mycoses
Diagnosis, Therapy and Prophylaxis of Fungal Diseases

Original article

Treatment and outcomes of invasive fusariosis: review of 65 cases from the PATH Alliance® registry

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Summary

Invasive *Fusarium* infections occur in immunosuppressed patients, especially those with haematological malignancies. We conducted a descriptive analysis of data from patients with invasive fusariosis identified in the Prospective Antifungal Therapy Alliance registry, which collected data on invasive fungal infections in the United States and Canada from 2004 to 2008. In this series of 65 patients with proven (83.1%) and probable (16.9%) invasive fusariosis, the most common underlying condition was haematological malignancy, in which neutropenia and corticosteroid usage frequently occurred. Seven patients with invasive *Fusarium* infections had cross-reactive galactomannan assay results. The survival rate for all patients at 90 days was 44%, which was an improvement compared with historical data. Disseminated disease occurred frequently (35.4%), and patients with and without disseminated disease had survival rates of 33% and 50%, respectively. Posaconazole and voriconazole were the most frequently employed therapies and may be linked to the improved survival rate observed in this patient series. In summary, patients with invasive *Fusarium* infections continue to have high fatality rates, especially those with disseminated disease. *Fusarium* infections should be strongly considered in the absence of *Aspergillus* isolation in patients at high risk of mould infections with positive galactomannan assay test results.

Key words: *Fusarium*, epidemiology, invasive mould infection, PATH Alliance®.

Introduction

Among immunocompromised patients, *Fusarium* spp. are second to *Aspergillus* spp. as the most common cause of invasive mould infections.[1] *Fusarium* infections are associated with a high mortality rate, especially in patients who have haematological malignancies or have received an allogeneic haematopoietic cell transplant and have severe and persistent neutropenia or graft-versus-host disease. The airway is the primary portal of entry for fungal conidia, leading to lung and sinus disease in immunocompromised patients. Entry via the skin at sites of trauma or breakdown may yield localised infection or disseminated disease, depending on the degree of immune dysfunction. The *Fusarium* spp. that most frequently cause human infections include *F. solani*, *F. oxysporum* and *F. moniliforme*.[1–7]

Therapy of infections caused by *Fusarium* spp. is challenging due to a paucity of clinical trial data and to the relative resistance of these organisms to available antifungal agents. Antifungal therapy of fusariosis may include amphotericin B, liposomal amphotericin B, itraconazole, voriconazole and posaconazole, either

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Submitted for publication 7 March 2014
Revised 22 May 2014
Accepted for publication 28 May 2014

doi:10.1111/myc.12212

alone or in combination. *Fusarium solani* appears to be the most resistant, but other species also are resistant to azoles or have high amphotericin B minimum inhibitory concentrations. Voriconazole and posaconazole are more active against most *Fusarium* species than other, older azole agents.[1,3,5–9]

Most studies of infections due to *Fusarium* species are from single centres, and most of those are cancer centres.[10–13] However, Nucci *et al.* [9] recently reported on 233 cases of invasive fusariosis from centres in 11 different countries. In addition, Muhammed *et al.* [14] analysed 26 cases of proven and probable fusariosis treated at Massachusetts General Hospital, and reviewed an additional 97 cases from the medical literature. The Prospective Antifungal Therapy (PATH) Alliance prospectively collected data on 6845 evaluable patients with 7526 proven or probable invasive fungal infections (IFIs) from 25 tertiary care centres in the United States and Canada between 2004 and 2008.[15] Using the PATH Alliance® registry, we sought to describe the epidemiology, diagnosis, treatment and outcomes of invasive fusariosis in 65 identified patients.

Methods

The PATH Alliance® registry is a surveillance network that has collected data prospectively from patients with IFIs. Participating centres included those caring for haematopoietic cell transplant recipients, solid organ transplant recipients, haematology–oncology patients, and general medical and surgical patients. Data collection methods have been described in detail previously.[16] Briefly, an electronic case report form was used to collect prospective patient data for 12 weeks after diagnosis, or until patients had died or were lost to follow-up. Information collected included patient demographic characteristics at baseline, underlying diseases and concomitant conditions, transplant type, corticosteroid usage and/or other immunosuppressive therapies, absolute neutrophil count, infecting species, site of infection and antifungal and adjunctive therapies. Enrolment of patients was approved by the individual institutional review boards at each of the participating centres.

