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Magnetic Resonance Imaging Findings of Intracranial Dural Metastases

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Abstract

BACKGROUND/AIMS: To evaluate the magnetic resonance imaging (MRI) findings of intracranial dural metastases (IDM) due to various cancers.

MATERIALS AND METHODS: Fifty-six male and thirty female patients (total: 86) aged 2-94 years (mean: 58.10±16.32 years) diagnosed with IDM between April 2010 and May 2020 were included in this retrospective study. Dural tumoral involvement patterns [focal, multifocal, diffuse linear, diffuse linear and nodular (mixed)], bone involvements (focal, diffuse, none), tumoral involvement areas (dural; bone and dural; parenchymal and dural; bone, dural, and parenchymal), locations (supratentorial, infratentorial), leptomeningeal involvement and the presence of perineural spread were evaluated in these cases.

RESULTS: IDM were most commonly observed in head and neck cancers (23.3%), lung cancer (17.4%), and breast cancer (15.1%). Focal pattern was observed in 55.8% of the dural tumoral involvements while 16.3% were multifocal, 16.3% diffuse linear and 11.6% mixed pattern. Fifty-seven percent of the cases involved had bone and dural area involvement, whereas 24.4% had parenchymal and dural involvement, 13.9% bone, dural and parenchymal combined involvement, and 4.7% only had dural involvement. Supratentorial involvement alone was seen in 39.5% and infratentorial involvement alone was observed in 7% of the cases, while 53.5% of the cases had both supratentorial and infratentorial involvement. In 38.3% of the cases found to have dural metastasis, cerebral parenchyma invasion was observed. Leptomeningeal involvement was observed in 41.9% of the cases whereas 9.3% had perineural spread.

CONCLUSION: IDM are more commonly observed in the male gender and in head and neck, lung and breast cancers. IDM are more commonly accompanied by bone or parenchymal involvement, while isolated dural metastases are less frequently observed.

Keywords: Dural metastasis, intracranial metastasis, leptomeningeal metastasis, magnetic resonance imaging, perineural spread

INTRODUCTION

Intracranial dural metastases (IDM) can develop due to direct extension from the metastasis of the adjacent skull as well as due to hematogenic extension from distant regions.[1] Dural metastases more frequently develop in breast, prostate, lung cancers and multiple myelomas while in pediatric patients, they develop due to neuroblastoma and sarcoma. Sinonasal or nasopharyngeal cancers, on the other hand, can lead to direct invasion of the dura from an adjacent primary tumor sites or to dural infiltration through perineural spread. In clinical trials, the frequency of IDM due to malignant neoplasms were reported to be approximately 4%.[2] Contrast-enhanced magnetic resonance imaging (MRI) is the method of choice for detecting IDM due to its high resolution and multiplanar nature.[3] On MRI, dural metastases are typically characterized by linear or nodular type thickening and contrast involvement in dura mater.[4] In this retrospective study, the radiological

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imaging findings of IDM in patients who had undergone contrast-enhanced brain MRI due to various cancers in the previous ten-year period were evaluated.

MATERIALS AND METHODS

Radiological reports from April 2010 to May 2020 in the Picture Archiving and Communication System (PACS) of our hospital were searched using the phrase "dural metastasis", and 107 patients with dural metastasis were identified. Twenty-one patients for whom contrast-enhanced brain MRIs were not carried out or whose images were not of sufficient quality to perform radiological evaluation, and those patients with trauma or surgical history were excluded. Thus, a total of 86 patients were included. Fifty-six of them (65.1%) were male and 30 (34.9%) were female. Their mean age was 58.10±16.32 years (range: 2-94).

MRI examinations up to 2017 were carried out using an 8-channel 1.5 T MRI machine (GE Signa Excite HD; GE Healthcare, Milwaukee, WI, United States, 2005), and a 16-channel 1.5 T MRI machine (GE Signa Explorer SV 25; GE Healthcare, Milwaukee, WI, United States, 2016) was used after 2017. All radiological examinations were evaluated by two experienced neuroradiologists (E.G. with more than 10 years of experience and M.B. with more than five years of experience). Dura matter tumoral involvement patterns were evaluated in four groups: focal when there were one or two foci; multifocal when there were three or more foci; diffuse linear when there was common linear involvement; or mixed pattern when there was diffuse involvement along with nodular foci. Tumoral of bone involvements were of three types: focal, diffuse or no bone involvement. Dural and adjacent structures involvements were evaluated in four groups: only dura, bone and dura, parenchyma and dura, and bone, dura and parenchyma combined involvement. Involvements of dural metastases in supratentorial, infratentorial and both supratentional and infratentorial localizations were evaluated. In addition, leptomeningeal and parenchymal involvement and the presence of perineal spread were also evaluated in our cases. The presence of subdural effusion associated with metastases was determined.

