Review Article

Characteristics of cranial vault lymphoma from a systematic review of the literature

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ABSTRACT

Background: Cranial vault lymphomas are rare and their clinical features are often similar to those of cranial vault meningiomas. The objective of this review was to identify the features helpful for differentiating lymphomas of the cranial vault, from meningiomas which were the most common diagnosis before the definitive pathological diagnosis.

Methods: The inclusion criterion was a histologically proven malignant lymphoma initially appearing in the calvarium. We conducted a literature search of the electronic PubMed and Ichushi-Web databases up to June 1, 2020. Cranial vault lymphoma that was diagnosed after an original diagnosis of lymphoma in a nodal or soft-tissue site was excluded from the study. Descriptive analyses were used to present the patient characteristics.

Results: A total of 111 patients were found in 98 eligible articles. Almost all studies were case reports. The most common symptom was a growing subcutaneous scalp mass (84%) present for a mean duration of 5.9 months before the patient presented for treatment in analyzable cases; this fast growth may distinguish lymphomas from meningiomas. The tumor vascularization was often inconspicuous or poor, unlike well-vascularized meningiomas. A disproportionately small amount of skull destruction compared with the soft-tissue mass was observed in two-thirds of the analyzable cases.

Conclusion: This qualitative systematic review identified several features of cranial vault lymphomas that may be useful in differentiating them from meningiomas, including a rapidly growing subcutaneous scalp mass, poor vascularization, and limited skull destruction relative to the size of the soft-tissue mass.

Keywords: Calvarial lymphoma, Calvarium, Lymphosarcoma, Reticulum cell sarcoma, Skull

INTRODUCTION

Malignant lymphoma of the bone is uncommon and, hence, presents diagnostic and therapeutic problems.[71] Cranial vault involvement has been reported to account for 5.5% of bone lymphoma cases and the number of reported cases of lymphoma initially appearing in the calvarium is limited.[21] The diagnosis of this rare cranial vault tumor before pathological diagnosis has usually been not lymphoma but meningioma, metastatic tumor, or other mesenchymal tumors, which has tended to lead to radical operative treatments like gross total removal of the tumor.[1,25,96] If we can make a differential diagnosis of cranial vault lymphoma preoperatively, we may choose less radical procedures like biopsy and can start chemotherapy at an earlier time. This article presents...
a systematic review of the literature to show demographic, clinical, and imaging characteristics, as well as treatments and outcomes of cranial vault lymphoma. We specify characteristic features of cranial vault lymphoma that may be helpful for their diagnosis, especially to distinguish them from meningiomas, which have been the most common diagnosis of cranial vault lymphomas before definitive pathological diagnosis [1,2,4,13,35,36,37,50,54,65,66,70,75,84,86,88,96,105].

MATERIALS AND METHODS

Eligibility criteria

The inclusion criterion was a histologically proven malignant lymphoma initially appearing in the calvarium. Cranial vault lymphoma that was diagnosed after an original diagnosis of lymphoma in nodal or soft-tissue site was excluded from the study. Skull base lymphoma and dural lymphoma were also excluded from the study. Articles whose full text was unable to be located were excluded from the study. We excluded systematic and retrospective review articles and case series articles that did not include case-specific data.

Information sources and search strategy

We conducted a literature search of the electronic PubMed and Ichushi-Web databases up to June 1, 2020, using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. We extracted all human reports on cranial vault lymphomas, using the following terms: cranial vault lymphoma; skull lymphoma; calvarial lymphoma; transcalvarial lymphoma; dural lymphoma; and combinations of the variables of lymphoma, lymphosarcoma (an obsolete classification of non-Hodgkin lymphoma), reticulum cell sarcoma (another obsolete classification of non-Hodgkin lymphoma), cranial vault, skull, and calvarium. The search resulted in 1492 PubMed citations and 391 Ichushi-Web citations, 113 of which were duplicated, resulting in a total of 1770 articles [Figure 1].

Selection process

Two reviewers (N.N. and T.F.) independently and in duplicate screened, reviewed, and discussed all the selected articles. The full text of all eligible articles was reviewed, and their data extracted and collated. In cases where questions regarding the inclusion of certain articles arose, this was discussed with a third reviewer, K.N.

Data collection process and data items

Data of the eligible works were obtained through careful analysis of the full text by two authors (N.N. and T.F.) independently. The senior author, K.N., was available in case of a split decision. Questions arising as to pathological diagnosis were discussed with a pathologist, S.M. We analyzed the clinical and radiological characteristics of the patients, as well as their treatments and survival in these published studies. Specifically, we extracted the following items: age of the patient; sex; clinical symptoms; location of tumors; findings of palpation; skin condition; speed of growth; existence of other lesions; types of treatment; extent of resection; duration of follow-up and outcomes; laboratory data; imaging data of skull X-ray, angiogram, computed tomography (CT), magnetic resonance imaging (MRI), and others; bone images on CT; extra- and intracranial tumor extension on CT and MRI; dural tail and brain invasion on MRI; and histopathological types. Due to the heterogeneity of patient descriptions, some clinical and imaging features were not explicitly reported for each patient. We extracted and reported only unambiguously described data. Data on clinical and imaging features were also extracted from the patient imaging data. Evaluation of publication bias was not feasible because of heterogeneity and because most of the included studies were case reports and case series.

Figure 1: The PRISMA flowchart of our systematic review. New studies were those identified from the reference lists of articles identified in the initial screen.
Nitta, et al.: Cranial vault lymphoma

Statistical analysis

Descriptive analyses were used to present the patient characteristics. Continuous variables were expressed as mean ± standard deviation, and categorical variables were expressed as number and percentage. Because of the limited follow-up data included in each intervention and the lack of standardization of assays and treatments across the many laboratories included in the present review, we were unable to statistically compare the findings on images and the changes in clinical outcomes. All calculations were performed with JMP 13.2.1 (SAS Institute, Inc., Cary, North Carolina, U.S.).

RESULTS

From among the articles found, we selected all studies reporting patients with cranial vault lymphoma (n = 106) without limitation of language and identified additional studies from the reference lists of the articles (n = 3). After discarding duplicate references and publications (n = 2), as well as excluding reports of secondary cranial vault lymphoma, skull base lymphoma, or dural lymphoma (n = 9), we settled on 98 articles for careful review. The number of articles retained at each stage of data acquisition is shown in a PRISMA flowchart [Figure 1].

We found 111 cases of histologically proven malignant lymphomas initially appearing in the cranial vault in the 98 articles and analyzed the data of 111 patients [Tables 1, S1, and S2].

The average patient age was 52 ± 20 years (range, 3–85 years) [Table 1]. The male-to-female ratio was 1.09:1. Common symptoms were a growing subcutaneous mass on the scalp (84%), headache (33%), focal neurological deficit (25%), and seizure (6%) in the 110 cases with available data. The parietal (57%), frontal (54%), occipital (21%), and temporal (15%) bones were the affected sites in 110 cases with analyzable data. The subcutaneous scalp mass was firm (57%), soft (16%), nontender (56%), tender (22%), or accompanied by reddish skin or ulcer (7%) in 68 cases with a description of the scalp mass. In the 49 cases with a description of mass growth, the mean duration of growth was 5.9 ± 6.3 months before the patient presented for treatment. In 23% of 93 cases with available data, lesions outside the cranial vault were present.

Laboratory data were described in 59 cases, with human immunodeficiency virus positivity in 5 cases (8%), elevated lactate dehydrogenase in 6 cases (10%), anemia in 4 cases (7%), increased white blood cell count in 3 cases (5%), elevated erythrocyte sedimentation rate in 2 cases (3%), elevated alkaline phosphatase in 1 case (2%), increased soluble interleukin-2 receptor (sIL2R) in 1 case (2%), and decreased platelets in 1 case (2%) [Table S1]. Findings on plain skull X-ray were described in 38 cases, including osteolytic changes at the tumor site in 29 cases (76%), no change in 6 cases (16%), hyperostosis in 2 cases (5%), and periosteal reaction in 4 cases (11%). A sharp margin of the skull lesion was observed in 6 cases (16%) and an indistinct or irregular margin of the skull lesion in 15 cases (40%). In 12 cases with description of tumor vascularization on angiogram, no or poor tumor vascularization was found in 7 cases (58%). If any vascularization was present, it was mainly derived from the external carotid artery circulation. Among 32 cases with analyzable CT data, the tumor was hyperdense in 25 cases (78%), isodense in 5 cases (16%), and hypodense in 2 cases (6%). Among 42 cases with contrast-enhanced (CE) CT data, the tumor was enhanced well in 37 cases (88%) and slightly in 5 cases (12%). Most tumors were enhanced diffusely, either homogeneously or heterogeneously, whereas some extracranial components showed peripheral enhancement. On MRI, T1-weighted imaging (T1WI) with analyzable data (n = 38) showed a hyper- and isointense tumor in 1 case (3%), isointense tumor in 11 cases (29%), iso- and hypointense tumor in 4 cases (11%), and hypointense tumor in 22 cases (58%). T2-weighted imaging (T2WI) (n = 40) showed a hyperintense tumor in 21 cases (53%), hyper- and isointense tumor in 1 case (3%), isointense tumor in 12 cases (30%), iso- and hypointense tumor in 5 cases (13%), and hypointense tumor in 1 case (3%). CE-T1WI (n = 48) showed an enhancing tumor in 48 cases (100%). The tumors tended to show uptake on 18F-fluorodeoxyglucose positron emission tomography (FDG-PET) and on bone scintigraphy and gallium scintigraphy, which were also used for the evaluation of lesions outside the cranial vault.

