INTRODUCTION

The incidence of brain metastases is increasing, likely due to the improved systemic therapies resulting in prolonged overall survival[19,39] and improved radiological techniques, leading to increased diagnosis.[4,5,8,9,31,37,43] On the other hand, improved medical therapies can potentially decrease the incidence of brain metastases[19]. The most common malignancy, leading to brain metastasis, is nonsmall cell lung cancer (NSCLC),[4,5,9,11,28,37,45] followed by breast adenocarcinoma,
melanoma, renal cell carcinoma, and colorectal adenocarcinoma.[4,5,8,9,11,14,19,20,28,30-33,37,41,43,45]

Craniotomy and resection of a brain metastasis can prolong overall survival in select patients.[1,4,7,10,11,14,20,26-28,34,41,43,45] Neurosurgeons may also resect metastatic lesions located intraventricularly, those which are durally based, within the pituitary gland and intrasosseous within cranial bone. Ideal candidates for surgery include patients with a good performance status diagnosed with a solitary metastasis in a noneloquent area, associated with stable systemic disease.[8,11,27,28,45] Additional advantages of surgical resection include instant relief from symptoms of raised intracranial pressure due to mass effect, treatment of obstructive hydrocephalus without the need for cerebrospinal fluid diversion,[4,26,36,45] to provide histological diagnosis, reduce the need for Dexamethasone, improve functional performance status,[28,35] and facilitate stereotactic radiosurgery (STRS).[35] Surgical resection may not be required in patients with a metastasis <3 cm in maximal diameter, as these lesions can successfully be treated through STRS.[4,21]

MATERIALS AND METHODS

The aim of this study was to identify prognostic factors associated with resection of intracranial metastases. Before data collection, this study was formally registered with the local audit department, the ethics and methodology of the study were reviewed and signed off by the clinical governance lead. A retrospective study was carried out at a single centre, Hull Royal Infirmary. Data collection occurred from May 12, 2021, to July 19, 2021. All patients who underwent attempted neurosurgical resection of a cranial metastasis between March 2014 and April 2021 were included in the study. Clinic letters, radiology and histology reports, and operation notes were used for data collection. One hundred and twenty-six patients were identified. However, 14 patients were excluded from the study and the reasons included; no available information, nonmetastatic histological diagnosis such as glioblastoma or lymphoma, biopsy of metastasis, treated through cyst aspiration, and insertion of Ommaya reservoir. Therefore, 112 patients were included who underwent a total of 124 resections. The diagnosis was concluded from the neurosurgical histological result and imaging available to the neuro-oncology multidisciplinary team. Biopsy results for any systemic lesions targeted were not available for analysis as these procedures would have been performed at a different hospital.

Neurosurgery clinic letters describing referral for consideration of whole-brain radiotherapy (WBRT) or STRS were not adequate to be recorded as having received treatment. The treatment reports stating the radiation dose (Gy) and fractions (WBRT) or number of target lesions (STRS) were reviewed to confirm adjuvant radiation administered. The extent of surgical resection was defined as unclear in patients where MRI was contraindicated, if they were too unwell for appropriate investigations, if no MRI was available, or if unable to distinguish residual from recurrent disease. Gross-total resection included cases where a postcontrast MRI did not demonstrate any residual enhancing material whereas cases were classified as sub-total resection if there was a tiny or small volume of enhancing material at the surgical site. Debulking included cases where there was either a large residual or limited resection performed. The extent of surgical resection was formally reported by a neuroradiologist and reviewed by a neurosurgeon.

Statistical analysis was carried out using GraphPad Prism 9.2.0 and P < 0.05 was deemed statistically significant. For the survival analysis, 1 month was defined as 28 days. Kaplan–Meier graphs were used and the statistical significance was calculated through the Log rank (Mantel–Cox) test.

