Safety and efficacy of liposomal amphotericin B for the empirical therapy of invasive fungal infections in immunocompromised patients

Marisa H Miceli 1
Pranatharthi Chandrasekar 2
1 Oakwood Hospital and Medical Center, Dearborn, 2 Division of Infectious Diseases, Wayne State University School of Medicine, Detroit, MI, USA

Abstract: Liposomal amphotericin B is a “true” liposomal formulation of amphotericin B with greatly reduced nephrotoxicity and minimal infusion-related toxicity. This broad spectrum polyene is well tolerated and effective against most invasive fungal infections. In view of the current limitations on diagnostic capability of invasive fungal infections, most clinicians are often compelled to use antifungal drugs in an empiric manner; liposomal amphotericin B continues to play an important role in the empiric management of invasive fungal infections, despite the recent availability of several other drugs in the azole and echinocandin classes.

Keywords: invasive fungal infections, immunocompromised hosts, empiric therapy, polyenes, efficacy and safety

Introduction
Invasive fungal infections (IFIs) have become a leading cause of morbidity and mortality among immunocompromised patients. 1 The incidence of IFIs in these patient populations has increased dramatically over the past three decades. The most common fungal pathogens include Candida albicans and Aspergillus fumigatus and cryptococcus. However, uncommon pathogens such as non-albicans Candida spp, opportunistic yeast-like fungi (eg, Trichosporon and Rhodotorula spp), non-fumigatus Aspergillus spp, Mucorales and hyaline molds (eg, Fusarium and Scedosporium spp) are now emerging as not-so-uncommon opportunistic pathogens. 2, 3 Etiologic identification of fungal pathogens is frequently difficult, particularly in compromised hosts, since reliable, noninvasive diagnostic tests are presently not available; such situations often compel the clinician to use drugs in an empiric fashion. However, the suspected fungal pathogens are often less susceptible to many antifungal agents including the “broadly-active” amphotericin B (AmB). 4–8 Thus, the choice of appropriate agents for empirical antifungal therapy has become a challenge; in the context of recently available, non-invasive diagnostic tests and newer antifungal drugs, the role of amphotericin B as a drug for empiric therapy has become less clear. This review will provide an overview of liposomal amphotericin B (L-AmB) and focus on efficacy studies as well as the safety and tolerability of this drug for the empiric treatment of IFIs.

Management of IFIs in the immunocompromised host
Multiple factors have contributed to the new epidemiologic trends of IFIs, notably a growing number of immunocompromised states (ie, cancer, hematologic stem cell
Infection and Drug Resistance 2012:5

and solid organ transplantation, major surgeries, acquired immune deficiency syndrome, the elderly, etc), the advent of potent immunosuppressant drugs and their widespread use, and the use of antifungal prophylaxis.9–12

In contrast to most bacterial infections, the diagnosis of IFIs is challenging. Delay in diagnosis leads to delayed initiation of appropriate antifungal therapy and, hence, increased mortality. In this setting, early and definitive diagnosis is critical in the management of IFIs. However, clinical presentation of IFIs is often nonspecific; moreover, signs and symptoms could be absent in the early stages of the disease. Fever without signs of localized infection is the most common clinical presentation.13 Fever is of particular concern in severely immunosuppressed patients such as those with profound and prolonged neutropenia following chemotherapy for cancer. Radiographic signs and laboratory tests such as galactomannan and 1,3-beta-D-glucan are used as surrogate markers for the diagnosis and management of IFIs.14,15

Prompt initiation of appropriate antifungal therapy of IFIs is crucial for optimal outcome. Current strategies for the management of IFIs include prophylactic, empiric, preemptive, and targeted therapy15,16 (Figure 1). Prophylactic strategy includes administration of a narrow- or broad-spectrum antifungal drug (active against yeasts or yeasts and molds) to high-risk patient population before the onset of signs/symptoms of infection. Empirical antifungal therapy is often initiated when a microbiological diagnosis of IFI is unavailable in high-risk presently neutropenic patients presenting with persistent or recurring fevers despite 4–7 days of appropriate antibiotic therapy (duration of neutropenia expected to be more than 7 days).