Extra- and intracranial extensions of the tumor were evaluated by CT, MRI, or both in 87 cases [Table S2]; the extracranial extension was much larger than the intracranial extension in 35 cases (40%), both were nearly the same size in 35 cases (40%), the intracranial extension was much larger than the extracranial extension in 16 cases (18%), and there was neither intra- nor extracranial extension in 1 case (1%). Bone changes of the cranial vault due to the tumor were evaluated by CT, MRI, or both in 84 cases. The images showed no skull changes and/or preserved skull contour in 11 cases (13%), osteolytic changes in 68 cases (81%), hyperostosis in 4 cases (5%), and only sclerosis at the lesion in 1 case (1%). In the 68 cases with osteolytic skull changes due to the tumor, the skull was penetrated or dissolved to less than half of the thickness in 26 cases (38%), whereas permeative dissolution with relatively preserved skull contour was observed in 35 cases (51%). Periosteal bone formation was observed in 10 cases (15%). In seven cases, there was no detailed description. A disproportionately small area of cortical destruction of the cranial vault relative to the volume of the extra- or intracranial soft-tissue mass, which we defined as cortical destruction less than one-fifth of the soft-tissue mass in diameter, was observed in 50 cases (67%) on CT, MRI, or...
Table 1: Clinical features, treatment, and outcome of 111 patients with cranial vault lymphoma.

| Author year (reference) | Age (years) | Sex | Symptoms at onset | Lesion location | Properties of mass | Other lesions | Surgery | Adjuvant therapies | Outcomes (follow-up) |
|-------------------------|-------------|-----|-------------------|----------------|-------------------|--------------|---------|-------------------|----------------------|
| Wichtl, 1949            | 66          | F   | Subcutaneous mass on the scalp | Occipital | NA | NA | Biopsy | R | Died* (55 mo) |
| Strange and De Lorimier, 1954 | 50 | F | Subcutaneous mass on the scalp | Frontal | Soft, growing for 6 mo, 8 cm | NA | Biopsy | R | Alive (7 y) |
|                         | 47 | F | Subcutaneous mass on the scalp, neurological deficit | Frontal | Soft, nontender, growing for 6 mo | NA | Biopsy | R | Alive (1 y) |
|                         | 66 | F | Subcutaneous mass on the scalp | Parietotemporal | Firm, nontender, growing for 8 mo, 6 cm | Preauricular LNs | Biopsy | R | Alive (10 mo) |
| Ullrich and Bucy, 1958  | 53 | F | Subcutaneous mass on the scalp, headache | Frontal, occipital | Soft, tender, 9 cm | None | Gross total removal | R | Alive (5.5 y) |
| Piendak and Alder, 1959 | 33 | M | Subcutaneous mass on the scalp, diplopia, ophthalmalgia | Frontal | Soft | None | Subtotal removal | R | Alive (9 y) |
| Block and Peck, 1964    | 68 | M | Subcutaneous mass on the scalp | Frontal | Firm, nontender, nonreddish, growing for 1 mo, 5 cm | Axillary LNs | Biopsy | R | NA |
| Topolnicki and White, 1969 | 67 | F | Subcutaneous mass on the scalp, headache | Frontoparietal | Soft, nontender, 12 cm Ulcerated | None | Biopsy | R | Alive (4 y) |
| Wainwright, 1973        | 77 | M | Subcutaneous mass on the scalp, ulceration | Fronto-parietal | Soft, nontender, growing for 5 mo, 17 cm | Anterior cervical LNs | Subtotal removal | C | Alive (22 mo) |
| Gawish, 1976            | 8  | M | Subcutaneous mass on the scalp | Frontal | Soft, nontender, growing for 5 mo, 17 cm | None | Gross total removal | R | Alive (7 mo) |
| Agbi et al., 1983       | 58 | F | Subcutaneous mass on the scalp, neurological deficit, seizure, headache | Parietotemporal | Firm | None | Biopsy | Steroid | Alive (6 mo) |
| Holtás et al., 1985     | 60 | F | Subcutaneous mass on the scalp | Frontal | Firm, nontender, 6 cm | None | Biopsy | R+C | Alive (5 mo) |
|                         | 20 | M | Seizure | Frontal | NA | None | Surgery (NA) | R+C | Alive (5 mo) |

(Contd...)
Table 1: (Continued).

| Author year (reference) | Age (years) /sex | Symptoms at onset | Lesion location | Properties of mass | Other lesions | Surgery | Adjuvant therapies | Outcomes (follow-up) |
|-------------------------|-----------------|------------------|----------------|--------------------|--------------|--------|-------------------|----------------------|
| Kinjo and Satoh, [45] 1985 | 23/M | Subcutaneous mass on the scalp, neurological deficit, headache, vomiting, | Frontal and occipital | Soft, 13 cm | Multifocal bone lesions | Subtotal removal | R | Died (5 mo) |
| Thomas and Kennedy, [97] 1986 | 28/F | Subcutaneous mass on the scalp | Occipital | Firm, tender, 10 cm | Supraclavicular LNs | Biopsy | R | Alive (14 mo) |
| Howat et al., [32] 1987 | 3/M | NA | Frontal | NA | None | NA | R+C | Alive (13 y) |
| Maiuri et al., [56] 1987 | 51/F | Neurological deficit, headache | Parieto-occipital | NA | None | Gross total removal | R | Alive (2 y) |
| Tagawa et al., [94] 1987 | 65/F | Subcutaneous mass on the scalp | Frontal | Growing for 3 mo, 9 cm | None | Biopsy | R+C | Alive (1 y) |
| Kawakami et al., [42] 1988 | 52/F | Subcutaneous mass on the scalp | Parietal | Firm, 5 cm | None | Gross total removal | R | Alive (6 y) |
| Morgello et al., [63] 1989 | 56/M | Subcutaneous mass on the scalp | Occipital | Growing for 5 mo | NA | Biopsy | R+C | Died (20 mo) |
| Herkes et al., [29] 1991 | 73/F | Seizure | Frontal | Firm, nontender, 5 cm Ulcerated | Retroperitoneal LNs, multifocal bone lesions | Biopsy | R+C | Alive (3 mo) |
| | 55/M | Neurological deficit | Parietal | Firm, nontender, 6 cm | None | Biopsy | R | Died (3 mo) |
| Kumon et al., [49] 1991 | 74/F | Subcutaneous mass on the scalp | Frontal | Firm, nontender, 6 cm | None | Subtotal removal | C | Alive (8 mo) |
| Natsuda et al., [66] 1991 | 41/F | Subcutaneous mass on the scalp | Temporal | Ulcerated, growing for 3 mo, 15 cm | None | Biopsy | R+C | Alive (6 mo) |
| Lonjon et al., [53] 1993 | 71/F | Subcutaneous mass on the scalp | Occipital | Growing for 3 mo, 11 cm | None | Subtotal removal | C | Alive (6 mo) |
| Parekh et al., [75] 1993 | 65/F | Neurological deficit, headache | Parietal | Firm, nontender, 3 cm | None | Gross total removal | R | Died* (6 y) |
| Sato et al., [89] 1993 | 65/M | Subcutaneous mass on the scalp, neurological deficit | Parietal | Firm, nontender, growing for 1 mo, 13 cm | None | Subtotal removal | R+C | Alive (20 mo) |
| Kelleher et al., [41] 1994 | 30/F | Headache | Frontotemporal | Tender | None | Biopsy | C | Alive (27 mo) |
| Loembe et al., [52] 1994 | 32/M | Subcutaneous mass on the scalp | Frontoparietal | Firm, nontender, growing for 6 mo | None | Subtotal removal | Refused | Died* (6 wk) |

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Table 1: (Continued).

| Author year (reference) | Age (years) /sex | Symptoms at onset | Lesion location | Properties of mass | Other lesions | Surgery | Adjuvant therapies | Outcomes (follow-up) |
|------------------------|------------------|-------------------|-----------------|---------------------|--------------|---------|-------------------|----------------------|
| Morioka et al.,[64] 1994 | 69/M | Subcutaneous mass on the scalp | Frontal | Firm, nontender, growing for 1 mo | None | Biopsy | R+C | Died (18 mo) |
| Vigushin et al.,[103] 1994 | 68/M | Neurological deficit | Parieto-temporal | NA | None | Partial removal | C | Alive (2 y) |
| Wittram et al.,[107] 1994 | 31/M | Subcutaneous mass on the scalp, seizure | Parietal | Soft, 8 cm | LNs in the abdomen | NA | NA | |
| Aslan et al.,[6] 1995 | 12/M | Subcutaneous mass on the scalp, neurological deficit, neck pain | Occipital | Firm, nontender, growing for 0.5 mo, 8 cm | None | Biopsy | R+C | Alive (2 mo) |
| Landys et al.,[50] 1995 | 62/M | Neurological deficit, malaise, abdominal pain | Fronto-parietal | Firm, nontender, 16 cm | Retroperitoneal lesion, spleen | Biopsy | C | Alive (5 y) |
| Paige and Bernstein,[72] 1995 | 51/M | Subcutaneous mass on the scalp, headache | Parieto-occipital | Firm, growing for 3 mo, 10 cm | None | Biopsy | R+C | NA |
| | 78/M | Subcutaneous mass on the scalp | Temporal | Nontender, growing for 12 mo, 5 cm | None | Removal | R+C | Alive (3 y) |
| Isla et al.,[14] 1996 | 75/F | Seizure | Frontal | NA | None | Removal | R+C | Alive (3 y) |
| Bhatia et al.,[2] 1997 | 50/M | Headache | Parietal | Firm, tender, 3 cm | None | Biopsy | R+C | Died (7 mo) |
| Curti et al.,[14] 1997 | 19/F | Subcutaneous mass on the scalp, neurological deficit, headache, vomiting | Parietal | NA | Multifocal bone lesions | Gross total removal | C | NA |
| Muin et al.,[65] 1997 | 60/M | Neurological deficit, headache | Parietal | NA | None | Gross total removal | R+C | Alive (8 mo) |
| Jamjoom et al.,[37] 1998 | 25/M | Subcutaneous mass on the scalp | Parietal | Firm, nontender, growing for 12 mo, 5 cm | None | Gross total removal | R | Alive (5 mo) |
| Jiménez Moragas et al.,[38] 1999 | 38/M | Incidentally found | Whole of the cranial vault | NA | Hepatomegaly | Biopsy | None | Died* (5 d) |
| Dai et al.,[16] 2000 | 21/M | Subcutaneous mass on the scalp | Frontal | Firm, nontender, growing for 4 mo, 5 cm | Preauricular LNs | Gross total removal | R+C | Alive (6 mo) |

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Table 1: (Continued).