The ethics committee approval was received for this study from institutional ethics committee (no: 15- KAEK-155). Informed consent is not necessary due to the retrospective nature of this study.

Statistical Analysis

Descriptive data are given as mean ± standard deviation, while categorical data are expressed as n (%). Analyses were performed using SPSS software (IBM SPSS Statistics 22, SPSS Inc., an IBM Co., Armonk, NY, United States).

RESULTS

IDM were more commonly detected in head and neck cancers (23.3%), lung (17.4%), breast (15.1%) and prostate (11.6%) cancers. Of all head and neck cancers, nasopharyngeal cancers are most frequently caused by metastases. In two cases in the pediatric group, the cause of metastasis was neuroblastoma. Primary cancer types, numbers and percentages of intracranial dural metastasis cases are given in Table 1.

Dural tumoral involvement patterns were of a focal type (Figure 1a) in 48 cases, multifocal (Figure 1b) in 14 cases, diffuse linear (Figure 1c) in 14 cases and mixed (Figure 1d) in 10 cases. No bone tumoral involvement was observed in 25 cases while 34 cases had focal and 24 cases had diffuse bone involvement. Isolated dural involvement (Figure 2a) was observed in only four cases. Bone and dural involvement (Figure 2b) areas were observed in 49 cases, parenchyma and dura (Figure 2c) in 21 cases, and bone, dural and parenchyma (Figure 3a) combined in 12 cases. Forty-six cases had both supratentorial and infratentorial dural involvement (Figure 3a) while supratentorial involvement alone was observed in 34 cases and infratentorial involvement alone was observed in six cases. The cerebral parenchyma was invaded in 38.3% of dural metastasis cases. Leptomeningeal tumoral infiltration was found in 36 cases and perineural spread (Figure 3b) was observed in eight cases. Tumors causing perineural spread were in the head and neck cancers group, and they developed from squamous cell cancer (SCC) in five cases and from adenoid cystic cancer (ACC) in three cases. Bone and dural tumoral involvement patterns, tentorial localizations, leptomeningeal infiltration and perineural spread numbers and percentages in cases who were found to have intracranial dural metastasis are given in Table 2. Subdural effusion associated with dural metastasis was seen in two cases.

DISCUSSION

Dura mater (pachymeninx) forming the outer meningeal layer in the central nervous system is in two layers in the cerebral convexity. These are the outer layer, rich in vascular structures which is periosteum of inner tabula of skull, and the inner layer which is the true meningeal dura mater.[5] After intravenous contrast matter administration, contrast enhancement is observed in the periosteum of the skull bones and in the real meningeal layer. This contrast enhancement could extend to falx cerebri, falx cerebelli, tentorium cerebelli and dural structures in cavernous sinuses.[6]

Table 1. Primary cancer types, numbers and percentages of cases found to have intracranial dural metastases

Primary cancer type	n	%
Head and neck cancer	20	23.3
- Nasopharyngeal cancer	11	12.8
- Sinonasal cancer	7	8.1
- Oral cancer	1	1.2
- Orbital cancer	1	1.2
Lung cancer	15	17.4
Breast cancer	13	15.1
Prostate cancer	10	11.6
Others	11	12.8
- Malignant mesothelioma	2	2.3
- Neuroblastoma	2	2.3
- Non-Hodgkin lymphoma	1	1.2
- Multiple myeloma	1	1.2
- Chronic myeloid leukemia	1	1.2
- Acute myeloid leukemia	1	1.2
- Thyroid follicular cancer	1	1.2
- Hepatocellular cancer	1	1.2
- Adrenocortical cancer	1	1.2
Skin cancer	8	9.3
Glial tumor	5	5.8
Gastrointestinal cancer	4	4.7

