AMERICAN THORACIC SOCIETY DOCUMENTS

Treatment of Invasive Pulmonary Aspergillosis and Preventive and Empirical Therapy for Invasive Candidiasis in Adult Pulmonary and Critical Care Patients

An Official American Thoracic Society Clinical Practice Guideline

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Abstract

Background: The incidence of invasive fungal infections is increasing in immune-competent and immune-compromised patients. An examination of the recent literature related to the treatment of fungal infections was performed to address two clinical questions. First, in patients with proven or probable invasive pulmonary aspergillosis, should combination therapy with a mold-active triazole plus echinocandin be administered versus mold-active triazole monotherapy? Second, in critically ill patients at risk for invasive candidiasis who are nonneutropenic and are not transplant recipients, should systemic antifungal agents be administered either as prophylaxis or as empiric therapy?

Methods: A multidisciplinary panel reviewed the available data concerning the two questions. The evidence was evaluated, and recommendations were generated using the GRADE (Grading of Recommendations Assessment, Development and Evaluation) approach.

Results: A conditional recommendation was made for patients with proven or probable invasive pulmonary aspergillosis to receive either initial combination therapy with a mold-active triazole plus an echinocandin or initial mold-active triazole monotherapy, based on low-quality evidence. Furthermore, a conditional weak recommendation was made against routine administration of prophylactic or empiric antifungal agents targeting *Candida* species for critically ill patients without neutropenia or a history of transplant, based on low-quality evidence.

Conclusions: The recommendations presented in these guidelines are the result of an analysis of currently available evidence. Additional research and new clinical data will prompt an update in the future.

Keywords: pulmonary aspergillosis; invasive candidiasis; therapeutics; echinocandins; triazoles

Overview

The purpose of this guideline is to analyze evidence relevant to treatment decisions in selected scenarios encountered by pulmonary and critical care providers. These guidelines examine recent and relevant data to address the potential mortality benefit from the use of different antifungal strategies in two distinct clinical scenarios. The first examined whether, in patients with proven or probable invasive pulmonary aspergillosis (IPA), combination therapy with a mold-active triazole plus echinocandin should be favored over mold-active triazole

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monotherapy. The second examined whether, in critically ill patients at risk for invasive candidiasis (IC) who are nonneutropenic and are not transplant recipients, systemic antifungal agents should be administered either as prophylaxis or as empiric therapy.

Introduction

The incidence of invasive fungal infections (IFIs) is rising in immune-competent and immune-compromised individuals (1). This is likely multifactorial and a result of expanding therapies for malignancies and rheumatological disorders, increasing indications for solid organ and hematological transplant, HIV, prolonged ICU stays, and climate change (2, 3). Despite available new extended-spectrum antifungal agents, the mortality for IFIs remains high (4, 5). Many treatment recommendations from the last American Thoracic Society (ATS) clinical practice guidelines for the treatment of fungal infections in 2011 remain relevant (6). For instance, the treatment of endemic mycoses has changed relatively little, and limited new literature has become available. In contrast, there are two clinical scenarios for which recent clinical trials have resulted in a greater understanding of the role(s) of extended-spectrum antifungals and are the focus of these guidelines. The first focuses on whether combination therapy with a mold-active azole plus echinocandin compared with mold-active azole monotherapy alone improves survival in IPA. The second examines whether prophylactic or empiric systemic antifungal therapy improves survival in critically ill patients at risk for IC.

Methods

Panel Composition

We convened a panel with broad expertise in the clinical and treatment aspects of fungal infections commonly encountered by pulmonary and critical care providers. Representative backgrounds from pulmonary medicine, critical care, and infectious diseases were included, as well as expertise in pharmacology. The guideline included one patient who participated on the guideline panel and provided perspective on patient values and preferences. The committee membership included Oleg Epelbaum, Tina Marinelli, Kelly M. Pennington, Scott E. Evans, Eva M. Carmona, Shahid Husain, Kenneth S. Knox, Benjamin J. Jarrett, Elie Azoulay, William W. Hope, Ashley Meyer-Zilla (patient representative), Andrew H. Limper, and Chadi A. Hage. M. Hassan Murad and Qusay Haydour provided methodological expertise. The committee was cochaired by Andrew H. Limper and Chadi A. Hage.

Confidentiality Agreement and Conflict-of-Interest Management

All committee members declared and signed conflict-of-interest declarations at the onset of the project, and these were updated annually. All conflicts were declared and managed by the chairs and cochairs who had no conflicts. None of the conflicts affected the final recommendations. When even potential perceived conflicts were present, the individual did not vote or discuss that related recommendation. The committee cochairs (C.A.H. and A.H.L.) solicited updated conflict-of-interest declarations routinely at the start of each conference call. The opinions and interests of the ATS did not influence recommendations on either topic.

Meetings and Process

After initial discussions in 2020, the members of the ATS fungal working group convened by conference call to review fungal treatment topics commonly encountered in pulmonary and critical care practice with the express purpose of identifying those fungal treatment topics with new data since the 2011 ATS guidelines. After survey of the available literature, two selected questions were proposed, discussed with the ATS documents chair, and finalized for submission to the project review committee in July 2021. These selected topics were revised and approved for the project beginning in January 2022. All work was performed virtually with monthly or bimonthly conference calls. Literature search and analysis were performed under the direction of ATS-designated methodologists (M.H.M. and Q.S.H.). They presented the GRADE (Grading of Recommendations Assessment, Development and Evaluation) approach for guideline development (7). The committee performed the literature review, data evaluation, GRADE recommendation development, and guideline formation and drafted the document.

Formulating Clinical Questions

The panel reviewed emerging literature relevant to commonly encountered fungal

treatment topics since the last ATS fungal treatment guidelines (6). The committee selected the two most relevant clinical treatment questions. The topics were selected by committee consensus and included the use of combination antifungal therapy in IPA and the use of prophylaxis and empiric treatment for IC in critically ill patients. Two specific PICO (patient/population, intervention, comparison, and outcome) questions were formulated. These PICO questions guided the systematic reviews of the literature, grading, and recommendations. In an ongoing fashion, the committee is currently formulating and reviewing additional questions that will serve as the basis for future guidelines.

Literature Search and Study Selection

A comprehensive search was conducted from January 1, 2000, to January 11, 2022, and included Medline In-Process and Other Non-Indexed Citations, MEDLINE, Embase, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, and Scopus. Search results were limited to English and were designed and executed by a librarian. Controlled vocabulary supplemented with keywords was used to search for studies of fungal diagnosis. The actual strategies for PICO 1 and PICO 2 are available in the online supplementary material and yielded 2,260 citations for PICO 1 and 1,600 citations for PICO 2. The panel also assisted in identifying additional resources and monitored the literature for studies outside of the search dates and strategies. The methodologists and the committee members selected studies for inclusion by consensus.

Evidence Synthesis and Rating of Certainty in the Evidence

When deemed appropriate, random-effects meta-analysis was used to generate pooled relative risk (RR). The quality of evidence (certainty in the estimates) was graded as high, moderate, low, and very low following the GRADE approach for treatment studies (7). All final recommendations were reached by consensus and were unanimous unless otherwise specified. The panel considered all patient-important outcomes but focused on overall mortality as the driver for treatment decisions in these two clinical settings. When deemed necessary, the panel added an implementation remark to make a particular recommendation more practical and implementable by clinicians. Implementation remarks are not derived from the systematic review; rather, they are derived from the clinical experience of the panel and their knowledge of the literature. Therefore, implementation remarks should not be conflated with the graded recommendation.

Manuscript Preparation

The writing committee (O.E., K.M.P., S.E.E., T.M., E.M.C., S.H., C.A.H., and A.H.L.) provided the initial draft of guideline document sections for review and editing by the entire panel. The entire panel provided input to correct interpretive or factual errors. The final document was integrated, edited, and approved by the committee. The complete guideline was submitted to the ATS Documents Committee and then to the ATS Board for review. The guideline underwent anonymous peer review by four content experts and one methodologist. After multiple cycles of review and revision, the guideline was reviewed and approved by a multidisciplinary board of directors. The guideline will be reviewed by the ATS 3 years after publication, and it will be determined if updating is necessary.

Recommendations for Selected Fungal Treatment Questions

Question 1. In patients with proven or probable IPA, does combination therapy with a mold-active triazole plus echinocandin reduce mortality compared with mold-active triazole monotherapy?

Recommendation. Question 1. In patients with proven or probable IPA, we suggest either initial monotherapy with a mold-active triazole or initial combination therapy with a mold-active triazole plus an echinocandin (conditional recommendation, low-quality evidence).

Implementation Remark. The available evidence and contextual considerations were insufficient to favor one approach over the other. This recommendation derived exclusively from data on patients with hematological malignancy (HM) and/or history of hematopoietic stem cell transplant (HSCT). Applicability of this recommendation to patients without HM or history of HSCT is unclear. Combination therapy is likely more appropriate in the setting of critical illness or concern for triazole resistance. Patients diagnosed with IPA by a positive galactomannan (GM) assay result in serum or BAL fluid may be particularly suitable candidates for the dual regimen in any setting.

Background

Aspergillus is a genus of ubiquitous environmental molds capable of causing invasive human infection in the context of compromised innate or cell-mediated immunity. The classical scenario associated with the former is neutropenia induced by chemotherapy for HM or resulting from a myeloablative conditioning regimen in preparation for HSCT. Cell-mediated immunodeficiency predisposing to IPA is typically related to suppression of T cell immunity after solid-organ transplant or allogeneic HSCT, especially when the latter is accompanied by graft-versus-host disease. IPA is the most common IFI in both HM (8), where it accounts for up to 90% of such infections with an attributable mortality of 42%, and HSCT, with approximately 70% of isolates and an attributable mortality of 72% (9). Given the frequency and lethality of IPA in these two populations, prompt and maximally effective antifungal therapy is essential to patient survival. A pivotal randomized controlled trial (RCT) (10) published in 2002 established the superior efficacy and safety of voriconazole, a mold-active triazole, compared with amphotericin B deoxycholate (AmB), the prior standard. As a result, voriconazole has been considered the drug of choice for IPA since that time. Concurrent with the ascent of voriconazole has been the evolution of the echinocandin class of antifungal agents. The currently available evidence does not support replacing voriconazole with an echinocandin as first-line monotherapy (11). However, the possible benefit of adding an echinocandin to voriconazole as a form of combination therapy has been entertained for many years. Because the triazoles inhibit fungal cell membrane synthesis, whereas the echinocandins act at the cell wall, the potential for synergy between these compounds in treating *Aspergillus* spp. is mechanistically plausible. Results of an *in vitro* experiment (12) and an *in vivo* rabbit model of IPA have lent credence to the notion that adding an echinocandin to a triazole (13) could produce results superior to triazole alone, although positive results have not been replicated in other animal models (14). Clinically, the addition of an echinocandin to a mold-active triazole for

the treatment of IPA could occur in two distinct settings: primary and salvage therapy. Primary combination therapy is defined as the upfront use of both agents in a treatment-naive individual. Salvage combination therapy refers to conversion from initial monotherapy. Before voriconazole supplanted AmB as the drug of choice for IPA, the trigger for salvage combination therapy would have been failure or toxicity of AmB. In contemporary practice, salvage combination therapy typically means the addition of an echinocandin after inadequate response to treatment with a mold-active triazole alone.

