The management of patients with leptomeningeal metastases (LM) is multifaceted and complex. Even with an aggressive approach, therapeutic outcomes are uniformly disappointing. This is because of the relentless growth of the central nervous system (CNS) and/or the systemic cancers, or their lethal complications. Advances in the understanding of the homing of cancer cells to the CNS, and of cancer metastasis in general, and more effective anticancer drugs that are adequately delivered to the CNS and cerebrospinal fluid (CSF) are needed to improve outcomes for patients with LM. These advances may lead to better treatments for this disease and, ultimately, its prevention.

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Despite the passing of nearly 140 years since its original description, little progress has been made in improving survival for patients with LM. Hematologic malignancies can result in LM in up to 24% of patients. The most common solid tumors causing LM are breast cancer, lung cancer, and melanoma, with incidences ranging between 5% and 23%. Leptomeningeal metastases risk rises with longer cancer survival.

In the United States, standard treatment for LM includes CSF diversion when indicated, radiation, local intrathecal (refers to intraventricular administration, unless otherwise specified) chemotherapy, and systemic chemotherapy. Recent reviews discuss management of LM. With standard interventions, median survival for patients with LM ranges from 8 to 16 weeks. Roughly 24% to 34% die of LM alone, 22% to 25% die of LM simultaneously with progressive systemic cancer, 19% to 44% die of systemic disease progression, and up to 10% die of other causes.

The incidence of brain metastases (BM) and LM may increase in the near future for at least 2 reasons: (1) longer control of non-CNS cancers may allow for more time for the development of CNS metastases and (2) the use of large-molecule antineoplastic agents with limited CNS and CSF penetration may control systemic disease but leave LM unaffected behind the blood-brain barrier (BBB) and blood-CSF barrier (BCSFB). Paradoxically, the newer large-molecule therapies may improve overall cancer survival while increasing the incidence of CNS metastases. Longer survival and exposure of tumor cells to genotoxic chemotherapy may select for increasingly chemoresistant cell clones, making LM even more resistant to therapy over time.

THE BIOLOGY OF CNS METASTASES AND LM

Once we understand the biology behind LM, we can develop therapies targeting these biological changes. Metastasis is a cascade of events with multiple cellular and molecular changes. For LM to develop, tumor cells must detach from the primary site, invade a blood or lymphatic vessel, survive vascular transit, adhere to host organ endothelium, invade the host organ, proliferate, and develop a blood supply. Molecular factors implicated in CNS metastases and LM include E-cadherin–catenin complexes, plasmin, urokinase-type plasminogen activator, metallopro-
teinases, tissue inhibitors of metalloproteinases (associated with brain invasion), and activated integrin α,β1. Metalloproteinases can degrade endothelial tight junction proteins at the BBB. Along with vascular endothelial growth factor (VEGF) and stromal-derived factor 1, metalloproteinases may allow for transendothelial migration of tumor cells. Other mechanisms that may contribute to the development of LM include an ectodermal origin of the primary tumor, which may allow for advantageous cell-cell interactions between the metastatic tumor cells and native brain cells. Further, tumor cell surface markers, such as the extracellular domain of the epidermal growth factor receptor 2 protein, are associated with a higher risk of BM in breast cancer and possibly LM.

**DRUG DELIVERY**

The delivery of many anticancer drugs from blood to the brain and from blood to CSF is restricted, for multiple reasons. Drug-related factors include the drug’s level of protein binding and its molecular weight, polarity, and lipid solubility. Physical factors include the architectural properties of the BBB and BCSFB, such as the tight junctions between the endothelial cells of brain capillaries and the epithelial cells of the choroid plexuses, limiting paracellular diffusion of polar compounds. Further, adenosine triphosphate–dependent pumps such as the P-glycoprotein system, multidrug resistance proteins, and organic and inorganic ion transporters can mediate efflux of some anticancer drugs away from the brain.