Pre-emptive therapy is initiated when suggestive but nonspecific radiographic signs are present and/or laboratory tests are suggestive of IFIs, without microbiological or histopathological confirmation of IFI. Targeted therapy is initiated when there is microbiologically and/or histologically proven IFI.15,16

### Antifungal drugs

There are three main classes of systemic antifungal drugs available for the treatment of IFIs: polyenes, azoles, and echinocandins. Azoles deplete ergosterol and compromise fungal cell-wall integrity by dose-dependent inhibition of cytochrome-P450-dependent 14α-demethylase.17 Currently available systemic azoles include fluconazole, itraconazole, voriconazole, and posaconazole. Echinocandins are compounds that disrupt cell-wall synthesis by inhibiting the synthesis of 1,3-beta-D-glucan, which is a critical component of most fungal cell walls.18 Echinocandins include caspofungin, anidulafungin, and micafungin. Azoles and echinocandins are relatively safe and well tolerated.18,19

The polyenes include conventional amphotericin B (AmB-D) and lipid formulations of amphotericin B (amphotericin B lipid complex [ABLC], L-AmB, and amphotericin B collo-

| Without signs or symptoms of infection | Prophylaxis |
|---------------------------------------|------------|
| Fever plus established signs and symptoms of infection (such as persistent fevers) | Empiric therapy |
| – unknown source of infection         |            |
| High risk for IFI*                    | Pre-emptive therapy |
| Fever plus radiologic findings suggestive of fungal infection* and/or POSITIVE serologic test (GM, B-D-glucan and/or PCR) | Targeted therapy |
| – NO definitive histopathological antifungal culture identification of pathogen | |

**Figure 1** Current strategies for the management of IFI in high-risk patients.

**Notes:** *High-resolution computed tomography scan of the lungs showing new ≥1 cm single or multiple nodules with or without halo sign, lobar consolidation, wedge-shaped consolitative infarct; **classic example: patients with prolonged and profound neutropenia after intense chemotherapy for hematologic malignancy.

**Abbreviations:** GM, serum Galactomannan; IFI, invasive fungal infection; PCR, polymerase chain reaction.
Liposomal amphotericin B and empiric antifungal therapy

dal dispersion [ABCD] formulations). AmB-D binds with sterols, principally ergosterol in the fungal cell membrane. This binding is followed by increased leakage of intracellular ions out of the fungal cells resulting in osmotic disruption with increased membrane permeability and, ultimately, cell death. Polyenes also interfere with membrane-associated oxidative enzyme function, which is also lethal for the cell.

Lipid formulations of amphotericin B were developed to decrease toxicity and improve the tolerability profile of AmB-D. Lipid formulations of amphotericin B have different structures. ABLC has a ribbon-like structure, ABCD is composed of disc-like structures, and L-AmB forms small uniform spherical lipid vesicles or liposomes containing amphotericin B. The three formulations produce tissue amphotericin B concentrations ranging from 90% lower than, to 500% higher than the serum levels seen with AmB-D. Most consistently, reduced concentrations are seen in the kidney, thus accounting for the markedly lower nephrotoxicity. The doses of lipid forms of amphotericin B are higher than that of amphotericin B deoxycholate; such high but equipotent doses are better tolerated and there is also a clear reduction in the frequency and severity of nephrotoxicity.

Spectrum of activity: amphotericin B

Despite the differences in the structures of lipid formulations and AmB-D, their spectrum of activity is comparable. Amphotericin B is active against clinically relevant yeasts such as most Candida spp and Cryptococcus neoformans and molds, including most Aspergillus spp and Mucorales. AmB is also active against Histoplasma spp, Paracoccidioides spp, Blastomyces spp, and Coccidioides spp.

Several Candida species such as Candida lusitaniae, Candida guilliermondii, and Candida rugosa may be resistant to AmB. Also, Trichosporon spp, an infrequent cause of catheter-related fungemia, are resistant to AmB.