Cultures for fungi and specimens for histopathological examination were processed and identified employing methods routinely used at each institution. Galactomannan tests were sent at the discretion of the PATH investigators; however, the body fluid origins of these specimens were not known and only positive results were recorded. Proven disseminated fusariosis was defined as the isolation of *Fusarium* spp. from blood cultures with or without multiple organ involvement. Localised invasive infection was designated as either proven or probable based on criteria published by 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.[17]

The day that a *Fusarium* infection was diagnosed clinically was designated as day 1. Concomitant fungal infection was defined as an infection that occurred within 14 days of diagnosis of a *Fusarium* infection. Infections that occurred 14 days or more after a diagnosis of fusariosis were defined as secondary infections. Fungal infections that may have occurred 14 days before diagnosis of *Fusarium* were not evaluated. Initial therapy was designated to be that given on day 3.

Due to the large heterogeneity of the *Fusarium*-infected population, descriptive statistics are reported for baseline characteristics and subgroup analyses, and statistical inference has been avoided. Descriptive survival analyses are provided by the whole patient group and by infection site. Patients who were lost to follow-up prior to the week 12 assessment were censored on the day of their last reported activity. SAS version 9.2/Enterprise Guide 4.2 (SAS Institute, Cary, NC, USA) was used for statistical analyses.

Results

Baseline characteristics

Within the PATH Alliance® database, 65 patients were identified with invasive *Fusarium* infection (Table 1). Fifteen patients had one or more concomitant fungal infections (nine with *Aspergillus* spp., two with candidemia, one with *Cladosporium* plus *Aspergillus* infection and one each with *Curvularia*, *Paecilomyces* and *Trichosporon* spp. infections), and two patients had a secondary fungal infection [*Aspergillus fumigatus* ($n = 1$) and *Candida glabrata* ($n = 1$)]. One patient had both a concomitant and secondary infection (*Aspergillus* and *Curvularia* spp. respectively). Of the 25 centres in the PATH Alliance®, 19 reported cases of fusariosis. The number of patients per centre ranged from 1 to 15 [median 2.0; mean ± standard deviation (SD): 3.4 ± 3.4]. The regional distribution of cases was South ($n = 30$), Midwest ($n = 16$), Northeast ($n = 11$), West ($n = 7$) and Canada ($n = 1$).[15]

The mean ± SD age of patients with fusariosis was 51.2 ± 18.6 years, and the majority were male ($n = 41$, 63.1%) and Caucasian ($n = 51$, 78.5%). The

Table 1 Underlying conditions and demographics of 65 patients with fusariosis.