The BBB and BCSFB are not identical. The BCSFB has a more relaxed tight junction architecture that correlates with differential diffusion capacities between it and the BBB. Recent work has investigated the effect of P-glycoprotein–modulating drugs on the CSF penetration of some chemotherapies. Tamoxifen, a P-glycoprotein inhibitor, decreased the CSF penetration of paclitaxel, supporting the concept that the pumping direction of P-glycoprotein at the choroid plexus is in the opposite direction to the BBB. The P-glycoprotein system appears to direct natural product toxins away from the brain. Animal models reveal similar findings with the tyrosine kinase inhibitor gefitinib. Its administration results in lower CSF levels and higher brain parenchymal levels of the topoisomerase I inhibitor topotecan.

**Table 1** shows the CSF:plasma ratios for some of the drugs studied in humans and rhesus monkeys. A CSF:plasma ratio lower than 0.05 signifies nonspecific leakage of drug. Table 1 shows that many drugs normally achieve CSF:plasma ratios lower than 0.05. However, once LM has arisen, or if radiation is directed to the CNS, leakage of the BCSFB develops, and larger molecules can leak from blood into CSF. Further, some drugs have an intrinsically high CSF:plasma ratio, suggesting their possible utility in treating LM. As the understanding of the BBB and BCSFB advance, we may ultimately be able to facilitate the CNS and CSF penetration of therapeutic molecules, which are now excluded.

**TREATMENTS**

Intrathecal chemotherapies typically used in LM include methotrexate, cytarabine, liposomal cytarabine, and thiopeta. Systemic therapies are usually chosen based on tumor histology, drug penetration into the CSF, and a patient’s prior drug exposure.

**Intrathecal Treatments**

Even though intrathecal chemotherapy is widely used in the United States for solid-tumor LM, proof of its benefit has not been established in randomized controlled trials. Randomized controlled trials do suggest modest improvements with long-acting over standard intrathecal chemotherapies, and some retrospective studies suggest intrathecal chemotherapy prolongs survival, but there exists contrary evidence. A recently begun randomized controlled trial, European Organization for Research and Treatment of Cancer 26051, is testing intrathecal liposomal cytarabine vs supportive care in solid-tumor LM.

Intraventricular (as opposed to intralumbar) chemotherapy delivery results in improved CSF drug levels and less interpatient variability of drug distribution. This form of regional chemotherapy has led to effective treatment of occult and overt meningeal leukemia in humans, and based on this success, investigators continue its evaluation in patients with solid tumor, hoping for similar outcomes. Pharmacokinetics of commonly used intrathecal anticancer agents shows that high drug concentrations can be achieved in the CSF and leptomeninges but not deep into the brain. Because of this, intrathecal administration is not effective for bulky disease in the meninges. Further, in solid-tumor LM, intraventricular administration, or the use of sustained-release chemotherapeutic agents if the lumbar route is used, appears to improve treatment outcome.

**Experimental and Newer Agents.** The most promising recently tested cytotoxic and radiotherapeutic agents are presented in Table 2. The topoisomerase inhibitors appear as effective as traditionally used intrathecal agents, and both etoposide and topotecan hydrochloride have little toxicity, so may be useful in combination with other agents or as prophylaxis. A concentration × time study of intrathecal topotecan is open and accruing patients within the Pediatric Brain Tumor Consortium. Because of pain associated with intrathecal administration, mafosfamide requires slow delivery and premedication with steroids and narcotics but may be useful in childhood CNS malignancies to help delay or avoid radiation exposure. Because of almost no toxicity and some efficacy (29% CSF clearance), sodium iodide I 131(131I) will be further studied in a phase 2 trial with a higher-dose, multiday schedule. For similar reasons, a phase 2 studies evaluating serial intrathecal injections of the GD2-targeted monoclonal antibody 131I–3F8, are under way. Early data suggest efficacy in childhood primitive neuroectodermal tumors and neuroblastoma.

