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REVIEW

Novel immune regulatory pathways and their role in immune reconstitution syndrome in organ transplant recipients with invasive mycoses

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Abstract Immune regulatory pathways involving the newly discovered T regulatory (Treg) and Th17 cells are amongst the principal targets of immunosuppressive agents employed in transplant recipients and key mediators of host inflammatory responses in fungal infections. These novel signaling pathways, in concert with or independent of Th1/Th2 responses, have potentially important implications for yielding valuable insights into the pathogenesis of immune reconstitution syndrome (IRS) in transplant recipients, for aiding the diagnosis of this entity, and for achieving a balance of immune responses that enhance host immunity while curbing unfettered inflammation in IRS.

Introduction

Reduction or resolution of immunosuppression in immunocompromised hosts with opportunistic mycoses can trigger inflammatory reactions known as immune reconstitution syndrome (IRS) that mimic worsening disease expression [1–3]. IRS, however, is often not recognized as an inflammatory entity with an immunologic basis and its occurrence is virtually always regarded as failure of therapy or relapse of infection [1]. Characterization of its biologic basis that is also poorly understood is pivotal in determining clinical or laboratory criteria that may be diagnostically useful and in devising therapeutic approaches for optimizing its management. This discussion focuses on current understanding of immune regulatory and signaling pathways that have a potentially critical role in modulating inflammatory responses in IRS.

An illustrative case

A 52-year-old renal transplant recipient presented 7 months posttransplant with an ulcerative skin lesion and a cavitary pulmonary mass. His immunosuppression comprised tacrolimus, mycophenolate mofetil, and prednisone. Biopsy of both lesions yielded *Cryptococcus neoformans* in culture, and serum cryptococcal antigen was 1:256. A CT scan of the head and CSF analysis were unremarkable. Tacrolimus was withdrawn and prednisone dosage was reduced. Therapy with a lipid formulation of amphotericin B and 5 flucytosine was employed and converted to fluconazole 21 days later. Serum cryptococcal antigen had declined to 1:64. Four weeks later, fever and confusion developed. An enhancing lesion in the left occipital lobe and an inguinal mass were documented. Serum cryptococcal antigen was 1:64. Biopsy of the inguinal mass showed well-formed granulomas with yeast forms visualized, but the cultures remained negative. Treatment with a lipid formulation of amphotericin B was resumed for "presumed failure of therapy", although failure was never microbiologically documented. An extensive workup failed to yield a new pathogen or an alternative etiology for the patient's symptoms. Complete recovery eventually occurred after a protracted illness.

Discussion

This case fulfills the proposed criteria for defining IRS [1] and illustrates a complex and poorly understood entity that

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is becoming increasingly relevant in the management of invasive mycoses. Disease expression and outcomes in infectious diseases have typically been regarded as damage afflicted by the pathogen. Increasingly however, the host immune response is considered to play a critical role in microbial pathogenesis [4]. The tenets of "Damage Response Framework of Microbial Pathogenesis", a conceptual paradigm that integrates host and pathogen interactions, dictate that while host immunity is critical in facilitating the eradication of infection, an overly robust immune response may in fact be detrimental to the host [4]. Overzealous inflammatory responses may contribute to immune reconstitution syndrome (IRS) and poor outcomes in patients with opportunistic mycosis [1, 4]. IRS associated with invasive fungal infections has been documented in diverse patient populations including organ transplant recipients; however, its pathophysiologic basis has not been fully defined [5–8].

Cytokine secreting regulatory T cells

A key mediator of immunity against pathogenic fungi are proinflammatory host responses due to adaptive T cell immunity [9, 10]. Cytokine secreting T cells play a major role in the development of these antigen-specific adaptive immune responses [10, 11]. Activation by cognate ligand causes precursor or naïve $CD4^+$ helper T cells (Th0) to differentiate into effector cells with distinct functional characteristics depending upon the cytokine milieu [12]. Historically, two major types of T helper cells, Th1 and Th2, have been recognized [9, 12]. IL-12 driven differentiation through transcription factor T-Bet skews the development of Th0 cells towards Th1 [13]. These cells, through production of their signature cytokine IFN-γ, activate macrophages, promote NK cell induced cytotoxicity, and elicit proinflammatory responses [12]. IL-4 signal transduction by expression of GATA binding protein-3 (GATA-3) polarizes the differentiation of Th0 to Th2 cells that produce antiinflammatory and immunosuppressive cytokines [14, 15].