Non-fumigatus Aspergillus spp, in particular Aspergillus terreus, Aspergillus flavus and Aspergillus nidulans, have demonstrated clinical resistance to AmB. Similarly, Aspergillus ustus is an uncommon clinical species that may have decreased susceptibility to AmB. However, Aspergillus lentulus, a recently described Aspergillus species, has demonstrated variable in vitro susceptibility to AmB. AmB has limited activity against Fusarium spp (especially Fusarium solani), although it has better activity as compared with other agents such as the older azoles (eg, Itraconazole) and echinocandins. Mucorales are susceptible to AmB – the drug has been the drug of choice for the treatment of mucormycosis; however, clinical response has been variable and the overall mortality of patients with mucormycosis has remained high, particularly in patients with persistent immunosuppression or poor source control. A newer azole, posaconazole is active against most Mucorales and appears to be promising for the treatment of this disease. Isavuconazole, a more recent broad-spectrum azole, available in oral and parenteral forms, is under clinical investigation. Scedosporium spp are intrinsically resistant to AmB. While Scedosporium apiospermum is susceptible to itraconazole, voriconazole, and posaconazole, Scedosporium prolificans is considered resistant to all available antifungal agents. Limited data are available to support the optimal antifungal therapy against Acremonium spp. Clinically relevant species of Acremonium, Alternaria, Cladosporium and Exophiala have demonstrated high minimal inhibitory concentrations for AmB.

Safety and tolerance: L-AmB

Conventional amphotericin B (AmB-deoxycholate [AmB-D]) was considered the gold standard of antifungal treatment for many decades. Infusion-related reactions and dose-dependent nephrotoxicity are major limitations of this drug. Indeed, these side effects are associated with increased morbidity in immunocompromised patients. Other toxicities reported with the use of AmB-D include local thrombophlebitis, nausea and vomiting, and anemia. Less frequently, hepatotoxicity (ie, transient elevation of transaminase levels and acute liver failure) has been associated with the use of AmB-D.

In general, all lipid formulations of AmB have been associated with reduced nephrotoxicity compared with AmB-D. White et al reported a randomized, double-blind multicenter superiority trial in which ABCD (4 mg/kg/d) was compared with AmB-D (0.8 mg/kg/d) for the empiric management of febrile neutropenia. Therapeutic response was similar (43%–50%), but renal dysfunction was less likely to develop and occurred later in ABCD recipients (P < 0.001 for both parameters). Infusion-related hypoxia and chills were more common in ABCD recipients than AmB-D recipients (P = 0.013 and P = 0.018, respectively). In clinical practice, in view of its frequent infusion-related intolerability, ABCD is not favored.

In a randomized, double-blind comparative study, Wingard et al evaluated the safety of L-AmB versus ABLC in the empirical treatment of febrile neutropenia. In this study, L-AmB at a dose of 3 or 5 mg/kg/d was associated with significantly fewer infusion-related reactions and other toxicities (ie, nausea, vomiting) when compared to ABLC at a dose of 5 mg/kg/d. There was nonsignificant difference in
the rates of hepatotoxicity, hypokalemia, and anemia between patients receiving either ABLC or L-AmB. Since the publication of Wingard et al’s study, it has been widely believed that L-AmB is less nephrotoxic than ABLC. However, in a recently published study, Saifdar et al conducted a meta-analysis to evaluate nephrotoxicity associated with ABLC and L-AmB. After adjusting for heterogeneity across the studies included in the meta-analysis, the authors found that the nephrotoxicity was similar for ABLC and L-AmB in patients receiving either drug as antifungal therapy or prophylaxis.

While all three lipid formulations of AmB exhibit reduced nephrotoxicity compared with AmB-D, L-AmB appears to be the safest in terms of infusion-related reactions. Table 1 summarizes the current US Food and Drug Administration (FDA)-approved indications for the use of L-AmB and all available antifungal agents.

**Empirical therapy: liposomal amphotericin B (L-AmB)**

The strategy of empirical antifungal therapy has been systematically evaluated only in the setting of antibiotic-refractory fever in patients with chemotherapy-induced neutropenia. Table 2 summarizes the clinical trials of L-AmB in the empirical management of fever in neutropenic patients.

