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Meningioma after radiotherapy for malignancy

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Abstract

Complications of radiation exposure have gained importance with increasing cancer survivorship. Secondary malignancies have been associated with cranial radiation exposure. We present our experience with intracranial radiation-induced meningioma (RIM) and discuss the implications of its presentation and natural history for patient management. Patients diagnosed with meningioma who had received radiation therapy between 1960 and 2014 were identified. Records were retrospectively reviewed for details of radiation exposure, previous malignancies, meningioma subtypes, multiplicity and pathologic descriptions, treatment and follow-up. Thirty patients were diagnosed with RIM. Initial malignancies included acute lymphocytic leukemia (33.3%), medulloblastoma (26.7%) and glioma (16.7%) at a mean age of 8.1 years (range 0.04–33 years). The mean radiation dose was 34 Gy (range 16–60 Gy) and latency time to meningioma was 26 years (range 8–51 years). Twenty-one patients (70%) underwent surgery. Of these, 57.1% of tumors were World Health Organization (WHO) grade I while 42.9% were WHO II (atypical). The mean MIB-1 labeling index for patients with WHO I tumors was 5.44%, with 33.3% exhibiting at least 5% staining. Mean follow-up after meningioma diagnosis was 5.8 years. Mortality was zero during the follow-up period. Meningioma is an important long-term complication of therapeutic radiation. While more aggressive pathology occurs more frequently in RIM than in sporadic meningioma, it remains unclear whether this translates into an effect on

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Conflicts of Interest/Disclosures

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survival. Further study should be aimed at delineating the risks and benefits of routine surveillance for the development of secondary neoplasms after radiation therapy.

Keywords

Meningioma; Radiation induced meningioma; Radiation therapy

1. Introduction

After the discovery of X-rays in the late 1800s, radiation for an array of applications became increasingly widespread in the early twentieth century. Shortly after its inception, it became clear that radiation could also have harmful effects, though its potential to induce malignancy did not come to the forefront until the extensive exposures associated with atomic explosions in Hiroshima and Nagasaki.[1]

Meningioma as a consequence of radiation exposure has been described in multiple settings. Secondary neoplasia has been shown to be a dose-dependent phenomenon, whether accidental or for intended therapeutic purposes.[1-4] Although the definition of radiation-induced meningioma (RIM) is not standardized, meningioma within a previously irradiated field is the most broad and common diagnostic criterion.[1] As we consider the clinical implications of RIM, the effects of radiation dose on subsequent management decisions cannot be ignored. Standard follow-up surveillance for patients receiving radiation is not well established, and the amount of radiation exposure has a significant impact on the potential for subsequent complications. Studies performed over the last 20 years have focused on large population-based exposure studies,[4] low dose exposures with long-term follow-up [2] and individual reports or small series of cases after therapeutic radiation.[5-10]

While these studies have established a relationship between radiation dose and the development of meningioma, and a trend toward more aggressive pathologies, a cohort of patients who have developed meningioma after high dose radiation for prior malignancy has not been explored in detail. We present a series of patients who developed RIM after therapeutic radiation and discuss potential implications for screening procedures and management of these individuals.

2. Methods

This study was approved by the Memorial Sloan Kettering Cancer Center Institutional Review Board. Patients were identified by query of the institution's electronic medical records. Brain tumor diagnosis data was used, with data available from 1991–2014, to identify patients with a diagnosis of meningioma of any pathologic subtype who had also received prior radiation therapy for malignancy. These patients were screened for timing of radiation therapy greater than 5 years prior to meningioma diagnosis documented in the patient record, for which records were available dating back to 1960. Further screening selected patients whose radiation field included the meningioma site and a latency period of 5 years or greater in order to exclude coincidental sporadic meningioma.

Thirty patients were identified with radiation exposure occurring between 1960 and 1997. Meningioma diagnoses occurred between 1997 and 2014. Patient records were retrospectively reviewed and data collected regarding dates, doses and fields of radiation exposure, previous malignancies, meningioma subtypes, multiplicity and pathologic descriptions, treatments and follow-up. Pathology data was reviewed to ensure that assigned World Health Organization (WHO) grade was consistent with the 2007 criteria. MIB-1 labeling was recorded when available, as standard practice at this institution is to measure this index of proliferation for WHO I meningioma. MIB-1 index was measured by an attending pathologist by manual count using an ocular grid superimposed over an area containing >1000 tumor cells. Recurrent RIM was defined as meningioma reoccurring at the same site after complete resection.