Thus, while inflammation is a protective antifungal host response, optimal outcomes in immunocompromised hosts with invasive mycoses are critically dependant upon achieving a fine balance between pro- and antiinflammatory responses. Underactivity of Th1 can result in failure to resolve infection; however, inflammatory responses that ensue or continue unabated after the infection is mycologically controlled may worsen fungal disease and contribute to tissue damage [1, 15]. Indeed, an imbalance characterized by an inadequate or excessive expression of either response can be detrimental to the infected host.

Th17 pathway and T regulatory cells

It has recently come to be recognized that potent inflammatory responses that were earlier considered to be due to Th1 may in fact be mediated by two completely separate lineages of T cells, i.e., regulatory T cells (Tregs) and Th17 [15–20]. Emerging data show that transforming growth factor (TGF-β), depending upon the presence or absence of IL-6, can promote the differentiation of Th0 cells into two functionally distinct subsets of effector T cells [21, 22] (Fig. 1). In the presence of TGF-β, precursor T helper cells differentiate toward Tregs that are characterized by the expression of transcription factor foxhead box P3 (FoxP3),

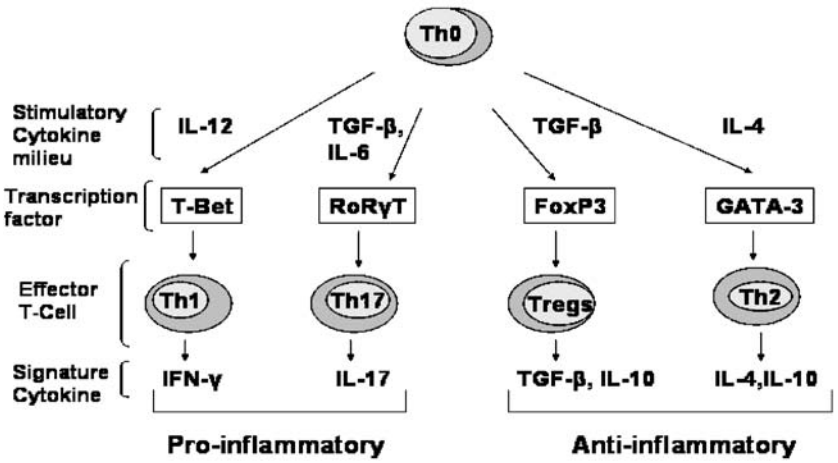

Fig. 1 Schematic diagram depicting T-cell differentiation. Depending upon the cytokine milieu, i.e., IL-12, TGF-β plus IL-6, TGF-β, or IL-4, the naïve or precursor T helper cells (Th0) develop into Th1, Th17, Treg, or Th2 cells, respectively, via expression of their specific transcription factors T-Bet, retinoid orphan receptor (RoR)γT, foxhead box protein (FoxP3), and GATA binding protein (GATA-3), respectively. IFN-γ and IL-17, the signature cytokines of Th1 and Th17 cells, mediate proinflammatory responses, whereas TGF-β, IL-10, and IL-4 production by Tregs and Th2 cells mediate antiinflammatory responses

and likewise in the presence of TGF-β and IL-6, toward Th17 cells [21–24]. FoxP3 is the master regulatory gene responsible for the function and development of Tregs [25, 26]. Mice deficient in FoxP3 fail to generate $CD25^{+}CD4^{+}$ Tregs and succumb to a scruffy-like inflammatory disorder [26, 27]. Experimental data in animal models show that the development of Th17 and Tregs occurs in a mutually exclusive manner [16, 22].