Analysis of Literature

For the purposes of the literature search, mold-active triazole agents included voriconazole (Vfend; Pfizer), itraconazole (Sporanox [Janssen Pharmaceuticals], Tolsura [Mayne Pharma]), posaconazole (Noxafil; Merck), isavuconazole, and isavuconazonium (Cresemba; Astellas Pharma). The echinocandins included caspofungin (Cancidas; Merck), micafungin (Mycamine; Astellas Pharma), and anidulafungin (Eraxis; Pfizer). The literature search produced 2,260 references, of which 2,140 were excluded on the basis of abstract review. Full-text sources for the remaining 120 references were retrieved and examined in detail. The first screening phase eliminated 103 of these 120 publications for meeting broad exclusion criteria, such as having fewer than 25 subjects or having pediatric participants. Thirteen of the 17 remaining publications were eliminated after a second round of full-text screening based on more nuanced incompatibility with the question (results summarized in Table E1 in the online supplement). The two most common reasons for elimination of these 13 publications were lack of a mortality endpoint (7 of 13; 54%) and use of a monotherapy comparator (e.g., echinocandin or AmB) other than a triazole (4 of 13; 31%). To the four studies thus identified (15–18), a fifth study (19) was added on the basis of inspection of the reference list of an existing systematic review (20). The reference list of another systematic review (21) yielded two conference abstracts (22, 23) for which corresponding full-text publications could not be located, so these documents were not included. A flow diagram summarizing the literature search process is depicted in Figure 1. In addition, we also reviewed previous relevant Infectious Diseases Society of America (IDSA) guidelines and European Society of Intensive Care Medicine/European Society of Clinical Microbiology and Infectious Diseases (ESCMID) guidelines.

The characteristics of the five studies that constituted the evidence for this question are presented in Table 1. Four of them are retrospective cohort studies (15–19) of voriconazole with or without caspofungin, and the fifth is an RCT of voriconazole with or without anidulafungin (18). All of the studies included either patients with HM, recipients of HSCT, or a mixed population. The observational studies were limited to cases of proven or probable IPA according to international consensus criteria (24). The RCT permitted enrollment of possible cases, but to be considered evaluable, they needed to have been upgraded to proven or probable in the week after randomization. One of the observational studies (15) examined combination therapy exclusively in the salvage setting, and there was a subgroup in

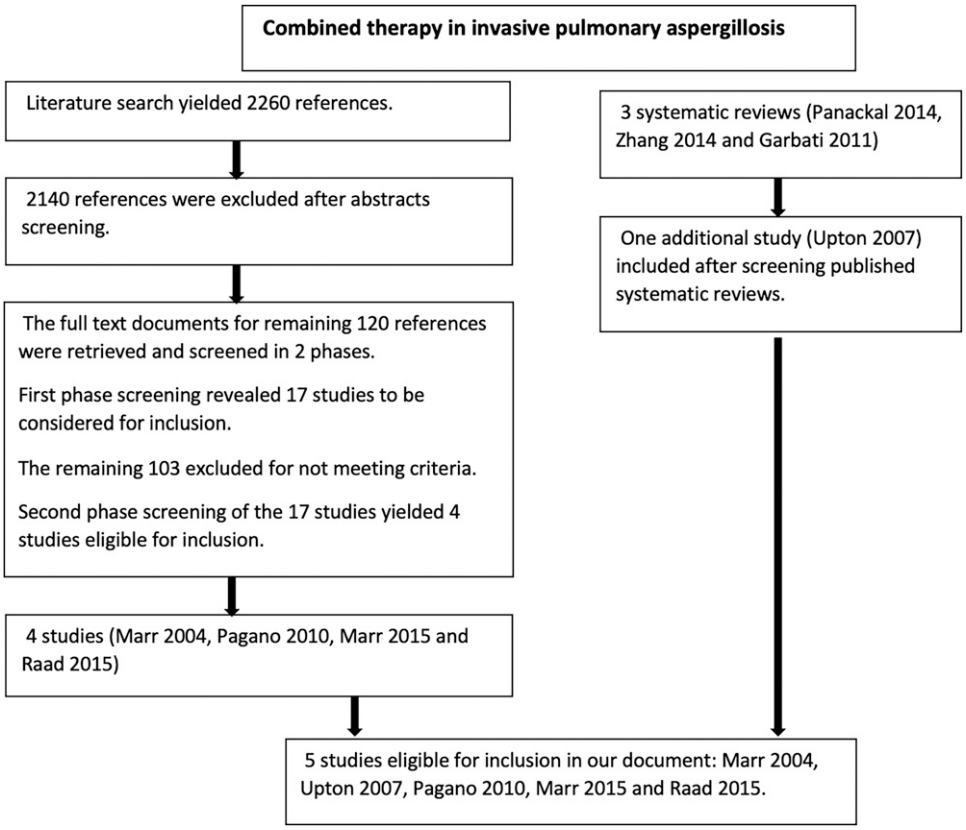

Figure 1. Flow diagram of literature selection and review for question 1.

Table 1. Characteristics of Studies Included in Question 1

Study ID	Population	Combination Regimen	Comparison	Study Design	Outcomes
Marr *et al.*, 2004 (15)	IPA cases who received salvage therapy after hematopoietic stem cell transplant or cytotoxic chemotherapy for hematologic malignancy	Voriconazole plus caspofungin	Voriconazole	Retrospective	3-mo IPA attributable mortality after salvage therapy
Upton *et al.*, 2007 (19)	IPA cases who received primary therapy in patient with hematopoietic cell transplant	Voriconazole plus caspofungin	Voriconazole	Retrospective	3-mo IPA attributable mortality after primary therapy
Pagano *et al.*, 2010 (16)	IPA cases who received primary therapy in patients with acute myeloid leukemia	Voriconazole plus caspofungin	Voriconazole	Retrospective	4-mo IPA attributable mortality in patient receiving first-line target therapy
Raad *et al.*, 2015 (17)	IPA cases who received primary or salvage therapy in patients with hematological malignancies	Voriconazole plus caspofungin	Voriconazole	Retrospective	3-mo IPA attributable/ all-cause mortality after primary therapy, 3-mo IPA attributable/all-death mortality after salvage therapy
Marr *et al.*, 2015 (18)	IPA cases who received primary therapy in patients with hematologic malignancies and hematopoietic cell transplant	Voriconazole plus anidulafungin	Voriconazole	Randomized, double-blind, placebo-controlled multicenter trial	3-mo mortality in mITT population, 6-wk mortality in mITT population (mITT: only probable and confirmed IPA)

Definition of abbreviations: IPA = invasive pulmonary aspergillosis; mITT = modified intention to treat.

another (17) that received salvage therapy; the other studies were restricted to primary therapy only. Overall, in the observational studies, a total of 72 patients received primary combination therapy and 101 patients received primary monotherapy ($n = 173$), whereas a total of 51 patients received salvage combination therapy and 55 patients received salvage monotherapy ($n = 106$). Three of the four observational studies reported 3-month mortality; the fourth reported 4-month mortality (16). The RR of death at these time points in combination therapy recipients versus monotherapy recipients stratified by primary versus salvage therapy was the outcome measure analyzed in the pooled analysis for this question. IPA-attributable mortality was used preferentially if it was available as an explicit endpoint. Information on mold-active prophylaxis was provided by two of the observational studies and was used in greater than 70% of patients in both (16, 17). The international, multicenter, double-blind, placebo-controlled trial randomized 277 patients with IPA to either voriconazole alone ($n = 142$) or voriconazole plus anidulafungin ($n = 135$) as primary therapy (18). The mold-active prophylaxis rate was 7.6%. The RCT was not meta-analyzed with the observational studies because of evident methodological heterogeneity. The RCT reported its primary outcome as mortality at 6 weeks and a secondary outcome as mortality at 3 months.

Summary of the Evidence for Primary Therapy

Meta-analysis of the three observational studies that evaluated primary therapy (16, 17, 19) is shown in Figure 2. The pooled RR of death was 2.13 (95% confidence interval [CI], 1.18–3.83), suggesting a possible increase in mortality with the combination of voriconazole and caspofungin compared with voriconazole alone. The I^2 statistic revealed no important heterogeneity, with a P value of 0.67. However, these studies were judged to be at high risk of bias in the domain of comparability because the provided estimates were unadjusted (Table 2). Certainty in this pooled estimate was rated as very low because of the observational nature of the studies, lack of adjustment for critical confounders, and serious concern related to imprecision (small sample size). A summary of the certainty in the evidence is presented in Table 3. Contrary to the result obtained when pooling the observational studies, the RCT suggested a nonsignificant but clinically meaningful reduction in mortality with the combination regimen of voriconazole plus anidulafungin compared with voriconazole monotherapy at 3 months (calculated RR, 0.75; 95% CI, 0.53–1.04). The absolute reduction in mortality was 98 fewer deaths per 1,000 patients (182 fewer to 15 more). Certainty in this estimate was considered low, and it was rated down because of very serious concern related to imprecision (small sample size and CI crossing clinically important thresholds as presented in Table 3). Six-week mortality also favored the combination arm but likewise fell short of reaching statistical significance: 19.5% versus 27.8% (absolute risk reduction, −8.2; 95% CI, −19.0 to 1.5; $P = 0.087$). Mortality reduction at 6 weeks did reach statistical significance in the predominant subgroup of patients (80% of participants) with probable IPA based on radiographic abnormalities and positive GM antigen with a calculated RR of 0.57 (95% CI, 0.33–0.98). The absolute

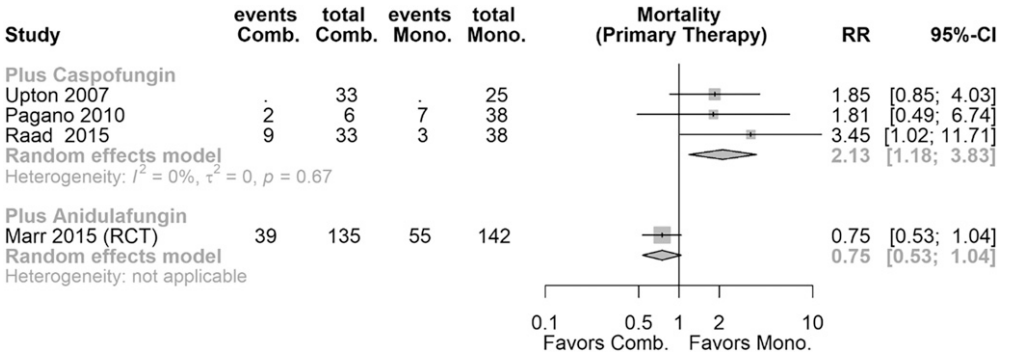

Figure 2. Meta-analysis of mortality following primary therapy in question 1. Events numbers for study by Upton and colleagues (19) were not reported in the published article and therefore we used the calculated RR to perform the meta-analysis. Studies by Upton and colleagues (19) and Raad and colleagues (17) reported 3 months mortality and Pagano and colleagues (16) reported 4 months mortality. RCT by Marr and colleagues (18) reported 3 months mortality. CI = confidence interval; RCT = randomized controlled trial; RR = relative risk.

reduction in mortality in this subgroup was 117 fewer deaths per 1,000 patients (183 fewer to 5 fewer). Certainty in this estimate was considered low because of imprecision (Table 3).

Summary of the Evidence for Salvage Therapy

The pooled estimate for salvage therapy was obtained by combining results of the entire population from one of the observational studies (15) with results of the subgroup of patients from another observational study (17) who received either voriconazole plus caspofungin or voriconazole alone in the salvage setting (15, 17). In these two studies, a total of 51 patients received salvage combination therapy and 55 patients received salvage monotherapy. This analysis is depicted in Figure 3. The pooled RR of death was 1.01 (95% CI, 0.28–3.72) with combination therapy versus voriconazole monotherapy. There was, notably, significant heterogeneity between these studies, with an I^2 statistic of 78% and a P value of 0.03. These studies were judged to be at high overall risk of bias, and the certainty in this estimate was considered very low because of serious concerns related to imprecision and risk of bias (Tables 2 and 3).