| Author year (reference) | Age (years) /sex | Symptoms at onset | Lesion location | Properties of mass | Other lesions | Surgery | Adjuvant therapies | Outcomes (follow-up) |
|-------------------------|------------------|-------------------|-----------------|-------------------|--------------|---------|-------------------|---------------------|
| Pardhanani et al.,[74] 2000 | 77/M             | Subcutaneous mass on the scalp, neurological deficit | Frontotemporal | Firm  | NA  | Biopsy | R  | Died (3 wk)       |
| Parker et al.,[76] 2001 | 11/M             | Subcutaneous mass on the scalp | Frontal         | Growing for 1 mo | None  | Removal | C  | Alive (1 y)       |
| Thurnher et al.,[39] 2001 | 36/M             | Subcutaneous mass on the scalp | Frontoparietal  | Tender, 8 cm     | A lesion in the mouth | Partial removal | R+C | Died (8 mo)       |
| Duyndam et al.,[19] 2002 | 71/F             | Subcutaneous mass on the scalp | Frontal         | Firm, tender, 7 cm | None  | Biopsy  | C  | Alive (6 mo)       |
| Pernot et al.,[78] 2002 | 40/M             | Subcutaneous mass on the scalp, headache | Frontoparietal  | NA  | None  | Gross total removal | R  | Alive (1 y)       |
| Kanai et al.,[39] 2003 | 71/F             | Subcutaneous mass on the scalp | Frontoparietal  | Firm, nontender, growing for 3 mo, 8 cm | None  | Subtotal removal | C  | Died (3.5 y)      |
| Kantarci et al.,[41] 2003 | 65/M             | Subcutaneous mass on the scalp | Fronto-parietal | Firm, nontender, ulcerated, 10 cm | Cervical LNs | Biopsy  | NA  | NA                 |
| Koral et al.,[47] 2003 | 15/M             | Subcutaneous mass on the scalp | Temporo-occipital | Growing for 24 mo, 7 cm | None  | Biopsy  | C  | Alive (2.5 y)     |
| Mongia et al.,[62] 2003 | 25/M             | Subcutaneous mass on the scalp | Frontotemporo-parietal | Firm, tender, growing for 6 mo, 15 cm | None  | Subtotal removal | R+C | Alive (2.5 y)     |
| Nishimoto et al.,[69] 2003 | 63/M             | Subcutaneous mass on the scalp | Frontoparietal  | Firm, nontender, growing for 2 mo, 4 cm | None  | Biopsy  | C  | Alive (NA)        |
| Aquilina et al.,[5] 2004 | 72/F             | Subcutaneous mass on the scalp, seizure, headache, fatigue | Frontotemporal  | Firm, nontender | None  | Biopsy  | C  | Alive (6 mo)      |
| Horstman et al.,[31] 2004 | 80/F             | Subcutaneous mass on the scalp | Parieto-occipital | Growing for 6 mo, 18 cm | A neck lesion | Biopsy  | C  | Died (NA)         |
| Madan et al.,[88] 2004 | 70/F             | Subcutaneous mass on the scalp, weight loss | Parieto-occipital | Nontender, reddish, growing for 12 mo, 7 cm | None  | NA  | C  | Alive (NA)        |
| Szucs-Farkas et al.,[93] 2005 | 42/F             | Subcutaneous mass on the scalp, malaise, nausea, and headache | Parieto-occipital | NA  | None  | Biopsy  | R  | Alive (NA)        |

(Contd...)
Table 1: (Continued).

| Author year (reference) | Age (years) /sex | Symptoms at onset | Lesion location | Properties of mass | Other lesions | Surgery | Adjuvant therapies | Outcomes (follow-up) |
|-------------------------|------------------|------------------|----------------|-------------------|--------------|---------|-------------------|---------------------|
| Tanimura et al.,[95] 2005 | 85/F             | Subcutaneous mass on the scalp | Parietal | 4 cm | None | Refused (autopsy) | Refused | Died (4 mo) |
| Evliyaoglu et al.,[21] 2006 | 78/F             | Subcutaneous mass on the scalp, neurological deficit, headache | Parietal | Firm, growing for 0.25 mo, 5 cm | None | Subtotal removal | R+C | Alive (4 y) |
| Galarza et al.,[23] 2006 | 61/M             | Headache | Parietal | NA | None | Gross total removal | R+C | Alive (23 mo) |
| Palled et al.,[23] 2006 | 13/M             | Subcutaneous mass on the scalp, proptosis, neck swelling | Frontal | Nontender, growing for 2 mo, 9 cm | Cervical LNs | Biopsy | C | Alive (NA) |
| Agrawal et al.,[2] 2007 | 43/F             | Subcutaneous mass on the scalp | Frontal | Firm, nontender, growing for 8 mo, 4 cm | None | Gross total removal | R | NA |
| Fukushima et al.,[23] 2007 | 60/F             | Subcutaneous mass on the scalp | Parietal | Firm, nonpulsatile, 6.5 cm | None | Removal | R+C | Alive (3 y) |
| Mohindra et al.,[61] 2007 | 30/M             | Subcutaneous mass on the scalp, headache | Frontal | Growing for 2 mo | NA | Removal | R+C | Alive (6 mo) |
| Uff and Shieff,[100] 2007 | 76/F             | Subcutaneous mass on the scalp, neurological deficit | Parietal | NA | None | Biopsy | R | Died* (2 wk) |
| Gaitonde et al.,[24] 2008 | 70/F             | Subcutaneous mass on the scalp | Frontal | Growing for 12 mo, 3.4 cm | None | Gross total removal | R+C | Alive (NA) |
| Gonzalez-Bonet et al., [28] 2008 | 84/F             | Subcutaneous mass on the scalp, seizure | Frontoparietal | Growing for 0.75 mo, 2.5 cm | None | Gross total removal | Refused | Died (5 mo) |
| Yoon et al.,[109] 2008 | 53/M             | Neurological deficit | Frontoparietal | NA | Retrobulbar lesion | Removal | R | Alive (3 y) |
| Renard et al.,[84] 2009 | 67/F             | Subcutaneous mass on the scalp | Frontal | Tender | None | Biopsy | C | NA |
| da Rocha et al.,[111] 2010 | 13/M             | Subcutaneous mass on the scalp | Parietal | NA | NA | C | NA |
|                          | 66/F             | Subcutaneous mass on the scalp | Frontoparietal | NA | NA | C | NA |
|                          | 72/F             | Subcutaneous mass on the scalp | Pariet-occipital, frontal | NA | NA | R+C | NA |

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Table 1: (Continued).

| Author year  | Age (years) | Symptoms at onset | Lesion location | Properties of mass | Other lesions | Surgery | Adjuvant therapies | Outcomes (follow-up) |
|--------------|-------------|-------------------|-----------------|--------------------|--------------|---------|--------------------|----------------------|
| Khalid et al.,[44] 2010 | 19/M | Subcutaneous mass on the scalp | Parietal, occipital | Firm, nontender, growing for 6 mo, 6 cm | None | Biopsy | C | Alive (2 y) |
| Ochiai et al.,[70] 2010 | 72/M | Subcutaneous mass on the scalp | Temporoparietal | Firm, nontender, 7 cm | None | Gross total removal | R+C | Alive (1 y) |
| Castro-Bouzas et al.,[10] 2011 | 59/F | Subcutaneous mass on the scalp | Occipital | Firm, tender, 3 cm | None | Gross total removal | R+C | Alive (30 mo) |
| Fadoukhair et al.,[22] 2011 | 42/F | Subcutaneous mass on the scalp | Parietal | Firm, tender, 8 cm | None | Biopsy | R+C | Alive (9 mo) |
| Ciarpaglini and Otten,[13] 2012 | 74/F | Subcutaneous mass on the scalp | Temporoparietal | Firm, tender, growing for 36 mo, 15 cm | None | Gross total removal | R+C | Alive (2 y) |
| El Asri et al.,[20] 2012 | 52/M | Subcutaneous mass on the scalp | Frontotemporal | Firm, tender, growing for 7 mo | None | Biopsy | R | Alive (18 mo) |
| Martin et al.,[58] 2012 | 50/M | Subcutaneous mass on the scalp | Parieto-occipital | Nontender, growing for 4 mo, 10 cm | None | Partial removal | R+C | NA |
| Rezaei-Kalantari et al.,[83] 2012 | 42/M | Subcutaneous mass on the scalp, headache | Frontal, parietal | Soft, nontender, growing for 4 mo, 10 cm | None | Removal | R+C | NA |
| Ko et al.,[46] 2013 | 81/F | Subcutaneous mass on the scalp | Frontoparietal | Firm, nontender, 6 cm | None | Removal | C | Alive (9 mo) |
| Kosugi et al.,[48] 2013 | 82/F | Subcutaneous mass on the scalp | Parietal | Firm, 3 cm | Ileocecal lesion | Biopsy | R+C | Alive (30 mo) |
| Mishra et al.,[90] 2013 | 34/M | Subcutaneous mass on the scalp | Frontal | Nontender, growing for 12 mo, 7 cm | None | Removal | R+C | Alive (6 mo) |
| Salunke et al.,[86] 2013 | 30/M | Subcutaneous mass on the scalp, headache | Frontal | Firm, nontender, growing for 3 mo | None | Removal | R+C | Alive (6 mo) |
| Sanjayan et al.,[84] 2013 | 29/M | Subcutaneous mass on the scalp, headache, and vomiting | Parieto-occipital | NA | Axillary LNs | Gross total removal | R+C | Alive (7 y) |
| Rasouli et al.,[83] 2014 | 48/F | Subcutaneous mass on the scalp | Frontoparietal | Firm, growing for 4 mo, 5.5 cm | None | Removal | R | Alive (NA) |
| Sugimoto et al.,[95] 2014 | 39/F | Subcutaneous mass on the scalp | Frontal | NA | Biopsy | C | Alive (2 y) |