Role of Th17 and Tregs in transplant recipients with IRS

The biology and novel immunoregulatory function of these cells has gained significant attention in the pathogenesis of a number of inflammatory diseases, antitumor immunity, and immune disorders such as allograft rejection [15, 17, 18, 28, 29]. Th17 cells have been considered to play a role in the pathogenesis of collagen-induced arthritis, experimental allergic encephalitis, and other inflammatory conditions previously thought to be Th1-mediated [15, 30]. Tregs on the other hand have antiinflammatory characteristics and contribute to tolerance towards self and foreign antigens [26, 31]. Accumulating evidence suggests that skewing of T-helper phenotype towards Th17 and Th1 is responsible for allograft rejection whereas differentiation towards Tregs and Th2 promotes graft tolerance [13, 26, 32–34]. Tregs have been documented in the peripheral blood of stable renal allograft recipients and within tolerated transplanted graft itself [35, 36]. Indeed, induction of FoxP3 expression and generation of Tregs has been identified as a pivotal pathway in achieving enduring transplant tolerance [28, 32].

The Th17 pathway is also a major target of immunosuppressive agents employed in transplant recipients. Campath-1 H, a humanized CD52 antibody, antithymocyte globulin, and corticosteroids enhance FoxP3 expression and promote the development of Treg cells [37–40]. Calcineurin-inhibitor agents tacrolimus and cyclosporine A, on the other hand, inhibit Tregs [41, 42]. The suppressive effect of calcineurin-inhibitors on Tregs may be due to impaired IL-2 production due to these agents as IL-2 signaling is necessary for the generation and expansion of Tregs [43, 44]. Rapamycin led to selective expansion of Tregs in one study [45] and neither enhancement nor inhibition of Tregs in two others [41, 42]. In a clinical setting, the cumulative effect of an immunosuppressive regimen in transplant recipients with a functioning allograft reflects induction of tolerance by expansion and long-term maintenance of Tregs [41, 42].

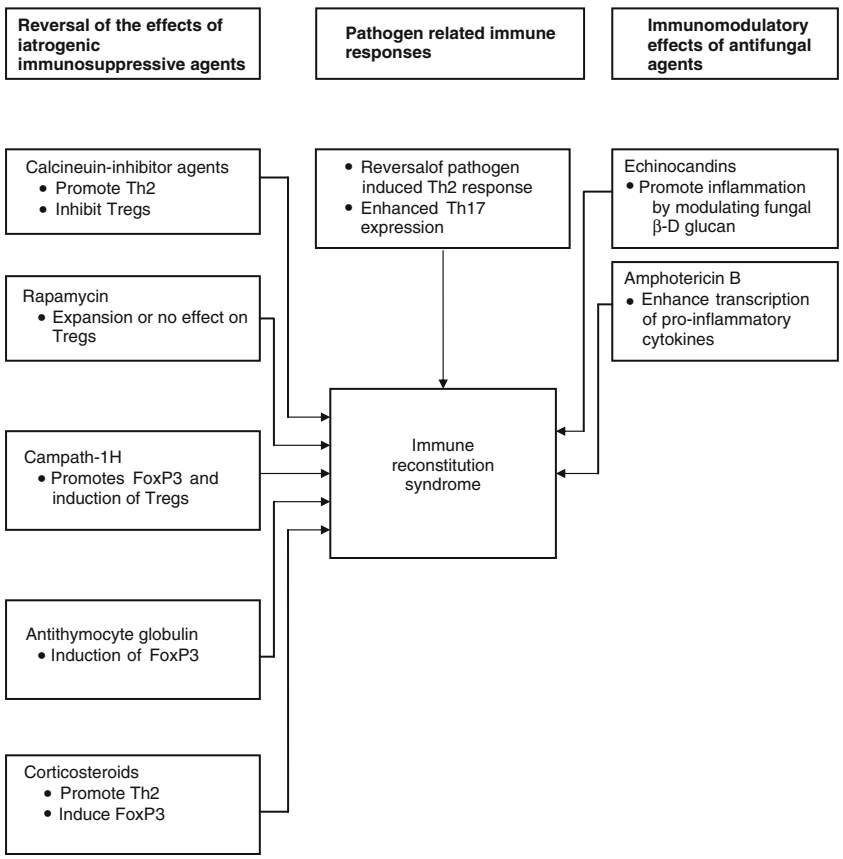

Fig. 2 Proposed model of immune responses leading to immune reconstitution syndrome in transplant recipients with invasive fungal infections [38, 50, 51, 53, 54]