Parameter	All	CNS	Lung	Sinus	Skin/soft tissue	Abdominal	Endophthalmitis	Disseminated[1]
Patients, *n*	65	1	10	6	21	2	2	23
Age, mean years ± SD[2]	51.2 ± 18.6	39.0	56.6 ± 18.0	50.2 ± 21.8	51.2 ± 21.1	65.0 ± 12.7	66.0 ± 2.8	47.2 ± 16.5
Male, *n* (%)	41 (63.1)	1 (100)	7 (70.0)	4 (66.7)	10 (47.6)	2 (100)	2 (100)	15 (65.2)
Ethnicity, *n* (%)								
White	51 (78.5)	0	10 (100)	3 (50.0)	17 (81.0)	2 (100)	2 (100)	17 (73.9)
Black	4 (6.2)	1 (100)	0	1 (16.7)	0	0	0	2 (8.7)
Hispanic	3 (4.6)	0	0	0	3 (14.3)	0	0	0
Asian	6 (9.2)	0	0	1 (16.7)	1 (4.8)	0	0	4 (17.4)
Other or unknown	1 (1.5)	0	0	1 (16.7)	0	0	0	0
Underlying conditions, *n* (%)								
Haematologic malignancy	47 (72.3)	1 (100)	3 (30.0)	6 (100)	16 (76.2)	0	0	21 (91.3)
HCT	8 (12.3)	0	1 (10.0)	0	1 (4.8)	0	0	6 (26.1)
HIV/AIDS	2 (3.1)	1 (100)	0	0	1 (4.8)	0	0	0
Diabetes mellitus	10 (15.4)	0	3 (30.0)	0	4 (19.0)	1 (50.0)	0	2 (8.7)
Solid organ transplantation	8 (12.3)	0	6 (60.0)	0	0	0	0	2 (8.7)
Solid tumour	3 (4.6)	0	1 (10.0)	0	1 (4.8)	0	0	1 (4.3)
Surgical (non-transplant)	9 (13.8)	0	1 (10.0)	1 (16.7)	4 (19.0)	1 (50.0)	1 (50.0)	1 (4.3)
General medicine	19 (29.2)	0	5 (50.0)	2 (33.3)	4 (19.0)	1 (50.0)	2 (100)	5 (21.7)
Concomitant infection, *n* (%)								
Cytomegalovirus	3 (4.6)	1 (100)	0	0	0	0	0	2 (8.7)
Bacterial infection	28 (43.1)	0	3 (30.0)	2 (33.3)	8 (38.1)	1 (50.0)	1 (50.0)	13 (56.5)
Fungal infection	18 (27.7)	0	4 (40.0)	4 (66.7)	3 (14.3)	0	1 (50.0)	6 (26.1)
Corticosteroid therapy, *n* (%)	31 (47.7)	1 (100)	3 (30.0)	2 (33.3)	8 (38.1)	0	0	17 (81.0)
Neutropenia (baseline)								
ANC <100, mean ± SD days	15.7 ± 12.8	0	0	8.8 ± 14.4	13.5 ± 12.4	0	0	21.8 ± 10.7
ANC <500, mean ± SD days	18.6 ± 11.9	0	8.5 ± 12.0	18.8 ± 11.2	16.1 ± 13.2	0	0	22.6 ± 10.2
ANC <1000, mean ± SD days	20.8 ± 10.7	0	14.5 ± 19.1	20.8 ± 10.9	18.8 ± 11.5	0	0	23.9 ± 9.1

ANC, absolute neutrophil count; CNS, central nervous system; SD, standard deviation; HCT, haematopoietic cell transplant.

[1]There were 23 patients with disseminated disease: 10 with fungaemia only, four patients with blood and skin/soft tissue; two patients with blood, lung and skin/soft tissue; one patient with blood, lung, sinus and skin/soft tissue; one patient with blood, lung and sinus; one patient with blood and lung; one patient with blood and catheter site; one patient with blood and central nervous system; one patient with sinus, skin/soft tissue, other and eye; one patient with sinus and skin/soft tissue.

[2]Range was 4–79 years with two paediatric patients aged 4 and 7 years.

most common underlying condition was haematological malignancy ($n = 47$, 72.3%), in which corticosteroid usage frequently occurred ($n = 31$, 66.0%). Neutropenia (absolute neutrophil count <1000 cells mm^{-3}) at baseline was noted in 40 (61.5%) patients. An absolute neutrophil count of <100 cells mm^{-3} at baseline occurred in 28 (43.1%) patients. Among the 47 patients with a haematological malignancy, eight (17.0%) had received an allogeneic haematopoietic cell transplant. A large number of patients ($n = 28$, 43.1%) had a bacterial infection within 7 days prior to diagnosis of the *Fusarium* infection.

Diagnosis and sites of infection

A total of 54 (83.1%) patients had proven fusariosis and 11 (16.9%) had probable fusariosis. Of the 65 patients with *Fusarium* infection, 64 (98.5%) had a positive culture and 1 (1.5%) patient had a diagnosis based on PCR. Twenty-seven (41.5%) patients had supporting histopathology and one (1.5%) had a

supporting molecular diagnosis. Twenty-two (33.8%) patients had blood cultures that yielded *Fusarium* spp.