In a randomized trial by Walsh et al, L-AmB was as effective as AmB-D for the empirical therapy of fever in adult and pediatric neutropenic patients. In this study, 687 patients were randomized to empirical treatment with L-AmB at a dose of 3.0 mg/kg/d or AmB-D at 0.6 mg/kg/d. Rates of successful treatment were similar (50.1% for patients receiving L-AmB and 49.4% for those receiving AmB-D.) Rates of survival were also similar (93% for L-AmB and 90% for AmB-D). Significantly, the use of L-AmB was associated with fewer proven breakthrough IFIs (11 patients [3.2%]) compared to patients receiving AmB-D (27 patients [7.8%], \( P = 0.009 \).

As previously discussed, Wingard et al conducted a randomized, double-blind comparative study of L-AmB (3–5 mg/kg/d) versus ABLC (5 mg/kg/d) in the empirical treatment of febrile neutropenia. Among 244 patients included, actual response rates were 40% (3 mg/kg/d) and 42% (5 mg/kg/d) for L-AmB, and 33% for ABLC. While the primary endpoint in this study was the incidence of infusion-related reactions, the authors found no significant differences in successful response and survival in both adult and pediatric patients.

With the introduction of new classes of antifungal agents, the efficacy of L-AmB for empirical therapy has been compared with that of caspofungin and voriconazole. Many prospective, randomized, multicenter comparative trials evaluating echinocandins have been published (Table 2). In these studies, efficacy assessment was based on a composite endpoint consisting of five criteria: (1) successful treatment of any baseline fungal infection, (2) absence of any breakthrough fungal infection during therapy or within 7 days after the completion of therapy, (3) survival for 7 days after the completion of therapy, (4) no premature discontinuation of study therapy because of drug-related toxicity or lack of efficacy.

**Table 1** US Food and Drug Administration-approved indication of antifungal agents for the management of IFIs

| Indication                                      | Echinocandins | Newer azoles | Polyenes |
|------------------------------------------------|---------------|--------------|----------|
| Empiric treatment of invasive fungal infections | YES           |              |          |
| Prophylaxis of Candida infections              | YES           |              |          |
| Prophylaxis of invasive aspergillosis          | YES           |              |          |
| Target therapy of invasive aspergillosis       | YES           |              |          |
| Target therapy of mucormycosis                 | YES           |              |          |
| Salvage treatment of IFIs                      | YES           |              |          |
| Oropharyngeal candidiasis                      | YES           | YES          |          |
| Invasive candidiasis                           | YES           | YES          | YES      |

Notes: *In patients aged ≥13 years, who are at high risk of developing these infections due to being severely immunocompromised, such as hematopoietic stem-cell transplant recipients with graft versus host disease or those with hematologic malignancies with prolonged neutropenia from chemotherapy; 1 in patients undergoing allogeneic hematopoietic stem-cell transplant; 2 infections with Scedosporium spp and Fusarium spp in patients refractory to or intolerant of other agents. 3 in nonneutropenic patients. 4AmB-D is approved for the treatment of potentially life-threatening fungal infections: aspergillosis; cryptococcosis (torulosis); North American blastomycosis; systemic candidiasis; coccidioidomycosis; histoplasmosis; and zygomycosis including mucormycosis due to susceptible species of the genera Absidia, Mucor, and Rhizopus and infections due to related susceptible species of Conidiobolus and Basidiobolus, and sporotrichosis. 5 L-AmB approved for the treatment of invasive fungal infections in patients who are refractory to or intolerant of conventional amphotericin B. 6 ABCD is approved for the treatment of invasive aspergillosis in patients who are refractory to or intolerant of conventional amphotericin B. 7 L-AmB (AmBisome) is approved for the treatment of patients with Aspergillus spp, Candida spp, and/or infections due to Cryptococcus spp refractory to conventional AmB or in patients with marked renal impairment or when severe toxicity precludes the use of conventional AmB; also approved for the treatment of cryptococcal meningitis in human immunodeficiency virus–infected patients and visceral leishmaniasis.**
Table 2 Summary of clinical trials comparing efficacy and safety of liposomal amphotericin B with other antifungal agents for empirical antifungal therapy in patients with neutropenia and persistent fevers