RESULTS

The median age was 65 years old (24 to 84). The male-to-female ratio was 1:1.54 with 44 (39%) males and 68 (61%) females. There were 81 patients (72%) with a solitary cranial metastasis, 29 (26%) with multiple intracranial metastases, and in 2 (2%), MRI was contraindicated with only a preoperative CT available. The metastasis location most frequently involved the frontal lobe (frontal, frontoparietal, and frontotemporal [53 patients, 47%]), [Table 1]. Ninety-five (85%) were supratentorial intraparenchymal metastases,

| Patients (n=112) |
|------------------|
| **Left**       |
| **Right**      |

| Intrinsc |     |     |
|----------|-----|-----|
| Frontal  | 23  | 24  |
| Frontoparietal | 2  | 2   |
| Frontotemporal  | 1  | 1   |
| Parietal    | 7   | 9   |
| Parieto-occipital | 3  | 1   |
| Temporal   | 3   | 5   |
| Temporoparietal | 2  | 0   |
| Occipital  | 7   | 5   |
| Cerebellar | 3   | 2   |

| Extrinsic |     |     |
|-----------|-----|-----|
| Cerebelloptine angle | 1  | 1   |
| Supratentorial dural based | 6  | 5   |
| Extradural/intraventricular | 1  | 1   |
| 4th ventricle | 1  | 1   |
| Left lateral ventricle | 1  | 1   |
| Pituitary | 1  | 1   |
| Multiple | 1  | 1   |
| Right parietal bone and left temporal brain | 1  | 1   |
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5 (6%) were dural based, 2 (2%) were intraventricular, and 1 (1%) was within the pituitary gland. The most common presenting symptoms before dexamethasone treatment included: headaches (32%), motor deficit (31%), speech disturbance (31%), visual deterioration (15%), and seizures (13%), [Table 2].

The primary histological diagnosis was NSCLC in 63 patients (56%) which included one patient with an adenocarcinoma metastasis within a gliosarcoma, breast adenocarcinoma in 14 (12%), melanoma in 7 (6%), colorectal adenocarcinoma in 7 (6%), renal cell carcinoma in 6 (5%), esophageal adenocarcinoma in 4 (4%), endometrial sarcoma in 2 (2%), endometrial adenocarcinoma in 1 (1%), ovarian adenocarcinoma in 2 (2%), bladder transitional cell carcinoma in 1 (1%), anal squamous cell carcinoma in 1 (1%), prostate adenocarcinoma in 1 (1%), ethmoid air sinus adenocarcinoma in 1 (1%), and small cell lung cancer in 2 (2%).

Postoperative MRI with contrast was carried out within 48 hours of surgery in 63 patients (56%), between 3 and 7 days in 6 (5%) and was delayed or not performed at all in 41 patients (37%). MRI scanning was contraindicated in 2 patients (2%). Gross-total resection was achieved in 46 patients (41%), sub-total in 26 (23%), debulking in 9 (8%), and the extent of surgical resection was unclear in 31 patients (28%). Adjuvant STRS to the resection cavity was not carried out. However, 46 (41%) underwent radiation treatment for residual, recurrent, or additional intracranial metastatic disease. This included 27 (24%) who received WBRT, 18 (16%) received STRS, and 1 (1%) who received both WBRT and STRS [Supplementary Figure 1].

Of the total 112 patients, 10 (9%) underwent further resections of brain metastases, including 10 redo resections for recurrence at the surgical site and two resections of discrete lesions at a different intracranial site [Table 3]. Of the 124 tumor resections, 9 (7%) returned to theater for emergency neurosurgical intervention which included evacuation of intracranial hematoma (3, 2%), washout of brain abscess or subdural empyema (5, 4%), and decompressive craniectomy (1, 1%). There were 3 (2%) arterial territory cerebral infarcts and 4 (3%) new symptomatic venous thromboembolic events [Table 4]. The surgical mortality (death within 30 days due to an operative complication) was 1/124 (<1%).

At the time of data collection, 26/112 (23%) were still alive and the median follow-up for those patients was 1070 days (68–2484). Including the total patient cohort, the rates of overall survival were as follows: 1 month = 93%, 6 months = 58%, 1 year = 35%, and 5 years = 17%, with a median survival of 233 days [Figure 1]. Of the 19 patients who died within 90 days of surgery, 5 (26%) had respiratory failure (causes included pneumonia, pulmonary embolism, and mediastinal lymphadenopathy), 5 (26%) had cancer progression (three had new systemic metastases and two had new intracranial metastases), and 6 (32%) had an unknown cause of death [Table 5].