Rationale and Evidence-to-Decision Considerations

Although the observational studies suggested potential harm of combination therapy, the panel emphasized the results of the lone RCT over those of the observational studies because of the greater methodological rigor of the RCT and thus lower concern about selection bias whereby more severely ill patients may have been preferentially administered combination therapy. Therefore, in issuing its conditional recommendation for equipoise, the panel relied heavily on the RCT's imprecise but clinically meaningful estimate of survival benefit with combination therapy. Importantly, the survival benefit of combination therapy in the RCT was more precise in the dominant subgroup of patients who were diagnosed with probable IPA on the basis of a positive GM assay finding. This result contributed to the recommendation because GM detection is currently the most common pathway for the diagnosis of IPA in clinical practice and is incorporated into the latest international consensus criteria (24). The panel deemed the outcome of mortality to be universally important for a condition as lethal as IPA, and, although the certainty of the evidence was low to moderate, the possibility of a survival benefit was believed to offset the potential undesirable effects of combination therapy in the critically ill and in those in whom triazole resistance is a concern. The main undesirable effects that were considered were cost and additive drug toxicity. A cost-effectiveness analysis of combination therapy with a triazole plus an echinocandin versus triazole monotherapy for IPA has not been performed, but the incremental cost of an antifungal as widely available as an echinocandin was thought to be acceptable when viewed in the context of the overall cost of care for a critically ill patient with IPA. The RCT reported a higher incidence of hepatobiliary adverse events in the combination therapy arm (12.7% vs. 8.4%), but the difference was not statistically significant, and treatment discontinuation rates were similar between the groups. The panel acknowledged the very sparse data pertaining to combination therapy in the salvage setting and therefore did not issue a separate recommendation regarding this scenario. The panel deemed that the evidence relied upon to support combination therapy in the primary setting could be extrapolated to the salvage setting in the absence of sufficient direct evidence to guide decision making.

The Panel recognized that its recommendation is based exclusively on voriconazole-containing regimens—this reflects the primacy of voriconazole as an anti-*Aspergillus* triazole for the past two decades. The potential advantages of combining a triazole and echinocandin may predominantly relate to the well-described limitations of voriconazole, which include *1*) inherent or acquired resistance to voriconazole that may not necessarily extend to other triazoles (25), *2*) highly variable pharmacokinetics and frequent subtherapeutic voriconazole concentrations despite use of standard oral or intravenous loading regimens (26), and *3*) unrecognized polymicrobial fungal infections with pathogens that are resistant or inherently less susceptible to voriconazole (e.g., mixed infections of *Aspergillus* spp. and *Mucorales* [27]). Aside from overcoming the specific challenges posed by voriconazole, a generic combination of a triazole and echinocandin may be beneficial by compensating for limitations of monotherapy with a drug in either class. The following are some potential considerations in that regard: *1*)] differential

Table 2. Risk-of-Bias Assessment for Studies Included in Question 1

	Risk-of-Bias Assessment									
	Randomized Controlled Trial									
Study	Randomization	Deviations from Intended Interventions	Missing Outcome Data	Measurement of the Outcome	Selection of the Reported Result	Funding Source
Marr *et al.*, 2015 (18)	Low risk	Low risk	High risk	Low risk	Some concerns	Some concerns
	Observational Studies									
Study	Selection of Cohort 1	Selection of Cohort 2	Ascertainment of Exposure	Demonstration that Outcome of Interest Was Not Present at Start of Study	Comparability	Ascertainment of Outcome	Follow-Up Long Enough for Outcomes to Occur	Adequacy of Follow-Up
Marr *et al.*, 2004 (15)	Low risk	Low risk	Low risk	Low risk	High risk	Low risk	Low risk	Low risk
Pagano *et al.*, 2010 (16)	Low risk	Low risk	Low risk	Low risk	High risk	Low risk	Low risk	Low risk
Raad *et al.*, 2015 (17)	Low risk	Low risk	Low risk	Low risk	High risk	Low risk	Low risk	Low risk
Upton *et al.*, 2007 (19)	Low risk	Low risk	Low risk	Low risk	High risk	Low risk	Low risk	Low risk

partitioning of the two drug classes in different tissue compartments, meaning that at least one drug is present at the effect site (28), which may be especially relevant for disseminated disease; *2*) overcoming unfavorable drug–drug interactions that may render triazole therapy less effective; *3*) possible positive pharmacological interactions (i.e., additive or synergistic interactions) in terms of antifungal killing as supported by multiple nonclinical studies (29, 30); and *4*) (theoretically at least) prevention of the emergence of resistance—in a way that is increasingly understood with combination therapy for bacterial pathogens.

Implementation Considerations

Clinical Settings

Although the Panel refrained from suggesting combination therapy for the diagnosis of IPA as a whole, two clinical settings were proposed as potentially suitable for combination therapy (*see* implementation remark). Neither setting was proposed on the basis of available study data; rather, the setting was based on the collective experience of panel members and indirect evidence. One such setting is IPA in the critically ill. For patients admitted to the ICU, the mortality of IPA is particularly high (31), so it would be reasonable to surmise that the potential benefit of combination therapy would be maximized, and the risk of overtreatment minimized, in this high-risk setting. The echinocandins are widely available in the ICU and are routinely used to treat other fungal infections such as IC. Therefore, access of the critically ill to an echinocandin-containing regimen would not be expected to present an obstacle to implementation, except for the most resource-limited parts of the globe. Echinocandins also have a favorable use profile in patients with renal or hepatic impairment—both common conditions in the ICU—and do not pose a major challenge with drug–drug interactions.

The other setting in which the panel favored consideration of combination therapy is when there is concern for triazole resistance. Triazoles are often used for *Aspergillus* prophylaxis in patients at risk for IPA. It is unknown at present whether the prophylactic use of triazoles impacts the efficacy of monotherapy compared with

Table 3. Certainty in Evidence, GRADE Summary of Findings (Both Key Questions)

Outcome	No. of Participants (Studies), Follow-Up	Certainty Assessment	Relative Effect (95% CI)	Anticipated Absolute Effects	Overall Certainty
Mortality outcome for administering combination therapy with mold-active triazole plus echinocandin compared with mold-active triazole monotherapy when used as primary therapy in patients with proven or probable invasive pulmonary aspergillosis	173 patients (3 observational studies) 3 mo	Risk of bias: very serious due to lack of adjustment for critical confounders Inconsistency: no concern Indirectness: no concern Imprecision: serious concern (small sample size)	RR, 2.13 (1.18–3.83)	98 more deaths per 1,000 patients (182 more to 15 more)	Very low
	277 patients (1 RCT) 3 mo	Risk of bias: not serious Inconsistency: no concern Indirectness: no concern Imprecision: very serious concern due to small sample size and CI crossing clinically important thresholds	RR, 0.75 (0.53–1.04)	98 fewer deaths per 1,000 patients (182 fewer to 15 more)	Low
	218 patients (probable IPA based on radiographic abnormalities and positive galactomannan antigen 6-wk all-cause mortality	Risk of bias: not serious Inconsistency: no concern Indirectness: no concern Imprecision: very serious concern due to small sample size	RR, 0.57 (0.33–0.98)	117 fewer deaths per 1,000 patients (183 fewer to 5 fewer)	Low
Mortality outcome for administering combination therapy with mold-active triazole plus echinocandin compared with mold-active triazole monotherapy when used as salvage therapy in patients with proven or probable invasive pulmonary aspergillosis	106 patients (2 observational studies)	Risk of bias: serious due to lack of adjustment for critical confounders Inconsistency: no concern Indirectness: no concern Imprecision: very serious concern due to small sample size and CI crossing clinically important thresholds	RR, 1.01 (0.28–3.72)	5 more deaths per 1,000 patients (327 fewer to 1,000 more)	Very low
Mortality outcome of systemic antifungal agents when administered as prophylaxis or empiric therapy in critically patients who are nonneutropenic and not transplant recipients	1,577 (8 RCTs)	Risk of bias: some concern due to bias in randomization and missing outcome data Inconsistency: no concern Indirectness: no concern Imprecision: serious concern due to CI crossing clinically important thresholds	RR, 1.03 (0.86–1.23)	7 more per 1,000 (31 fewer to 51 more)	Low

Definition of abbreviations: CI = confidence interval; RCT = randomized controlled trial; RR = relative risk.

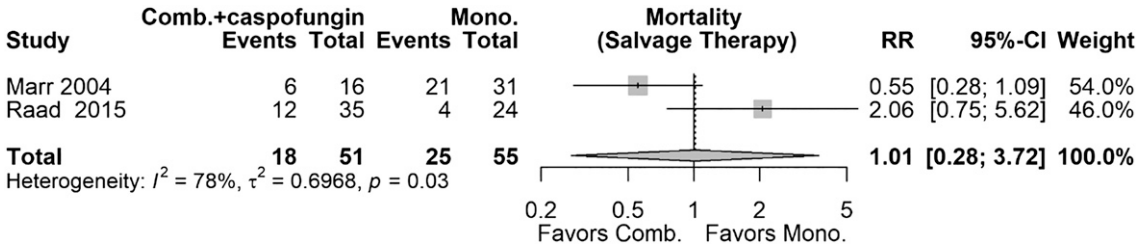

Figure 3. Meta-analysis of mortality following salvage therapy in question 1. CI = confidence interval; RR = relative risk.

combination therapy for IPA in the context of breakthrough infections. Overall, in Europe, the prevalence of triazole resistance in clinical *A. fumigatus* isolates has been reported to be 3.2% (32), whereas in the United States, the prevalence is substantially lower at 1.4% (33). On a related note, the availability and use of antifungal susceptibility testing of *A. fumigatus* isolates in U.S. laboratories is reduced compared with their European counterparts. This has translated into less environmental surveillance, especially on a state-by-state level, in the United States and thus more limited awareness of the epidemiology of *Aspergillus* resistance than exists in Europe. On other continents, some countries have registered a prevalence of resistance exceeding 10%, especially when environmental isolates are examined (34). The benefit of initial combination therapy is likelier to outweigh the risk in settings with increased triazole resistance: International expert opinion (35) and European guidelines (36) already advocate for this approach at an environmental resistance threshold of >10%. Subsequent performance of antifungal susceptibility testing on the clinical isolate of a particular patient could enable deescalation to triazole monotherapy in susceptible cases.

Patient Characteristics

In the lone RCT, a statistically significant reduction in 6-week mortality with combination therapy was observed in two subpopulations. One was the aforementioned dominant subgroup (80% of subjects) diagnosed with IPA by GM positivity. The result of this *post hoc* analysis raises the possibility that patients diagnosed in such a contemporary and practical manner could be particularly suitable candidates for the dual regimen (*see* implementation remark). Whether this apparent differential response is explained by pathogen, host, or technical factors is currently unknown. The other was a much smaller prespecified subgroup (99 of 277; 36% of subjects) consisting of those without neutropenia at diagnosis. The calculated RR for death of 0.42 for this subgroup was associated with a very wide 95% CI (0.19–0.94). Given the methodological limitations of a small subgroup analysis within a single RCT, this result was not incorporated by the guideline panel into the evidence-to-decision process. Nonetheless, the panel acknowledged that special attention to an individual patient's neutrophil count is warranted when deciding whether to administer monotherapy or combination therapy for IPA.

Antifungal Agents

In light of their comparable clinical efficacy with more predictable pharmacokinetics and more favorable toxicity profile, the newer triazoles posaconazole and isavuconazole have been increasingly competing with voriconazole as first-line therapy for IPA in clinical practice even as voriconazole still retains primacy in guidelines (37). By extension, these drugs are also being used as part of combination regimens in the clinical arena. In light of their fundamental similarity, the panel considered voriconazole to be a reasonable stand-in for the newer agents and, in the absence of direct data, believed that the current recommendation based on studies of voriconazole could reasonably extend to posaconazole and isavuconazole. Conversely, the most recently approved echinocandin, rezafungin, has not been studied in human trials of IPA and, owing to its extremely long half-life, cannot be considered interchangeable with the conventional echinocandins (micafungin, anidulafungin) that are addressed by this guideline (38).

Areas of Research Need

All of the studies considered for this recommendation compared voriconazole monotherapy with voriconazole-based regimens containing either micafungin or anidulafungin. The newer triazoles posaconazole and isavuconazole have not been investigated as part of a combination regimen for IPA. If conducted in the coming years (none is registered with ClinicalTrials.gov as of this writing), studies of combination therapy using these newer agents might alter subsequent guideline recommendations on this topic. The same may apply to future studies of rezafungin for the treatment of IPA. The number of possible combination regimens is destined to evolve with the advent of novel categories of antifungal agents. Promising animal data for efficacy against *Aspergillus* spp. are already available for regimens containing fosmanogepix (39), ibrexafungerp (40), and olorofim (41), but results of human trials have not been reported to date.