| Reference/type of study | Treatment regimen (dose) | Number of patients | Mean age (range) | Patient population (% of patients) | Mean duration of treatment | Renal toxicity* (% of patients) | Infusion related reactions† (% of patients) | Treatment success rate* (% of patients) | Comments |
|-------------------------|--------------------------|--------------------|-----------------|-----------------------------------|---------------------------|--------------------------------|-----------------------------------------|------------------------------------------|-----------|
| Walsh47                 | L-AmB (3 mg/kg/d)        | 343                | 41 (2–79)       | HSCT: 45% Non-HSCT: 55%           | 10.8 days                 | 19%                            | 17%† (95% CI: 45–56)                | 50.1%                                    | L-AMB was associated with significant reduction of breakthrough infections (mostly non-albicans Candida infections) |
| Wingard45               | L-AmB (3 mg/kg/d)        | 344                | 42 (2–80)       | HSCT: 47% Non-HSCT: 53%           | 10.3 days                 | 34% (P < 0.001)                  | 44%† (P < 0.001)                    | 49.4%                                    | Study designed to detect differences in toxicity, not efficacy. Breakthrough infection rates were similar in three groups. |
| Walsh51                 | voriconazole             | 415                | 46.3 (12–82)    | HSCT: 48% Non-HSCT: 52%           | 7 days                    | 14.1%                          | 51.8%† (P < 0.001)                  | 33.3%                                    | Breakthrough IFI occurred in 8 patients on voriconazole and 21 patients on L-AmB (P = 0.02). Hepatotoxicity was similar in both groups. |
| Walsh50                 | L-AmB (3 mg/kg/d)        | 422                | 45 (12–80)      | HSCT: 51.4%                       | 7 days                    | 26%                            | Abnormal vision 22%                  | 30.6%                                    | Most patients included in the study had acute leukemia. Breakthrough infections were similar in both groups. |
| Caspofungin             | (70 mg in day 1 and then 50 mg/d) | 556 | 51 (17–83) | Acute leukemia: 75.8% (Allo-HSCT: 6.5%) | 13 days | 2.6% (P < 0.001) | 47% (P < 0.001) | 33.9% | Most patients included in the study had acute leukemia. Breakthrough infections were similar in both groups. |
| L-AmB (0.6 mg/kg/d)    | 539                      | 49 (16–83)         | Acute leukemia: 72.2% (Allo-HSCT: 7.2%) | 12.5 days | 11.5% (P < 0.001) | 59% (P < 0.001) | 33.7% | Most patients included in the study had acute leukemia. Breakthrough infections were similar in both groups. |

* Denotes statistically significant difference.
† Denotes abnormal vision, flushing, and chills.
‡ Denotes renal toxicity.
§ Denotes infusion-related reactions.
¶ Denotes with concomitant nephrotoxic drugs.
\( P \) denotes statistical significance.
Table 2 (Continued)

| Reference/ type of study | Treatment regimen (dose) | Number of patients | Mean age (range) | Patient population (% of patients) | Mean duration of treatment | Renal toxicity (% of patients) | Infusion related reactions (% of patients) | Treatment success rate (% of patients) | Comments |
|--------------------------|--------------------------|-------------------|-----------------|-----------------------------------|--------------------------|-------------------------------|------------------------------------------|--------------------------------------|----------|
| Maertens et al\(^a\) | Caspofungin (70 mg/m\(^2\) on day 1, then 50 mg/m\(^2\) daily) | 56 | 6 (2–16) | Acute leukemia: 60.7% (Allo-HSCT: 10.7%) | 11.6 days | 5.5% | 48.2% | 46.6% | Study conducted exclusively in pediatric population. |
| Randomized, double-blind, multicenter clinical trial | L-AmB (3 mg/kg/d) | 26 | 5.5 (2–16) | Acute leukemia: 65.4% (Allo-HSCT: 65.4%) | 11.4 days | 8% | 46.2% | 32.2% | Limitation: small sample. Only 1 patient in L-AmB group had breakthrough nephrotoxicity. |