Of the 10 patients who underwent redo resection and/or resection of an additional cranial metastatic lesion [Table 3], 5 (50%) were alive at the time of data collection with a median follow-up of 1377 days (1099–2848). The median overall survival including all 10 patients was 1101 days (101–2848).

Age was significantly associated with survival (Log rank [Mantel–Cox] \( P = 0.009 \)), with an age >70 being a negative prognostic predictor of survival [Table 6]. Extent of neurosurgical resection was significantly associated with survival (Log rank [Mantel–Cox] \( P = 0.022 \)), with gross-total resection being a positive predictor of survival. Squamous subtyping of NSCLC was a negative predictor of survival (Log rank [Mantel–Cox] \( P = 0.048 \)) [Figures 1 and 2]. On recursive partitioning analysis [Figure 3] using extent of resection and age, age <70 and confirmed gross-total resection yield a median survival of 27.5 months which was statistically significant (Log rank [Mantel–Cox] \( P = 0.0001 \)).

Table 2: Preoperative clinical presentation.

| Symptoms                  | Patients (n=108)* |
|---------------------------|------------------|
| Motor deficit**           | 34 (31%)         |
| Facial asymmetry          | 8 (7%)           |
| Limb weakness             | 31 (29%)         |
| Visual field deficit      | 16 (15%)         |
| Reduced visual acuity     | 4 (4%)           |
| Seizures                  | 14 (13%)         |
| Tonic–clonic seizures     | 4 (4%)           |
| Focal seizures            | 8 (7%)           |
| Absence seizures          | 1 (1%)           |
| Nocturnal seizure          | 1 (1%)           |
| Speech disturbance        | 33 (31%)         |
| Dysphasia                 | 14 (13%)         |
| Confusion                 | 14 (13%)         |
| Dysarthria                | 4 (4%)           |
| Reduced mobility          | 19 (18%)         |
| Ataxia                    | 2 (2%)           |
| Gait disturbance          | 3 (3%)           |
| Impaired limb coordination| 5 (5%)           |
| Impaired balance          | 3 (3%)           |
| Falls                     | 7 (6%)           |
| Headaches                 | 35 (32%)         |
| Vomiting                  | 4 (4%)           |
| Nystagmus                 | 1 (1%)           |
| Dysgraphia                | 1 (1%)           |
| Hearing loss              | 1 (1%)           |
| Sensory deficit           | 3 (3%)           |
| Low conscious level       | 2 (2%)           |
| Personality change        | 10 (9%)          |
| Memory loss               | 7 (6%)           |
| Unintentional weight loss | 1 (1%)           |
| Reduced appetite          | 1 (1%)           |

**Missing information on the clinical presentation of 4/112 (4%) patients from the total sample size. *Neurological deficits were before administration of dexamethasone.
DISCUSSION

Our study demonstrated that achieving gross-total resection can lead to prolonged survival. However, there was a large number of patients (37%) where MRI scanning was either delayed or not performed at all, resulting in patients with an unclear extent of surgical resection. Neurosurgical services in England are commissioned by the National Health Service (NHS) based on guidelines written by the National Institute for Health and Care Excellence (NICE). At present, NICE recommends MRI scanning within 72 hours of resection of malignant gliomas; however, this is not the case for brain metastases. It is common practice at Hull Royal Infirmary to perform an intraoperative ultrasound to evaluate the extent of resection; however, these results were not available for analysis. The long-term radiological follow-up was not assessed in our study. Our current protocol is MRI scanning every 3 months if residual disease is identified; however, once adjuvant STRS is completed the radiological follow-up is managed by the primary oncologist.

Schackert et al. found in their series of 127 patients; gross-total resection was associated with a longer duration of survival when compared to those with a residuum and median survivals of 10.6 and 5.8 months, respectively. Olesrud et al. found in their study of 68 patients; no residual tumor, nonmeasurable residual tumor, and measurable residual tumor were associated with median survivals on 12.0, 9.5, and 5.6 months, respectively. Sivasanker et al. found in their series of 124 patients; those who achieved gross-total resection had a median survival of 12.5 months and those who did not survived for a median of 4.2 months; however, this did not reach statistical significance. Tendulkar et al. showed in their study of 271 patients; a median survival of 10.6 months following gross-total resection compared to 8.7 following subtotal resection; however, this did not reach statistical significance. On the other hand, Jünger et al. found no difference in overall survival when comparing gross-total versus subtotal resection in 197 patients.

