Intracranial Meningeal Carcinomatosis and Non-neoplastic Meningeal Diseases: Evaluation with Contrast-Enhanced MR Imaging

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This study was performed to correlate meningeal enhancement patterns with intracranial meningeal carcinomatosis and non-neoplastic meningeal diseases.

From 1993 to 1998, 48 patients with a clinical diagnosis of meningeal carcinomatosis and non-neoplastic meningeal diseases with abnormal meningeal enhancement on MR imaging were reviewed. Two enhancement patterns of the meninges were characterized: pachymeningeal and leptomeningeal. The distribution and shape of the enhancement were also inspected. The meningeal enhancement was classified into six etiologic subgroups: carcinomatosis, infection, inflammation, cerebrovascular disease, reactive meningitis, and chemical meningitis. Nineteen of the 48 patients with enhanced meninges had carcinomatosis of the meninges. The other 29 patients without neoplasms included 10 with infectious meningitis, 5 with inflammatory disease, 8 with cerebrovascular disease (7 with early brain infarction and 1 with Sturge-Weber disease), 5 with reactive changes and 1 with chemical meningitis.

Pachymeningeal enhancement occurred in 11 patients with meningeal metastasis, 1 with amebic meningitis, 4 with inflammatory meningeal disease, 7 with early infarction, 5 with reactive meningeal disease, and 1 with chemical meningitis while leptomeningeal enhancement was shown in 8 meningeal metastases, 9 with infectious meningitis, 2 with inflammatory changes and 2 with vascular disease (1 with early brain infarction and 1 with Sturge-Weber disease). Both enhancement patterns were noted in 1 with inflammatory changes (Wegener granulomatosis) and 1 with early brain infarction.

Diffuse linear leptomeningeal enhancement favored non-neoplastic etiologies while enhanced leptomeningeal nodules indicated meningeal metastasis and some non-neoplastic disease such as tuberculosis and neurosarcoidosis. Focal nodular pachymeningeal enhancement presented mostly due to meningeal carcinomatosis. Diffuse linear pachymeningeal enhancement could be meningeal carcinomatosis or reactive meningeal change.

Key words: Meninges, Magnetic resonance imaging, Meningitis, Meningeal metastasis.

Clinical evaluation of meningeal disorders has limitations in nonspecific clinical presentations and confusing cerebrospinal fluid (CSF) analysis.
However, advances in magnetic resonance (MR) imaging have had great impact on the evaluation of the meninges [1]. Cranial meninges may be involved by varied pathological process leading to carcinomatosis, infection, inflammation, vascular disease, reactive meningitis and chemical meningitis [2]. Anatomically, the cranial meninges is composed of the dura, arachnoid and pia layers. Postcontrast images can visualize two distinguishing enhancement patterns, leptomeningeal (pia-subarachnoid) and pachymeningeal (dura-arachnoid) [1]. Meningeal enhancement shown by MR scanner is considered a sensitive aid for diagnosing meningeal diseases, selecting proper modalities for disease follow-up and providing high successful surgical biopsy rates [3]. The purpose of this study was to investigate the relationship between meningeal enhancement patterns on MR imaging and various meningeal abnormalities.

**MATERIALS AND METHODS**

In this retrospective study, we reviewed the imaging studies of 48 cases with evidence of abnormal meningeal enhancement on MR imaging who were treated between 1993 and 1998. There were 18 women and 30 men with the ages ranging from six months to 74 years. The etiologies of abnormal meningeal enhancement were classified into six subgroups (Table 1): carcinomatosis, infection, inflammation, vascular disease, reactive meningitis and chemical meningitis. Three meningeal metastasis patients had positive malignant cytology in the CSF. Another 16 patients had a clinical diagnosis of meningeal metastasis by history of primary cancer. Seven brain infarction cases were diagnosed of patients’ symptoms and correlated imaging findings. Ten infectious meningitis patients had CSF analysis for diagnosis. Three patients had pathological evidence including neuro-sarcoidosis, hypertrophic cranial pachymeningitis, and dermoid cyst rupture. Post-neurologic surgery, subarachnoid hemorrhage or CSF pressure changes (iatrogenic shunting or CSF leakage) were considered to be reactive changes in the meninges. The consequences of rupture of intracranial dermoid or epidermoid cysts were classified as a chemical reaction. Meningeal involvement due to collagen-vascular disease or neuro-sarcoidosis was considered inflammatory. Final diagnoses were based on medical histories, surgical findings, pathology reports or CSF analyses.