In addition, the studies considered herein were limited to patients with HM and HSCT; future studies involving other high-risk populations such as lung transplant recipients would fill an important data gap. No existing study of triazole plus echinocandin combination therapy has addressed breakthrough infections despite mold-active prophylaxis, infections in the setting of suspected or documented triazole resistance, or infections in the critically ill. Once combination therapy is initiated, its optimal duration remains to be established, as do strategies for deescalation to monotherapy. Also, as mentioned, a cost-effectiveness analysis of combination therapy versus monotherapy for IPA has yet to be performed. Finally, future trials of combination therapy for IPA will need to account for the possibility that patients diagnosed by means of GM positivity respond differently to treatment from those diagnosed by culture, as suggested by the RCT that underpinned this recommendation (18).

Recommendations for Selected Fungal Treatment Questions

Question 2. In critically ill patients who are nonneutropenic and are not transplant

recipients, should systemic antifungal agents be administered as either prophylaxis or empiric therapy to reduce mortality?

Recommendation. In critically ill patients without neutropenia or a history of transplant, we suggest against routine administration of prophylactic or empiric antifungal agents targeting *Candida* species (conditional recommendation based on low-quality evidence).

Background

Candida species are frequent colonizers of mucosal and cutaneous surfaces of healthy individuals; however, when there is breakdown of mechanical or immunologic defenses, invasion can occur (42). This may manifest as deep-seated IC and/or candidemia, and the latter can lead to metastatic complications, including but not limited to endophthalmitis, bone and joint infections, endovascular infections, and hepatosplenic abscesses (43, 44). In critically ill patients, the incidence of candidemia varies from 3.5 to 16.5 episodes per 1,000 ICU admissions (45–50); however, the incidence of deep-seated IC without concomitant candidemia is less clear because of challenges associated with confirming the diagnosis. Outcomes associated with IC are poor with a crude mortality of 40–55% (45–47, 51). Host risk factors for IC in critically ill patients include diabetes, systemic immunosuppression, organ failure, total parenteral nutrition, malignancy, *Candida* colonization, and genetic polymorphisms. Clinical risk factors encompass breaches in barrier of defense because of surgery, loss of mucosal integrity (e.g., of an abdominal viscus), burns, indwelling vascular access catheters, and hemodialysis (43, 52).

Candida colonization logically precedes infection, and in critically ill patients, the presence and density of *Candida* colonization is predictive of development of IC (53, 54). Deep-seated IC, particularly intraabdominal IC, occurs in critically ill patients and, because of limitations of available diagnostics, is likely underdiagnosed (44). Nonetheless, IC complicates a minority of ICU admissions (55). The use of antifungal therapy in the ICU, whether as prophylaxis or empiric therapy, is of great interest to providers treating critically ill patients. To our knowledge, no clear recommendations on the subject have been published.

Available Literature

For this analysis, we categorized the use of systemic anti-*Candida* therapy into three categories (prophylactic, preemptive, and empiric) by definitions described in the ESCMID guideline for the diagnosis and management of *Candida* diseases (56). A prophylaxis strategy entails administration of antifungals to high-risk patients without microbiologic or radiographic evidence of infection; a preemptive strategy entails administration of antifungals to high-risk patients based on the presence of positive surrogate markers (e.g., β-D-glucan [BDG], mannan, antimannan antibody); an empiric strategy entails administration of antifungals to high-risk patients based on signs of infection but absence of microbiologic confirmation of infection.

We included RCTs that assessed the mortality effect of systemic antifungal therapy compared with placebo in nonneutropenic, nontransplant, critically ill adult patients. The primary outcome was all-cause mortality. We excluded studies on pediatric populations, nonabsorbable antifungal agents, and studies that used antifungal therapy for "antiinflammatory" effect. We also excluded studies with fewer than 25 patients, commentaries, editorial letters, and case reports.

The initial literature search yielded 1,600 references, of which 1,526 were excluded after abstract screening (flow diagram in Figure 4). The full-text articles of the remaining 74 references were reviewed. Of these, 9 studies were not RCTs and 60 studies did not include the relevant population, intervention, control, and/or outcome, leaving 5 RCTs (57–61) that met the inclusion criteria (Table E2).

Three published systematic reviews and meta-analyses (62–64) were examined for potentially eligible studies not identified by the primary literature search. An additional three eligible studies were thus identified (65–67). Data from a fourth study (68) was included in the meta-analysis performed by Dupont and colleagues (64); however, because this trial was discontinued early as a result of inadequate enrollment and a detailed description of the methods and results remains unpublished, it was not included in this analysis. In total, eight RCTs were finally included. The characteristics of these trials are summarized in Tables 4 and E3.

We examined mortality outcome on the basis of the antifungal strategy used. Five placebo-controlled RCTs examined the impact of antifungal prophylaxis, totaling 441 patients in the intervention groups and 421 in the control group. Three RCTs examined fluconazole (57, 65, 66) and two an echinocandin (59, 67). Three RCTs were from a single center (57, 65, 66), and two were multicenter (59, 67). Although all RCTs exclusively enrolled critically ill patients, some had other specific inclusion criteria, such as trauma or surgical patients (57, 65), mechanically ventilated (MV) patients with ventilator-associated pneumonia (67), MV patients receiving selective digestive decontamination (SDD) (66), and patients with positivity of a clinical prediction rule for IC (59). The duration of antifungal prophylaxis varied from a defined duration of 14 days (57) to ICU length of stay (57, 59, 65) to development of IC (57, 65, 66). None of the RCTs designated mortality as a primary outcome; however, these data were extractable from the published articles. The study by Albert and colleagues (67) was included in the prophylaxis rather than empiric category because the indication for empiric antifungals was ventilator-associated pneumonia in the presence of *Candida* isolated from the respiratory tract. Although *Candida* spp. are frequent colonizers of the respiratory tract, *Candida* pneumonia is rare and would require visualization of invasive forms of *Candida* on histopathologic examination of the lung parenchyma to confirm the diagnosis, which was not achieved in this study (69).

None of the eligible studies identified by our search examined preemptive therapy as per the definition used herein. In the trial by Ostrosky-Zeichner and colleagues (59), some patients were subjected to two different antifungal strategies: initial prophylaxis with either caspofungin or placebo with a permitted switch to open-label drug therapy for placebo recipients who developed proven or probable IC during follow-up. The authors termed such crossover therapy "preemptive." The panel considered this trial to be one of prophylaxis, and thus it was analyzed in that antifungal strategy category. On the basis of the definitions used herein, the "preemptive" therapy in this trial would be classified as either empiric (probable IC) or directed (proven IC) antifungal therapy. Recipients of open-label empiric antifungal therapy in this trial were not analyzable for the purposes of

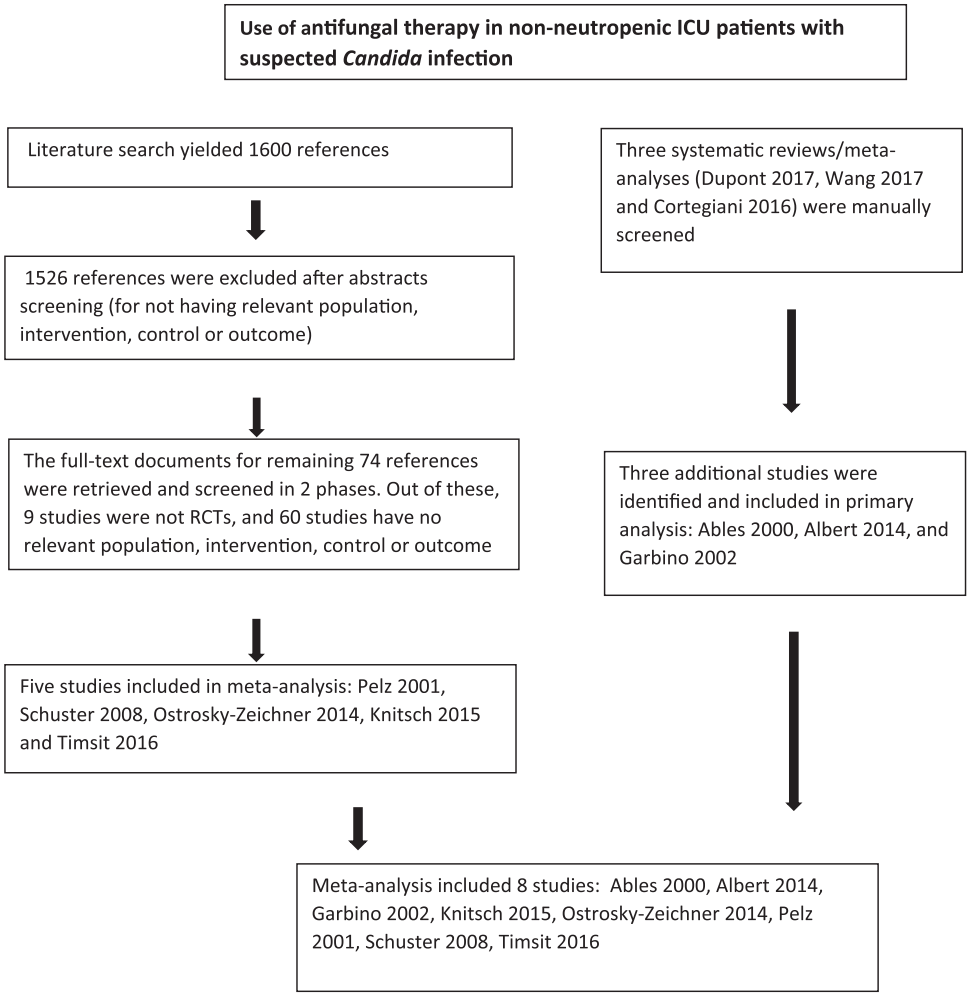

Figure 4. Flow diagram of literature selection and review for question 2. RCT = randomized controlled trial.

the present guideline, because there was no comparison group.

Three studies examined empiric antifungal therapy; all were multicenter, placebo-controlled trials (58, 60, 61) and totaled 372 patients in the intervention group and 376 in the control group. Two studies examined micafungin (60, 61) and one fluconazole (58). Infection syndromes serving as inclusion criteria were different in each study: generalized or localized intraabdominal infection (60), more than 4 days of fever (58), and ICU-acquired sepsis (61). Twenty-eight-day survival without proven IC was the primary outcome in one study only (61); the others examined incidence of IC (60) and resolution of the sepsis syndrome (58).

We also examined mortality outcomes on the basis of the antifungal agent used (fluconazole or an echinocandin). Fluconazole was administered in four studies; however, there was heterogeneity in dosing. Two studies administered a loading dose of 800 mg followed by 400 mg daily (57, 65), one study used 800 mg daily (58), and one used 100 mg daily (58). One of these four studies used fluconazole as empiric therapy (58); the remaining three used fluconazole as prophylaxis (57, 65, 66). Four studies used an echinocandin. One study used anidulafungin 200 mg loading followed by 100 mg daily (67), and one study used caspofungin 70 mg loading followed by 50 mg daily (59), both as prophylaxis. The remaining two studies used micafungin 100 mg daily as empiric therapy (60, 61).

Summary of the Evidence Based on Antifungal Strategy

Overall

The result of meta-analysis of the eight RCTs that evaluated either prophylaxis (57, 59, 65–67) or empiric antifungal therapy (58, 60, 61) is shown in Figure 5. This overall analysis consisted of 798 critically ill patients who received systemic antifungals and 779 who received placebo, of whom 183 (22.9%) and 173 (22.2%) died, respectively. The pooled RR of death was 1.03 (95% CI, 0.86–1.23), indicating no statistically significant difference in mortality whether systemic antifungals were administered or not. The I^2 value revealed no important heterogeneity, with a P value of 0.90. The absolute change in mortality was 7 more deaths per 1,000 (31 fewer to 51 more). Certainty in the evidence was rated as low because of concerns related to risk of bias and imprecision, as detailed in Tables 3 and 5.

Antifungal Prophylaxis

The result of meta-analysis of the five RCTs (57, 58, 65–67) that evaluated antifungal prophylaxis is available in Figure 5. The pooled RR of death was 0.99 (95% CI, 0.77–1.27).