Fluorescence-guided surgery using 5-aminolevulinic acid (5-ALA) has been shown to increase the likelihood of achieving gross-total resection in glioblastoma multiforme. 5-ALA-guided resection of cerebral metastases has been attempted; however, the rate of tumor fluorescence is variable and its utility remains unclear. Supramarginal resection can also be performed to reduce the probability of residual tumor; however, this is not common.

Table 3: Redo resection for recurrent intracranial metastatic disease.

| Age | Primary cancer | Secondary location | Extent of primary resection | Radiation treatment | Days from primary resection to further neuro-oncological surgery | Overall survival (days) |
|-----|----------------|--------------------|---------------------------|---------------------|---------------------------------------------------------------|------------------------|
| 54  | Colorectal adenocarcinoma | Left frontal | Unknown* | None | 157 | 2484 (Alive) |
| 69  | Breast adenocarcinoma | Left occipital | Unknown** | None (Was referred for WBRT) | 884, 1236 | 1402 (Deceased) |
| 66  | NSCLC | Right frontal | Gross total | Yes (WBRT after 2nd surgery) | 126 | 1700 (Alive) |
| 57  | NSCLC | Right frontal | Sub-total | None (was referred for STRS) | 50 | 101 (Deceased) |
| 69  | NSCLC | Right temporal | Gross total | None | 238 | 1377 (Alive) |
| 42  | Breast | Right occipital | Gross total | None | 1068 | 1103 (Alive) |
| 37  | Esophageal adenocarcinoma | Right cerebellum | Debulking | Yes (STRS after primary surgery, received 6x STRS in total) | 483 | 1099 (Alive) |
| 60  | Renal cell carcinoma | Right frontoparietal | Debulking | None (Not suitable for STRS as tumor invaded into wound) | 76 | 195 (Deceased) |
| 84  | Endometrial adenocarcinoma | Left frontal | Sub-total | None | 628 | 972 (Deceased) |
| 70  | NSCLC | Right temporal | Gross total | Yes (WBRT after 2nd surgery) | 206 | 345 (Deceased) |

NSCLC: nonsmall cell lung cancer, WBRT: whole-brain radiotherapy, STRS: stereotactic radiosurgery. *MRI demonstrating metastatic disease was performed at day 45 postoperatively, therefore unable to determine if this was residual disease following sub-total resection or recurrent disease following gross-total resection. **No postoperative MRI
practice in the UK. Intraoperative imaging modalities such as ultrasound can be used to facilitate gross-total resection. Our study demonstrates that redo resection can be safely performed in patients with recurrent intracranial metastases with good overall survival. However, earlier detection of recurrent disease and treatment with STRS could obviate the need for redo resection. 2/10 patients who underwent redo resection had an unknown extent of resection following their primary surgery. On the other hand, 4/10 of those who underwent redo resection had an MRI scan demonstrating a higher incidence of infection.