Table 2. Bone and dural tumoral involvement patterns, tentorial localizations, leptomeningeal infiltration and perineural spread numbers and percentages in cases found to have intracranial dural metastases

Anatomical involvement of dural metastases		n	%
Dural involvement pattern	Focal	48	55.8
	Multifocal	14	16.3
	Diffuse linear	14	16.3
	Mixed (diffuse linear and nodular)	10	11.6
Bone involvement pattern	Focal	34	39.5
	Diffuse	27	31.4
	None	25	29.1
Involvement area	Bone and dural	49	57.0
	Parenchymal and dural	21	24.4
	Bone, dural, and parenchymal	12	13.9
	Dural	4	4.7
Tentorial location	Supratentorial and infratentorial	46	53.5
	Supratentorial	34	39.5
	Infratentorial	6	7.0
Leptomeningeal infiltration	-	36	41.9
Perineural spread	-	8	9.3

Laigle-Donadey et al.[4] studied 198 dural metastasis cases published in the literature during the 1904-2003 period, and found that the average age of the patients was 59 years (range: 4 months to 84 years). Nayak et al.[7] reported that 61% of cases with intracranial dural metastasis were female gender and that their mean age was 59 years. In the present study, the mean age of the cases with intracranial dural metastasis was 58.1 years, which was in accordance with the literature reports. However, unlike what has been reported in the literature, the frequency of IDM was higher in the male gender (65.1%) in our study. Tumors causing intracranial dural metastasis listed in the literature by their frequency were prostate (19.5%), breast (16.5%) and lung (11.0%) cancers.[4] In the present study, however, the tumors most commonly causing IDM were head and neck cancers (23.3%), followed by lung (17.4%) and breast cancers (15.1%). The higher frequency of dural metastases originating from head and neck cancers and in the male gender in the present study could be related to the genetic and environmental factors affecting the study population as well as to the number of patients.

The radiological diagnosis of dural metastases are based on contrast-enhanced computed tomography (CT) and MRI. Non-contrast-enhanced CT of the brain is often the first imaging method in patients presenting with neurological symptoms. CT imaging has the advantages of being able to detect metastatic lesions and also to reveal bone involvement. Although less reliable than MRI for the assessment of the extent of intracranial lesions, CT scan is a useful method to show lytic bone lesions. However, CT scan does not clearly show extension and degrees of dural invasion of bone metastases.[3,4] MRI is the best imaging modality to accurately identify dural metastases extending along bone structures.[4,8] Careful evaluation of T2-weighted, T1-weighted and contrast-enhanced images is crucial in detecting dural metastases. On T1-weighted MRI, normal dura mater and the inner table of bone is uniformly hypointense. After gadolinium-based contrast matter administration, normal dura mater shows a thin, linear and discontinuous enhancement.[9] MRI findings suggesting dural metastasis are contrast-enhancing in dura mater and thickening which shows a linear continuity which can sometimes be nodular and signal enhancement on T2-weighted images.[2] The lack of blood-brain barrier in dura mater explain intense contrast-enhancing on MRI.[7] The diagnostic feature of dural metastases is the presence of a signal gap between the dural mass and dislocated brain. This gap might contain cerebrospinal fluid or subdural vessels with varying signal intensities depending upon the sequence used.[2] On contrast-enhanced MRI studies in the literature, the radiological appearances of dural metastases were discussed, and classified as simply localized thickening or nodular mass, classical lenticular or biconvex shape, diffuse dural thickening or diffuse involvement with nodular areas.[1,4,7,10] Although dural metastases can be single or multiple, dural tail finding can be observed in contrast-enhanced examinations.[7] Nayak et al.[7] observed single metastasis in 56% of their cases and multiple metastases in 16%, while 25% of their cases had diffuse involvement and 3% had diffuse and nodular dural involvement. In addition, they found brain parenchymal invasion in 34% and subdural effusion in 2% of their cases, and only 11% of them had infratentorial lesions. Similarly, invasion of brain parenchyma was reported in about one third of the cases with dural metastasis.[11] Similar to the literature, focal and multifocal involvement patterns were observed in 55.8% and 16.3% of the cases, respectively, in the present study. Mixed pattern frequency (11.6%) was higher while diffuse linear involvement frequency (16.3%) was lower compared to the literature. In addition, supratentorial localization, parenchymal invasion and subdural effusion frequencies were similar to the ones reported in the literature. Nayak et al.[7] reported a skull metastasis frequency of 70% in cases with dural metastasis, which was very similar to the present study (70.9%).