Notes: \(^1\)Infusion related reactions include fevers, chills, hypotension, chest pain, tachycardia, etc. \(^2\)Nephrotoxic effect was defined by an elevation in the serum creatinine level to more than 1.5 times the baseline value. \(^3\)Treatment success rate was determined by a composite outcome score consisting of five criteria: (1) successful treatment of any baseline fungal infection, (2) absence of any breakthrough fungal infection during therapy or within seven days after the completion of therapy, (3) survival for 7 days after the completion of therapy, (4) no premature discontinuation of study therapy because of drug related toxicity or lack of efficacy, and (5) resolution of fever during neutropenia. Treatment was considered successful if all five criteria were met. \(^4\)Infusion-related reactions on day 1 study drug infusion; \(^5\)Fevers within 1 hour of drug infusion (increase of \(\geq 1.0\)°C); overall rate of infusion-related reactions was not provided; \(^6\)Nephrotoxic drugs were aminoglycosides, cyclosporine, and foscarnet. \(^7\)Abbreviations: ABLC, amphotericin B lipid complex; AmB-D, amphotericin B deoxycholate; CI, confidence interval; L-AmB, liposomal amphotericin B; BMT, bone marrow transplant; Allo, allogeneic; HSCT, hematological stem cell transplant.
Infection and Drug Resistance downloaded from https://www.dovepress.com/ by 54.191.40.80 on 01-Apr-2017
For personal use only.
Powered by TCPDF (www.tcpdf.org)

neutropenia for many decades. However, antifungal agents that have become available over the past 15 years are less toxic and are as effective as AmB-D in the empiric treatment of IFIs.\textsuperscript{45-51} Indeed, based on the data discussed, L-AmB and caspofungin have now been approved by the FDA for the empiric antifungal therapy in febrile neutropenic patients.\textsuperscript{52,53}

All echinocandins are safe, well tolerated, and have a similar spectrum of antifungal activity. However, FDA-approved indications of these drugs differ.\textsuperscript{52,53} Caspofungin is approved for empirical therapy of febrile neutropenia and for the treatment of invasive aspergillosis in patients refractory of or intolerant to other approved drugs.\textsuperscript{51} Micafungin, however, has been approved for antifungal prophylaxis in stem-cell transplantation. Limited data suggest that the safety and efficacy of caspofungin and micafungin are comparable in the empiric treatment of invasive aspergillosis, but micafungin has not been licensed for this use.\textsuperscript{54} Similarly, despite the widespread use of voriconazole as empiric therapy and prophylaxis of IFIs, voriconazole is not FDA approved for these indications.\textsuperscript{55} Posaconazole, based on available data, has been approved for the prophylaxis of invasive Aspergillus and Candida infections in high-risk, severely immunocompromised adult patients.\textsuperscript{55}

In summary, the three lipid formulations of AmB have demonstrated similar efficacy and fewer adverse events compared with conventional amphotericin B deoxycholate. Amphotericin B colloidal dispersion, in view of its unacceptably high frequency of infusion-related toxicities similar to amphotericin B deoxycholate, is no longer favored. L-AmB has fewer infusion-related adverse reactions as compared with ABLC. Both L-AmB and ABLC appear to have similar nephrotoxic potential.

L-AmB has been rigorously evaluated in the empiric treatment of patients with neutropenia and antibiotic-refractory fever. The drug appears safe as well as effective. Besides neutropenic fever, empiric therapy may be required in some nonneutropenic situations as well. For example, allogeneic stem-cell recipients with graft versus host disease may require empiric antifungal therapy in the setting of undiagnosed, nodular pulmonary infiltrates. Although not clinically proven, L-AmB may be an appropriate empiric choice in such situations, particularly in the background of prophylactic use of broad-spectrum azoles. During the last decade, many thought that amphotericin B-deoxycholate and its lipid forms would become obsolete in view of the recently released, less-toxic azoles and echinocandins. That has not turned out to be so. Despite the fact that amphotericin B is an “old” drug, L-AmB plays and will continue to play an important role in the empiric antifungal management of patients at high risk for invasive fungal infections.