Table 4. Characteristics of Studies Included in Question 2

Study Author, Publication Year, and Timing	Study Design	Inclusion Criteria (Patients)	Exclusion Criteria (Patients)	Intervention	Control	Duration of Therapy	Duration of Follow-Up	Outcome
Antifungal strategy: prophylaxis								
Ables *et al.*, 2000 (65) October 1994–December 1996	Single-center, double-blind, randomized, placebo-controlled trial	Trauma or surgical patients ⩾14 yr with anticipated ICU stay of >48 h, with at least one additional risk factor within 48 h of ICU admission (CVC, TPN, MV >24 h, broad-spectrum antibiotics)	Documented history of serious adverse reaction(s) to azole drugs, pregnancy, anticipated life expectancy <3 mo, severe liver disease, current systemic antifungal use, transfer from another ICU	Fluconazole 800 mg loading followed by 400 mg intravenous/by mouth/enteral (adjusted for renal impairment)	Placebo	ICU LOS or until the patient developed an infection due to *Candida* species requiring treatment	Hospitalization	Primary: incidence of severe *Candida* infection Secondary: mortality, hospital length of stay
Albert *et al.*, 2014 (67) August 2010–July 2012	Multicenter, double-blind, placebo-controlled randomized pilot trial	Nonimmunocompromised adult patients admitted to ICU ⩾96 h, clinically suspected VAP with >48 h of MV, and positive respiratory secretions for *Candida* sp.	Positive *Candida* sp. outside lungs	Anidulafungin 200 mg loading then 100 mg intravenous	Placebo	14 d	The sooner of ICU stay or 28 d after enrollment	Primary: feasibility as judged by enrollment rate Secondary: changes to innate immune responsiveness, organ function, ICU and hospital LOS, acquired infection, acquired resistance to antifungal therapy, duration of MV, ICU 28-d postrandomization and hospital survival reported 28 d, 90 d, and hospital mortality
Garbino *et al.*, 2002 (66) Timing not stated	Single-center, double-blind, randomized, placebo-controlled trial	Adult medical and surgical ICU patients >18 yr, MV for ⩾48 h and expected to remain on MV for ⩾72 h and receiving selective decontamination of the digestive tract (nonabsorbable syrup consisting of polymyxin B, neomycin, vancomycin)	Life expectancy <7 d after randomization, candidemia at study entry, AIDS, persistence of PT time <50% after 24 h of vitamin K, neutropenia, pregnancy	Fluconazole 100 mg intravenous	Placebo	Continued until the earlier of end of MV, development of fungal infection, serious AE	Not stated; presumed ICU LOS	Primary: severe *Candida* sp. infection Secondary: adverse events, time from study entry to development of severe candida infection and *Candida* sp. colonization
Ostrosky-Zeichner *et al.*, 2014 (59) August 2007–March 2010	Multicenter, randomized, double-blind, placebo-controlled trial Patients who developed proven or probable invasive candidiasis received preemptive therapy	ICU patients, ⩾18 yr of age, nonpregnant, admitted to the ICU during the preceding 3 d (minimum 48 h in ICU) and expected to stay for at least 48 h, and meeting the following conditions of the clinical prediction rule: MV, CVC, and use of broad-spectrum antibiotics and at least one additional risk factor for IC, including TPN or dialysis, on any of Days 1–3, major surgery, pancreatitis use of systemic steroids, or any other immunosuppressive agent <7 d before or on ICU admission	Allergy or intolerance to echinocandin, ANC <500 cells/μl, AIDS, aplastic anemia, chronic granulomatous disease, moderate-severe hepatic insufficiency, pregnancy or lactation, expected survival <24 h from time of enrollment, previous enrollment in this study, receipt of an investigational agent <10 d before study entry	Caspofungin 70 mg, load 50 mg intravenous daily	Placebo Placebo	ICU LOS up to 28 d		Primary: incidence of proven/probable IC Secondary: prospectively verify the performance of a clinical prediction rule, evaluate safety, evaluate the effect of a preemptive approach, evaluate the effect of prophylaxis and preemptive therapy on all-cause mortality and ICU + hospital LOS

(*Continued*)

Table 4. (*Continued*)

Study Author, Publication Year, and Timing	Study Design	Inclusion Criteria (Patients)	Exclusion Criteria (Patients)	Intervention	Control	Duration of Therapy	Duration of Follow-Up	Outcome
Pelz *et al.*, 2001 (57) January 1998–January 1999	Prospective, single-center, randomized, placebo-controlled trial	Critically ill surgical patients aged ⩾18 yr with a length of ICU stay of at least 3 d	Pregnancy, receipt of antifungal agents <7 d before ICU admission, expected survival <24 h	Fluconazole by mouth, loading dose of 800 mg followed by maintenance 400 mg daily (renally adjusted)		ICU LOS or initiation of empiric antifungals	The earlier of death, initiation of antifungal therapy, diagnosis of a fungal infection, or 3 d after ICU discharge	Primary: occurrence of fungal infection during the surgical ICU stay or up to 3 d after ICU discharge
Antifungal strategy: empiric								
Knitsch *et al.*, 2015 (60) July 2010–December 2011	Multicenter, randomized, double-blind, placebo-controlled trial	ICU patients ⩾18 yr of age requiring surgery for generalized or localized intraabdominal infection Patients were included within 48 h (nosocomial acquired) or 72–120 h (community acquired) of surgery, provided they had an expected ICU LOS ⩾48 h	Pancreatitis, infected intraperitoneal dialysis, solid organ transplant, severe liver disease, neutropenia, receipt of a systemic antifungal ⩽14 d before study drug, documented IC at randomization, expected survival <48 h	Micafungin intravenous 100 mg daily	Placebo	Up to 6 wk Stopped earlier if confirmed IC, improvement in surgical condition, alternative antifungal required, death	End of treatment (1–3 d after last dose of study medication)	Primary: incidence of IC Exploratory: biomarker analysis
Schuster *et al.*, 2008 (58) 1995–2000	Multicenter, double-blind, placebo-controlled, randomized controlled trial, 1995–2000	ICU patients ⩾ 18 yr with an ICU stay of at least 96 consecutive hours, APACHE II score within 24 h of randomization of ⩾ 16 or more, 4 d of fever, broad spectrum antibiotics for at least 4 of the preceding 6 d, CVC for at least 24 h before the study	ALT, AST or bilirubin >5× ULN, ANC $<1.0 \times 10^9$ cells/L, AIDS or HIV with CD4 cell count $<0.5 \times 10^9$ cells/L, bone marrow or organ transplant on systemic immunosuppression, ICU admission due to burn injury, receipt of terfenadine, cisapride, or any investigational drug <14 d before study enrollment, evidence of IFI <7 d before study entry, life expectancy of <48 h, previous enrollment in the study	Fluconazole 800 mg intravenous daily	Placebo	2 wk	4 wk	Primary outcome (composite): at 4 d after receipt of the last dose of the study drug: resolution of fever, absence of IFI, no discontinuation because of toxicity, nonrequirement for additional antifungal therapy Secondary outcomes: ICU and hospital LOS, death at 30 d
Timsit *et al.*, 2016 (61) July 2012–February 2015	Multicenter, double-blind, placebo-controlled trial, 2012–2015	Critically ill ICU patients with MV ⩾5 d, at least one colonization site positive *Candida* sp., at least one organ failure, previous treatment ⩾4 d using broad-spectrum antibiotics, arterial line or CVC, one new finding of ICU-acquired sepsis	ANC <500 mm^3, previous bone marrow or solid organ transplant, systemic immunosuppression other than corticosteroids at doses <2 mg/kg/d of prednisolone, antifungal treatment with an echinocandin for >1 d or with any antifungal agent for >72 h during the week before inclusion	Micafungin 100 mg daily	Placebo	14 d	90 d	Primary: survival without proven IFI 28 d after randomization Secondary: new, proven IFI, survival at Day 28 and Day 90, organ failure, serum (1-3)-β-D-glucan level evolution, incidence of ventilator-associated bacterial pneumonia

Definition of abbreviations: AE = adverse event; ANC = absolute neutrophil count; ALT = alanine transaminase; AST = aspartate transaminase; CVC = central venous catheter; IC = invasive candidiasis; IFI =invasive fungal infection; LOS = length of stay; MV = mechanically ventilated; PT = prothrombin time; TPN = total parenteral nutrition; ULN = upper limit of normal; VAP = ventilator-associated pneumonia.

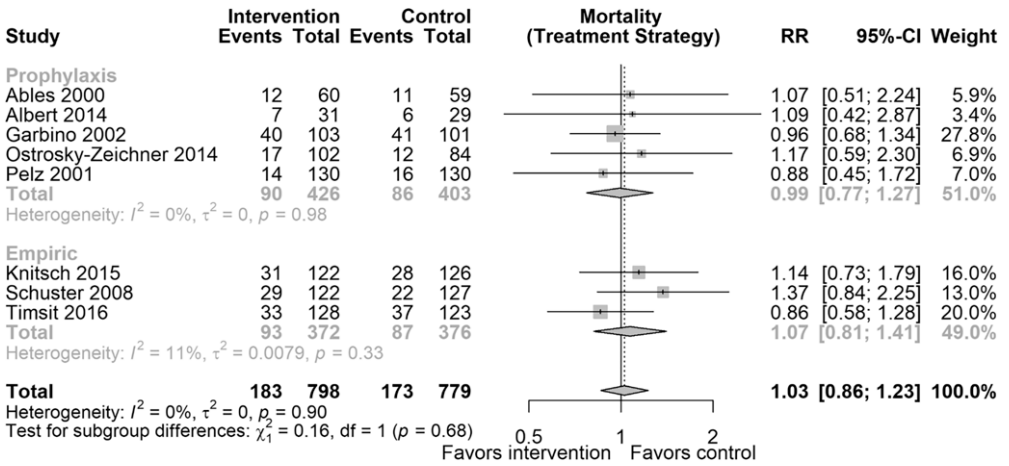

Figure 5. Meta-analysis of mortality in question 2 according to strategy of therapy. CI = confidence interval; RR = relative risk.

The absolute mortality was similar in those who received prophylaxis (97 of 441; 21.9%) compared with those who did not (90 of 421; 21.3%).

Empiric Antifungal Therapy

The result of meta-analysis of the three studies (58, 60, 61) that evaluated empiric antifungal therapy is likewise available in Figure 5. The pooled RR of death was 1.07 (95% CI, 0.81–1.41). The absolute mortality was similar in those who received empiric antifungal therapy (93 of 372; 25.0%) and those who did not (87 of 376; 23.1%).

Summary of Evidence Based on Antifungal Drug Class

The result of meta-analysis of the four studies (57, 58, 70, 66) that evaluated fluconazole therapy is shown in Figure 6. The pooled RR of death was 1.04 (95% CI, 0.82–1.33). The result of meta-analysis of the four studies (59–61, 67) that evaluated echinocandin therapy is also shown in Figure 6. The pooled RR of death was 1.01 (95% CI, 0.86–1.31). The consistency of the results across the two antifungal drug classes suggests that the drug class may not have an effect on mortality, although fluconazole has not been directly compared with an echinocandin in this setting.

Rationale and Evidence-to-Decision Considerations

The pooled RR from the eight included RCTs suggests little or no mortality benefit of systemic antifungal therapy when used as prophylaxis or as empiric therapy. The rationale for assessing mortality as the outcome of interest rather than IC was twofold. The first reason is that the purpose of prophylaxis or empiric antifungal therapy in critically ill patients is to prevent or treat IC as a contributor to mortality. The second reason is that within the reviewed and included studies, there was heterogeneity of definitions used for IC. In particular, *Candida* colonization was often reported as IC. The latter reflects the uncertainty and evolution of our understanding of IC over recent decades. For example, whereas the 2004 IDSA Invasive Candidiasis Treatment Guidelines (71) recommended treatment of *Candida* isolated from the respiratory tract, more contemporary guidelines acknowledge this as a state of colonization rather than an etiology of infection (72). Although *Candida* colonization is a prerequisite for subsequent invasion, the two states are not synonymous, and progression from the former to the latter depends on various factors, including nutrient availability, the host microbiota, and immune defenses (73). Because of inconsistent or absent reporting in the included studies, the panel was unable to assess the potential harms of antifungal use, including drug side effects, the impact on the mycobiome, and risk of infection with resistant fungi. This uncertainty contributed to the issuance of a negative rather than neutral recommendation.