(Contd...)
| Author year (reference) | Age (years) / sex | Symptoms at onset | Lesion location | Properties of mass | Other lesions | Surgery | Adjuvant therapies | Outcomes (follow-up) |
|-------------------------|------------------|------------------|----------------|-------------------|--------------|---------|-------------------|----------------------|
| Tashiro et al.,[96] 2015 | 63/F             | Subcutaneous mass on the scalp | Frontal        | Growing for 4 mo   | None         | Subtotal removal | C         | Alive (9 y)        |
|                         | 53/M             | Subcutaneous mass on the scalp | Frontal        | Growing for 2 mo   | Cervical LNs | Subtotal removal | R+C      | Alive (2 y)        |
| Wang et al.,[105] 2015  | 45/M             | Subcutaneous mass on the scalp, neurological deficit | Parietal       | Growing for 6 mo, 9 cm | None        | Gross total removal | R+C      | Alive (12 mo)      |
| Akamatsu et al.,[4] 2016 | 76/F             | Subcutaneous mass on the scalp | Frontal        | Soft, nontender, growing for 1 mo, 10 cm | Multifocal bone lesions, retroperitoneal lesion | Biopsy | C         | Alive (9 mo)        |
| Bhatoe and Ambastha,[8] 2016 | 14/F             | Subcutaneous mass on the scalp | Frontoparietal | Soft, nontender, growing for 6 mo, 5 cm | NA          | Gross total removal | NA      | NA                  |
| Issara et al.,[35] 2016 | 56/F             | Enlarging lacuna image of skull | Multiple       | NA               | None         | Removal | R+C      | Alive (4 mo)        |
| Jaiswal et al.,[36] 2016 | 40/F             | Subcutaneous mass on the scalp, headache deficit | Frontoparietal | Firm, tender, growing for 12 mo | None | Gross total removal | NA      | NA                  |
| Lv et al.,[54] 2016     | 56/M             | Neurological deficit, headache deficit | Parietal       | NA               | None         | Removal | C         | Alive (50 mo)       |
| Mascolo et al.,[59] 2016 | 58/M             | Subcutaneous mass on the scalp | Parietal, frontal | Growing for 3 mo, 12 cm | None | Biopsy | C         | Alive (6 mo)        |
| Kanaya et al.,[40] 2017 | 65/M             | Subcutaneous mass on the scalp, neurological deficit | Parietal       | NA               | Multifocal LNs | Removal | C         | Alive (18 mo)       |
| Naama et al.,[96] 2017  | 67/F             | Subcutaneous mass on the scalp | Parietal       | Nontender, growing for 2 mo, 6 cm | None         | Biopsy | R+C      | Alive (20 mo)       |
| Chan et al.,[11] 2018   | 49/F             | Subcutaneous mass on the scalp | Frontal        | Growing for 12 mo, 11 cm | None         | Biopsy | C         | Alive (6 mo)        |
| Lee and Yun,[91] 2018   | 50/M             | Subcutaneous mass on the scalp, headache deficit | Frontal        | Nontender, 3 cm   | None         | Gross total removal | C         | Alive (6 mo)        |
| Salvo et al.,[87] 2018  | 74/F             | Neurological deficit | Parietotemporal | NA               | None         | Removal | C         | Alive (6 mo)        |
| Huang et al.,[39] 2019  | 31/M             | Subcutaneous mass on the scalp | Parietooccipital | Tender, growing for 2 mo | None         | Gross total removal | C         | Alive (12 mo)       |

(Contd...)
Table 1: (Continued).

| Author year (reference) | Age (years) /sex | Symptoms at onset | Lesion location | Properties of mass | Other lesions | Surgery | Adjuvant therapies | Outcomes (follow-up) |
|-------------------------|------------------|-------------------|-----------------|-------------------|--------------|---------|-------------------|---------------------|
| Umemura et al.,[102] 2019 | 72/F             | Subcutaneous mass on the scalp | Parietal | Nontender, 10 cm | None | Removal | R | NA |
|                         | 63/M             | Subcutaneous mass on the scalp, neurological deficit | Occipital | Nontender, 4 cm | None | Partial removal | C | NA |
| Xing et al.,[108] 2019  | 53/M             | Subcutaneous mass on the scalp, headache | Parietal | 8.2 cm | NA | NA | NA | NA |
|                         | 28/M             | Subcutaneous mass on the scalp | Occipital | 5 cm | NA | NA | NA | NA |
|                         | 68/F             | Subcutaneous mass on the scalp | Fronto-temporo-parietal | 6.3 cm | NA | NA | NA | NA |
|                         | 39/M             | Subcutaneous mass on the scalp | Frontoparietal | 11.2 cm | NA | NA | NA | NA |
|                         | 45/M             | Subcutaneous mass on the scalp, neurological deficit, headache | Parieto-occipital | 10.4 cm | NA | NA | NA | NA |
| Ahmad et al.,[3] 2020  | 37/M             | Subcutaneous mass on the scalp, neurological deficit | Frontoparietal | Growing for 3 mo, 5 cm | NA | Biopsy | R+C | NA |
| Nasim et al.,[67] 2020 | 69/M             | Neurological deficit | Parietal | NA | None | Gross total removal | None | Alive (1 y) |

The size shown in “Properties of mass” is the greatest diameter of the scalp mass. C: Chemotherapy, Dead*: Died of a cause unrelated to the skull lesion, F: Female, LN: Lymph node, M: Male, NA: Not available, R: Radiotherapy, y: Year, mo: Month

both (n = 75). On MRI (n = 57), a dural tail was observed in 42 cases (74%), and invasion of the brain was observed in 15 cases (26%).

Surgery was detailed in 98 cases, of which 45 (46%) involved a biopsy or partial removal and 53 (54%) involved subtotal or gross total removal [Table 1]. Adjuvant therapy was reported for 96 cases. The breakdown was radiotherapy alone for 24 cases (25%), chemotherapy alone for 34 cases (35%), and both for 38 cases (40%).

The type of lymphocyte was described in 80 cases: 75 (94%) were B-cell lymphomas and 5 (6%) were T-cell lymphomas [Table S2]. Diffuse large B-cell lymphoma (DLBCL) was the most common, being reported in 34 cases.

To determine the rates of survival, we excluded cases in which the patients died of a cause unrelated to the skull lesion and included cases with follow-up periods of more than 6 months (n = 74) or 1 year (n = 54). In the included cases, 67 (90.5%) and 45 (83.3%) patients were alive at the follow-up of 6 months and 1 year, respectively [Table 1].

**DISCUSSION**

We reviewed the demographic, clinical, and imaging characteristics of cranial vault lymphoma to specify the features that might be helpful for differential diagnosis, especially between lymphomas and meningiomas of the cranial vault.
When a tumor with intra- and extracranial extension sandwiching the skull is seen, meningioma with extracranial extension is often first suspected. In many cases, the subcutaneous scalp mass was firm and nontender, which is also similar to meningioma with extracranial extension. However, in our review, the subcutaneous scalp mass grew very rapidly before the patient presented for treatment, for a mean duration of 5.9 months, which is atypical for meningioma, which is generally slow growing.\textsuperscript{[18,79]}

Laboratory data were unremarkable in many cases. Kosugi et al.\textsuperscript{[48]} reported elevated sIL2R, a marker of lymphoproliferative neoplasms,\textsuperscript{[61]} in a patient with cranial vault lymphoma, suggesting that elevated sIL2R associated with a cranial vault tumor might indicate lymphoma rather than meningioma. Another finding that could be used to differentiate the two tumor types is poor or no tumor vascularization on angiograms, which differs from the rich tumor vascularization from the external carotid artery circulation observed in many cases of meningioma.\textsuperscript{[90]} The tumor also showed high uptake on FDG-PET.\textsuperscript{[4,11,40,86,92,96]} Because meningiomas are mostly slow-growing tumors and their glucose metabolism might be only moderately elevated, the high physiological glucose uptake of the normal cerebral cortex leads to a low meningioma-to-background ratio.\textsuperscript{[26]}

Hence, a high tumor-to-background ratio may indicate a lymphoma and contribute to ruling out a meningioma.

The extracranial component tended to be at least as large as the intracranial component in cranial vault lymphoma. Because meningioma usually originates from the meninges, theoretically, it tends to grow intracranially rather than extracranially. Extracranial-dominant extension might, therefore, also contribute to distinguishing cranial vault lymphoma from meningioma.

However, other findings are unlikely to clarify the diagnosis. For example, the tumors tended to be hyper- to isodense on CT, iso- to hypointense on T1WI, and hyper- to isointense on T2WI, which are nonspecific features of skull tumors. Although a dural tail was observed in many cases, as reported by Xing et al.,\textsuperscript{[108]} this finding is also observed in meningiomas.\textsuperscript{[79]}

It has been suggested that lymphoma cells infiltrate the spaces within the diploe and extend along the emissary veins to infiltrate the soft tissues on either side of the bone.\textsuperscript{[5,20,107,77]} Osteolytic changes were most frequently observed on CT and MRI (68 cases) followed by no changes and/or preserved skull contour (11 cases). In the cases with osteolytic skull changes, permeative dissolution with relatively preserved skull contour was observed in 35 cases. Although the destruction of the cranial vault tended to be small, the extracranial and intracranial components of the tumor tended to be large. These data support the characteristic permeating growth pattern of cranial vault lymphoma involving a large soft-tissue component and slight bony destruction, as reported previously.\textsuperscript{[20,62,90,108]}

After histological confirmation of the diagnosis, patients were usually treated with adjuvant chemotherapy, radiotherapy, or both. Although the best treatment for cranial vault lymphoma has not been elucidated because of the paucity of cases and lack of clinical studies, treatments based on those for systemic malignant lymphoma tended to be adopted.

B-cell lymphomas accounted for approximately 94% of the cranial vault lymphomas, whereas T-cell lymphomas roughly accounted for the remaining 6% of cases. Peripheral T-cell lymphomas account for 6–10% of all cases of non-Hodgkin lymphoma\textsuperscript{[57]} and T-cell lymphomas account for 5–6% of cases of primary lymphoma of bone.\textsuperscript{[11,82]} However, T-cell lymphomas account for only 2% of all primary lymphomas in the central nervous system (CNS),\textsuperscript{[27]} suggesting that cranial vault lymphomas are more similar to extracranial lymphomas than they are to CNS lymphomas. We could not determine the subtypes of lymphoma of all cases using the present classification because our study included some very old reports from before the discovery of lymphocyte markers. Nonetheless, DLBCL accounted for the majority of cases of cranial vault lymphoma in the available data, which is also true for cases of bone lymphoma.\textsuperscript{[82]}

In analyzable follow-up data, 67 and 45 patients were alive after 6 months (\(n = 74\)) and 1 year (\(n = 54\)), respectively [Table 1]. Although our review does not allow for predicting prognosis due to the limited numbers and the limited duration of follow-up data, the 6-month survival rate and 1-year survival rate are not <60.4% and 40.5%, respectively.

In the present review, we have provided objective data from patients reported in published studies. The difficulty in systematically reviewing the data reported in the literature is the heterogeneity of the data. In particular, almost all reports reviewed for this study were case reports. Because of the limited number and the heterogeneity of described data of preoperative findings and treatments, we could perform only descriptive analyses. Another weakness of the present review resulted from biased reporting in the published studies, with likely underreporting of recent cases in the United States and European countries because of decreased novelty in inverse proportion to the accumulation of reported cases. The data that were more likely to be reported, if present, included findings on MRI and CT. Findings of plain skull X-ray and angiography and long-term follow-up data were less likely to be reported.