There were 23 (35.4%) patients with disseminated disease: 10 with fungaemia only, four patients with blood and skin/soft tissue; two patients with blood, lung and skin/soft tissue; one patient with blood, lung, sinus and skin/soft tissue; one patient with blood, lung and sinus; one patient with blood and lung; one patient with blood and catheter site; one patient with blood and central nervous system; one patient with sinus, skin/soft tissue, other and eye; one patient with sinus and skin/soft tissue. In non-disseminated disease (n = 42; 64.6%), the distribution of infection sites was skin/soft tissue (n = 21; 32.3%), lung (n = 10, 15.4%), sinus (n = 6, 9.2%), eye (n = 2, 3.1%), abdomen (n = 2, 3.1%) and central nervous system (n = 1, 1.5%).

Ten patients, all of whom had a haematological malignancy, had positive galactomannan assays (Table 2). *Aspergillus* was not isolated in culture in seven of these 10 patients, and of the seven, one patient each had concurrent isolation of *Candida parapsilosis* or *Trichosporon* spp. in addition to *Fusarium.*

Table 3 Antifungal therapies administered on days 3, 10 and 30.[1]

	Patients (N = 65)		
Parameter	Day 3	Day 10	Day 30
Monotherapy			
Echinocandin	3	1	0
Amphotericin B[2]	5	2	0
Fluconazole	1	0	0
Voriconazole	12	12	15
Posaconazole	2	3	5
Blinded	1	1	0
Combination therapy			
Voriconazole + echinocandin	4	3	1
Voriconazole + amphotericin B	10	10	7
Amphotericin B + echinocandin	1	3	0
Voriconazole + amphotericin B + echinocandin	5[3]	1[4]	0
Posaconazole + amphotericin B	2	3	0

[1]Complete treatment records were not available for 19 patients.

[2]All patients received a lipid formulation of amphotericin B except where noted.

[3]Two of these patients received amphotericin B deoxycholate.

[4]This patient received amphotericin B deoxycholate.

Treatment and outcomes

Forty-six (70.8%) patients received antifungal therapy (including agents not recommended for therapy of *Fusarium* infections) on day 3, the day designated by the study at which initial therapy was evaluated (Table 3). Twenty-four patients received monotherapy and 22 patients received combination therapy. For monotherapy, voriconazole was most commonly administered, and an amphotericin B formulation was the second most commonly administered agent. For combination therapy, voriconazole plus amphotericin B formulations were most commonly used. The second most commonly used combination therapy was voriconazole plus an amphotericin B formulation plus an echinocandin. Nineteen patients did not have treatment recorded on day 3, including four patients with missing data, four who had not received antifungal therapy by day 3 and 11 who had received therapy

Table 2 Patients with invasive fusariosis who had positive galactomannan assay reported.

Patient[1]	Only *Fusarium* isolated	Presence of *Aspergillus* in culture	Site of *Fusarium* Infection	Comment
A	No	Yes	Blood; skin/soft tissue	*A. terreus* isolated from BAL culture
B	No	Yes	Lung	*A. flavus* and *A. terreus* isolated from BAL culture[2]
C	Yes	No	Sinus	*Aspergillus* not identified but presumed in lung[2]
D	Yes	No	Skin/soft tissue	*Aspergillus* not identified but presumed in lung[2]
E	No	Yes	Blood	*A. flavus* isolated from BAL culture
F	Yes	No	Lung	*Fusarium* only infection
G	No	No	Blood; lung; skin/soft tissue	*Candida parapsilosis* isolated from blood
H	No	No	Blood; lung; skin/soft tissue	*Trichosporon* also isolated
I	Yes	No	Blood; skin/soft tissue	*Fusarium* only infection
J	Yes	No	Skin/soft tissue	*Fusarium* only infection

BAL, bronchoalveolar lavage.

[1]All patients had haematological malignancy and were neutropenic except patient B who had haematological malignancy only; patients A, B, F, G, H, I also had prior corticosteroid treatment; patient E also had prior corticosteroid treatment, solid tumour and surgery.

[2]These patients were diagnosed with a concomitant infection (invasive fusariosis + invasive aspergillosis).

before day 3 but no actual therapy on day 3 itself. Six patients died before day 3.