Implementation Considerations

A key consideration when determining whether prophylactic and/or empiric antifungals reduce mortality in the ICU is whether IC is driving mortality. Because of reporting biases, the true incidence of IC in the ICU is unclear; however, candidemia has been well studied. Mortality in an individual ICU patient with candidemia is reported to be as high as 10–47%; however, when factors such as age, disease severity, the presence of organ failure, and immunosuppression are accounted for, the attributable mortality is likely much lower (43, 74, 75). Although candidemia is more common in critically ill patients than in most other populations, the reported incidence is still relatively low: from 3.6 to 16.5 per 1,000 admissions (45–50). In a large study of 60,778 ICU admissions in nonneutropenic patients in the United Kingdom over a 2-year period, the incidence of IFI, consisting primarily of IC, was just 0.6% (55). When it did occur, IC was associated with a high rate of mortality (55). Simple risk models for predicting the development of IC were developed and incorporated into economic models to advise thresholds for initiating antifungal prophylaxis; however, because of the small number of outcomes, the certainty of these models was low. Thus, although it is relatively easy to identify ICU patients at risk of IC, the utility of prophylaxis remains unclear. To further complicate these decisions, ICU practices and the ICU environment are constantly evolving. Factors such as improved vascular access catheter management, more judicious use of total parenteral nutrition with a preference for enteral feeding, a greater focus on more appropriate use of antibiotics, and better surgical techniques may contribute to a decreased incidence of IC (52); thus, data

Table 5. Risk-of-Bias Assessment for Studies Included in Question 2

Study	Randomization	Deviations from Intended Interventions	Missing Outcome Data	Measurement of the Outcome	Selection of the Reported Result	Funding
Ables *et al.*, 2000 (65)	Some concerns	Low risk	Low risk	Low risk	Low risk	Some concerns (private funding, sponsor's role is not clear)
Albert *et al.*, 2014 (67)	Low risk	Low risk	Some concerns	Low risk	Low risk	Some concerns (private funding, sponsor's role is not clear)
Garbino *et al.*, 2002 (66)	Some concerns	Low risk	Some concerns	Low risk	Low risk	Some concerns (private funding, sponsor's role is not clear)
Ostrosky-Zeichner *et al.*, 2014 (59)	Some concerns	Low risk	Low risk	Low risk	Low risk	High risk (private funding, sponsor reviewed the results and contributed to the manuscript)
Pelz *et al.*, 2001 (57)	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Knitsch *et al.*, 2015 (60)	Some concerns	Some concerns	Some concerns	Low risk	Low risk	Some concerns (private funding, sponsor conducted all statistical analysis)
Schuster *et al.*, 2008 (58)	Low risk	Low risk	Low risk	Low risk	Low risk	Some concerns (private funding, sponsor aided in the analysis but not in the interpretation of the data)
Timsit *et al.*, 2016 (61)	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk

produced 20 years ago may not apply to a modern ICU setting.

The examined literature does not support the use of empiric antifungal therapy in critically ill, nonneutropenic, nontransplant patients; however, in the subset of these patients who are proven to have IC, early initiation of antifungal therapy is associated with reduced mortality (76, 77). Early diagnosis of IC to allow prompt initiation of targeted antifungal therapy is challenging because blood culture, the standard-of-care diagnostic test, has a sensitivity of less than 50%, with results delayed for up to 3–4 days (44, 78). Non–culture-based diagnostics, including serum BDG and the T2Candida assay, were included in the most recent European Organisation for Research and Treatment of Cancer and Mycoses Study Group Education and Research Consortium consensus guidelines as criteria for "probable" IC (69) and may overcome the limitations of blood cultures. The use of serum BDG is limited by low specificity, which improves with serially positive tests and with results that exceed the positivity threshold (>80 pg/ml) (79). The T2Candida assay has a high negative predictive value for the detection of common *Candida* spp. in whole blood, and although the positive predictive value varies, depending on the IC prevalence in the population, the time to diagnosis is shortened when compared with blood cultures with retained sensitivity in the setting of antifungal therapy (79, 80). Interpretation algorithms for these diagnostic assays have been proposed, and further studies are required to understand their place in guiding initiation of antifungal therapy (81).

In the ICU, the prescription of antifungals to prevent or treat IC requires consideration of risks associated with widespread antifungal administration. For the individual patient, antifungals may be associated with adverse effects and drug interactions. The panel was unable to assess adverse effects in this guideline iteration because of inconsistent reporting, but, reassuringly, echinocandins and fluconazole are generally better tolerated than mold-active azoles and AmB formulations (82). Increasingly, the influence of the gut mycobiome on maintenance of various aspects of human health and disease, particularly the gut bacterial microbiome assembly, is being appreciated and is likely perturbed by antifungal use (83).

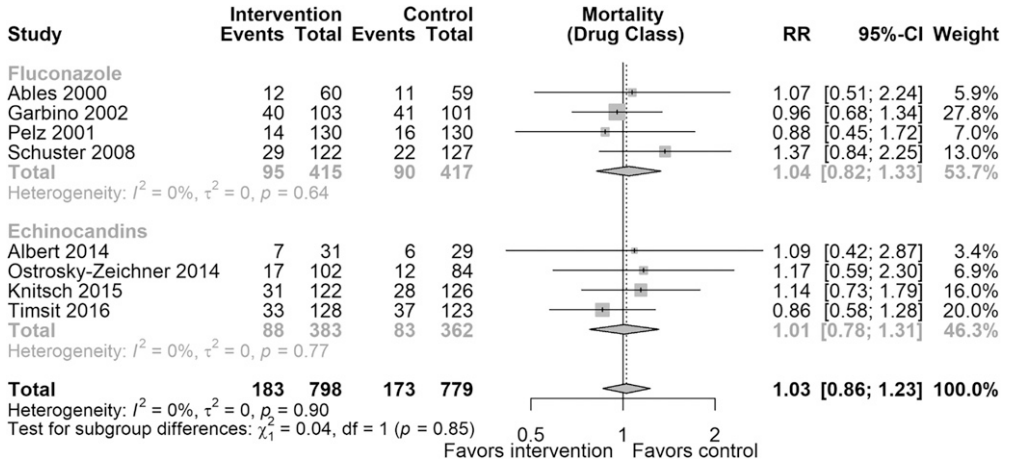

Figure 6. Meta-analysis of mortality in question 2 according to drug class. CI = confidence interval; RR = relative risk.

The sequelae of prophylactic and empiric antifungals on the gut mycobiome has not been studied. Beyond the individual, the epidemiology of *Candida* in ICUs is changing. Both the patient and the environment can be reservoirs of resistance (52), but it is not yet clear whether antifungal use is, at least in part, driving this change. In the United States, two-thirds of *Candida* isolates are non-*albicans*, with increasing incidence of *Candida glabrata* (84) with increased minimum inhibitory concentrations to a triazole (70, 85). The global threat of *Candida auris*, which is often resistant to all available antifungals, persists on environmental surfaces and is resilient to decontamination (86) and requires close surveillance. Close surveillance of antifungal use, species causing IC, and fungal epidemiology within ICUs is required for early detection of associations and trends.

Limitations of the Current Literature

One of the main limitations of this analysis is the heterogeneity among the included studies. As described, a range of antifungal durations and doses was used, particularly for fluconazole. Some studies used additional therapies to reduce infection, such as SDD (66). The eligibility criteria for antifungal prophylaxis varied from MV patients receiving SDD (66), to ICU patients with ventilator-associated pneumonia (67), to critically ill surgical patients (57), to critically ill trauma patients (65). Similarly, each of the three studies of empiric antifungal therapy (58, 60, 61) used different combinations of risk factors for inclusion. Despite the differences in the design of the studies, the outcomes were similar. Further studies of antifungal prophylaxis focused on specific subgroups that are at significantly increased risk of IC, such as those with severe pancreatitis (87), could help to identify populations that may benefit from prophylaxis. We excluded neutropenic and solid organ transplant recipients because, in certain subsets within these groups, the utility of anti-*Candida* prophylaxis has been long established (88, 89).

The 2016 IDSA guidelines, the 2019 European Society of Intensive Care Medicine/ESCMID guidelines, and the 2021 Australian guidelines recommend empiric therapy for suspected IC in critically ill patients with risk factors for IC (71, 90, 91). The former but not the latter two guidelines recommend prophylactic antifungals for high-risk adult ICU patients, although this is a weak recommendation based on low- to moderate-quality evidence (71).

Areas of Research Need

Given the clinical equipoise that persists regarding the use of prophylactic and empiric antifungals in ICU patients, further study is warranted. With respect to prophylaxis, the specific contribution of IC to ICU mortality requires further delineation. Then the question remains: In ICU patients who are at increased risk of IC, does receipt of a systemic antifungal prevent IC, and, if so, which antifungal drug or strategy is most beneficial, and what is the number needed to treat to prevent one episode of IC? With regard to preemptive therapy, current implementation of a true preemptive antifungal strategy to prevent IC is limited by the availability of a well-studied, sensitive biomarker that can be used to detect preclinical disease; however, should such a test become available, this strategy should be revisited. There are several new drugs in the antifungal pipeline (92) that have not been assessed in this context and, given the novel mechanism of action of some, warrant consideration. Future studies must take into account risks to the individual, such as adverse effects of the antifungal, the impact on the host mycobiome, and the progression to infection with resistant fungi, as well as implications for local fungal ecology.

Recommendations

Question 1. In patients with proven or probable IPA, we suggest either initial monotherapy with a mold-active triazole or initial combination therapy with a mold-active triazole plus an echinocandin (conditional recommendation, low-quality evidence).

Implementation Remark. The available evidence and contextual considerations were insufficient to favor one approach over the other. This recommendation derived exclusively from data on patients with HM and/or a history of HSCT. Applicability of this recommendation to patients without HM or a history of HSCT is unclear. Combination therapy is likely more

appropriate in the setting of critical illness or concern for triazole resistance. Patients diagnosed with IPA by a positive GM assay result in serum or BAL fluid may be particularly suitable candidates for the dual regimen in any setting.

Question 2. In critically ill patients without neutropenia or a history of transplant, we suggest against routine administration of prophylactic or empiric antifungal agents targeting *Candida* species (conditional recommendation based on low-quality evidence).

Conclusions

Our multidisciplinary review of the available data provided the following recommendations. A conditional recommendation was made for patients with proven or probable IPA to receive either initial combination therapy with a mold-active triazole plus an echinocandin or initial mold-active triazole monotherapy based on low-quality evidence. Furthermore, a conditional weak recommendation was made against routine administration of prophylactic or empiric antifungal agents targeting *Candida* species for critically ill patients without neutropenia or a history of transplant based on low-quality evidence. ■

This official clinical practice guideline was prepared by an *ad hoc* subcommittee of the ATS Assembly on Pulmonary Infections and Tuberculosis.