Descriptive statistics such as frequencies, medians, means, and ranges were utilized for characterization of the population under study. Correlation between total radiation dose to the meningioma site and latency in this series was analyzed by Pearson correlation coefficient. Correlations between receipt of chemotherapy and categorical characteristics of interest (WHO grade, and age at radiation dichotomized at 5 years) were examined with Fisher's exact test. Correlations between receipt of chemotherapy and continuous characteristics of interest (latency and MIB) were analyzed with the Wilcoxon rank sum test. All p-values were two-sided with a level of significance less than 0.05 and all statistical analyses were done in SAS (version 9.4, SAS Institute, Cary, NC, USA).

3. Results

Thirteen women and 17 men were diagnosed with RIM. The mean age at diagnosis of the primary malignancy was 8.1 years (range 0.04–33 years). Common initial malignancies included acute lymphocytic leukemia (33.3%), medulloblastoma (26.7%), and glioma (16.7%) and the mean radiation dose was 34 Gy (range 16–60 Gy, Table 1). The mean age at RIM diagnosis was 34.7 years (range 12.2–57.7), and mean latency time to meningioma diagnosis was 26 years (range 8–51 years, Table 2).

Patients were most commonly asymptomatic at diagnosis (60.0%), while 26.7% of patients presented with headache and a smaller number with other signs and symptoms (Table 2). There was no difference in latency time between patients receiving radiation under or over the age of 5 years ($p=0.95$) and no correlation between radiation dose and latency time ($r^2=0.11$, $p=0.64$). Patients receiving chemotherapy had a significantly later date of primary diagnosis (72% after 1983 *versus* 18% before 1983, $p=0.0047$) and shorter latency period between radiation therapy and meningioma diagnosis than those who were not treated with chemotherapy for their first malignancy (21 *versus* 32 years, $p=0.03$, Table 3). Supratentorial meningiomas comprised 80.0%, while the remainder were intraventricular or occurred in the posterior fossa (Table 4).

Twenty-one patients (70.0%) were treated with surgical resection, one patient (3.3%) was treated with radiation therapy and eight (26.7%) were observed without intervention (Table 2). Of those undergoing surgical resection, 57.1% were WHO I and 42.9% were WHO II (Table 5). The mean MIB-1 labeling index for patients with WHO I tumors was 5.44%, with

33.3% exhibiting 5% staining (Table 6). The mean number of meningiomas per patient in the cohort was 1.6 (range 1–6). Ten patients had multiple lesions. The mean duration of follow-up after meningioma diagnosis in the overall cohort was 5.8 years, and in the surgical subset was 5.9 years. The mortality was zero during the follow-up period and four patients developed recurrent meningioma in that time.

4. Discussion

RIM is a pathologic entity that has received increasing attention over the last several decades as the use of ionizing radiation for diagnostic and therapeutic purposes and concomitant public concerns about the risks of exposure grow. Simultaneously, the resolution of MR imaging has vastly improved, enabling identification of smaller lesions and perhaps contributing to the observed incidence of this phenomenon. Various groups have identified individual cases of RIM, while others have described larger cohorts through different lenses. The Israeli Tinea Capitis Cohort is a study of the characteristics of 253 individuals diagnosed with RIM after low dose radiation (1–6 Gy) to the scalp for the treatment of tinea capitis. The authors discussed key differences between the RIM and sporadic meningioma (SM). Among these were multiple neoplasms, younger age at diagnosis, higher rates of recurrence (not statistically significant) and calvarial location.[2] To our knowledge this is the largest published descriptive cohort of patients with RIM, but is somewhat limited by the low doses of radiation exposure specifically to the scalp, rather than observing the effects of higher doses and broader cranial exposure.