MR images were obtained with a 1.5 Tesla superconductive magnet. T1-weighted spin echo (TR/TE 500-800/15-25), T2-weighted spin echo (TR/TE 2200-3000/80-120) and proton density (TR/TE 2200-3000/30-40) were routinely obtained in the axial and coronal planes (parameters included: matrix size, 256X192; section thickness, 5mm; intersection gap, 2.5 mm; and field of view, 24 cm). After precontrast images were obtained, gadopentetate dimeglumine (Magnevist) was administrated by intravenous injection at a dose of 0.1 mmol/kg. Multiplanar post contrast T1-weighted imaging was obtained in the axial and coronal planes. Meningeal enhancement patterns were subsequently divided into two categories: 1. leptomeningeal (pia-arachnoid) enhancement, and 2. pachymeningeal (dura-arachnoid) enhancement. The enhancement area (focal or diffuse) and shape (linear or nodular) were also inspected and distinguished by two radiologists unaware of the final diagnoses.

**RESULTS**

Pachymeningeal enhancement was seen in 11 patients with meningeal metastasis, 1 with amebic meningitis, 1 with hypertrophic cranial pachymeningitis, 1 with Wegener granulomatosis, 2 with Tolosa-Hunt syndrome, 7 with early infarction, 4 who were postoperative change, 1 with intracranial hypotension and 1 with chemical meningitis while leptomeningeal enhancement was found in 8 with meningeal metastasis, 9 with infectious meningitis, 1 with neuro-sarcoidosis, 1 with Sturge-Weber syndrome and 2 with vascular disease (1 with early brain infarction and 1 with

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*One Wegener granulomatosis showed both enhancement patterns.

# One brain infarction showed both enhancement patterns.
Sturge-Weber disease). Both enhancement patterns were identified in 1 patient with Wegener granulomatosis and 1 with early brain infarction. MR imaging findings of the six etiologic groups are described below.

**Meningeal Carcinomatosis**

Nineteen patients with primary malignancy were subsequently considered to have meningeal tumor involvement. Lung carcinoma, breast carcinoma and melanoma were the common primary malignancies. Of eleven patients with pachymeningeal carcinomatosis, eight had focal nodular pachymeningeal enhancement and the other three patients presented diffuse linear pachymeningeal patterns (Fig. 1). All eight leptomeningeal carcinomatosis patients had nodular leptomeningeal enhancement (Fig. 2).

**Infection**

Nine of the ten infectious meningitis cases showed leptomeningeal enhancement, including 3 with bacterial, 3 with tuberculosis (TB), 2 with cryptococcus and 1 with Angiostrongylus meningitis. Two cases of TB meningitis (Fig. 3) and one case of cryptococcus meningitis showed basal cistern leptomeningeal nodular enhancement. One case of bacterial meningitis was complicated with empyema and the MR images showed linear leptomeningeal enhancement with subdural fluid collection.

One case of amebic (Acanthamoeba) meningitis had focal pachymeningeal nodular enhancement (Fig. 4).

**Inflammatory Meningeal Disease**

Inflammatory meningitis was seen in 2 patients with Tolosa-Hunt syndrome, 1 with neurosarcoidosis, 1 with hypertrophic cranial pachymeningitis and 1 with Wegener granulomatosis. Two Tolosa-Hunt syndrome cases had temporal base focal nodular pachymeningeal enhancement adjacent to the cavernous sinus (Fig. 5). One neuro-sarcoidosis case showed diffuse nodular leptomeningeal enhancement. One Wegner granulomatosis case displayed both enhancement patterns (Fig. 6). One Sjogren syndrome revealed diffuse linear pachymeningeal thickening with strong enhancement and hypertrophic cranial pachymeningitis was diagnosed on biopsy.
Cerebrovascular Disease

Most cerebrovascular diseases with abnormal meningeal enhancement in our study were early infarction (within one week after clinical ictus). All abnormal meningeal enhancements were associated with cerebral or cerebellar large-territory infarction. The seven cases of early infarction showed focal pachymeningeal enhancement and four cases showed various degrees of parenchyma enhancement at the involved area. In one case, leptomeninges was also involved (Fig.7a and b). One Sturge-Weber syndrome case displayed linear leptomeningeal enhancement (Fig. 8).