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References

1. Webb BJ, Ferraro JP, Rea S, Kaufusi S, Goodman BE, Spalding J. Epidemiology and clinical features of invasive fungal infection in a US health care network. *Open Forum Infect Dis* 2018;5:ofy187.
2. Chu S, McCormick TS, Lazarus HM, Leal LO, Ghannoum MA. Invasive fungal disease and the immunocompromised host including allogeneic hematopoietic cell transplant recipients: improved understanding and new strategic approach with sargramostim. *Clin Immunol* 2021;228: 108731.
3. Hoving JC, Brown GD, Gomez BL, Govender NP, Limper AH, May RC, *et al.*; Working Group from the Workshop on AIDS-related Mycoses. AIDS-related mycoses: updated progress and future priorities. *Trends Microbiol* 2020;28:425–428.
4. Rayens E, Norris KA. Prevalence and healthcare burden of fungal infections in the United States, 2018. *Open Forum Infect Dis* 2022;9: ofab593.
5. Brown GD, Denning DW, Gow NA, Levitz SM, Netea MG, White TC. Hidden killers: human fungal infections. *Sci Transl Med* 2012;4: 165rv13.
6. Limper AH, Knox KS, Sarosi GA, Ampel NM, Bennett JE, Catanzaro A, *et al.*; American Thoracic Society Fungal Working Group. An official American Thoracic Society statement: treatment of fungal infections in adult pulmonary and critical care patients. *Am J Respir Crit Care Med* 2011;183:96–128.
7. Schunemann HJ, Oxman AD, Brozek J, Glasziou P, Jaeschke R, Vist GE, *et al.*; GRADE Working Group. Grading quality of evidence and strength of recommendations for diagnostic tests and strategies. *BMJ* 2008;336: 1106–1110.
8. Pagano L, Caira M, Candoni A, Offidani M, Fianchi L, Martino B, *et al.* The epidemiology of fungal infections in patients with hematologic malignancies: the SEIFEM-2004 study. *Haematologica* 2006;91: 1068–1075.
9. Pagano L, Caira M, Picardi M, Candoni A, Melillo L, Fianchi L, *et al.* Invasive aspergillosis in patients with acute leukemia: update on morbidity and mortality—SEIFEM-C Report. *Clin Infect Dis* 2007;44: 1524–1525.
10. Herbrecht R, Denning DW, Patterson TF, Bennett JE, Greene RE, Oestmann JW, *et al.*; Invasive Fungal Infections Group of the European Organisation for Research and Treatment of Cancer and the Global Aspergillus Study Group. Voriconazole versus amphotericin B for primary therapy of invasive aspergillosis. *N Engl J Med* 2002;347: 408–415.
11. Cadena J, Thompson GR, Patterson TF. Aspergillosis: epidemiology, diagnosis, and treatment. *Infect Dis Clin North Am* 2021;35:415–434.
12. Perea S, Gonzalez G, Fothergill AW, Kirkpatrick WR, Rinaldi MG, Patterson TF. In vitro interaction of caspofungin acetate with voriconazole against clinical isolates of *Aspergillus* spp. *Antimicrob Agents Chemother* 2002;46:3039–3041.
13. Petraitis V, Petraitiene R, McCarthy MW, Kovanda LL, Zaw MH, Hussain K, *et al.* Combination therapy with isavuconazole and micafungin for treatment of experimental invasive pulmonary aspergillosis. *Antimicrob Agents Chemother* 2017;61:e00305-17.
14. van de Sande WW, Mathot RA, ten Kate MT, van Vianen W, Tavakol M, Rijnders BJ, *et al.* Combination therapy of advanced invasive pulmonary aspergillosis in transiently neutropenic rats using human pharmacokinetic equivalent doses of voriconazole and anidulafungin. *Antimicrob Agents Chemother* 2009;53:2005–2013.

15. Marr KA, Boeckh M, Carter RA, Kim HW, Corey L. Combination antifungal therapy for invasive aspergillosis. *Clin Infect Dis* 2004;39: 797–802.
16. Pagano L, Caira M, Candoni A, Offidani M, Martino B, Specchia G, *et al.* Invasive aspergillosis in patients with acute myeloid leukemia: a SEIFEM-2008 registry study. *Haematologica* 2010;95:644–650.
17. Raad II, Zakhem AE, Helou GE, Jiang Y, Kontoyiannis DP, Hachem R. Clinical experience of the use of voriconazole, caspofungin or the combination in primary and salvage therapy of invasive aspergillosis in haematological malignancies. *Int J Antimicrob Agents* 2015;45: 283–288.
18. Marr KA, Schlamm HT, Herbrecht R, Rottinghaus ST, Bow EJ, Cornely OA, *et al.* Combination antifungal therapy for invasive aspergillosis: a randomized trial. *Ann Intern Med* 2015;162:81–89.
19. Upton A, Kirby KA, Carpenter P, Boeckh M, Marr KA. Invasive aspergillosis following hematopoietic cell transplantation: outcomes and prognostic factors associated with mortality. *Clin Infect Dis* 2007;44: 531–540.
20. Garbati MA, Alasmari FA, Al-Tannir MA, Tleyjeh IM. The role of combination antifungal therapy in the treatment of invasive aspergillosis: a systematic review. *Int J Infect Dis* 2012;16:e76–e81.
21. Panackal AA, Parisini E, Proschan M. Salvage combination antifungal therapy for acute invasive aspergillosis may improve outcomes: a systematic review and meta-analysis. *Int J Infect Dis* 2014;28:80–94.
22. Munoz L, Ruthazer R, Boucher H, Loudon S, Skarf L, Hadley S. Combination antifungals for primary treatment of invasive aspergillosis (IA): do they work? 44th Interscience Conference on Antimicrobial Agents and Chemotherapy. 2004, Washington, DC. Abstract M-1024.
23. Waala K Jr, Xie H, Fredericks DN, Pottinger PS. Combination antifungal therapy as primary therapy for invasive aspergillosis. Philadelphia, PA: IDSA; 2009.
24. De Pauw B, Walsh TJ, Donnelly JP, Stevens DA, Edwards JE, Calandra T, *et al.*; European Organization for Research and Treatment of Cancer/Invasive Fungal Infections Cooperative Group, National Institute of Allergy and Infectious Diseases Mycoses Study Group (EORTC/MSG) Consensus Group. Revised definitions of invasive fungal disease from the European Organization for Research and Treatment of Cancer/Invasive Fungal Infections Cooperative Group and the National Institute of Allergy and Infectious Diseases Mycoses Study Group (EORTC/MSG) Consensus Group. *Clin Infect Dis* 2008;46: 1813–1821.
25. Gregson L, Goodwin J, Johnson A, McEntee L, Moore CB, Richardson M, *et al.* In vitro susceptibility of *Aspergillus fumigatus* to isavuconazole: correlation with itraconazole, voriconazole, and posaconazole. *Antimicrob Agents Chemother* 2013;57:5778–5780.
26. Ashbee HR, Barnes RA, Johnson EM, Richardson MD, Gorton R, Hope WW. Therapeutic drug monitoring (TDM) of antifungal agents: guidelines from the British Society for Medical Mycology. *J Antimicrob Chemother* 2014;69:1162–1176.
27. Magira EE, Jiang Y, Economides M, Tarrand J, Kontoyiannis DP. Mixed mold pulmonary infections in haematological cancer patients in a tertiary care cancer centre. *Mycoses* 2018;61:861–867.
28. Felton T, Troke PF, Hope WW. Tissue penetration of antifungal agents. *Clin Microbiol Rev* 2014;27:68–88.
29. Petraitis V, Petraitiene R, Sarafandi AA, Kelaher AM, Lyman CA, Casler HE, *et al.* Combination therapy in treatment of experimental pulmonary aspergillosis: synergistic interaction between an antifungal triazole and an echinocandin. *J Infect Dis* 2003;187:1834–1843.
30. Jeans AR, Howard SJ, Al-Nakeeb Z, Goodwin J, Gregson L, Warn PA, *et al.* Combination of voriconazole and anidulafungin for treatment of triazole-resistant aspergillus fumigatus in an in vitro model of invasive pulmonary aspergillosis. *Antimicrob Agents Chemother* 2012;56: 5180–5185.
31. Chao CM, Lai CC, Chan KS, Yang CC, Chen CM, Ho CH, *et al.* Characteristics and outcomes for pulmonary aspergillosis in critically ill patients without influenza: a 3-year retrospective study. *J Infect Public Health* 2023;16:2001–2009.
32. van der Linden JW, Arendrup MC, Warris A, Lagrou K, Pelloux H, Hauser PM, *et al.* Prospective multicenter international surveillance of azole resistance in *Aspergillus fumigatus*. *Emerg Infect Dis* 2015;21: 1041–1044.
33. Berkow EL, Nunnally NS, Bandea A, Kuykendall R, Beer K, Lockhart SR. Detection of TR(34)/L98H CYP51A mutation through passive surveillance for azole-resistant *Aspergillus fumigatus* in the United States from 2015 to 2017. *Antimicrob Agents Chemother* 2018;62: e02240-17.
34. Bosetti D, Neofytos D. Invasive aspergillosis and the impact of azole-resistance. *Curr Fungal Infect Rep* 2023;17:77–86.
35. Verweij PE, Ananda-Rajah M, Andes D, Arendrup MC, Bruggemann RJ, Chowdhary A, *et al.* International expert opinion on the management of infection caused by azole-resistant *Aspergillus fumigatus*. *Drug Resist Updat* 2015;21-22:30–40.
36. Ullmann AJ, Aguado JM, Arikan-Akdagli S, Denning DW, Groll AH, Lagrou K, *et al.* Diagnosis and management of *Aspergillus* diseases: executive summary of the 2017 ESCMID-ECMM-ERS guideline. *Clin Microbiol Infect* 2018;24 Suppl 1:e1–e38.
37. Ostrosky-Zeichner L, Nguyen MH, Bubalo J, Alexander BD, Miceli MH, Pappas PG, *et al.* Multicenter registry of patients receiving systemic mold-active triazoles for the management of invasive fungal infections. *Infect Dis Ther* 2022;11:1609–1629.
38. Boyer J, Feys S, Zsifkovits I, Hoenigl M, Egger M. Treatment of invasive aspergillosis: how it's going, where it's heading. *Mycopathologia* 2023; 188:667–681.
39. Gebremariam T, Gu Y, Alkhazraji S, Youssef E, Shaw KJ, Ibrahim AS. The combination treatment of fosmanogepix and liposomal amphotericin B is superior to monotherapy in treating experimental invasive mold infections. *Antimicrob Agents Chemother* 2022;66:e0038022.
40. Petraitis V, Petraitiene R, Katragkou A, Maung BBW, Naing E, Kavaliauskas P, *et al.* Combination therapy with ibrexafungerp (formerly SCY-078), a first-in-class triterpenoid inhibitor of (1−>3)-β-D-glucan synthesis, and isavuconazole for treatment of experimental invasive pulmonary aspergillosis. *Antimicrob Agents Chemother* 2020;64:e02429-19.
41. Seyedmousavi S, Chang YC, Law D, Birch M, Rex JH, Kwon-Chung KJ. Efficacy of olorofim (F901318) against *Aspergillus fumigatus*, *A. nidulans*, and *A. tanneri* in murine models of profound neutropenia and chronic granulomatous disease. *Antimicrob Agents Chemother* 2019; 63:e00129-19.
42. Gow NA, van de Veerdonk FL, Brown AJ, Netea MG. *Candida albicans* morphogenesis and host defence: discriminating invasion from colonization. *Nat Rev Microbiol* 2011;10:112–122.
43. Kullberg BJ, Arendrup MC. Invasive candidiasis. *N Engl J Med* 2015;373: 1445–1456.
44. Clancy CJ, Nguyen MH. Finding the "missing 50%" of invasive candidiasis: how nonculture diagnostics will improve understanding of disease spectrum and transform patient care. *Clin Infect Dis* 2013;56: 1284–1292.
45. Bassetti M, Giacobbe DR, Vena A, Trucchi C, Ansaldi F, Antonelli M, *et al.* Incidence and outcome of invasive candidiasis in intensive care units (ICUs) in Europe: results of the EUCANDICU project. *Crit Care* 2019;23:219.
46. Kett DH, Azoulay E, Echeverria PM, Vincent JL; Extended Prevalence of Infection in ICU Study (EPIC II) Group of Investigators. Candida bloodstream infections in intensive care units: analysis of the extended prevalence of infection in intensive care unit study. *Crit Care Med* 2011;39:665–670.
47. Koehler P, Stecher M, Cornely OA, Koehler D, Vehreschild M, Bohlius J, *et al.* Morbidity and mortality of candidaemia in Europe: an epidemiologic meta-analysis. *Clin Microbiol Infect* 2019;25: 1200–1212.
48. Tortorano AM, Dho G, Prigitano A, Breda G, Grancini A, Emmi V, *et al.*; ECMM-FIMUA Study Group. Invasive fungal infections in the intensive care unit: a multicentre, prospective, observational study in Italy (2006-2008). *Mycoses* 2012;55:73–79.
49. Montagna MT, Caggiano G, Lovero G, De Giglio O, Coretti C, Cuna T, *et al.* Epidemiology of invasive fungal infections in the intensive care unit: results of a multicenter Italian survey (AURORA Project). *Infection* 2013;41:645–653.
50. Baldesi O, Bailly S, Ruckly S, Lepape A, L'Heriteau F, Aupee M, *et al.*; REA-RAISIN network. ICU-acquired candidaemia in France: epidemiology and temporal trends, 2004-2013—a study from the REA-RAISIN network. *J Infect* 2017;75:59–67.