The USA Childhood Cancer Survivor Study (CCSS) has reported on the incidence of second and third malignancy in children with cancer surviving longer than 5 years. They noted that the cumulative incidence of secondary malignancy at 30 years after primary diagnosis was 20.5%, 3.1% for meningioma alone. Radiation exposure was identified as an independent risk factor, with a relative risk of 2.7, while other risk factors included older age at primary diagnosis, Hodgkin lymphoma, and female sex.[11] The other large study available today is the British Childhood Cancer Survivor Study. Like the CCSS it clearly demonstrates a relationship between incidence of RIM and radiation dose in childhood.[4] Unfortunately, while these studies establish the incidence and risk factors for all secondary malignancies after radiation, the information necessary to analyze other characteristics of the patients developing RIM such as their pathologies and disease specific outcomes, is not available. This leaves us to rely on case reports and small series of patients for information about detection and clinical behavior of these tumors.[5-10,12-25]

Common themes have emerged, identifying several important characteristics that distinguish RIM from SM. Patients with RIM are typically younger than those with SM and more frequently have multiple meningiomas. Additionally, some have suggested that patients irradiated under the age of 5 years are likely to develop secondary malignancy in more rapid course than older patients.[16,23] However, our cohort demonstrates no statistically significant difference in latency time when one compares patients receiving radiation therapy at an early age with adolescents and adults, nor did we find any relationship between dose and latency time. These conclusions support prospectively collected data in the Israeli Tinea Capitis Cohort.[2] However, it is important to note that the exact dose of radiation to

the meningioma site is quite difficult to estimate retrospectively. We therefore cannot make a definitive assertion as to the presence or absence of a correlation between the exact radiation dose and latency time when patients are receiving higher doses of radiation than the Tinea Capitis Cohort experienced.

Of the 30 patients in our study, 18 received chemotherapy at the time of their initial cancer diagnosis. We found that the presence of prior chemotherapy was significantly correlated with a shorter latency time to meningioma diagnosis. The importance of this observation is unclear at this time, as the difference we identified is driven by a later date of diagnosis for those receiving chemotherapy. It could also be confounded by diagnosis (10 of these patients had acute lymphocytic leukemia as the primary malignancy) and other characteristics that could not be excluded by multivariate analysis because of the small size of our cohort. Despite these caveats, this is a potential area for further investigation as we collect data prospectively and perhaps combine data sets with other institutions.

A critical difference between RIM and SM is clinical behavior. In some reports it has been shown that there is a higher rate of more aggressive pathologic subtypes in RIM than in SM. [1,2,14,16,25,26] Our data supports the observations of these smaller studies, with 42.9% of surgically resected tumors qualifying as atypical (WHO II) meningioma, compared with estimates of 5–35% of SM, depending on which version of the WHO grading criteria was applied.[26,27] Another striking observation from our cohort is the proliferation rate of WHO I tumors. We demonstrate a greater percentage of patients with increased MIB-1 labeling in WHO I tumors, another indicator of more aggressive pathology.[14,16,27] The largest available cohort of patients with SM to our knowledge exhibited a 3.28% mean MIB-1 labeling index.[28] We find a mean MIB-1 index of 5.4% in patients with pathologic samples available, and we find that 33.3% of patients had at least 5% staining, more than would be expected in WHO I SM. This may indicate that WHO I RIM is a less benign entity than WHO I, warranting a different clinical approach. A larger prospective study would address this question.

For patients with available pathology data, we saw a higher rate of WHO II tumors in our RIM series than described elsewhere in the literature, but this has not clearly translated to decreased survival. Some have suggested that atypical SM may portend a worse prognosis than atypical RIM,[25] but substantive evidence to support this conclusion remains elusive. Our data support this conclusion in that we see a higher rate of atypical pathology without a consequent increase in mortality in more than 5 years mean follow-up. We acknowledge, however, that the retrospective nature of our series limits the strength of this observation.

An important limitation of this report lies in data accrual. Based on our experience in identifying patients it is likely that this does not comprise the entire subset of RIM at our institution due to incomplete radiation records prior to 1980 and the fact that some patients received radiation at other institutions that was not well documented at our center. Furthermore, several patients in this cohort had surgical resections at outside institutions and pathology reports could not be obtained. Going forward we will collect information on patients with RIM prospectively to allow for more robust study.