The pattern of antifungal agents administered on day 10 was largely similar to day 3, except for less usage of amphotericin B formulations as monotherapy and a reduction in overall usage of echinocandins (Table 3). On day 30, 20 patients were receiving monotherapy with voriconazole or posaconazole, and eight patients were receiving combination therapy with voriconazole plus an amphotericin B formulation or voriconazole plus an echinocandin. Surgery was performed in nine patients (13.8%). Procedures included debridement ($n = 7$), resection/excision ($n = 2$) and drainage ($n = 1$).

The 12-week Kaplan–Meier survival rate for all patients was 44% (Fig. 1), and deaths occurred throughout the follow-up period. Patients with and without disseminated disease had survival rates of 33% and 50% respectively (Fig. 1). The survival rates of patients with non-disseminated disease of the skin/soft tissue, lung and sinuses were 45%, 68% and 50% respectively.

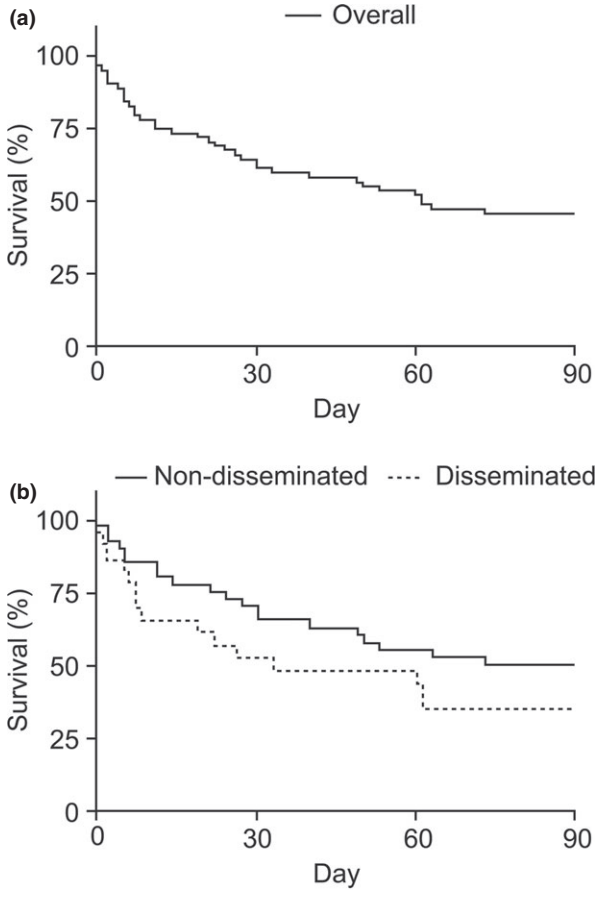

Figure 1 Survival rates for 65 patients who had invasive fusariosis. Overall survival (a) and Disseminated vs. Non-disseminated disease (b).

Discussion

This large multicentre experience of proven and probable fusariosis expands our knowledge of this often devastating infection. We report on the epidemiology, therapy and outcomes of 65 patients with invasive *Fusarium* infections in 19 of the 25 North American medical centres participating in the PATH Alliance® registry from 2004 to 2008. Most patients had a haematological malignancy (72.3%), and 17% of these patients had received a haematopoietic cell transplant. Neutropenia and corticosteroids were commonly found as risk factors. The majority of patients (83.1%) had proven fusariosis. Fungaemia and disseminated disease occurred frequently in our series, as has been noted in other reports.[6]

Ten patients had a positive galactomannan assay, of whom only three had culture evidence of *Aspergillus* spp. False-positive or cross-reactive galactomannan assays have been reported previously with *Fusarium* infections. Tortorano and colleagues have noted 10 of 12 patients with haematological malignancy and disseminated/deep-seated *Fusarium* infections as having positive galactomannan assays in the absence of *Aspergillus* isolation in culture.[18] In a more recent report, Nucci *et al.* [19] identified 15 of 18 patients with invasive fusariosis with a positive galactomannan assay. Eleven of the 15 patients had a positive galactomannan assay prior to diagnosis of invasive fusariosis. It appears that cross-reactive results for galactomannan assays may be recorded frequently in patients with *Fusarium* infections. *Fusarium* infections should be considered in the absence of *Aspergillus* isolation in patients at high risk of mould infections with positive galactomannan assay test results.