Disclosure
The authors report no conflicts of interest in this work.

References
1. Mohr J, Johnson M, Cooper T, Lewis JS, Ostrosky-Zeichner L. Current options in antifungal pharmacotherapy. Pharmacotherapy. 2008;28(5):614–645.
2. Miceli MH, Diaz JA, Lee SA. Emerging opportunistic yeast infections. Lancet Infect Dis. 2011;11:142–151.
3. Miceli MH, Lee SA. Emerging moulds: epidemiological trends and antifungal resistance. Mycoses. 2011;54(6):e666–e678.
4. Bornman AM, Petch R, Linton CJ, Palmer MD, Bridge PD, Johnson EM. Candida nivariensis, an emerging pathogenic fungus with multidrug resistance to antifungal agents. J Clin Microbiol. 2008;46(3):933–938.
5. Snyderman DR. Shifting patterns in the epidemiology of nosocomial Candida infections. Chest. 2003;123(Suppl):508S–503S.
6. Pfaller MA, Diekema DJ, Gibbs DL, et al. Results from the ARTEMIS DISK Global Antifungal Surveillance Study, 1997–2005. An 8.5-year analysis of susceptibilities of Candida species and other yeast species to fluconazole and voriconazole by CLSI standardized disk diffusion testing. J Clin Microbiol. 2007;45(6):1735–1745.
7. Baddley JW, Moser SA. Emerging fungal resistance. Clin Lab Med. 2004;24(3):721–735, vii.
8. Sabatelli F, Patel R, Mann PA, et al. In vitro activities of posaconazole, fluconazole, itraconazole, voriconazole, and amphotericin B against a large collection of clinically important molds and yeasts. Antimicrob Agents Chemother. 2006;50(6):2009–2015.
9. Imhof A, Balajee SA, Fredricks DN, Englund JA, Marr KA. Breakthrough fungal infections in stem cell transplant recipients receiving voriconazole. Clin Infect Dis. 2004;39(5):743–746.
10. Kobayashi K, Kami M, Murashige N, Kishi Y, Fujisaki G, Mitamura T. Breakthrough zygomycosis during voriconazole treatment for invasive aspergillosis. Haematologica. 2004;89(11):ECR42.
11. Marty FM, Cosimi LA, Baden LR. Breakthrough zygomycosis after voriconazole treatment in recipients of hematopoietic stem-cell transplants. N Engl J Med. 2004;350(9):950–952.
12. Procop GW, Roberts GD. Emerging fungal diseases: the importance of the host. Clin Lab Med. 2004;24(3):691–719, vii–viii.
13. Asciglou S, Rex JH, de Pauw B, et al. Defining opportunistic fungal infections in immunocompromised patients with cancer and hematopoietic stem cell transplants: an international consensus. Clin Infect Dis. 2002;34(1):7–14.
14. Chandrasekar P. Invasive mold infections: recent advances in management approaches. Leuk Lymphoma. 2009;50(5):703–715.
15. Ruhnke M, Bohme A, Buchheidt D, et al. Diagnosis of invasive fungal infections in hematology and oncology – guidelines from the Infectious Diseases Working Party in Haematology and Oncology of the German Society for Haematology and Oncology (AGHIHO). Ann Oncol. Epub 2011 Sep 23.
16. Freifeld AG, Bow EJ, Sepkowitz KA, et al. Clinical practice guideline for the use of antimicrobial agents in neutropenic patients with cancer: 2010 update by the infectious diseases society of america. Clin Infect Dis. 2011;52(4):e56–e93.
17. Ghannoum MA, Rice LB. Antifungal agents: mode of action, mechanisms of resistance, and correlation of these mechanisms with bacterial resistance. Clin Microbiol Rev. 1999;12(4):501–517.
18. Sucher AJ, Chahine EB, Balcer HE. Echinocandins: the newest class of antifungals. Ann Pharmacother. 2009;43(10):1647–1657.
19. Walsh TJ, Driscoll T, Milligan PA, et al. Pharmacokinetics, safety, and tolerability of voriconazole in immunocompromised children. Antimicrob Agents Chemother. 2010;54(10):4116–4123.