IRS in transplant recipients with opportunistic mycoses

Th1/Th2 responses have been recognized as important determinants of host susceptibility and outcome in medically important fungi, e.g., *Candida, Cryptococcus,* and *Aspergillus* spp. [9, 10, 46]. Depletion of Th1 enhances susceptibility to invasive fungal infections and an increase in Th2 compromises protective immunity and allows fungal pathogens to evade host defenses [47–49]. Pathogenic fungi per se have immunomodulatory characteristics and the potential to inhibit Th1 while inducing Th2 response [50, 51]. Emerging data now show functional activities of the Th17 pathway are a key contributor to the pathogenesis of fungal infections [20, 52, 53]. The Th17 pathway was preferentially associated with inflammation and impaired antifungal resistance to *Candida* and *Aspergillus* [53]. In an experimental model, IL-23 and IL-17 increased the susceptibility of mice to *Candida* and *Aspergillus* infections by inhibition of protective Th1 immunity [53]. Antifungal activity of polymorphonuclear cells was inhibited even in the presence of IFN-γ, suggesting that the Th17 effector pathway prevailed over Th1 [53].

Treatment of fungal infections has been shown to revert host immunity toward an inflammatory phenotype [8]. It should be noted that several antifungal agents employed as therapy for fungal infections also have immunomodulatory effects. Amphotericin B formulations, particularly amphotericin B deoxycholate, promote the transcription and production of proinflammatory cytokines in murine and human immune cells [54–56]. Fungal β-D glucan, through mammalian dectin-1 signaling, can trigger potent inflammatory responses [57]. Echinocandins target fungal β-D glucan and therefore have the potential to modulate host immune response by altering β-D glucan surface content of the fungi [57, 58].

Reversal of pathogen-induced immunosuppression, reduction, or withdrawal of iatrogenic immunosuppressive agents and employment of effective antifungal therapy may be associated with a shift in immunologic repertoire towards physiologic or even pathologic proinflammatory responses leading to IRS (Fig. 2). IRS in invasive fungal infections such as cryptococcosis and histoplasmosis typically presents as lymphadenitis, enhancing central nervous system lesions, and skin or soft tissue masses [1, 59–61]. In a subset of patients with *Pneumocystis jiroveci* pneumonia and invasive pulmonary aspergillosis, worsening or symptomatic disease during receipt of appropriate therapy is also considered to be due to IRS [1, 62, 63]. There is no proven therapy for IRS. Current approaches using antiinflammatory agents and corticosteroids as empirical treatment of symptomatic cases remain suboptimal [1].

Future prospects

Novel immune regulatory pathways involving Tregs and Th17 cells have significant implications for discerning the pathophysiologic basis of IRS. Interventions targeted to downregulate inflammation by manipulating regulatory T cells are increasingly proposed to be useful for the management of inflammatory and autoimmune disorders, for enhancement of tumor immunity, and for the establishment of transplant tolerance [15, 28, 64]. Experimental data show that antigen-specific Tregs expanded in vitro can be successfully used for the prevention and treatment of autoimmune disorders [31, 64–66]. Such immunomodulatory approaches also have a potentially promising role for the treatment of IRS in opportunistic mycoses.

IRS remains a poorly understood entity and patient populations at risk for it in the current era are growing [67]. Diagnosis and management of IRS pose daunting challenges for care providers largely because its pathophysiologic basis has not been defined. Use of pharmacologic agents for the treatment if IRS such as corticosteroids that increase Tregs are associated with adverse sequelae and nonspecific immunosuppressive effects [1]. Thus, investigations to assess the role of the novel immunoregulatory pathways have significant implications for optimizing outcomes in IRS associated with opportunistic mycoses not only in organ transplant recipients but in other hosts as well.