The strength of the present review is the comprehensive nature of the literature search. We analyzed cases from all over the world, reported not only in English but also in four non-English languages.
CONCLUSION

Cranial vault lymphoma is a rare entity among skull tumors. To the best of our knowledge, this is the largest reported pooled database describing cranial vault lymphoma patients. The most common symptom was a rapidly growing subcutaneous scalp mass. The tumor was poorly vascularized on angiography. Skull destruction on images was mild and disproportionately small despite the large size of the extracranial and/or intracranial component in two-thirds of the cases. These features should help to distinguish lymphoma from meningioma.

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Declaration of patient consent

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

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Conflicts of interest

There are no conflicts of interest.

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**Table S1:** Laboratory data and features on images of patients with cranial vault lymphoma.

| Author year (reference) | Labo data | Plain skull X-ray | Angiogram | Density on CT | Enhancement on CECT | Intensity on T1WI | Intensity on T2WI | Enhancement on CET1WI | Additional |
|-------------------------|-----------|--------------------|-----------|---------------|--------------------|------------------|------------------|------------------------|------------|
| Wichtl, [106] 1949      | N/A       | Destruction of bones | NA        | NA            | NA                | NA              | NA               | NA                     | NA         |
| Strange and De Lorimier, [91] 1954 | Unremarkable | Dissolution of the tables, periosteal reaction | NA        | NA            | NA                | NA              | NA               | NA                     | NA         |
| Ullrich and Bucy, [101] 1958 | Unremarkable | Dissolution and erosion of the tables, periosteal reaction | NA        | NA            | NA                | NA              | NA               | NA                     | NA         |
| Piendak and Alder, [90] 1959 | Unremarkable | Patchy decalcification, progressive bone destruction | NA        | NA            | NA                | NA              | NA               | NA                     | NA         |
| Block and Peck, [91] 1964 | Mild increase in WBCs | N/A | Periosteal reaction, the diploic space, and inner table were normal | NA        | NA            | NA                | NA                | NA               | NA                     | NA         |
| Topolnicki and White, [89] 1969 | N/A       | Destruction of the outer table | NA        | NA            | NA                | NA              | NA               | NA                     | NA         |
| Wainwright, [104] 1973    | Unremarkable | Marked erosion | NA        | NA            | NA                | NA              | NA               | NA                     | NA         |
| Gawish, [27] 1976        | Lymphocytosis, eosinophilia | Rarefaction of the bone with erosion | Mass effect with no blood circulation to the tumor | NA        | NA            | NA                | NA                | NA                     | NA         |
| Agbi et al., [1] 1983    | Unremarkable | An area of hyperostosis | Mass effect with no pathological circulation | Hyper    | Well, homogeneous | NA              | NA                | NA                     | NA         |
| Holtås et al., [30] 1985 | N/A       | NA                | NA        | NA            | NA                | NA              | NA               | NA                     | NA         |
| Kinjo and Satoh, [45] 1985 | Unremarkable | Dehydration, hypercalcemia | Multiple punched out lesions | NA        | NA            | NA                | NA                | NA                     | NA         |
| Thomas and Kennedy, [97] 1986 | N/A       | A large lytic lesion | NA        | Hypo          | Well, diffuse     | NA              | NA               | NA                     | NA         |

(Contd...)
| Author year (reference) | Labo data | Plain skull X-ray | Angiogram | Density on CT | Enhancement on CECT | Intensity on T1WI | Intensity on T2WI | Enhancement on CET1WI | Additional |
|-------------------------|-----------|-------------------|-----------|--------------|---------------------|-----------------|-----------------|---------------------|-----------|
| Howat et al. [32] 1987 | N/A       | NA                |           | NA           | Hyper               | NA              | NA              | NA                  | NA        |
| Maiuri et al. [56] 1987| Unremarkable | Osteolytic area with irregular margins | Mass effect with no pathological vascularization | Hyper, slight, diffuse | NA             | NA              | NA              | NA                  | Uptake of Ga-67 |
| Tagawa et al. [94] 1987| Increase in LDH | NA            | Mass effect with no pathological vascularization | Hyper, slight, diffuse | NA             | NA              | NA              | NA                  | Uptake of Ga-67 |
| Kawakami et al. [42] 1988| Unremarkable | Sharp bone defect | An avascular mass | NA            | NA              | NA              | NA              | NA                  | Uptake of Ga-67 |
| Morgello et al. [63] 1989| N/A       | NA                | NA        | NA           | NA                  | NA              | NA              | NA                  | Uptake of Ga-67 |
| Herkes et al. [29] 1991 | Unremarkable | A permeative lytic lesion | NA        | NA           | NA                  | NA              | NA              | NA                  | Marked |
| Kuno et al. [48] 1991 | Hyperglycemia, increase in Cre and urea | Unremarkable | No abnormalities | NA        | NA                  | NA              | NA              | NA                  | |
| Natsuda et al. [48] 1991 | HTLV-1 positive | N/A | Multiple lytic lesions with sharp margin, no sclerosis Osteolysis | Vascularization from ophthalmic artery branches | Iso, slight, diffuse | Iso, Iso | NA    | Marked |
| Lonjon et al. [53] 1993 | N/A       | NA                | NA        | NA           | NA                  | NA              | NA              | NA                  | Uptake of Ga-67 |
| Parekh et al. [79] 1993 | Unremarkable | Hyperostosis | NA        | Hyper        | Well, diffuse       | NA              | NA              | NA                  | Uptake on bone scintigraphy |
| Sato et al. [90] 1993 | Unremarkable | An osteolytic lesion with an irregular margin | NA        | Iso to hyper | Well, diffuse       | Hypo             | Hyper           | Marked |
| Kelleher et al. [103] 1994 | HIV positive | NA | NA | NA | NA | NA | NA | NA | Uptake of 123I-SAP |
| Loembe et al. [52] 1994 | Anemia, accelerated ESR | Osteolysis with intratumoral calcifications | Vascularization from the meningeal and scalp vessels | NA | NA | NA | NA | NA | |
| Morioka et al. [84] 1994 | N/A       | NA                | NA        | NA           | NA                  | NA              | NA              | NA                  | NA        |
| Vigushin et al. [100] 1994 | Monoclonal κ chains in urine | N/A | NA | NA | NA | Hypo | NA | NA | Uptake of 123I-SAP |
| Wittram et al. [107] 1994 | N/A       | NA                | NA        | Hyper        | Well, diffuse       | Hypo             | NA              | NA                  | |

(Contd...)
Table S1: (Continued).

| Author year (reference) | Labo data | Plain skull X-ray | Angiogram | Density on CT | Enhancement on CECT | Intensity on T1WI | Intensity on T2WI | Enhancement on CET1WI | Additional |
|-------------------------|-----------|-------------------|------------|---------------|---------------------|-----------------|-----------------|----------------------|------------|
| Aslan *et al.*,[6] 1995 | Unremarkable | An osteolytic soft tissue mass | NA | NA | Hypo | Hyper | Marked | NA |
| Landys *et al.*,[50] 1995 | N/A | Destruction of bones | NA | Hyper | Well, diffuse | NA | NA | NA |
| Paige and Bernstein,[23] 1995 | N/A | NA | Vascularization from ICA and ECA circulation | NA | Well, diffuse | Iso to hypo | Iso to hypo | Marked | NA |
| N/A | NA | Poor vascularization from ICA and ECA circulation | NA | NA | Marked | NA |
| Isla *et al.*,[34] 1996 | Unremarkable | NA | NA | Well, diffuse | NA | NA | NA |
| Bhatia *et al.*,[7] 1997 | HIV positive | Ill-defined serpentine bone resorption | NA | NA | NA | Enhanced | Uptake of 99Tc |
| Curty *et al.*, [14] 1997 | N/A (HIV negative) | NA | Hyper | Well, diffuse | NA | NA | NA |
| Muin *et al.*, [65] 1997 | N/A | NA | Well, diffuse | NA | NA | NA |
| Jamjoom *et al.*, [37] 1998 | N/A (HIV negative) | NA | Slight peripheral vascularization from ECA circulation. | NA | Well, diffuse | NA | NA | NA |
| Jiménez Moragas *et al.*, [38] 1999 | HIV positive, decreased PLTs, | NA | | | | | | | |
| Dai *et al.*, [16] 2000 | Increase in LDH | NA | | | | | | | |
| Pardhanani *et al.*, [74] 2000 | N/A | NA | | | | | | | |
| Parker *et al.*, [76] 2001 | Unremarkable | An osteolytic lesion | NA | Hyper | Well, diffuse (intracranial), peripheral (extracranial) | NA | NA | NA |
| Thurnher *et al.*, [19] 2001 | HIV positive | NA | | | | | | | |
| Duyndam *et al.*, [19] 2002 | Unremarkable | No abnormalities | NA | NA | Hypo | Iso | Heterogeneous | NA |
| Pernot *et al.*, [78] 2002 | N/A | NA | | | | | | | |

(Contd...)
| Author year (reference) | Labo data | Plain skull X-ray | Angiogram | Density on CT | Enhancement on CECT | Intensity on T1WI | Intensity on T2WI | Enhancement on CET1WI | Additional |
|-------------------------|-----------|------------------|-----------|---------------|---------------------|------------------|------------------|-----------------------|-------------|
| Kanai et al. [39] 2003 | Increase in LDH and ALP | NA | NA | Hyper | Well, diffuse | Hypo | Hyper | Enhanced | Uptake on bone and Ga scintigraphy |
| Kantarci et al. [41] 2003 | Increase in LDH | NA | NA | NA | NA | Iso | Iso | Marked | NA |
| Koral et al. [47] 2003 | N/A | No bony erosion | NA | NA | NA | NA | NA | NA | NA |
| Nishimoto et al. [62] 2003 | Unremarkable | NA | NA | Hypo | Well, diffuse | Hypo | Hypo | Homogeneous | NA |
| Aquilina et al. [5] 2004 | N/A (HIV negative) | NA | NA | NA | Well, diffuse | NA | NA | NA | NA |
| Horstman et al. [55] 2004 | N/A | NA | NA | Well, diffuse | NA | NA | NA | NA | NA |
| Madan et al. [69] 2004 | N/A | NA | Hyper | NA | NA | NA | NA | NA | NA |
| Szucs-Farkas et al. [73] 2005 | HIV positive | NA | Hyper | Well, diffuse | NA | NA | NA | NA | NA |
| Tanimura et al. [88] 2005 | Anemia, increase in LDH and ferritin | Ill-defined serpentine bone resorption | NA | Iso | NA | Iso to hyp | Iso to hypo | Homogeneous | NA |
| Evliyaoglu et al. [21] 2006 | N/A | No abnormalities | NA | Hyper | Slight, diffuse | NA | NA | NA | NA |
| Galarza et al. [23] 2006 | N/A | NA | NA | Hyper | Well, diffuse | Hypo | Hyper | Enhanced | NA |
| Palled et al. [73] 2006 | N/A | NA | NA | Well, diffuse | NA | NA | Enhanced | NA | NA |
| Agrawal et al. [73] 2007 | Accelerated ESR | NA | NA | Well, diffuse | NA | NA | NA | NA | NA |
| Fukushima et al. [73] 2007 | Unremarkable | An osteolytic lesion | NA | NA | Slight, diffuse | Hypo | Hyper | Homogeneous | Uptake on bone scintigraphy |
| Mohindra et al. [88] 2007 | N/A | NA | NA | Well, diffuse | NA | NA | Marked | NA | NA |
| Uff and Shieff [90] 2007 | N/A (HIV negative) | NA | NA | Well, diffuse | NA | Hyper | Enhanced | NA | NA |
| Gaitonde et al. [93] 2008 | N/A | NA | NA | NA | NA | NA | NA | NA | NA |
| Gonzalez-Bonet et al. [100] 2008 | Hypogammaglobulinemia | NA | NA | NA | NA | NA | Marked | NA | NA |