| Tumor resections (n=124) | Details | Postoperative day | Duration of survival (days) |
|--------------------------|---------|-------------------|----------------------------|
| Arterial territory infarct* | Left posterior cerebral | 2 | 160 (Deceased) |
| Intracranial hemorrhage | Left anterior cerebral | 2 | 1147 (Alive) |
| Intracranial hemorrhage | Right anterior cerebral | 1 | 56 (Deceased) |
| Surgical site infection** | Extracerebral hematoma | 2 | 252 (Deceased) |
| Surgical site infection** | Intracerebral hematoma | 1 | 88 (Deceased) |
| Surgical site infection** | Intracerebral and intraventricular hematoma | 0 | 11 (Deceased) |
| Cerebral edema | Brain abscess | 44 | 56 (Deceased) |
| Cerebral edema | Brain abscess | 69 | 124 (Deceased) |
| Cerebral edema | Brain abscess | 47 | 129 (Deceased) |
| Cerebral edema | Subdural empyema | 28 | 1377 (Alive) |
| Cerebral edema | Subdural empyema | 12 | 145 (Deceased) |
| Cerebral edema | Intraoperative brain swelling, prophylactic craniectomy. Returned for autologous bone cranioplasty | 8 | 125 (Alive) |
| Ventricleloperitoneal shunt inserted for hydrocephalus | Location of metastasis excised | 3 | 97 (Alive) |
| Ventricleloperitoneal shunt inserted for hydrocephalus | 4th ventricle | 12 | 129 (Deceased) |
| Ventricleloperitoneal shunt inserted for hydrocephalus | Left temporal | 303 | 1377 (Alive) |
| Ventricleloperitoneal shunt inserted for hydrocephalus | Right cerebellar | 265 | 303 (Deceased) |
| Ventricleloperitoneal shunt inserted for hydrocephalus | Lateral ventricle | 49 | 97 (Alive) |
| Venous thromboembolism** | Pulmonary embolism | 6 | 56 (Deceased) |
| Venous thromboembolism** | Pulmonary embolism | 8 | 37 (Deceased) |
| Venous thromboembolism** | Deep vein thrombosis | 3 | 208 (Deceased) |
| Venous thromboembolism** | Deep vein thrombosis | 34 | 100 (Deceased) |

*As stated by the postoperative MRI. Extent of neurological deterioration not documented. Does not include patients with small areas of restricted diffusion adjacent to the surgical resection site. **All patients returned to theater for drainage of intracranial pus and removal of infected bone flap. ***Does not include two patients who were diagnosed and anti-coagulated preoperatively and one patient who was found to have an incidental, asymptomatic pulmonary embolism on a staging CT chest/abdomen/pelvis scan 59 days following surgery. The same patient, the same patient, the same patient

The dose and duration of dexamethasone administration are missing. Dexamethasone can provide symptomatic relief and reduce the risk of neurological deterioration while awaiting surgery. Hutchinson et al. showed in a randomized controlled clinical trial that dexamethasone was associated with a higher incidence of unfavorable outcome (moderately severe disability to dead) in patients with chronic subdural hematoma; in particular, dexamethasone was associated with a higher incidence of infection. While these results may
not be applicable to neuro-oncology patients; in our study, 4% died within 90 days of surgery due to pneumonia and 4% returned to theater due to surgical site infection. Data on cigarette smoking were missing from our study. Concurrent cigarette smoking increases the risk of surgical site infection, pneumonia, and perioperative

| Age (Years) | Extent of intracranial disease | Secondary location | Extent of resection | Primary cancer | Survival (days) | Cause of death |
|-------------|-------------------------------|-------------------|-------------------|---------------|----------------|---------------|
| 70          | Multiple                       | Left occipital    | No postoperative MRI | Small cell lung cancer | 37             | Respiratory failure. Pulmonary embolism with community acquired pneumonia. Intracranial metastatic disease progression |
| 71          | Solitary                       | Right frontal     | Gross total       | Small cell lung cancer | 89             | Unknown |
| 67          | Multiple                       | Left cerebellum   | Gross total       | NSCLC          | 47             | Unknown |
| 63          | Solitary                       | Right frontoparietal | No postoperative MRI | NSCLC          | 88             | Unknown |
| 58          | Multiple                       | Left temporoparietal | Increased tumor volume | NSCLC          | 52             | Intracranial metastatic disease progression |
| 70          | Solitary                       | Left frontal      | Gross total       | NSCLC          | 19             | Acute pancreatitis |
| 72          | Solitary                       | Left temporal     | No postoperative MRI | NSCLC          | 13             | Bowel perforation, peritonitis, and sepsis |
| 74          | Solitary                       | Right parietal    | Gross total       | NSCLC          | 39             | Respiratory failure. Community acquired pneumonia on a background of pulmonary fibrosis |
| 74          | Solitary                       | Right frontotemporal | Sub-total         | NSCLC          | 81             | Unknown |
| 59          | Solitary                       | Left frontal      | No postoperative MRI | NSCLC          | 20             | Respiratory failure. Hospital acquired pneumonia with ongoing heavy cigarette smoking |
| 68          | Solitary                       | Right frontal     | No postoperative MRI | NSCLC          | 10             | Respiratory failure. Hospital acquired pneumonia on a background of severe COPD. Developed atrial fibrillation due to sepsis. |
| 60          | Solitary                       | Right frontal     | No postoperative MRI | NSCLC          | 87             | Unknown |
| 62          | Solitary                       | Left occipital    | Gross total       | NSCLC          | 76             | Systemic disease progression with metastases to liver and myocardium and intracranial disease progression |
| 46          | Multiple                       | Right frontal     | Gross total       | Melanoma       | 56             | Postoperative complication. Anterior cerebral artery territory infarct, surgical site infection with intracerebral abscess, venous thromboembolism |
| 78          | Multiple                       | Right frontal     | Gross total       | Esophageal adenocarcinoma | 27             | Unknown |
| 74          | Multiple                       | Left temporal     | Gross total       | Breast adenocarcinoma | 23             | Systemic disease progression with liver, spleen, kidney, and lung metastases |
| 63          | Solitary                       | Pituitary         | Debulking         | Colorectal adenocarcinoma | 57             | Systemic disease progression with liver metastasis and diabetes insipidus due to pituitary dysfunction |
| 71          | Solitary                       | Left parietal     | No postoperative MRI | Renal cell carcinoma | 54             | Respiratory failure. Mediastinal lymphadenopathy and pleural effusion |
| 62          | Solitary                       | Left frontal      | No postoperative MRI | Endometrial sarcoma | 11             | Postoperative complication. Intracerebral hematoma with intraventricular extension |