**Noncytotoxic Intrathecal Therapies. Immunotherapies.** The CSF space may be excluded from the benefits of the systemic antitumor effects of the immune system, so im-
munotherapeutic approaches to the treatment of LM are theoretically attractive. Unfortunately, immune responses are frequently associated with inflammation. Intrathecal administration of interleukin 2 or interferon alfa both resulted in responses in patients with LM but were also fairly toxic, limiting enthusiasm for further development. Rituximab. Rituximab is a humanized monoclonal antibody against the CD-20 antigen expressed on most B-cell lymphomas. It has been used intravenously since 1997. Cerebrospinal fluid levels of this large molecule (146 kDa) are only 0.1% of the serum level after intravenous administration. Several case reports demonstrating safety and possible benefits of intrathecal administration of rituximab led to a recently reported phase 1 study. In this study, the maximum tolerated dose of intrathecal rituximab was 25 mg twice weekly (9 doses total). Mean peak CSF concentration 1 hour postdose rose to 472 µg/mL and estimated half-life averaged 34.9 hours. Cytologic responses were seen in 6 of 10 patients; 4 patients experienced a complete response; 2 patients experienced improvement in intraocular lymphoma; and 1 patient’s intraparenchymal lymphoma improved. Toxic reactions were limited. Further studies developing this promising therapy are under way. Additionally, a study of intrathecal rituximab combined with intrathecal methotrexate for patients with intraocular or LM lymphoma has been initiated.

Table 1. Cerebrospinal Fluid to Plasma (or Serum) Drug Ratios After Intravenous or Oral Administration in Rhesus Monkeys or Humans