Questions remain as to how and whether patients exposed to ionizing radiation in childhood and beyond should be monitored over the long term. We understand that radiation can cause meningioma and that the dose is related to the probability of this occurrence, but a standardized protocol for surveillance has not been widely adopted. It is not clear that regular, routine surveillance imaging for meningioma screening after radiation therapy will reduce morbidity or mortality in patients of any age, or whether the addition of chemotherapy at the time of initial malignancy affects the risks associated with secondary malignancy. But based on the pathologies seen in our cohort and frequent asymptomatic presentation we suggest that these are important areas for further investigation.

5. Conclusions

RIM remains an important consequence of radiation exposure. We have demonstrated several important factors to consider in patients with RIM, including multiplicity, common presenting signs and symptoms, and proliferative behavior when compared with SM. However, it remains unclear how these findings affect overall survival. Going forward it will be important consider whether and how patients undergoing radiation treatment with or without chemotherapy should be screened for the development of meningioma in order to minimize harm associated with these potentially life-saving therapies.

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References

1. Umansky F, Shoshan Y, Rosenthal G, Fraifeld S, Spektor S. Radiation-induced meningioma. 2008; 24doi: 10.3171/FOC/2008/24/5/E7
2. Sadetzki S, Flint-Richter P, Ben-Tal T, Nass D. Radiation-induced meningioma: a descriptive study of 253 cases. *Journal of Neurosurgery*. 2002; 97:1078–82. [PubMed: 12450029]
3. al-Mefty O, Kersh JE, Routh A, Smith RR. The long-term side effects of radiation therapy for benign brain tumors in adults. *Journal of Neurosurgery*. 1990; 73:502–12. DOI: 10.3171/jns.1990.73.4.0502 [PubMed: 2204689]
4. Taylor AJ, Little MP, Winter DL, Sugden E, Ellison DW, Stiller CA, et al. Population-based risks of CNS tumors in survivors of childhood cancer: the British Childhood Cancer Survivor Study. *J Clin Oncol*. 2010; 28:5287–93. DOI: 10.1200/JCO.2009.27.0090 [PubMed: 21079138]
5. Kleinschmidt-DeMasters BK, Lillehei KO. Radiation-induced meningioma with a 63-year latency period. Case report. *Journal of Neurosurgery*. 1995; 82:487–8. DOI: 10.3171/jns.1995.82.3.0487 [PubMed: 7861229]
6. Tsukamoto H, Yoshinari M, Okamura K, Ishitsuka T, Fujishima M. Meningioma developed 25 years after radiation therapy for Cushing's disease. *Intern Med*. 1992; 31:629–32. [PubMed: 1504425]
7. Ijiri R, Tanaka Y, Hara M, Sekido K. Radiation-associated xanthomatous meningioma in a child. *Childs Nerv Syst*. 2000; 16:304–8. DOI: 10.1007/s003810050519 [PubMed: 10883374]
8. Korenkov AI, Imhof HG, Brandner S, Taub E, Huguenin PU, Gaab MR, et al. Growth Retardation and Bilateral Cataracts Followed by Anaplastic Meningioma 23 Years after High-Dose Cranial and Whole-Body Irradiation for Acute Lymphoblastic Leukemia: Case Report and Review of the Literature. *J Neurooncol*. 2005; 74:195–9. DOI: 10.1007/s11060-004-6151-8 [PubMed: 16193392]
9. Kawahara I, Masui K, Horie N, Matsuo T, Kitagawa N, Tsutsumi K, et al. Radiation-induced meningioma following prophylactic radiotherapy for acute lymphoblastic leukemia in childhood. *Pediatric Neurosurgery*. 2007; 43:36–41. DOI: 10.1159/000097524 [PubMed: 17190987]

