has been produced as part of the CRUK-PHE partnership. The study was exempt from gaining individual consent having obtained Section 251 approval from the UK Patient Information Advisory Group (PIAG) (now the Confidentiality Advisory Group [CAG]), under Section 251 of the NHS Act 2006 (PIAG 03(a)/2001).

Conflict of interest statement. None declared.

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