(Contd...)
| Author year (reference) | Labo data | Plain skull X-ray | Angiogram | Density on CT | Enhancement on CECT | Intensity on T1WI | Intensity on T2WI | Enhancement on CET1WI | Additional |
|------------------------|-----------|-------------------|-----------|---------------|---------------------|------------------|------------------|------------------------|------------|
| Yoon et al. [10] 2008  | Unremarkable | NA | NA | Hyper | NA | Hypo | Hyper | NA | NA |
| Renard et al. [8, 9] 2009 | N/A | NA | NA | Hyper | Well, diffuse | Iso | Iso | Marked, heterogeneous | Enhanced | NA |
| da Rocha et al. [15] 2010 | N/A | NA | NA | NA | NA | Hypo | Hyper | NA | NA |
| Khalid et al. [44] 2010 | Unremarkable | NA | NA | Hyper | Well, diffuse | Iso to hypo | Iso to hypo | Marked, homogeneous | NA |
| Ochiai et al. [70] 2010 | N/A | No destruction or periosteal reaction | NA | NA | NA | Hypo | Hyper | Homogeneous | NA |
| Castro-Bouzas et al. [10] 2011 | N/A | NA | NA | NA | NA | NA | NA | NA | NA |
| Fadoukhair et al. [22] 2011 | N/A | Unremarkable | NA | NA | NA | Hypo | Hyper | Homogeneous | NA |
| Ciarpaglini and Otten. [13] 2012 | Unremarkable | NA | NA | Hyper | Slight, diffuse | Iso | Iso | Marked | Uptake of 99 Tc MDP | NA |
| El Asri et al. [20] 2012 | Unremarkable | NA | NA | Hyper | Slight, diffuse | Iso | Iso | Marked | Uptake of 99 Tc MDP | NA |
| Martin et al. [58] 2012 | HBV positive | NA | NA | NA | NA | NA | NA | NA | NA |
| Rezaei-Kalantari et al. [85] 2012 | Unremarkable | Neither obvious bone erosion nor sclerosis | NA | Hyper | NA | Iso | Iso | Marked, homogeneous | NA |
| Ko et al. [60] 2012 | Unremarkable | An irregular inner cortical bone margin | Vascularization from ECA circulation. | Iso | Well, diffuse | Iso to hypo | Iso to hypo | Enhanced | A choline peak on MRS | NA |
| Kosugi, et al. 2013 | HCV positive, increase in sIL2R | NA | NA | NA | Iso to hypo | Iso to hypo | NA | Uptake on bone scintigraphy | NA |
| Mishra et al. [86] 2013 | N/A | Moth-eaten lytic lesion | NA | NA | NA | Iso to hypo | Iso to hypo | NA | NA |
| Salunke et al. [87] 2013 | Unremarkable | NA | NA | Hypo | Hyper | Enhanced | Uptake on PET-CT | NA | NA |
| Sanjayan et al. [88] 2013 | N/A | NA | NA | NA | NA | NA | NA | NA | NA |
| Rasouli et al. [83] 2014 | N/A | NA | NA | NA | NA | NA | NA | NA | NA |

(Contd...)
| Author year (reference) | Labo data | Plain skull X-ray | Angiogram | Density on CT | Enhancement on CECT | Intensity on T1WI | Intensity on T2WI | Enhancement on CET1WI | Additional |
|-------------------------|-----------|-------------------|-----------|---------------|---------------------|----------------|----------------|----------------------|------------|
| Sugimoto et al.,[92] 2014 | Anemia | Osteolytic bone destruction | NA | NA | NA | NA | NA | NA | Uptake on bone scintigraphy and FDG-PET |
| Tashiro et al.,[96] 2015 | N/A (HIV negative) | NA | NA | NA | NA | Hypo | Hyper | Homogeneous |
| Wang et al.,[106] 2015 | N/A (HIV negative) | NA | NA | NA | Hyper | NA | Hypo | Hyper | Homogeneous |
| Akamatsu et al.,[4] 2016 | N/A | NA | NA | NA | NA | NA | NA | NA | Uptake on FDG-PET |
| Bhatoe and Ambastha,[8] 2016 | Unremarkable | Erosion of the calvarium | NA | NA | NA | NA | NA | NA | Enhanced |
| Issara et al.,[93] 2016 | N/A | NA | NA | NA | NA | NA | NA | NA | Slight, heterogeneous |
| Jaiswal et al.,[94] 2016 | Unremarkable | NA | NA | Well, diffuse | NA | NA | Hypo | Hyper | Uptake on FDG-PET |
| Lv et al.,[34] 2016 | Unremarkable | NA | Hyper | NA | Hypo | NA | Iso | Marked |
| Mascolo et al.,[59] 2016 | Unremarkable | NA | NA | NA | NA | NA | NA | Heterogeneous |
| Kanaya et al.,[40] 2017 | N/A | NA | NA | NA | NA | NA | NA | NA | Uptake on FDG-PET |
| Naama et al.,[46] 2017 | Unremarkable | NA | NA | Hyper | Well, diffuse | Hypo | Hyper | Heterogeneous |
| Chan et al.,[11] 2018 | Increase in LDH | NA | NA | NA | NA | Hyper | NA | Uptake on FDG-PET |
| Lee and Yun,[31] 2018 | Unremarkable | NA | NA | NA | Hyper | NA | Iso | Hyper | Homogeneous |
| Salvo et al.,[87] 2018 | Unremarkable | NA | NA | Hyper | NA | Iso to iso | Hypo | Iso to hypo | Homogeneous |
| Huang et al.,[30] 2019 | Increase in WBCs | NA | NA | No vascular malformations | NA | NA | Iso | Iso | Hypointense on ADC map |
| Umemura et al.,[102] 2019 | Chronic renal failure | NA | Hyper | NA | Iso | Iso | NA | NA | Hyperintense on DWI |
| Xing et al.,[108] 2019 | Unremarkable | NA | NA | NA | Hypo | Hyper | Iso | Hyper | Homogeneous |
| N/A | NA | Hyper | NA | Iso | Hyper | Homogeneous |

(Contd..)
| Author year (reference) | Labo data | Plain skull X-ray | Angiogram | Density on CT | Enhancement on CECT | Intensity on T1WI | Intensity on T2WI | Enhancement on CET1WI | Additional |
|------------------------|-----------|-------------------|-----------|---------------|---------------------|------------------|------------------|-----------------------|------------|
| N/A                    | NA        | NA                | NA        | NA            | NA                  | Hypo             | Hyper            | Homogeneous           | NA         |
| N/A                    | NA        | NA                | NA        | Iso           | Iso                 | Iso              | Iso              | Homogeneous           | NA         |
| N/A                    | NA        | NA                | NA        | Hyper         | NA                  | Hypo             | Hyper            | Homogeneous           | NA         |
| Increase in WBCs       | NA        | NA                | NA        | NA            | NA                  | NA               | NA               | NA                    | NA         |

ADC: Apparent diffusion coefficient, ALP: Alkaline phosphatase, CE: Contrast enhanced, Cre: Creatinine, CT: Computed tomography, DWI: Diffusion-weighted imaging, ECA: External carotid artery, ESR: Erythrocyte sedimentation rate, FDG: Fluorodeoxyglucose F 18, Ga: Gallium, HBV: Hepatitis B virus, HCV: Hepatitis C virus, HIV: Human immunodeficiency virus, HTLV-1: Human T-cell leukemia virus type 1, I: Iodine, ICA: Internal carotid artery, LDH: Lactate dehydrogenase, MDP: Methylene diphosphonate, MRI: Magnetic resonance imaging, MRS: Magnetic resonance spectroscopy, N/A: Not available, PET: Positron emission tomography, PLT: Platelet, SAP: Serum amyloid P, sIL2R: Soluble interleukin 2 receptor, T1WI: T1-weighted imaging, T2WI: T2-weighted imaging, Tc: Technetium, WBC: White blood cell
Table S2: Bone imaging, dural tail, brain invasion, and pathological features of patients with cranial vault lymphoma.