Reactive Meningitis

All of the reactive meningitis in our study had the either focal or diffuse linear pachymeningeal enhancement pattern. Three post-craniotomy cases showed focal pachymeningeal enhancement adjacent to the previous surgery regions (Fig. 9). One case of post ventricle-peritoneum (V-P) shunting disclosed diffuse linear pachymeningeal enhancement (Fig.10). One case of intracranial hypotension showed diffuse linear pachymeningeal enhancement (Fig. 11).

Chemical Meningitis

One case of dermoid cyst rupture into ventricle and subarachnoid space showed focal linear pachymeningeal enhancement.

DISCUSSION

The meninges consists of the dura, arachnoid and pia matter. The dura matter is the outermost layer of the meninges. The outer layer of the dura is a fibrous layer of skull bone and the inner layer of dura is the meninges layer [1]. The falx cerebri is composed of the double layers of inner dura between the cerebral hemispheres at the midline. The tentorium cerebelli is a doubled dura partition located within the transverse fissure separating the occipital lobe and cerebellar hemispheres.

The leptomeninges is composed of arachnoid
and pia matter. The subarachnoid space is the trabecular space between the arachnoid and pia matter and contains CSF. Short-segment convexly meningeal enhancement is commonly seen and most likely represents intravascular contrast material in normal meningeal vessels. Long-segment (> 3 cm), diffusely convexly or a continuous meningeal enhancement pattern usually suggests meningeal abnormality and is correlated with clinical illness [1]. Two distinct patterns of meningeal enhancement may be observed in postcontrast MR imaging. Leptomeningeal enhancement extends into the depths of the sulci while pachymeningeal enhancement follows the inner surface of the skull. Meningeal enhancement surrounding the brain stem always indicates the leptomeningeal type because of the corresponding location of basal cistern pia-arachnoid space [1].

Different etiologies of meningeal enhancement are discussed below:

**Meningeal Carcinomatosis**

Dural metastasis may be caused by invasion directly from bone metastasis or hematogenous spreading to the dura [5]. Subarachnoid tumor deposits are due to hematogenous dissemination,
Meningeal enhancement on MR imaging

perineural spread and seeding of CSF from cerebral and ependymal metastasis [6]. Sze described normal Gd-MR images being normal in nearly one-third of the cases clinically diagnosed as meningeal carcinomatosis [7]. They suggested these may be in the early stage of leptomeningeal carcinomatosis [7].

In our study, pachymeningeal metastasis were commonly presented as solitary or multiple dural masses at the cerebral convexity adjacent to the skull or diffuse linear dural thickening. In patients with dura metastasis without leptomeninges invasion or negative CSF findings, image diagnosis can help in early diagnosis and treatment. MR allows us to assess the outcome because diffuse leptomeningeal or pachymeningeal involvement confers a poor prognosis.

Infectious Meningitis

Infectious meningitis can be direct extension from a contiguous extracerebral infection (otitis media or sinusitis) or hematogenous infection from the bloodstream [8]. In our study, the most common imaging finding of bacterial meningitis was leptomeningeal enhancement. Farhad et al. found all of their infectious meningitis cases (including bacteroids, virus and fungus) showed leptomeningeal enhancement only [2]. However there was some limitation in separating leptomeningeal and pachymeningeal enhancement when the infectious process progressed and involved all three layers of the meninges.

Tuberculosis meningitis was found in elderly patients in our study series. Tuberculous meningitis was characterized of the presence of inflammatory meningeal exudate involving the basal cistern meningeal surfaces and CSF spaces [9]. Infectious meningeal exudate showed intense nodular leptomeningeal contrast enhancement (Fig. 3). The exudate revealed a microscopic hypervascular nature of inflammatory neovessel leakage. Communicating hydrocephalus is the most common complication of cranial TB meningitis secondary to obstruction of CSF flow by meningeal exudates in the basal cistern [9,10].

Central nervous system (CNS) cryptococcus usually occurs in aged or immunocompetent patients. Meningitis is the most common finding of CNS cryptococcosis in AIDS patients [11]. Basal cistern leptomeningeal enhancement in cryptococcus meningitis was less common than TB meningitis in our study. Meningeal enhancement was less common compared to other meningitis, probably due to a lack of host reaction and immunosuppressive effect of the organism capsule [1,12,13].