In cases with known cancer, leptomeningeal metastasis frequency was reported to be in a wide range of 5-70%.[12] MRI findings of leptomeningeal metastases are thin, diffuse leptomeningeal contrast-enhancement which follows gyri and sulci or multiple nodular lesions in the subarachnoid space.[12,13] About half of the cases in the present study had leptomeningeal metastasis, and this frequency was in line with reports in the literature.

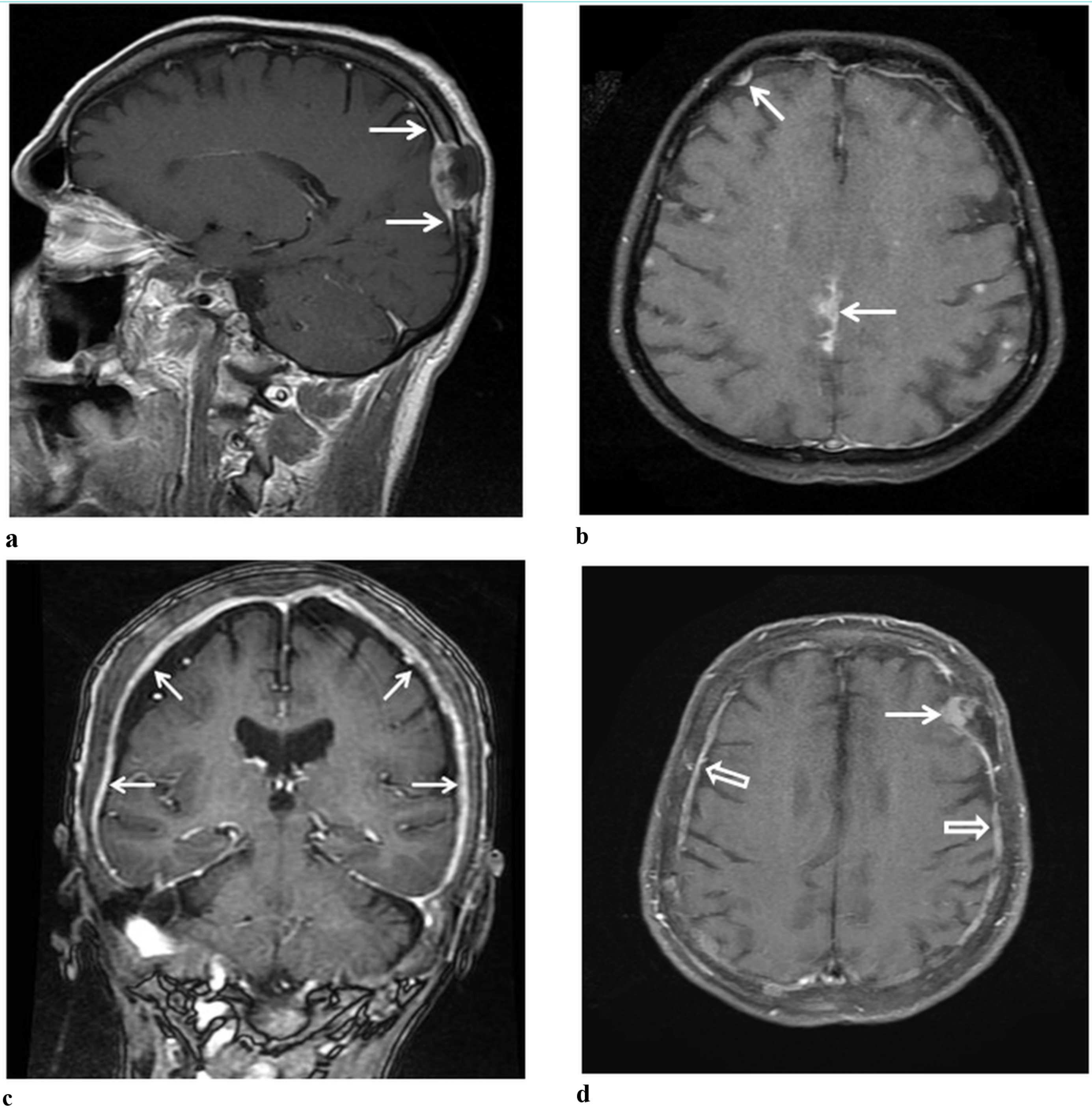

Figure 1. On contrast-enhanced T1-weighted magnetic resonance imaging, **a)** focal metastasis involving left occipital bone and adjacent dura and dural tail (white arrows) are shown. **b)** Multifocal cortical metastases are shown in right frontal and falcine dura and in cerebral parenchyma. **c)** Diffuse linear thickening and contrast-enhancing (arrows) due to tumoral involvement in dura are shown. **d)** Diffuse (open arrows) and nodular type (white arrows) dural thickening and enhancement with diffuse calvarial involvement are observed.