| Author year reference | Predominance in tumor extension | Findings of skull bone on CT and/or MRI | Disproportionately small amount of cortical destruction | Dural tail | Invasion of brain | Histology | Lymphocyte subtype |
|-----------------------|---------------------------------|----------------------------------------|--------------------------------------------------------|------------|------------------|-----------|-------------------|
| Wichtl, \(^{[106]}\) 1949 | NA | NA | NA | NA | NA | Reticulum cell sarcoma | NA |
| Strange and De Lorimier, \(^{[98]}\) 1954 | NA | NA | NA | NA | NA | Reticulum cell sarcoma | NA |
| | NA | NA | NA | NA | NA | Reticulum cell sarcoma | NA |
| Ullrich and Bucy, \(^{[101]}\) 1958 | NA | NA | NA | NA | NA | Reticulum cell sarcoma | NA |
| Piendak and Alder, \(^{[80]}\) 1959 | NA | NA | NA | NA | NA | Reticulum cell sarcoma | NA |
| Block and Peck, \(^{[9]}\) 1964 | NA | NA | NA | NA | NA | Reticulum cell sarcoma | NA |
| Topolnicki and White, \(^{[30]}\) 1969 | NA | NA | NA | NA | NA | Reticulum cell sarcoma | NA |
| Wainwright, \(^{[104]}\) 1973 | NA | NA | NA | NA | NA | Reticulum cell sarcoma | NA |
| Gawish, \(^{[27]}\) 1976 | NA | NA | NA | NA | NA | Burkitt lymphoma | NA |
| Agbi et al., \(^{[1]}\) 1983 | Intra | No change | Yes | NA | NA | Diffuse, non-Hodgkin malignant lymphoma with cleaved and notched nuclei | NA |
| Holtås et al., \(^{[30]}\) 1985 | None | Permeative dissolution with preserved skull contour | Yes | NA | NA | Undifferentiated large cell malignant lymphoma | NA |
| | None | No change | Yes | NA | NA | Poorly differentiated non-Hodgkin lymphoma | NA |
| Kinjo and Satoh, \(^{[43]}\) 1985 | None | Osteolytic skull defect | No | NA | NA | Malignant non-Hodgkin lymphoma, diffuse pleomorphic type Hodgkin disease | NA |
| Thomas and Kennedy, \(^{[99]}\) 1986 | Extra | Osteolytic skull defect | No | NA | NA | Malignant lymphoma of mixed large and medium-sized cells type, some with cleaved nuclei | NA |
| Howat et al., \(^{[32]}\) 1987 | NA | NA | NA | NA | NA | Lymphoblastic lymphoma | NA |
| Maiuri et al., \(^{[56]}\) 1987 | Intra | Osteolytic skull defect | No | NA | NA | Diffuse lymphoma, mixed cell type | NA |
| Tagawa et al., \(^{[94]}\) 1987 | None | Permeative dissolution with preserved skull contour | No | NA | NA | | (Contd...) |
Table S2: (Continued).

| Author year reference | Predominance in tumor extension | Findings of skull bone on CT and/or MRI | Disproportionately small amount of cortical destruction | Dural tail invasion of brain | Histology | Lymphocyte subtype |
|------------------------|---------------------------------|----------------------------------------|-------------------------------------------------------|-----------------------------|-----------|-------------------|
| Kawakami et al.,[42] 1988 | None                            | Osteolytic skull defect                | No                                                    | NA                          | NA        | Malignant lymphoma of diffuse medium-sized cell type |
| Morgello et al.,[63] 1989 | NA                              | NA                                     | No                                                    | NA                          | NA        | Large cell lymphoma                                    |
| Herkes et al.,[29] 1991 | Extra                           | Permeative dissolution                 | Yes                                                   | Yes                         | Yes       | Malignant lymphoma, diffuse mixed cell type            |
|                         |                                  |                                        |                                                       |                             |           | NA                                            |
|                        |                                  |                                        |                                                       |                             |           | NA                                            |
| Kumon et al.,[49] 1991 | Extra                           | Permeative dissolution with preserved skull contour | Yes                                                   | NA                          | No        | Malignant lymphoma of large- or medium-sized cell type with noncleaved nuclei |
|                        |                                  |                                        |                                                       |                             |           | B-cell                                           |
| Natsuda et al.,[68] 1991 | Extra                           | NA                                     | NA                                                    | Yes                         | NA        | Malignant lymphoma, diffuse large or medium-sized cell type with cleaved nuclei |
|                        |                                  |                                        |                                                       |                             |           | T-cell                                           |
| Lonjon et al.,[53] 1993 | Extra                           | Osteolytic skull defect                | No                                                    | NA                          | NA        | B centroblastic lymphoma                             |
| Parekh et al.,[73] 1993 | Intra                           | Preserved skull contour                | Yes                                                   | NA                          | NA        | Malignant B-cell non-Hodgkin lymphoma                |
|                        |                                  |                                        |                                                       |                             |           | B-cell                                           |
| Sato et al.,[69] 1993  | None                            | NA                                     | No                                                    | Yes                         | No        | Diffuse large B-cell type                           |
| Kelleher et al.,[41] 1994 | Extra                           | NA                                     | NA                                                    | NA                          | NA        | B-cell                                           |
|                        |                                  |                                        |                                                       |                             |           | High-grade, B2/HL/1-positive, diffuse large-cell anaplastic lymphoma |
| Loembe et al.,[52] 1994 | NA                              | NA                                     | NA                                                    | NA                          | NA        | NA                                              |
| Morioka et al.,[64] 1994 | Extra                           | Osteolysis with preserved skull contour | Yes                                                   | NA                          | NA        | Malignant lymphoma with thick fibrous stroma         |
|                        |                                  |                                        |                                                       |                             |           | B-cell                                           |
| Vigushin et al.,[103] 1994 | Intra                           | NA                                     | NA                                                    | NA                          | NA        | Lymphoplasmacytic lymphoma                           |
| Wittram et al.,[107] 1994 | None                            | Permeative dissolution with preserved skull contour | Yes                                                   | NA                          | NA        | Centrocytic/centroblastic low-grade non-Hodgkin lymphoma |

(Contd...)
Table S2: (Continued).

| Author year reference | Predominance in tumor extension | Findings of skull bone on CT and/or MRI | Disproportionately small amount of cortical destruction | Dural tail invasion of brain | Histology | Lymphocyte subtype |
|-----------------------|---------------------------------|----------------------------------------|--------------------------------------------------------|-----------------------------|-----------|-------------------|
| Aslan et al.,[6] 1995 | Extra                           | Permeative dissolution with preserved skull contour and periosteal reaction | Yes                                     | Yes                           | NA        | Undifferentiated Burkitt lymphoma B-cell |
| Landys et al.,[50] 1995 | None                            | Osteolytic defect                       | No                                      | NA                           | NA        | High-grade, malignant non-Hodgkin lymphoma of centroblastic type NA |
| Paige and Bernstein,[72] 1995 | None                            | Permeative dissolution with preserved skull contour | Yes                                     | Yes                           | Yes       | Large-cell malignant lymphoma NA |
|                          | Extra                           | Permeative dissolution with preserved skull contour | Yes                                     | Yes                           | No        | Large-cell malignant lymphoma NA |
| Isla et al.,[34] 1996   | None                            | Permeative dissolution with preserved skull contour and periosteal reaction | Yes                                     | NA                           | NA        | Low-grade, malignant non-Hodgkin lymphoma, centroblastic-centrocytic type with follicular pattern B-cell |
| Bhatia et al.,[7] 1997  | Extra                           | NA                                      | NA                                      | NA                           | No        | Large B-cell lymphoma B-cell |
| Curty et al.,[14] 1997  | Intra                           | Osteolytic skull defect                  | No                                      | NA                           | NA        | High-grade B-cell lymphoma B-cell |
| Muin et al.,[65] 1997   | Intra                           | Hyperostosis                            | Yes                                     | NA                           | NA        | High-grade B-cell non-Hodgkin lymphoma B-cell |
| Jamjoom et al.,[37] 1998 | Intra                           | Osteolytic skull defect                  | No                                      | NA                           | NA        | Large T-cell lymphoma, immunoblastic type T-cell |
| Jiménez Moragas et al.,[38] 1999 | NA                            | Multiple osteolytic lesions              | NA                                      | NA                           | NA        | Large B-cell non-Hodgkin lymphoma B-cell |
| Dai et al.,[16] 2000    | None                            | NA                                      | No                                      | Yes                           | No        | Diffuse large B-cell non-Hodgkin lymphoma B-cell |
| Pardhanani et al.,[74] 2000 | None                           | Osteolytic skull defect                  | No                                      | NA                           | NA        | Diffuse large B-cell lymphoma of follicular center cell origin B-cell |
| Parker et al.,[76] 2001 | NA                             | NA                                      | NA                                      | NA                           | NA        | Anaplastic large-cell lymphoma NA |
| Thurnher et al.,[98] 2001 | Extra                           | Permeative dissolution with preserved skull contour | Yes                                     | NA                           | NA        | Large B-cell lymphoma B-cell |

(Contd...)
| Author year reference | Predominance in tumor extension | Findings of skull bone on CT and/or MRI | Disproportionately small amount of cortical destruction | Dural tail invasion of brain | Histology | Lymphocyte subtype |
|------------------------|---------------------------------|----------------------------------------|---------------------------------------------------------|----------------------------|----------|-------------------|
| Duyndam et al.,[19] 2002 | Extra                           | NA                                     | Yes                                                     | Yes                        | No       | Malignant B-cell non-Hodgkin lymphoma |
| Pernot et al.,[19] 2002 | Extra                           | NA                                     | Yes                                                     | Yes                        | No       | B-cell lymphoma with small, cleaved cells |
| Kanai et al.,[39] 2003 | Extra                           | Permeative dissolution with preserved skull contour | Yes                                                     | NA                         | No       | Diffuse, medium-sized B-cell non-Hodgkin lymphoma |
| Kantarci et al.,[41] 2003 | None                            | NA                                     | Yes                                                     | Yes                        | Yes      | Diffuse, large-cell-type lymphoma |
| Koral et al.,[47] 2003 | None                            | Osteolysis of more than half of the skull thickness | No                                                      | NA                         | NA       | Diffuse, histiocytic, large-cell NHL |
| Mongia et al.,[62] 2003 | Extra                           | NA                                     | NA                                                      | NA                         | NA       | Non-Hodgkin lymphoma |
| Nishimoto et al.,[69] 2003 | Extra                           | Permeative dissolution with preserved skull contour | Yes                                                     | Yes                        | No       | Large B-cell lymphoma |
| Aquilina et al.,[5] 2004 | None                            | Permeative dissolution with preserved skull contour | Yes                                                     | NA                         | NA       | Small-to-intermediate B-cell lymphoma |
| Horstman et al.,[31] 2004 | Extra                           | Osteolytic skull defect                | Yes                                                     | NA                         | NA       | Diffuse large B-cell non-Hodgkin lymphoma |
| Madan et al.,[55] 2004 | Extra                           | Permeative dissolution with preserved skull contour | Yes                                                     | NA                         | NA       | Diffuse B-cell lymphoma |
| Szucs-Farkas et al.,[93] 2005 | Extra                         | Osteolytic skull defect                | No                                                      | Yes                        | No       | Peripheral B-cell lymphoma, Burkitt-like |
| Tanimura et al.,[93] 2005 | Extra                           | Osteolytic skull defect                | No                                                      | NA                         | No       | Large B-cell non-Hodgkin lymphoma |
| Evliyaoglu et al.,[21] 2006 | Intra                          | Permeative dissolution with preserved skull contour | Yes                                                     | NA                         | NA       | Diffuse, small B-cell non-Hodgkin lymphoma |
| Galarza et al.,[23] 2006 | Intra                           | No change                              | Yes                                                     | Yes                        | No       | Diffuse, large B-cell lymphoma |
| Palled et al.,[13] 2006 | None                            | Osteolysis with periosteal reaction    | NA                                                      | NA                         | No       | High-grade B-cell Burkitt-type non-Hodgkin lymphoma |
| Agrawal et al.,[2] 2007 | Intra                           | Hyperostosis                           | Yes                                                     | NA                         | NA       | Diffuse, large-cell non-Hodgkin lymphoma (MALToma type) |