NSCLC: Nonsmall cell lung cancer
Cigarette smoking can also cause other medical comorbidities such as chronic obstructive pulmonary disease which could contribute to poor clinical outcome. In our study, squamous NSCLC carried a shorter duration of survival than nonsquamous NSCLC \((P = 0.048)\), this could potentially be explained by the greater association between cigarette smoking in squamous NSCLC than adenocarcinoma.

*Table 6: Survival analysis.*

|                        | Patients | Median survival | \(P\) value |
|------------------------|----------|----------------|-------------|
|                        | Days     | Months (28 day) | Log rank (Mantel-Cox) |
| Total sample           | 112      | 233            | 8.3         | -          |
| Gender                 |          |                |             |
| Male                   | 44 (39%) | 160            | 5.7         | 0.051      |
| Female                 | 68 (61%) | 259            | 9.3         |            |
| Age                    |          |                |             |
| <50                    | 14 (13%) | 272            | 9.7         | 0.009      |
| 50–59                  | 22 (20%) | 320            | 11.4        |            |
| 60–69                  | 43 (38%) | 319            | 11.4        |            |
| >70                    | 33 (29%) | 151            | 5.4         |            |
| Intrinsic cerebral lesions |        |                |             |
| Preoperative seizures  |          |                |             |
| Yes                    | 13 (12%) | 215            | 7.7         | 0.980      |
| No                     | 83 (74%) | 235            | 8.4         |            |
| Location               |          |                |             |
| Frontal                | 48 (43%) | 215            | 7.7         | 0.065      |
| Frontoparietal         | 4 (4%)   | 145            | 5.2         |            |
| Frontotemporal         | 2 (2%)   | 170            | 6.1         |            |
| Parietal               | 15 (13%) | 1033           | 36.9        |            |
| Parieto-occipital      | 4 (4%)   | 171            | 6.1         |            |
| Occipital              | 12 (11%) | 181            | 6.5         |            |
| Temporal               | 9 (8%)   | 330            | 11.8        |            |
| Temporoparietal        | 2 (2%)   | 315            | 11.2        |            |
| Hemisphere             |          |                |             |
| Left                   | 49 (44%) | 215            | 7.7         | 0.575      |
| Right                  | 47 (42%) | 241            | 8.6         |            |
| Primary cancer histology |        |                |             |
| NSCLC*                 | 64 (65%) | 208            | 7.4         | 0.849      |
| Breast adenocarcinoma  | 14 (14%) | 303            | 10.8        |            |
| Colorectal adenocarcinoma | 7 (7%)  | 349            | 12.5        |            |
| Melanoma               | 7 (7%)   | 160            | 5.7         |            |
| Renal cell carcinoma   | 6 (6%)   | 326            | 11.6        |            |
| NSCLC                  |          |                |             |
| Nonsquamous            | 56 (87%) | 214            | 7.6         | 0.048      |
| Squamous               | 8 (13%)  | 152            | 5.4         |            |
| Number of intracranial metastases |          |                |             |
| Solitary               | 81 (74%) | 259            | 9.3         | 0.165      |
| Multiple               | 29 (26%) | 160            | 5.7         |            |
| Radiation treatment    |          |                |             |
| STRS or WBRT           | 41 (37%) | 319            | 11.4        | 0.129      |
| None                   | 71 (63%) | 185            | 6.6         |            |
| Extent of resection    |          |                |             |
| Gross total            | 46 (41%) | 330            | 11.8        | 0.022      |
| Sub-total              | 26 (23%) | 160            | 5.7         |            |
| Debulking              | 9 (8%)   | 195            | 7.0         |            |
| Unclear                | 31 (28%) | 252            | 9.0         |            |