Intracranial invasion through extra-cranial neoplasms are mostly associated with sinonasal or nasopharyngeal malign neoplasms. Neoplastic extension mechanisms are a direct infiltration of the periosteum-bone-dura composite layer or perineurial spread.[2] MRI findings of dural invasion in nasopharynx cancer or sinonasal malign tumors are dural thickening and nodular dural contrast-enhancement.[14] Perineural spread refers to the extension of tumor cells along with the nerve sheath. Perineural spread can also be observed in infections, granulomatous diseases and benign tumors. Among the head and neck cancers, perineural spread is most commonly observed in SCC cases since SCCs constitute most malignancies in the head and neck areas. The frequency of perineural spread in SCCs ranges from 2

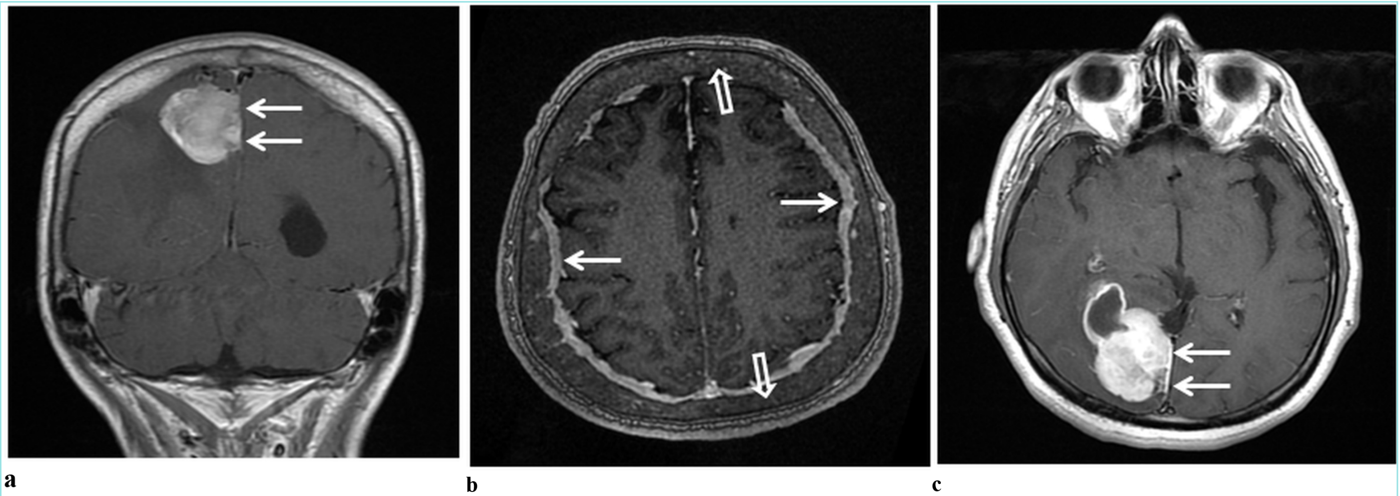

Figure 2. On contrast-enhanced T1-weighted magnetic resonance imaging, **a)** The dura-based mass reveals mildly heterogeneous and intense enhancement (arrows) direct dural involvement due to thyroid follicular cancer. **b)** Bone and dural involvement due to acute myeloid leukemia contrast-enhancing and thickening, nodular and linear in places, of mixed pattern dural involvement are shown. **c)** Pleomorphic xhantoastrocytoma which caused focal metastasis (white arrows) from parenchyma to falcine dura is shown.