Bacterial meningitis with subdural empyema is a neurosurgical emergency. Gadolinium-enhanced MR imaging has proven to be more sensitive than CT for detection of meningeal enhancement, parenchymal change and subdural fluid collection [1,14,15].

The leptomeningeal enhancement pattern is the most common feature of infectious meningitis while pachymeningeal enhancement is rare.
Although the CSF analysis is the gold standard for meningitis, MR images can offer more information about other intracranial abnormalities or contraindications for lumbar puncture. We know normal imaging cannot exclude meningitis, but it can help with patient management when meningitis is clinically suspected in patients with leptomeningeal enhancement.

**Inflammatory meningeal disease**

Inflammatory pachymeningitis is a rare disorder, with neuro-sarcoidosis, Wegener granulomatosis and syphilis being the most commonly considered etiologies.

Sarcoidosis involves the CNS in about 5% of the patients. In neurosarcoidosis, the pia is involved more frequently than the dura [1]. When sarcoidosis involves the CNS, multiple small nodular granulomas usually infiltrate the leptomeninges and the underlying brain parenchyma [16]. One patient showed diffuse nodular leptomeningeal enhancement.

Hypertrophic cranial pachymeningitis (HCP) was found in one patient with Sjogren syndrome. HCP is granulomatous thickening of the pachymeninges and has a wide range of etiologies. There is uniformly, dense and linear contrast enhancement of the thicken dural membrane [17].

Wegener granulomatosis is a multisystem disorder characterized by necrotizing granulomas and systemic vasculitis. Cerebral and meningeal involvement were uncommon [18,19]. Both diffuse pachymeningeal and leptomeningeal enhancement were present in our patient of Wegener granulomatosis, consisting with diffuse involvement of the whole layer meninges (Fig.6).

Tolosa-Hunt syndrome is characterized by painful ophthalmoplegia caused by cavernous sinus inflammation which is responsive to steroid therapy [20]. MRI revealed a convex enlargement of the symptomatic cavernous sinus by abnormal tissue which was isointense with gray matter on T1 weighted images and isohypointense on T2 weighted images. This abnormal tissue showed markedly increased signal intensity after contrast injection (Fig. 5) [21].

**Cerebrovascular Disease**

The two earliest signs of acute infarction are intravascular and meningeal enhancement, which tend to occur during the first week after stroke [22]. Abnormal enhancement of the meninges adjacent to the infarction area occurs due to collateral vascular enlargement, sluggish flow, and early breakdown resulting from underlying infarction. Enhancement is not seen in the brainstem or in deep cerebral (basal ganglia/internal capsule) infarctions [23]. Enhancement is seen mostly with large infarctions [24]. In all of our cases, enhancement presented as focal linear pachymeningeal pattern adjacent to the cortical infarction region with a various degree of early parenchymal enhancement or leptomeningeal enhancement (Fig.7).

Sturge-Weber syndrome is a neurocutaneous syndrome characterized by facial and leptomeningeal angiomas. MR findings include pial angiomatosis, cerebral atrophy, decreased in cortical veins, enlargement of deep veins, enlargement of the choroid plexus (Fig. 8), and parenchymal calcification [25]. On MR images, the most characteristic finding is diffuse linear leptomeningeal enhancement, believed to represent leakage of contrast medium through the anomalous pial vessel due to Blood brain barrier (BBB) disruption or enhancement of a pial angioma [25,26].

**Reactive Meningitis**

Irritation caused by bleeding into the subarachnoid space or physical disruption of the integrity of the meninges may cause meningeal enhancement after craniotomy. Elster studied 46 postoperative patients and found that nearly every postcraniostomy patient had nonneoplastic meningeal enhancement on MR images [27]. Enhancement of the brain or pia mater was inconspicuous and normally lasted less than 1 year while dural enhancement might persist for several years [27]. Postoperatively, the dura usually shows focal linear enhancement near the craniotomy site, but diffuse extensive dura thickening could also be found. Nodular pachymeningeal enhancement or persistent leptomeningeal enhancement is suggestive of recurrence [27].