<table>
<thead>
<tr>
<th>Drug</th>
<th>Cerebrospinal Fluid to Plasma Ratio</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triethylenethiophosphoramide</td>
<td>1.0</td>
<td>Heideman et al⁶³</td>
</tr>
<tr>
<td>Thiopeta</td>
<td>1.0</td>
<td>Heideman et al⁶³</td>
</tr>
<tr>
<td>Busulfan</td>
<td>0.95</td>
<td>Vassal et al⁶⁵</td>
</tr>
<tr>
<td>Temozolomide</td>
<td>0.20-0.33</td>
<td>Ostermann et al⁶⁷ and Patel et al⁶⁷</td>
</tr>
<tr>
<td>O6-benzylguanine; active metabolite O6-benzyl-8-oxoguanine</td>
<td>0.43; 0.36</td>
<td>Berg et al⁶⁸</td>
</tr>
<tr>
<td>Tiazofurin</td>
<td>0.28</td>
<td>Grygiel et al⁶⁹</td>
</tr>
<tr>
<td>6-Mercaptopurine</td>
<td>0.27</td>
<td>Zimm et al⁷⁰</td>
</tr>
<tr>
<td>S-Fuorouracil</td>
<td>0.155</td>
<td>Kerr et al⁷¹</td>
</tr>
<tr>
<td>Arabinosyl-5-azacytidine</td>
<td>0.15</td>
<td>Heideman et al⁷²</td>
</tr>
<tr>
<td>Cytosine arabinoside</td>
<td>0.06-0.22</td>
<td>Bailes and Poplack⁶⁸ and Sleinv et al⁷³</td>
</tr>
<tr>
<td>Gemicitabine hydrochloride</td>
<td>0.067</td>
<td>Kerr et al⁷⁴</td>
</tr>
<tr>
<td>Clofarabine</td>
<td>0.05</td>
<td>Berg et al⁷⁵</td>
</tr>
<tr>
<td>Vincristine sulfate</td>
<td>ND to 0.05</td>
<td>Bailes and Poplack⁶⁸ and Kellie et al⁷⁶</td>
</tr>
<tr>
<td>Spironolactone</td>
<td>0.047</td>
<td>Heideman et al⁷⁷</td>
</tr>
<tr>
<td>Cisplatin</td>
<td>0.029-0.03³</td>
<td>DeGregorio et al⁷⁸ and Jacobs et al⁷⁹</td>
</tr>
<tr>
<td>Carboplatin</td>
<td>0.028³</td>
<td>Jacobs et al⁸⁰</td>
</tr>
<tr>
<td>Oxaliplatin</td>
<td>0.02³</td>
<td>Jacobs et al⁸⁰</td>
</tr>
<tr>
<td>Etoposide</td>
<td>0.003-0.05³</td>
<td>Hande et al⁸¹ and Relling et al⁸²</td>
</tr>
<tr>
<td>Methotrexate</td>
<td>0.01-0.04</td>
<td>Thys et al⁸³ and Balis et al⁸⁴</td>
</tr>
<tr>
<td>Pemetrexed</td>
<td>&lt;0.02</td>
<td>Stapleton et al⁸⁵</td>
</tr>
<tr>
<td>Interferon alfa</td>
<td>0.033</td>
<td>Habib et al⁸⁶</td>
</tr>
<tr>
<td>Daunomycin</td>
<td>ND</td>
<td>Bailes and Poplack⁶⁸</td>
</tr>
<tr>
<td>L-asparaginase</td>
<td>ND</td>
<td>Bailes and Poplack⁶⁸</td>
</tr>
<tr>
<td>Trastuzumab</td>
<td>0.0023-0.02³</td>
<td>Pestalozzi and Brigioni⁸⁷ and Stemmler et al⁸⁸</td>
</tr>
<tr>
<td>Idarubicin hydrochloride; idarubicinol (active metabolite)</td>
<td>0.08-0.15 (2 animals); 0.019</td>
<td>Berg et al⁸⁹</td>
</tr>
<tr>
<td>Daunorubicin; daunorubcinol</td>
<td>0.04-0.12; 0.024±0.019</td>
<td>Berg et al⁸⁹</td>
</tr>
<tr>
<td>Topotecan hydrochloride (lactone)</td>
<td>0.29-0.42</td>
<td>Baker et al⁹⁰</td>
</tr>
<tr>
<td>Irinotecan hydrochloride (SN-38)</td>
<td>0.14%±3% (SN-38=0.08)</td>
<td>Blaney et al⁹¹</td>
</tr>
<tr>
<td>Rituximab</td>
<td>0.001</td>
<td>Rubenstein et al⁹² and Rubenstein et al⁹²</td>
</tr>
<tr>
<td>Erolitinib hydrochloride and OSI-420 (erlotinib metabolite)</td>
<td>&lt;0.05 (CSF exposure 30% plasma free-drug exposure)</td>
<td>Meany et al⁹³</td>
</tr>
<tr>
<td>Imatinib mesylate</td>
<td>0.05 (±2%) (concentration × time AUC)</td>
<td>Neville et al⁹⁴</td>
</tr>
<tr>
<td>Depsipeptide</td>
<td>0.02</td>
<td>Berg et al⁹⁵</td>
</tr>
<tr>
<td>Valproate sodium</td>
<td>0.13%±5.1% (total drug) 0.57%±8.7% (free drug)</td>
<td>Stapleton et al⁹²</td>
</tr>
<tr>
<td>Hydroxyurea</td>
<td>0.24³</td>
<td>Beckloff et al⁹⁶</td>
</tr>
<tr>
<td>ABT-888 (PARP inhibitor)</td>
<td>0.57</td>
<td>Muscal et al⁹⁷</td>
</tr>
<tr>
<td>Tasidotin hydrochloride (microtubule stabilizer)</td>
<td>1.1±0.4</td>
<td>Kilburn et al⁹⁸</td>
</tr>
<tr>
<td>Cyclophosphamide; ifosfamide</td>
<td>0.20 (0.00-1.1); 1.2 (0.4-1.6)³</td>
<td>Yule et al⁹⁹</td>
</tr>
</tbody>
</table>

Abbreviations: AUC, area under the curve; CSF, cerebrospinal fluid; ND, not detectable.