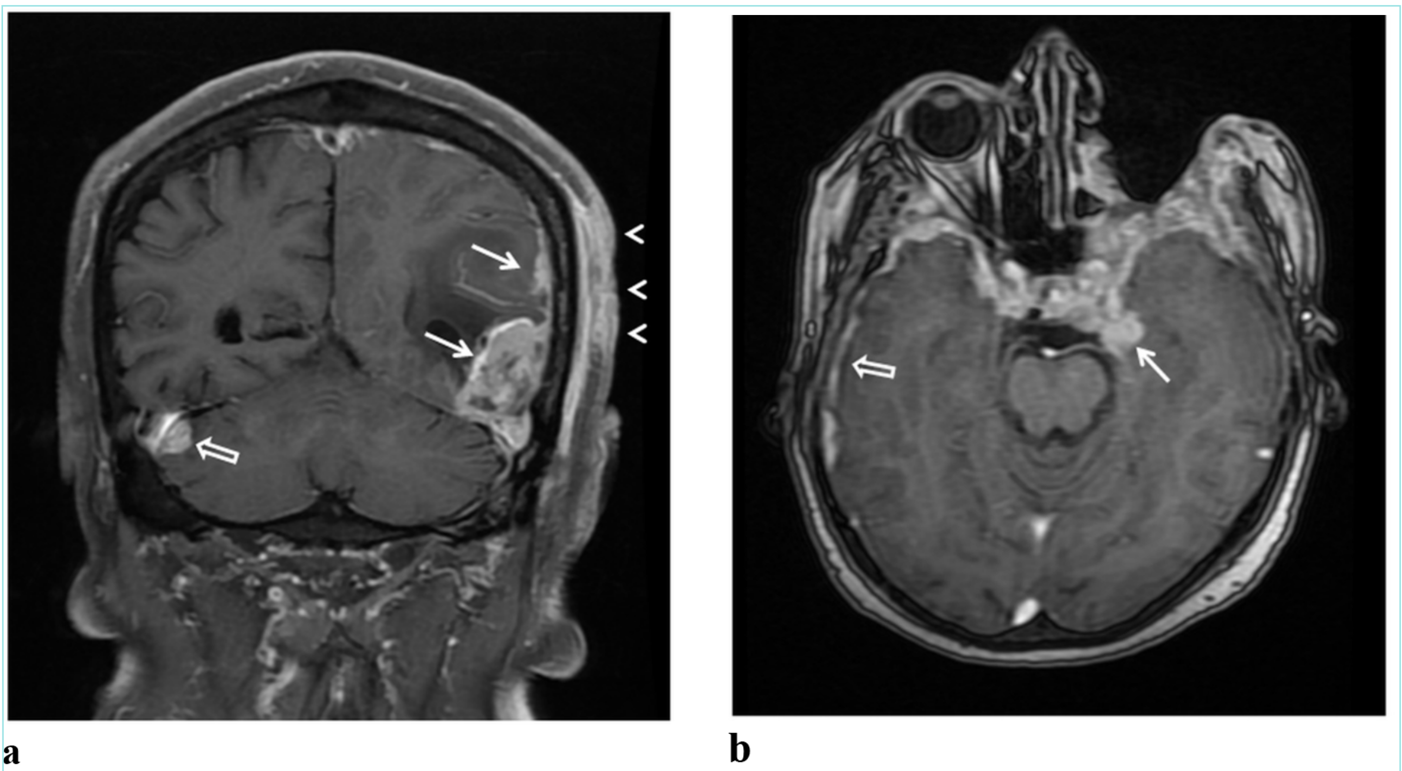

Figure 3. On contrast-enhanced T1-weighted magnetic resonance imaging, **a)** The patient with skin cancer (arrow heads) in addition bone, dural and parenchymal involvement, diffuse linear and nodular dural metastasis in both infratentorial (open arrows) and supratentorial locations (white arrows) are observed. **b)** The patient with adenoid cystic cancer, mixed pattern dural metastases which had both linear (open arrow) and nodular (white arrows) character and which developed from an adjacent tumor site and perineural spread are shown.

to 30%. Despite their very high perineural spread capabilities, ACCs are responsible for less perineural spreads than SCCs since they are rarely observed.[15] In the present study, both bone and dura were involved in all cases with head and neck cancers, and parenchymal involvement was also present in one case. In addition, eight cases were found to have perineural spread, the primary malignancy was head and neck tumors, and SCC was responsible for two-thirds of the cases.