(Contd...)
Table S2: (Continued).

| Author year reference | Predominance in tumor extension | Findings of skull bone on CT and/or MRI | Disproportionately small amount of cortical destruction | Dural tail invasion of brain | Histology | Lymphocyte subtype |
|------------------------|--------------------------------|----------------------------------------|------------------------------------------------------|-----------------------------|-----------|-------------------|
| Fukushima et al.,[23] 2007 | None | Osteolytic skull defect | No | No | No | Diffuse medium-sized B-cell non-Hodgkin lymphoma | B-cell |
| Mohindra et al.,[61] 2007 | None | Preserved skull contour | Yes | Yes | Yes | Diffuse, large B-cell lymphoma | B-cell |
| Uff and Shieff,[101] 2007 | Extra | Osteolytic destruction of more than half of the skull thickness | Yes | Yes | Yes | Diffuse, large B-cell lymphoma | B-cell |
| Gaitonde et al.,[24] 2008 | None | Osteolysis | NA | NA | NA | Follicular lymphoma, grade 2 | B-cell |
| Gonzalez-Bonet et al.,[25] 2008 | None | Osteolytic skull defect | No | No | No | B-cell lymphoma | B-cell |
| Yoon et al.,[109] 2008 | Intra | Permeative dissolution with preserved skull contour | Yes | NA | No | Small lymphocytic B-cell lymphoma | B-cell |
| Renard et al.,[44] 2009 | None | Osteolysis of more than half of the skull thickness with periosteal bone formation | No | Yes | No | Diffuse, malignant, large B-cell non-Hodgkin lymphoma | B-cell |
| da Rocha et al.,[15] 2010 | None | No change | NA | Yes | No | Diffuse, large B-cell lymphoma | B-cell |
| NA | No change | NA | NA | NA | Mantle cell lymphoma | B-cell |
| NA | No change | NA | NA | NA | Small lymphocytic lymphoma | NA |
| Khalid et al.,[44] 2010 | None | Permeative dissolution with preserved skull contour | Yes | NA | NA | Low-grade B-cell non-Hodgkin lymphoma | B-cell |
| Ochiai et al.,[190] 2010 | Intra | No change | Yes | Yes | Yes | Diffuse, large B-cell lymphoma | B-cell |
| Castro-Bouzas et al.,[191] 2011 | Extra | Permeative dissolution | NA | NA | NA | ALK-negative, T-cell non-Hodgkin lymphoma | T-cell |
| Fadoukhair et al.,[22] 2011 | Extra | Osteolytic skull defect | No | NA | NA | Diffuse, large B-cell non-Hodgkin lymphoma | B-cell |
| Ciarpaglini and Otten,[13] 2012 | Extra | Osteolysis | NA | Yes | Yes | None-Hodgkin lymphoma (MALT type) | B-cell |
| El Asri et al.,[20] 2012 | None | Sclerosis and hyperostosis | Yes | Yes | NA | Diffuse, B-cell lymphoma | B-cell |
| Martin et al.,[34] 2012 | Extra | Permeative dissolution with preserved skull contour and periosteal bone formation | Yes | NA | NA | (Contd...) |
| Author year reference | Predominance in tumor extension | Findings of skull bone on CT and/or MRI | Disproportionately small amount of cortical destruction | Dural tail invasion of brain | Histology | Lymphocyte subtype |
|-----------------------|---------------------------------|----------------------------------------|-------------------------------------------------------|----------------------------|----------|--------------------|
| Rezaei-Kalantari et al.,[85] 2012 | None | Hyperostosis | Yes | Yes | No | Diffuse, large B-cell lymphoma | B-cell |
| Ko et al.,[46] 2013 | None | Permeative dissolution with preserved skull contour and periosteal bone formation | Yes | Yes | No | Diffuse, large B-cell lymphoma | B-cell |
| Kosugi,[48] 2013 | None | NA | No | NA | NA | Diffuse, large B-cell lymphoma | B-cell |
| Mishra et al.,[60] 2013 | None | Permeative dissolution with preserved skull contour and periosteal bone formation | Yes | NA | NA | Diffuse, large B-cell lymphoma | B-cell |
| Salunke et al.,[86] 2013 | None | Permeative dissolution with preserved skull contour, periosteal bone formation and sclerosis | Yes | Yes | Yes | Diffuse, large B-cell lymphoma | B-cell |
| Sanjayan et al.,[88] 2013 | Intra | NA | Yes | Yes | No | Mixed small and large B-cell lymphoma | B-cell |
| Rasouli et al.,[83] 2014 | Extra | Permeative dissolution with preserved skull contour | Yes | NA | NA | Extranodal marginal zone lymphoma (EMZL) | B-cell |
| Sugimoto et al.,[92] 2014 | NA | Osteolysis of more than half of the skull thickness | NA | NA | NA | Spindle-shaped, diffuse, large B-cell lymphoma with a storiform pattern (germinal center type) | B-cell |
| Tashiro et al.,[96] 2015 | Extra | Permeative dissolution with preserved skull contour | Yes | Yes | No | Diffuse, large B-cell lymphoma | B-cell |
| Extra | No change | Yes | Yes | No | Diffuse, large B-cell lymphoma | B-cell |
| Wang et al.,[105] 2015 | Intra | NA | Yes | Yes | No | Diffuse, large B-cell lymphoma | B-cell |
| Akamatsu et al.,[4] 2016 | None | Osteolytic skull defect | No | NA | NA | Diffuse, large B-cell lymphoma | B-cell |
| Bhatoe and Ambastha,[8] 2016 | Extra | Osteolytic skull defect | Yes | Yes | Yes | Extranodal marginal zone lymphoma (EMZL) | T-cell |
| Issara et al.,[35] 2016 | No extension | Permeative dissolution with preserved skull contour | NA | No | No | Small B-cell lymphoma | B-cell |

(Contd...)
| Author year reference | Predominance in tumor extension | Findings of skull bone on CT and/or MRI | Disproportionately small amount of cortical destruction | Dural tail invasion of brain | Histology | Lymphocyte subtype |
|-----------------------|---------------------------------|-----------------------------------------|--------------------------------------------------------|----------------------------|-----------|-------------------|
| Jaiswal et al.,[36] 2016 | Extra                           | Osteolysis of more than half of the skull thickness | Yes                                      | Yes                                      | Yes            | Diffuse, large B-cell lymphoma |
| Lv et al.,[54] 2016    | Intra                           | Permeative dissolution with preserved skull contour and periosteal bone formation | Yes                                      | Yes                                      | Yes            | Diffuse, large B-cell lymphoma |
| Mascolo et al.,[59] 2016 | Extra                           | Permeative dissolution with preserved skull contour | Yes                                                  | Yes                                      | No            | Diffuse, large B-cell lymphoma |
| Kanaya et al.,[40] 2017 | NA                             | Osteolytic skull defect                  | No                                                   | NA                                      | NA            | Diffuse, large B-cell lymphoma |
| Naama et al.,[66] 2017 | None                           | Permeative dissolution with preserved skull contour | Yes                                                  | Yes                                      | Yes            | Diffuse, large B-cell lymphoma |
| Chan et al.,[11] 2018 | Extra                           | Preserved skull contour                  | Yes                                                  | Yes                                      | NA            | Diffuse, large B-cell lymphoma |
| Lee and Yun,[51] 2018  | None                           | Sclerosis and osteolysis                 | Yes                                                  | Yes                                      | No            | Diffuse, large B-cell lymphoma |
| Salvo et al.,[87] 2018 | None                           | Sclerosis                               | Yes                                                  | Yes                                      | Yes            | Diffuse, large B-cell lymphoma |
| Huang et al.,[33] 2019 | Extra                           | Osteolysis                              | No                                                   | Yes                                      | No            | Plasmablastic non-Hodgkin lymphoma (a rare subtype of DLBCL) |
| Umemura et al.,[102] 2019 | Extra                          | Permeative dissolution with preserved skull contour | Yes                                                  | NA                                      | NA            | Diffuse, large B-cell lymphoma |
|                         | None                           | Osteolysis of more than half of the skull thickness | No                                                   | Yes                                      | No            | Diffuse, large B-cell lymphoma |
| Xing et al.,[108] 2019 | NA                             | Permeative dissolution with preserved skull contour | NA                                                   | Yes                                      | NA            | B-cell non-Hodgkin lymphoma |
|                         | NA                             | Permeative dissolution with preserved skull contour | NA                                                   | Yes                                      | NA            | B-cell non-Hodgkin lymphoma |
|                         | NA                             | Permeative dissolution with preserved skull contour | NA                                                   | Yes                                      | NA            | B-cell non-Hodgkin lymphoma |
|                         | NA                             | Permeative dissolution with preserved skull contour | NA                                                   | Yes                                      | NA            | B-cell non-Hodgkin lymphoma |

(Contd...)
| Author year reference | Predominance in tumor extension | Findings of skull bone on CT and/or MRI | Disproportionately small amount of cortical destruction | Dural tail invasion of brain | Histology | Lymphocyte subtype |
|-----------------------|-------------------------------|----------------------------------------|---------------------------------------------------------|----------------------------|-----------|-------------------|
| Ahmad et al.,[3] 2020 | Extra                         | Osteolysis                             | NA                                                      | Yes                        | Yes       | Diffuse, large B-cell lymphoma | B-cell |
| Nasim et al.,[67] 2020| Intra                         | NA                                     | NA                                                      | NA                         | NA        | Low-grade B-cell lymphoma      | B-cell |

CT: Computed tomography, Extra: Extracranial extension is much larger than intracranial extension, Intra: Intracranial extension is much larger than extracranial extension, Both: Intra- and extracranial extensions are of similar size, MRI: Magnetic resonance imaging, NA: Not available