A similar proportion of patients received monotherapy vs. combination therapy as initial therapy. For monotherapy, voriconazole or an amphotericin B formulation was most commonly used. For combination therapy, voriconazole with an amphotericin B formulation was most commonly administered. By day 30, proportionally fewer patients were receiving combination therapy. On day 30, 20 patients were receiving monotherapy with voriconazole or posaconazole, and eight patients were receiving combination therapy. A similar reliance on voriconazole and combination therapy was also recently reported in a large multicentre experience in 11 countries from 2001 to 2011.[9]

In this study, survival at 90 days was 44%. This survival rate was strikingly similar to that recently reported by Nucci *et al.* [9], and appears to be an improvement compared with a 2003 report of 84 patients who had similar risk factors, including haematological malignancies, neutropenia and corticosteroid usage. In that study, survival at 90 days was only 21%.[20] This improvement in survival may be due to the availability of triazole antifungal agents, including voriconazole and posaconazole. In this study, the majority of patients received voriconazole, either as monotherapy or in combination with other agents. In a 2010 report, 73 patients with invasive fusariosis (60% with haematological malignancies) were treated with voriconazole and survival was 42% at 90 days. Combination therapy in 13 patients was reported to be no better than voriconazole monotherapy.[11] In the present series, patients with disseminated disease had a lower survival rate (33%) than those who had localised disease (50%). The survival rate appeared best in patients with disease isolated to the lung (68%).

Limitations of our study include an inability to calculate the incidence of invasive fusariosis due to a lack of information on the total number of at-risk patients, differences in clinical practices across different medical institutions, limited data regarding galactomannan assays, limitations in follow-up and an inability to distinguish between sequential and concomitant therapy. Other limitations that prevented robust statistical inference of treatment outcomes included the large heterogeneity of the patients reported and the likely presence of bias in the selection of antifungal therapy based on a mix of concomitant fungal and bacterial infections and comorbid conditions. In addition, data regarding identification of *Fusarium* isolates at the species level were not collected.

Conclusions

In this series of 65 patients with invasive *Fusarium* infections, the most common underlying condition was haematological malignancy, in which neutropenia and corticosteroid usage frequently occurred. Results from this analysis also showed that cross-reactive galactomannan assays may occur frequently in patients with *Fusarium* infections. Therefore, *Fusarium* infections should be strongly considered in the absence of *Aspergillus* isolation in patients who are at high risk of mould infections and who have positive galactomannan assay test results. Patients with fusariosis continue to have very high fatality rates, especially those with disseminated disease. However, survival appears improved compared with historical data. The frequent use of posaconazole and voriconazole may be linked to the improved rates of survival observed in this patient series. Clinical studies that can clarify effective treatment strategies for this often fatal infection are warranted.

Acknowledgements

We would like to acknowledge the PATH Alliance® investigators and site staff at the following centres who contributed data to the registry: City of Hope National Medical Center, Duke University Medical Center, Emory University, Hôpital Maisonneuve–Rosemont, Johns Hopkins Hospital, Massachusetts General Hospital, MD Anderson – Hematologic Malignancy, MD Anderson – Infectious Disease, Mount Sinai School of Medicine, Oregon Health and Science University, Thomas Jefferson University Hospital, University of Alabama at Birmingham, University of Arkansas for Medical Sciences, University of Iowa Health Care, University of Michigan Health System, University of Minnesota, University of Nebraska Medical Center, University of Washington, and University of Wisconsin Medical School. The PATH Alliance® registry was funded by Astellas Pharma. Statistical support was provided by Alan Fan of Astellas Pharma. Editorial support, funded by Astellas Pharma, was provided by Radhika Bhatia, PhD, and Neil M. Thomas, PhD, of Envision Scientific Solutions.

Conflicts of interest

This work was supported by Astellas. DH has received consultancy fees from Astellas. AF has received financial support from Astellas, Optimer and Merck. CK has received research support from Astellas. NA and BF are employees of Astellas. MS has nothing to disclose.