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References

1. Singh N, Perfect JR (2007) Immune reconstitution syndrome associated with opportunistic mycoses. Lancet Infect Dis 7:395–401
2. Lortholary O, Fontanet A, Memain N et al (2005) Incidence and risk factors of immune reconstitution inflammatory syndrome complicating HIV-associated cryptococcosis in France. AIDS 19:1043–1049
3. Shelburne SA, Hamill RJ, Rodriguez-Barradas MC et al (2002) Immune reconstitution inflammatory syndrome, emergence of a unique syndrome during highly active antiretroviral therapy. Medicine 81:213–227
4. Casadevall A, Pirofski LA (2003) The damage-response framework of microbial pathogenesis. Nat Rev Microbiol 1:17–24
5. Shelburne SA, Darcourt J, White C Jr et al (2005) The role of immune reconstitution inflammatory syndrome in AIDS-related *Cryptococcus neoformans* disease in the era of highly active antiretroviral therapy. Clin Infect Dis 40:1045–1052
6. Hirsch HH, Kaufmann G, Sendi P et al (2004) Immune reconstitution in HIV-infected patients. Clin Infect Dis 38:1159–1166

7. Cheng VCC, Yuen KY, Wong SSY et al (2001) Immunorestitution disease in patients not infected with HIV. Eur J Clin Microbiol Infect Dis 20:402–406
8. Einsiedel L, Gordon DL, Dyer JR (2004) Paradoxical inflammatory reaction during treatment of *Cryptococcus neoformans* var. *gattii* meningitis in an HIV seronegative woman. Clin Infect Dis 39:e78–e82
9. Clemons KV, Stevens DA (2001) Overview of host defense mechanisms in systemic mycoses and the basis for immunotherapy. Semin Respir Infect 16:60–66
10. Romani L, Pucetti P (2007) Controlling pathogenic inflammation to fungi. Expert Rev Anti Infect Ther 5:1007–1017
11. Cenci E, Perito S, Enssle KH et al (1997) Th1 and Th2 cytokines in mice with invasive aspergillosis. Infect Immun 65:564–570
12. Parkin J, Cohen B (2001) An overview of the immune system. Lancet 357:1777–1789
13. Goriely S, Goldman M (2007) The interleukin-12 family: new players in transplantation immunity? Am J Transplant 7:278–284
14. Nelms K, Keegan A, Zamorano J et al (1999) The IL-4 receptor: signaling mechanisms and biologic functions. Ann Rev Immunol 17:701–738
15. Afzali B, Lombardi G, Lechler R, Lord G (2007) The role of T helper (TH17) and regulatory T cells (Treg) in human organ transplantation and autoimmune disease. Clin Exp Immunol 148:32–46
16. Mangan P, Harrington L, O'Quinn D et al (2006) Transforming growth factor-beta induces development of the T (H) 17 lineage. Nature 441:231–234
17. Cooke A (2006) Th17 cells in inflammatory conditions. Rev Diabetic Stud 372–375
18. Bi Y, Guangwei L, Yang R (2007) Th17 cell induction and immune regulatory effects. J Cell Physiol 211:273–278
19. Schmidt-Weber C, Akdis M, Akdis C (2007) TH17 cells in the big picture of immunology. J Allergy Clin Immunol 120:247–254
20. Stockinger B, Veldhoen M (2007) Differentiation and function of Th17 T cells. Curr Opin Immunol 3:281–286
21. Bettelli E, Carrier Y, Gao W et al (2006) Reciprocal developmental pathways for the generation of pathogenic effector TH17 and regulatory T cells. Nature 441:235–238
22. Veldhoen M, Hocking R, Atkins C et al (2006) TGFbeta in the context of an inflammatory cytokine milieu supports de nova differentiation of IL-17-producing T cells. Immunity 24:179–189
23. Pyzik M, Piccirillo C (2007) TGF-beta 1 modulates FoxP3 expression and regulatory activity in distinct CD4+ T cell subsets. J Leukov Biol 82:335–346
24. Chen W, Jin W, Hardegen N et al (2003) Conversion of peripheral TGF-beta CD4+CD5-naive T cells to CD4+CD25+ regulatory T cells by TGF-beta induction of transcription factor Foxp3. J Exp Med 1875–1886