*Included one patient with a lung adenocarcinoma which had metastasized into a CNS gliosarcoma. NSCLC: Nonsmall cell lung cancer, STRS: stereotactic radiosurgery, WBRT: whole-brain radiotherapy*
Death due to an unknown cause within 90 days of surgery occurred in 5% of the patients. These patients could have potentially died of a preventable cause such as surgical site infection, seizures, or venous thromboembolism. However, these patients may have chosen to not undergo further hospital admission, to focus on palliative symptomatic relief in their home. Furthermore, postmortem investigations are seldom performed in patients with metastatic cancer.

Figure 1: Kaplan–Meier graphs for survival analysis including all patients and then stratified by gender, age, and multiplicity of intracranial disease (median survivals and P values are displayed in Table 6).

Figure 2: Kaplan–Meier graph for survival analysis stratified by histological diagnosis, adjuvant radiation treatment, and extent of neurosurgical resection (median survivals and P values are displayed in Table 6).
because it often does not add helpful information to the family members and can cause distress. While this is understandable, it is difficult to improve our service when there is missing information on the causes of postoperative death.

During the time period of data collection, there has been a change in the preferred adjuvant radiation treatment in our service. In 2017, Brown et al. demonstrated that when compared against WBRT, STRS is associated with a longer duration of cognitive-deterioration-free survival and no difference in overall survival for patients undergoing adjuvant radiation treatment to the surgical cavity following resection of a solitary brain metastasis. Our study includes patients who underwent surgery between March 2014 and April 2021, and in the early years, WBRT was common practice; however, currently, STRS is most frequently used. As our study was retrospective, it did not include cognitive-deterioration-free survival as an outcome. A significant number of patients did not receive cranial radiation treatment and potential explanations for this include; the patient died before treatment was administered, patient choice, radiation treatment not offered in cases where a solitary metastasis had been completely resected as this is not recommended by NHS England, and logistical errors as the service transitioned from WBRT to STRS as these treatments are carried out by different clinical teams working in separate hospitals.

Given the impact of the COVID-19 pandemic on neuro-oncology services in the UK, this could have led to a reduction in overall survival for some patients in this study.

**CONCLUSION**

Cranial metastatic disease represents a heterogeneous patient population with multiple factors influencing the clinical outcome, therefore, when considering neurosurgical intervention, each case should be considered on an individual basis. There are ongoing advancements, with new medical therapies becoming available for different types of cancer in which neurosurgeons may not be aware of. Therefore, input from oncologists who treat the primary disease is crucial when selecting patients who would be suitable candidates for neurosurgical intervention.
scanning is recommended to identify residual tumor or new discrete lesions which could benefit from adjuvant STRS. If required, redo resection can successfully be performed with benefits to overall survival. In our study, age and extent of surgical resection were prognostic predictors of survival.

Declaration of patient consent

Patient’s consent not required as patient’s identity is not disclosed or compromised.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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Supplementary Figure 1: Bar charts showing multiplicity of intracranial disease, day postoperative MRI performed and extent of resection and adjuvant radiation treatment.