References

1 Dignani MC, Anaissie E. Human fusariosis. *Clin Microbiol Infect* 2004; **10**(Suppl. 1): 67–75.
2 Bourgeois GP, Cafardi JA, Sellheyer K, Andea AA. Disseminated Fusarium infection originating from paronychia in a neutropenic patient: a case report and review of the literature. *Cutis* 2010; **85**: 191–4.
3 Carneiro HA, Coleman JJ, Restrepo A, Mylonakis E. Fusarium infection in lung transplant patients: report of 6 cases and review of the literature. *Medicine (Baltimore)* 2011; **90**: 69–80.
4 Hu S, Fan VC, Koonapareddy C, Du TT, Asbell PA. Contact lens-related Fusarium infection: case series experience in New York City and review of fungal keratitis. *Eye Contact Lens* 2007; **33**: 322–8.
5 Liu JY, Chen WT, Ko BS *et al.* Combination antifungal therapy for disseminated fusariosis in immunocompromised patients: a case report and literature review. *Med Mycol* 2011; **49**: 872–8.

6 Nucci M, Anaissie E. Fusarium infections in immunocompromised patients. *Clin Microbiol Rev* 2007; **20**: 695–704.
7 Torres HA, Raad II, Kontoyiannis DP. Infections caused by Fusarium species. *J Chemother* 2003; **15**(Suppl. 2): 28–35.
8 Muhammed M, Coleman JJ, Carneiro HA, Mylonakis E. The challenge of managing fusariosis. *Virulence* 2011; **2**: 91–96.
9 Nucci M, Marr KA, Vehreschild MJ *et al.* Improvement in the outcome of invasive fusariosis in the last decade. *Clin Microbiol Infect* 2013. [Epub ahead of print].
10 Ho DY, Lee JD, Rosso F, Montoya JG. Treating disseminated fusariosis: amphotericin B, voriconazole or both? *Mycoses* 2007; **50**: 227–31.
11 Lortholary O, Obenga G, Biswas P *et al.* International retrospective analysis of 73 cases of invasive fusariosis treated with voriconazole. *Antimicrob Agents Chemother* 2010; **54**: 4446–50.
12 Nucci M, Marr KA, Queiroz-Telles F *et al.* Fusarium infection in hematopoietic stem cell transplant recipients. *Clin Infect Dis* 2004; **38**: 1237–42.
13 Raad II, Hachem RY, Herbrecht R *et al.* Posaconazole as salvage treatment for invasive fusariosis in patients with underlying hematologic malignancy and other conditions. *Clin Infect Dis* 2006; **42**: 1398–403.
14 Muhammed M, Anagnostou T, Desalermos A *et al.* Fusarium infection: report of 26 cases and review of 97 cases from the literature. *Medicine (Baltimore)* 2013; **92**: 305–16.
15 Azie N, Neofytos D, Pfaller M, Meier-Kriesche HU, Quan SP, Horn D. The PATH (Prospective Antifungal Therapy) Alliance® registry and invasive fungal infections: update 2012. *Diagn Microbiol Infect Dis* 2012; **73**: 293–300.
16 Horn DL, Fishman JA, Steinbach WJ *et al.* Presentation of the PATH Alliance registry for prospective data collection and analysis of the epidemiology, therapy, and outcomes of invasive fungal infections. *Diagn Microbiol Infect Dis* 2007; **59**: 407–14.
17 De Pauw B, Walsh TJ, Donnelly JP *et al.* 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**: 1813–21.
18 Tortorano AM, Esposto MC, Prigitano A *et al.* Cross-reactivity of Fusarium spp. in the Aspergillus Galactomannan enzyme-linked immunosorbent assay. *J Clin Microbiol* 2012; **50**: 1051–3.
19 Nucci M, Carlesse F, Cappellano P *et al.* Earlier diagnosis of invasive fusariosis with Aspergillus serum galactomannan testing. *PLoS ONE* 2014; **9**: e87784.
20 Nucci M, Anaissie EJ, Queiroz-Telles F *et al.* Outcome predictors of 84 patients with hematologic malignancies and Fusarium infection. *Cancer* 2003; **98**: 315–9.