*Adapted from Levin et al.⁶⁷

b Concentration of active drug.

c Non–protein bound fractional ratio.

d One log increase in CSF levels for patients undergoing cranial irradiation or with neoplastic meningitis.

e Oral dose 80 mg/kg.

f Lowest levels in patients receiving dexamethasone.
showed that the CSF:serum trastuzumab ratio increased from 0.0023 prior to brain radiotherapy to 0.013 after completion of radiotherapy and was as high as 0.02 with concomitant LM after radiotherapy, revealing that CSF trastuzumab levels are low but can increase if BBB function is impaired.88

Promising results from a pilot study using intrathecal trastuzumab in patients with LM due to breast cancer, medulloblastoma, or glioblastoma were recently presented.92 In this report, 16 patients with LM (11 glioblastoma multiforme, 4 breast cancer, 1 medulloblastoma) were treated with intrathecal trastuzumab (20-60 mg per dose, either weekly or every other week) for 4 treatments. Stable patients continued every-other-week therapy until neurologic progression. Two patients with breast cancer, 7 with glioblastoma multiforme, and the one with medulloblastoma responded without reported adverse events; the epidermal growth factor receptor 2 protein status appeared to be predictive of response. Based on these results, further study of intrathecal trastuzumab is warranted.

**Systemic Treatments**

Numerous reports suggest that systemic therapy improves survival for patients with LM.72,93-100 Some authors feel systemic therapy is the most important part of the treatment of LM73,74 and exclude intrathecal therapy in patients with responsive cancers.95,97,101 Agents capable of producing adequate CSF concentrations following systemic administration may benefit patients with LM.

**Methotrexate.** Methotrexate inhibits dihydrofolate reductase and the synthesis of purine nucleotides and thymidylate, interfering with DNA synthesis and repair. At high doses, methotrexate has favorable CSF penetration. A prospective, nonrandomized study comparing intrathecal methotrexate (n=15) vs high-dose systemic methotrexate (n=16) in patients with LM produced provocative results. High-dose methotrexate (8 g/m² over 4 hours) resulted in a mean peak concentration of 17.1 µmol/L in the CSF; cytotoxic CSF methotrexate levels remained measurable much longer than with intrathecal dosing. Furthermore, there was higher CSF tumor cell clearance and survival was longer (13.8 months vs 2.3 months, P=.003) in the systemic methotrexate-treated cohort.102 Because of the favorable pharmacokinetics of high-dose methotrexate, further studies in patients with LM are warranted, possibly in combination with other agents.

**Capcitabine.** Capcitabine is a fluoropyrimidine carbamate designed as an oral alternative to 5-fluorouracil. Capcitabine is enzymatically converted to 5-fluorouracil at the tumor site. The increased drug concentration at the tumor site may enhance its antitumor activity and reduce systemic toxicity. Although there is no formal pharmacokinetic data regarding capcitabine’s behavior in the CNS, there are empirical observations of responses to the drug in patients with BM and LM.103,104 Capcitabine has also resulted in responses in a few patients with recurrent BM or LM even after previous capcitabine exposure.104,105 Based on the existing reports, capcitabine is now frequently being used in patients with LM or BM secondary to breast cancer, and further prospective study is under way.

**Temozolomide.** Temozolomide is an orally bioavailable alkylator that reaches CSF levels roughly 20% of those in the serum.31 In a pilot study of oral temozolomide in

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**Table 2. Promising Intrathecal Cytotoxic and Radiotherapeutic Treatments**