10. Char DH, Shiel MJ. Orbital Meningioma After Cranial Radiation for Acute Lymphocytic Leukemia. *Orbit*. 2008; 27:321–3. DOI: 10.1080/01676830802222761 [PubMed: 18716974]
11. Friedman DL, Whitton J, Leisenring W, Mertens AC, Hammond S, Stovall M, et al. Subsequent neoplasms in 5-year survivors of childhood cancer: the Childhood Cancer Survivor Study. *J Natl Cancer Inst*. 2010; 102:1083–95. DOI: 10.1093/jnci/djq238 [PubMed: 20634481]
12. Chourmouzi D, Papadopoulou E, Kontopoulos A, Drevelegas A. Radiation-induced intracranial meningioma and multiple cavernomas. *BMJ Case Rep*. 2013; 2013 bcr2013010041–1. doi: 10.1136/bcr-2013-010041
13. Zhou Q, Chang H, Gao Y, Cui L. Tumor-to-tumor metastasis from pituitary carcinoma to radiation-induced meningioma. *Neuropathology*. 2013; 33:209–12. DOI: 10.1111/j.1440-1789.2012.01343.x [PubMed: 22989053]
14. Goto Y, Yamada S, Yamada SM, Nakaguchi H, Hoya K, Murakami M, et al. Radiation-induced meningiomas in multiple regions, showing rapid recurrence and a high MIB 1 labeling index: a case report and review of the literature. *World J Surg Oncol*. 2014; 12:123.doi: 10.1186/1477-7819-12-123 [PubMed: 24767145]
15. Johnson MD, Piech K, Emandian S. Radiation-associated meningioma in the elderly: development of meningioma with olfactory neuroblastoma recurrence 10 years after irradiation. *Ann Clin Lab Sci*. 2013; 43:460–3. [PubMed: 24247807]
16. Elbabaa SK, Gokden M, Crawford JR, Kesari S, Saad AG. Radiation-associated meningiomas in children: clinical, pathological, and cytogenetic characteristics with a critical review of the literature. *J Neurosurg Pediatr*. 2012; 10:281–90. DOI: 10.3171/2012.7.PEDS1251 [PubMed: 22900483]
17. Kamoshima Y, Terasaka S, Kobayashi H, Kaneko S, Kubota K, Tanaka S, et al. Radiation induced intraparenchymal meningioma occurring 6 years after CNS germinoma: case report. *Clinical Neurology and Neurosurgery*. 2012; 114:1077–80. DOI: 10.1016/j.clineuro.2012.02.008 [PubMed: 22421255]
18. Ney DE, Huse JT, Dunkel IJ, Steinherz PG, Haque S, Khakoo Y. Intraventricular meningioma after cranial irradiation for childhood leukemia. *Journal of Child Neurology*. 2010; 25:1292–5. DOI: 10.1177/0883073810362267 [PubMed: 20207611]
19. Brassesco MS, Valera ET, Neder L, Pezuk JA, Oliveira RS, Scrideli CA, et al. Cytogenetic findings in pediatric radiation-induced atypical meningioma after treatment of medulloblastoma: case report and review of the literature. *J Neurooncol*. 2012; 110:397–402. DOI: 10.1007/s11060-012-0982-5 [PubMed: 23076602]
20. Brassesco MS, Valera ET, Neder L, Castro-Gamero AM, de Oliveira FM, Santos AC, et al. Childhood radiation-associated atypical meningioma with novel complex rearrangements involving chromosomes 1 and 12. *Neuropathology*. 2009; 29:585–90. DOI: 10.1111/j.1440-1789.2008.00991.x [PubMed: 19077038]
21. Hope AJ, Mansur DB, Tu P-H, Simpson JR. Metachronous secondary atypical meningioma and anaplastic astrocytoma after postoperative craniospinal irradiation for medulloblastoma. *Childs Nerv Syst*. 2006; 22:1201–7. DOI: 10.1007/s00381-006-0062-2 [PubMed: 16570196]
22. Rao MB, Rout D, Radhakrishnan VV. Suprasellar meningioma subsequent to treatment for a pituitary adenoma: case report. *Surg Neurol*. 1997; 47:443–6. [PubMed: 9131026]
23. Strojan P, Popovic M, Jereb B. Secondary intracranial meningiomas after high-dose cranial irradiation: report of five cases and review of the literature. *International Journal of Radiation Oncology Biology Physics*. 2000; 48:65–73.
24. Caroli E, Salvati M, Roperto R, D'Andrea G, Ferrante L. High-Dose Radiation-Induced Meningioma in Children. *Zentralbl Neurochir*. 2005; 66:39–42. DOI: 10.1055/s-2004-832472 [PubMed: 15744628]
25. Galloway TJ, Indelicato DJ, Amdur RJ, Swanson EL, Morris CG, Marcus RB. Favorable outcomes of pediatric patients treated with radiotherapy to the central nervous system who develop radiation-induced meningiomas. *International Journal of Radiation Oncology Biology Physics*. 2011; 79:117–20. DOI: 10.1016/j.ijrobp.2009.10.045