In the differential diagnosis of dural metastases, in addition to neoplasia such as meningiomas and lymphomas, non-neoplastic lesions such as subdural hematoma, intracranial hypotension, sarcoidosis (especially in the form of granulomatous meningitis), empyema and tuberculosis osteomyelitis should be considered.[2,16-18] While meningioma generally shows a signal intensity similar to that of the cortex on both T2 and T1-weighted sequences, most metastases are slightly hyperintense on T2-weighted MRI and slightly hypointense on T1-weighted MRI.[2] When the dural lesion is single and has a dural tail character, it may not be differentiated radiologically from meningioma. The presence of calvarium metastasis and bone erosion in these cases does not help in the differential diagnosis from meningioma. Diffuse dural involvement can also make diagnosis difficult. Diffuse dural involvement can depend on the dural invasion of the cancers, but it can also be the reactive response of dura to calvarium metastasis. Infectious-inflammatory etiologies can also lead to this appearance.[7] Non-Hodgkin lymphoma should be suspected in the differential diagnosis in soft tissue involvement associated with bone resorption and epidural mass observed in human immunodeficiency virus-positive patients. In patients with osteomyelitis, on the other hand, lytic bone lesions and soft tissue mass are generally observed.[2] When big in size, dural metastases can indent into the cerebral cortex, resulting to vasogenic edema. Dural metastases can sometimes be associated with spontaneous hemorrhages which can hide the underlying lesions, and, though rarely, they can also be associated with parenchymal hemorrhages.[11] Three mechanisms have been suggested to explain the association between dural metastasis and subdural hematoma: hemorrhagic effusion due to dural metastasis, dural venous occlusion due to neoplastic invasion or angiodesmoplastic response of dura against neoplastic cell invasion.[19] In these cases, hemorrhage was assumed to occur into subdural neomembrane, which is an abnormally areolar dural layer with abundant vascularization.[20] Intracranial hypotension, another entity which should be considered in the differential diagnosis of dural metastases, on the other hand, bilateral, diffuse, non-nodular meningeal contrast-enhancement, congestion in venous sinuses and congestion in posterior fossa are observed.[18]

The present study has some limitations. First, the study was only a retrospective screening-based on PACS search using the phrase “dural metastasis”, therefore the search is based on radiological reports, and not based on reviewing the images of the patients with primary malignancy. Second, in most of the cases with known primary tumor, dural involvements in the imaging studies were accepted as dural metastasis without histopathologic diagnosis. Third, while dura was not examined in detail during autopsy, dural thickening and enhancement were accepted as dural metastasis in some cases based only on the radiological imaging findings.

CONCLUSION

IDM are more frequently observed in the male gender and especially in head and neck, lung and brain cancers. Dural metastases frequently have both supratentorial and infratentorial localizations, while only infratentorial localization is rare. Dural metastases are generally accompanied by bone and parenchymal involvements, whereas isolated dural metastases are less frequently observed. The dural tumoral involvement pattern is mostly focal, but multifocal, diffuse linear or mixed type dural metastases can also be observed.

MAIN POINTS

- IDM are more frequently observed in the male gender and in head and neck cancers.
- Dural metastases mostly have supratentorial and infratentorial localizations combined, and isolated infratentorial localization is less frequent.
- Isolated dural metastases are rare, and dural metastases are more frequently accompanied by metastatic involvement of adjacent structures (calvarium and parenchyma).
- Dural metastases mostly have the appearance of focal pattern and less frequently mixed pattern (diffuse linear and nodular).
- Contrast-enhanced MRI is the best method for imaging dural metastases.

ETHICS

Ethics Committee Approval: The ethics committee approval was received for this study from institutional ethics committee (approval number: 15- KAEK-155).

Informed Consent: Informed consent is not necessary due to the retrospective nature of this study.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Concept: E.G., Design: E.G., M.B., Supervision: E.G., L.A., Resources: L.A., Materials: M.B., Data Collection and/or Processing: M.B., B.A., Analysis and/or Interpretation: E.G., M.B., Literature Search: L.A., Writing: E.G., M.B., L.A., Critical Review: E.G., B.A.

DISCLOSURES

Conflict of Interest: The authors have no conflicts of interest to declare.

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