<table>
<thead>
<tr>
<th>Agent/Phase/No. of Patients</th>
<th>Induction Intrathecal Dose and Frequency</th>
<th>Toxicity</th>
<th>Efficacy</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Etoposide/2/27</td>
<td>0.5 mg daily for 5 d, every other week for 8 wk</td>
<td>18% Mild arachnoiditis</td>
<td>26% CSF clearance; 11% 6-mo PFS; 4% 1-y survival</td>
<td>Chamberlain et al77</td>
</tr>
<tr>
<td>Topotecan hydrochloride/2/62</td>
<td>0.4 mg twice a week for 6 wk</td>
<td>32% Mild arachnoiditis</td>
<td>21% CSF clearance; 30% 13-wk PFS; 19% high-dose PFS; 15-wk median survival</td>
<td>Groves et al9</td>
</tr>
<tr>
<td>Mafosfamide/1/30 and 255</td>
<td>First group: 5 mg twice a week for 4 wk; second group: 14 mg twice a week for 6 wk (with steroid and morphine)</td>
<td>First group: headache and neck pain; second group: mild irritability in all patients</td>
<td>First group: 43% response or SD</td>
<td>Blaney et al92 and Blaney et al94</td>
</tr>
<tr>
<td>Busulfan/1/28 children and 20 adults</td>
<td>13 mg twice a week for 2 wk</td>
<td>First group: myelosuppression and GI symptoms common</td>
<td>First group: 39% SD at 2 wk; second group: 30% response or SD</td>
<td>Gururangan et al81 and Quinn et al92</td>
</tr>
<tr>
<td>5-Fluoro-2-deoxyuridine/1/25</td>
<td>1.0 mg/d continuous infusion until progression</td>
<td>20% Bacterial meningitis</td>
<td>16% CSF clearance; 8.4-mo median survival; 100% clinical improvement</td>
<td>Nakagava et al83</td>
</tr>
<tr>
<td>Sodium iodide I 131/1/31</td>
<td>Single dose, 4.44×10⁵ Bq, MTD not reached</td>
<td>None &gt; grade 1</td>
<td>29% CSF clearance</td>
<td>Wong et al84</td>
</tr>
<tr>
<td>Iodine 131-labeled monoclonal antibody 3F8/1/13</td>
<td>MTD 3.7×10⁵ Bq, single dose</td>
<td>Self-limited headache, fever, vomiting</td>
<td>23% CSF or MRI responses</td>
<td>Kramer et al85</td>
</tr>
</tbody>
</table>

Abbreviations: CSF, cerebrospinal fluid; GI, gastrointestinal; MRI, magnetic imaging resonance; MTD, maximum tolerated dose; PFS, progression-free survival; SD, stable disease.

*Adapted with permission from Groves.86

bChildren with embryonal tumors.
10 patients with LM, the drug was well tolerated, although no responses were seen. Two patients had stable disease through 2 courses (6 weeks receiving therapy, 4 weeks not receiving therapy) but progressed while not receiving treatment, suggesting that continuous treatment might be more efficacious.

**Hormonal Therapies**

There are several case reports of a beneficial contribution of hormonal therapy for patients with LM due to hormone-sensitive tumors (breast and prostate cancer). Responses are reported lasting more than 12 months. For patients with LM from hormone-sensitive cancers, hormonal treatment is reasonable to continue or initiate and may provide some activity against the LM.

**Experimental Treatment**

**Pemetrexed.** Pemetrexed, a chemotherapy molecule similar to methotrexate, is approved for mesothelioma and non–small cell lung cancer and is active in methotrexate-resistant malignancies. The CSF penetration of pemetrexed was low in an animal model, however, the CSF pharmacokinetics of systemically administered pemetrexed are being evaluated in an ongoing study in patients with LM. The drug is unique from methotrexate in that it is a “multitargeted” antifolate compound acting through several enzyme systems involved in folate metabolism. Pemetrexed gains intracellular access via at least 4 mechanisms, which may increase its activity over methotrexate. Early results demonstrate CSF responses in patients with breast cancer with LM (J. Raizer, MD, written communication, June 22, 2009).

**Bevacizumab.** Bevacizumab is a systemically administered monoclonal antibody directed against VEGF. Bevacizumab is approved for use in colorectal, breast, and non–small cell lung cancers and glioblastoma multiforme. Recent reports have identified elevated VEGF levels in the CSF of the majority of patients with LM due to melanoma or breast or lung cancer. Preliminary data suggest that in LM responders CSF VEGF levels fall and correlate with response. The degree to which bevacizumab penetrates the CSF is unknown but is likely limited. Testing is under way at MD Anderson Cancer Center in patients with LM due to breast and lung cancer and melanoma to determine if systemically administered bevacizumab can affect CSF VEGF levels or impact tumor cells in the CSF.