51. Rada G, Verdugo-Paiva F, Avila C, Morel-Marambio M, Bravo-Jeria R, Pesce F, *et al.*; COVID-19 L·OVE Working Group. Evidence synthesis relevant to COVID-19: a protocol for multiple systematic reviews and overviews of systematic reviews. *Medwave* 2020;20: e7868.
52. Logan C, Martin-Loeches I, Bicanic T. Invasive candidiasis in critical care: challenges and future directions. *Intensive Care Med* 2020;46: 2001–2014.
53. Lau AF, Kabir M, Chen SC, Playford EG, Marriott DJ, Jones M, *et al.* Candida colonization as a risk marker for invasive candidiasis in mixed medical-surgical intensive care units: development and evaluation of a simple, standard protocol. *J Clin Microbiol* 2015;53: 1324–1330.
54. Alenazy H, Alghamdi A, Pinto R, Daneman N. Candida colonization as a predictor of invasive candidiasis in non-neutropenic ICU patients with sepsis: a systematic review and meta-analysis. *Int J Infect Dis* 2021; 102:357–362.
55. Harrison D, Muskett H, Harvey S, Grieve R, Shahin J, Patel K, *et al.* Development and validation of a risk model for identification of non-neutropenic, critically ill adult patients at high risk of invasive Candida infection: the Fungal Infection Risk Evaluation (FIRE) Study. *Health Technol Assess* 2013;17:1–156.
56. Cornely OA, Bassetti M, Calandra T, Garbino J, Kullberg BJ, Lortholary O, *et al.*; ESCMID Fungal Infection Study Group. ESCMID* guideline for the diagnosis and management of Candida diseases 2012: non-neutropenic adult patients. *Clin Microbiol Infect* 2012;18 Suppl 7:19–37.
57. Pelz RK, Hendrix CW, Swoboda SM, Diener-West M, Merz WG, Hammond J, *et al.* Double-blind placebo-controlled trial of fluconazole to prevent candidal infections in critically ill surgical patients. *Ann Surg* 2001;233:542–548.
58. Schuster MG, Edwards JE Jr, Sobel JD, Darouiche RO, Karchmer AW, Hadley S, *et al.* Empirical fluconazole versus placebo for intensive care unit patients: a randomized trial. *Ann Intern Med* 2008;149:83–90.
59. Ostrosky-Zeichner L, Shoham S, Vazquez J, Reboli A, Betts R, Barron MA, *et al.* MSG-01: a randomized, double-blind, placebo-controlled trial of caspofungin prophylaxis followed by preemptive therapy for invasive candidiasis in high-risk adults in the critical care setting. *Clin Infect Dis* 2014;58:1219–1226.
60. Knitsch W, Vincent JL, Utzolino S, Francois B, Dinya T, Dimopoulos G, *et al.* A randomized, placebo-controlled trial of preemptive antifungal therapy for the prevention of invasive candidiasis following gastrointestinal surgery for intra-abdominal infections. *Clin Infect Dis* 2015;61:1671–1678.
61. Timsit JF, Azoulay E, Schwebel C, Charles PE, Cornet M, Souweine B, *et al.*; EMPIRICUS Trial Group. Empirical micafungin treatment and survival without invasive fungal infection in adults with ICU-acquired sepsis, Candida colonization, and multiple organ failure: the EMPIRICUS randomized clinical trial. *JAMA* 2016;316: 1555–1564.
62. Wang Y, Xie J, Xing Y, Chen L, Li Y, Meng T, *et al.* Choosing optimal antifungal agents to prevent fungal infections in nonneutropenic critically ill patients: trial sequential analysis, network meta-analysis, and pharmacoeconomic analysis. *Antimicrob Agents Chemother* 2017; 61:e00620-17.
63. Cortegiani A, Russotto V, Maggiore A, Attanasio M, Naro AR, Raineri SM, *et al.* Antifungal agents for preventing fungal infections in non-neutropenic critically ill patients. *Cochrane Database Syst Rev* 2016; 2016:CD004920.
64. Dupont H, Mahjoub Y, Chouaki T, Lorne E, Zogheib E. Antifungal prevention of systemic candidiasis in immunocompetent ICU adults: systematic review and meta-analysis of clinical trials. *Crit Care Med* 2017;45:1937–1945.
65. Ables AZ, Blumer NA, Valainis GT, Godenick MT, Kajdasz DK, Palesch YY. Fluconazole prophylaxis of severe Candida infection in trauma and postsurgical patients: a prospective, double-blind, randomized, placebo-controlled trial. *Infect Dis Clin Pract* 2000;9:169–175.
66. Garbino J, Lew DP, Romand JA, Hugonnet S, Auckenthaler R, Pittet D. Prevention of severe Candida infections in nonneutropenic, high-risk, critically ill patients: a randomized, double-blind, placebo-controlled trial in patients treated by selective digestive decontamination. *Intensive Care Med* 2002;28:1708–1717.
67. Albert M, Williamson D, Muscedere J, Lauzier F, Rotstein C, Kanji S, *et al.* Candida in the respiratory tract secretions of critically ill patients and the impact of antifungal treatment: a randomized placebo controlled pilot trial (CANTREAT study). *Intensive Care Med* 2014;40: 1313–1322.
68. Astellas Pharma. Comparative study of micafungin (FK 463) versus placebo as prophylactic antifungal therapy in the ICU. NCT00048750. 2003 [accessed 2024 Nov 9]. Available from: Https://clinicaltrials.gov/show/nct00048750.
69. Donnelly JP, Chen SC, Kauffman CA, Steinbach WJ, Baddley JW, Verweij PE, *et al.* Revision and update of the consensus definitions of invasive fungal disease from the European Organization for Research and Treatment of Cancer and the Mycoses Study Group Education and Research Consortium. *Clin Infect Dis* 2020;71:1367–1376.
70. Pfaller MA, Castanheira M, Lockhart SR, Ahlquist AM, Messer SA, Jones RN. Frequency of decreased susceptibility and resistance to echinocandins among fluconazole-resistant bloodstream isolates of *Candida glabrata*. *J Clin Microbiol* 2012;50:1199–1203.
71. Pappas PG, Rex JH, Sobel JD, Filler SG, Dismukes WE, Walsh TJ, *et al.*; Infectious Diseases Society of America. Guidelines for treatment of candidiasis. *Clin Infect Dis* 2004;38:161–189.
72. Pappas PG, Kauffman CA, Andes DR, Clancy CJ, Marr KA, Ostrosky-Zeichner L, *et al.* Clinical Practice guideline for the management of candidiasis: 2016 update by the Infectious Diseases Society of America. *Clin Infect Dis* 2016;62:e1–e50.
73. Alves R, Barata-Antunes C, Casal M, Brown AJP, Van Dijck P, Paiva S. Adapting to survive: how Candida overcomes host-imposed constraints during human colonization. *PLoS Pathog* 2020;16: e1008478.
74. Pappas PG, Lionakis MS, Arendrup MC, Ostrosky-Zeichner L, Kullberg BJ. Invasive candidiasis. *Nat Rev Dis Primers* 2018;4:18026.
75. Strollo S, Lionakis MS, Adjemian J, Steiner CA, Prevots DR. Epidemiology of hospitalizations associated with invasive candidiasis, United States, 2002-2012. *Emerg Infect Dis* 2016;23:7–13.
76. Morrell M, Fraser VJ, Kollef MH. Delaying the empiric treatment of candida bloodstream infection until positive blood culture results are obtained: a potential risk factor for hospital mortality. *Antimicrob Agents Chemother* 2005;49:3640–3645.
77. Garey KW, Rege M, Pai MP, Mingo DE, Suda KJ, Turpin RS, *et al.* Time to initiation of fluconazole therapy impacts mortality in patients with candidemia: a multi-institutional study. *Clin Infect Dis* 2006;43: 25–31.
78. Clancy CJ, Nguyen MH. The end of an era in defining the optimal treatment of invasive candidiasis. *Clin Infect Dis* 2012;54:1123–1125.
79. Hanson KE, Pfeiffer CD, Lease ED, Balch AH, Zaas AK, Perfect JR, *et al.* β-D-Glucan surveillance with preemptive anidulafungin for invasive candidiasis in intensive care unit patients: a randomized pilot study. *PLoS One* 2012;7:e42282.
80. Clancy CJ, Nguyen MH. T2 magnetic resonance for the diagnosis of bloodstream infections: charting a path forward. *J Antimicrob Chemother* 2018;73:iv2–iv5.
81. Clancy CJ, Shields RK, Nguyen MH. Invasive candidiasis in various patient populations: incorporating non-culture diagnostic tests into rational management strategies. *J Fungi (Basel)* 2016;2:10.
82. Yang YL, Xiang ZJ, Yang JH, Wang WJ, Xu ZC, Xiang RL. Adverse effects associated with currently commonly used antifungal agents: a network meta-analysis and systematic review. *Front Pharmacol* 2021; 12:697330.
83. Zhang F, Aschenbrenner D, Yoo JY, Zuo T. The gut mycobiome in health, disease, and clinical applications in association with the gut bacterial microbiome assembly. *Lancet Microbe* 2022;3:e969–e983.
84. Lockhart SR, Iqbal N, Cleveland AA, Farley MM, Harrison LH, Bolden CB, *et al.* Species identification and antifungal susceptibility testing of Candida bloodstream isolates from population-based surveillance studies in two US cities from 2008 to 2011. *J Clin Microbiol* 2012;50: 3435–3442.
85. Alexander BD, Johnson MD, Pfeiffer CD, Jimenez-Ortigosa C, Catania J, Booker R, *et al.* Increasing echinocandin resistance in *Candida glabrata*: clinical failure correlates with presence of FKS mutations and elevated minimum inhibitory concentrations. *Clin Infect Dis* 2013;56: 1724–1732.

86. Cortegiani A, Misseri G, Giarratano A, Bassetti M, Eyre D. The global challenge of *Candida auris* in the intensive care unit. *Crit Care* 2019; 23:150.
87. Trikudanathan G, Navaneethan U, Vege SS. Intra-abdominal fungal infections complicating acute pancreatitis: a review. *Am J Gastroenterol* 2011;106:1188–1192.
88. Winston DJ, Pakrasi A, Busuttil RW. Prophylactic fluconazole in liver transplant recipients. A randomized, double-blind, placebo-controlled trial. *Ann Intern Med* 1999;131:729–737.
89. Goodman JL, Winston DJ, Greenfield RA, Chandrasekar PH, Fox B, Kaizer H, *et al.* A controlled trial of fluconazole to prevent fungal infections in patients undergoing bone marrow transplantation. *N Engl J Med* 1992;326:845–851.
90. Keighley C, Cooley L, Morris AJ, Ritchie D, Clark JE, Boan P, *et al.*; Australasian Antifungal Guidelines Steering Committee. Consensus guidelines for the diagnosis and management of invasive candidiasis in haematology, oncology and intensive care settings, 2021. *Intern Med J* 2021;51 Suppl 7: 89–117.
91. Martin-Loeches I, Antonelli M, Cuenca-Estrella M, Dimopoulos G, Einav S, De Waele JJ, *et al.* ESICM/ESCMID task force on practical management of invasive candidiasis in critically ill patients. *Intensive Care Med* 2019;45:789–805.
92. Rauseo AM, Coler-Reilly A, Larson L, Spec A. Hope on the horizon: novel fungal treatments in development. *Open Forum Infect Dis* 2020;7: ofaa016.