26. Claus EB, Bondy ML, Schildkraut JM, Wiemels JL, Wrensch M, Black PM. Epidemiology of intracranial meningioma. *Neurosurgery*. 2005; 57:1088–95. discussion1088–95. DOI: 10.1227/01.NEU.0000188281.91351.B9 [PubMed: 16331155]
27. Rogers L, Gilbert M, Vogelbaum MA. Intracranial meningiomas of atypical (WHO grade II) histology. *J Neurooncol*. 2010; 99:393–405. DOI: 10.1007/s11060-010-0343-1 [PubMed: 20740303]
28. Roser F, Samii M, Ostertag H, Bellinzona M. The Ki-67 proliferation antigen in meningiomas. Experience in 600 cases. *Acta Neurochir (Wien)*. 2004; 146:37–44. discussion44. DOI: 10.1007/s00701-003-0173-4 [PubMed: 14740263]

Table 1

Characteristics of initial presentation and management of 30 patients undergoing radiation therapy and subsequently developing meningioma

Characteristic	Value (%)
Sex	
Male	17 (56.7)
Female	13 (43.3)
Age in years	
Mean	8.1
Median	6
Range	0.04–33
Primary malignancy	
Acute lymphocytic leukemia	10 (33.3)
Medulloblastoma	8 (26.7)
Glioma	5 (16.7)
Retinoblastoma	2 (6.7)
Ependymoma	2 (6.7)
Lymphoma	1 (3.3)
Neuroblastoma	1 (3.3)
Sarcoma	1 (3.3)
Radiation dose	
Mean	34 Gy
Median	34 Gy
Range	16–60 Gy

Table 2

Characteristics of 30 patients at meningioma diagnosis and management

Meningioma characteristics	Value (%)
Age at presentation in years	
Mean	34.7
Median	33.6
Range	12.2–57.7
Latency period in years	
Mean	26
Median	23
Range	8–51
Presenting signs/symptoms	
Asymptomatic	18 (60.0)
Headache	8 (26.7)
Seizure	1 (3.3)
Focal deficit	1 (3.3)
Visual loss	2 (6.7)
Physical deformity	1 (6.7)
Neck pain	1 (6.7)
Unknown	1 (6.7)
Management	
Observation	8 (26.7)
Surgical resection	21 (70.0)
Radiation therapy	1 (3.3)

Table 3

Relationship between chemotherapy for initial malignancy and RIM grade, MIB-1 labeling and latency time in 29 patients with RIM¹

Characteristic	No chemotherapy	Chemotherapy	Unavailable	p value ²
Grade (n)				
WHO I	5	6	1	0.50
Atypical	2	7	0	
Unavailable	4	5	0	
MIB-1 (median)	7.5%	8%	4%	0.82
Latency time (years)	32	21	27	0.03

¹ Patients who received chemotherapy had a later date of primary diagnosis than those who did not receive chemotherapy.

² p value describes the comparison of patients with and without chemotherapy.

RIM = radiation-induced meningioma, WHO = World Health Organization.

Table 4

Location of initial meningioma in 30 patients undergoing prior radiotherapy

Location	Tumors, n (%)
Frontal	10 (33.3)
Temporal	5 (16.7)
Parietal	7 (23.3)
Tentorial	2 (6.7)
Anterior skull base	2 (6.7)
Cerebellopontine angle	1 (3.3)
Foramen magnum	1 (3.3)
Intraventricular	1 (3.3)
Unknown	1 (3.3)

Table 5

Classification of meningioma grade in 21 patients with radiation-induced meningioma

Pathologic designation	Patients, n (%)
Benign (WHO I)	12 (57.1)
Atypical	9 (42.9)

WHO = World Health Organization.

Table 6

MIB-1 labeling index as reported by the reviewing pathologist at the time of surgery for 12 patients with World Health Organization grade I radiation-induced meningioma

MIB-1 labeling index	Patients, n (%)
<5%	5 (41.7)
5–9%	2 (16.7)
>9%	2 (16.7)
Not available	3 (25.0)
Mean	5.4%