**Gefitinib.** Gefitinib is a small-molecule tyrosine kinase inhibitor with activity against lung cancers that contain mutations of the epidermal growth factor receptor. Case reports have shown responses in patients with LM from non–small cell lung cancer. A prospective study evaluating high-dose gefitinib (up to 1250 mg/d) in patients with LM with non–small cell lung cancer and sensitizing epidermal growth factor receptor mutations was recently closed. High doses of gefitinib were used (standard dose, 250 mg/d) attempting to increase CNS and CSF drug levels and improve anticancer effects. Early reports of the clinical, CSF, and imaging outcomes were promising; final results are forthcoming (D. Jackman, MD, written communication, June 22, 2009).

**Combination and Disease-Specific Treatments**

Most reports of intrathecal LM treatments include patients who simultaneously receive systemic agents, and many investigators feel combination intrathecal and systemic therapy improves outcomes. Several planned studies will evaluate the concept of combination therapy, prospectively. Some clinical trials in development include a phase 2 study of intrathecal thiotepa for patients with LM due to primary brain tumors, a phase 2 study of lomustine plus cisplatin plus vincristine sulfate and intrathecal liposomal cytarabine for adults with medulloblastoma and CSF positive for tumor cells, and a phase 1/2 study of oral capecitabine plus liposomal cytarabine in patients with breast cancer with LM (R. Soffietti, MD, written communication, June 27, 2009).

Because of a paucity of available patients, LM studies often accrue multiple primary histologies. This heterogeneity obscures potential efficacy signals. Investigators, with respect to rituximab, gefitinib, and bevacizumab, as noted earlier, are beginning to design LM trials with specific histologies in mind.

**EARLY TREATMENT/PREVENTION OPPORTUNITIES**

Prevention strategies similar to those used for children with acute lymphoblastic leukemia or in patients with aggressive lymphoma may become feasible if genetic markers identifying tumors with a propensity to invade the CNS can be identified. High positive predictive value plasma or CSF biomarkers could allow for earlier treatment of LM, possibly affording better tumor control. Early studies suggest CSF VEGF may be useful as a biomarker, but further research is warranted. Until prevention is feasible, or biomarker use is validated, unique clinical scenarios may still hold opportunities for earlier treatment and better outcomes.

**BRAIN METASTASES**

Patients with BM may be at increased risk of developing LM, especially if the BM are located in the posterior fossa (BMPF). Among patients undergoing craniotomy for BMPF, estimates of the risk of developing LM are reported as high as 67%. Recent reports have begun to dissect out the details on the risk of CSF seeding after craniotomy. In a review of 379 patients with BMPF who were treated with either surgical resection or stereotactic radiation, 8.7% developed LM. But, there was a significantly higher risk of LM (14%); rate ratio, 2.45; P = .02) in those patients having a piecemeal resection of their BMPF when compared with either stereotactic radiation or en bloc resection. A follow-up study of 927 patients undergoing craniotomy for supratentorial BM found a similar result, with a hazard ratio of 5.8 (P = .002) comparing piecemeal resection vs stereotactic radiation and a hazard ratio of 2.7 (P = .009) comparing piecemeal re-
section vs en bloc resection.¹⁹ Patients with BM who undergo piecemeal tumor resection may be a good population in which to test biomarker-based or prophylactic interventions against LM.

CONCLUSIONS

Leptomeningeal metastases remain a neurologically devastating and fatal late complication of cancer. The molecular biology underpinning the development of LM is slowly being unraveled. To be effective, new treatments for LM need to reach the meninges and CSF and interact with relevant molecular targets. Since only about one-third of patients with LM die solely of LM, therapies that act with relevant molecular targets are necessary for major improvements in survival. Progress is slowly being made with the testing of new targeted agents and combination treatments, but obviously, there is much work to be done to improve outcomes for patients with LM.

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