Spontaneous intracranial hypotension is characterized by posture headache responding to epidural blood patch. The diagnosis is made when the pressure CSF is less than 60 mm H2O [1]. MR images reveal a bilateral subdural fluid collection and extensive diffuse pachymeningeal enhancement (Fig. 11) [1]. One patient in our study presented with posture headache and diffuse pachymeningeal enhancement on MR
images. Low CSF pressure was measured and nuclear medicine study showed CSF leakage in the thoracic spine region.

Post V-P shunting surgery can be thought of as the same mechanism as decreased intracranial pressure or over-shunting. Diffuse linear pachymeningeal enhancement has also been identified.

A pachymeningeal enhancement pattern and pathogenesis similar to postcraniotomy occurs in patients with subarachnoid hemorrhage (SAH) of any cause (trauma or aneurysm rupture). We found the reactive meningeal change due to surgery, shunting, intrathecal therapy, SAH or intracranial hypotension commonly presents the pachymeningeal rather than the leptomeningeal pattern. The intact intracranial BBB with increased granulation tissue and vascularity of the pachymeninges might explain the pachymeningeal enhancement.

Chemical Meningitis

Chemical meningitis has been reported after intrathecal injection of a variety of foreign substances or rupture of an infectious cyst [2]. Rarely chemical meningitis may develop as a consequence of rupture of an intracranial dermoid tumor, epidermoid tumor or craniopharyngiomas. The pattern is thought to be due to irritation by cholesterin crystals and keratin material. T1-weighted MR images can give the diagnosis by visualization of tumor rupture and high signal lipid material in the CSF [2].

CONCLUSION

The higher contrast provided by gadolinium-enhanced MR imaging, coupled with lack of beam-hardening artifact suggests that contrast-enhanced MRI is the most sensitive diagnostic imaging modality for meningeal diseases. Meningeal enhancement patterns are mostly non-specific findings and correlation with clinical history is necessary. In this study, we found diffuse linear leptomeningeal enhancement favored non-neoplastic etiologies while enhanced leptomeningeal nodules suggested meningeal metastasis and some non-neoplastic diseases such as tuberculosis and neuro-sarcoidosis. Focal nodular pachymeningeal enhancement represented mostly meningeal carcinomatosis. Diffuse linear pachymeningeal enhancement could be meningeal carcinomatosis or reactive meningeal change.

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顱內腦膜腫瘤轉移與非腫瘤腦膜疾病：
以注射顯影劑的磁振造影評估

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本文在討論腦膜腫瘤轉移與非腫瘤轉移腦膜疾病，在注射顯影劑後不正常磁振造影影像之分析。
從 1993 年至 1998 年間，共收集 60 例有臨床診斷且有不正常腦膜磁振造影影像的病人。注射
顯影劑後區分為軟腦膜及硬腦膜增強並觀察增強之分佈及形狀。同時我們將病人疾病歸納為 6
項分類：腫瘤轉移，感染，發炎性反應，腦血管疾病，反應性病變，化學性反應。

60 例病人中，60 例腦膜腫瘤轉移。其他 60 例非腫瘤疾病有 60 例腦膜感染，60 例腦膜發炎性
反應，60 例腦血管疾病（60 例早期腦梗塞，60 例 60 例）60 例疾病），60 例反應性腦膜病變，6
例化學性腦膜炎。

結果顯示呈現硬腦膜增強的共有 60 例腦膜腫瘤轉移，60 例阿米巴腦膜炎，60 例腦膜發炎性反
應，60 例腦梗塞，60 例反應性腦膜病變及 60 例化學性腦膜炎。而呈現軟腦膜增強的共有 60 例腦膜
腫瘤轉移，60 例腦膜感染，60 例腦膜發炎性反應及 60 例腦血管疾病（60 例早期腦梗塞及 60 例
60 例略 60 例疾病）。同時出現兩種腦膜增強的有一例腦膜發炎性反應（60 例 60 例略 60 例略
略 60 例略 60 例略 60 例略 60 例略）及一例早期腦梗塞。

分析結果認為廣泛型的軟腦膜增強較偏向非腫瘤腦膜疾病。結節狀軟腦膜造影增強可以是
腫瘤的轉移或其他疾病，如結核腦膜炎，中樞系統的結節病。局部結節狀硬腦膜增強大部份為
腫瘤轉移。廣泛型的硬腦膜增強則考慮腫瘤轉移或反應性腦膜病變。

關鍵詞：腦膜，磁振造影，腦膜炎，腦膜腫瘤轉移