25. Yagi H, Normura T, Nakamura K et al (2004) Crucial role of FoxP3 in the development and function of human CD25+ CD4+ regulatory T cells. Int Immunol 11:1643–1656
26. Sakaguchi S (2005) Naturally arising FoxP3-expressing CD25+ CD4+ regulatory T cells in immunological tolerance to self and non-self. Nature Immun 6:345–354
27. Fontenot J, Gavin M, Rudensky A (2003) FoxP3 programs the development and function of CD4+CD25+ regulatory T cells. Nature Immun 4:330–336
28. Waldmann H, Graca L, Cobbold S et al (2004) Regulatory T cells and organ transplantation. Semin Immunol 16:119–126
29. de Kleer I, Wedderburn L, Taams L et al (2004) CD4+CD25bright regulatory T cells activity regulate inflammation in the joints of patients with the remitting form of juvenile idiopathic arthritis. J Immunol 10:6423–6435
30. Matthys P, Vermeire K, Mitera T et al (1998) Anti-IL-12 antibody prevents the development and progression of collagen-induced arthritis in IFN-gamma receptor-deficient mice. Eur J Immunol 28:2143–2151
31. Tang Q, Henriksen K, Bi M et al (2004) In vitro-expanded antigen-specific regulatory T cells suppress autoimmune diabetes. J Exp Med 199:1455–1465
32. Long E, Wood K (2007) Understanding FOXP3: progress towards achieving transplantation tolerance. Transplantation 84:459–461
33. Gras J, Cornet A, Latinne D et al (2004) Evidence that Th1/Th2 immune deviation impacts on early graft acceptance after pediatric liver transplantation: results of immunological monitoring in 40 children. Am J Transplant 4:444
34. Saggi B, Fisher R, Naar J et al (1999) Intragraft cytokine expression in tolerant rat renal allografts with rapamycin and cyclosporin immunosuppression. Clin Transplant 13:90–97
35. Salama A, Najafian N, Clarkson M et al (2003) Regulatory CD25+ T cells in human kidney transplant recipients. J Am Soc Nephrol 6:1643–1651
36. Graca L, Cobbold S, Waldmann H (2002) Identification of regulatory T cells in tolerated allografts. J Exp Med 195:1641
37. Bloom DD, Brahmbhatt R, Knechtle S (2007) Flow cytometric characterization regulatory T lymphocyte populations in renal transplant patients treated with Campath and tacrolimus. Presented at the American Transplant Congress, May 5–7, San Francisco, CA
38. Lopez M, Clarkson M, Sayegh A et al (2006) A novel mechanism of action for anti-thymocyte globulin induction of CD4+CD25+ FoxP3+ regulatory T cells. J Am Soc Nephrol 10:2644–2646
39. Watanabe T, Masuyama J, Sohma Y et al (2006) CD52 is a novel costimulatory molecule for induction of CD4+ regulatory T cells. Clin Immunol 3:247–259
40. Karagiannidis C, Akdis M, Holopainen P et al (2004) Glucocorticoids up-regulate CAP3 expression and regulatory T cells in asthma. J Allergy Clin Immunol 114:1425–1433
41. Segundo D, Ruiz J, Izquierdo M et al (2006) Calcineurin inhibitors, but no rapamycin, reduce percentages of CD4+CD25+FoxP3+ Regulatory T cells in renal transplant recipients. Transplantation 82:550–557
42. Baan C, van der Mast B, Klepper M et al (2005) Differential effect of calcineurin inhibitors, anti-CD25 antibodies and rapamycin of the induction of FoxP3 in human T Cells. Transplantation 80: 110–117
43. Bensinger S, Walsh P, Zhang J (2004) Distinct IL-2 receptor signaling pattern in CD4+CD25+regulatory T cells. J Immunol 172:5287
44. Fontenot J, Rasmussen J, Gavin M et al (2005) A function for interleukin 2 in FoxP3-expressing regulatory T cells. Nat Immunol 6:1142
45. Battaglia M, Stabilini A, Roncarolo M (2005) Rapamycin selectively expands CD4+CD25+FoxP3+ regulatory T cells. Blood 105:4743–4748
46. Nagai H, Guo J, Choi H et al (1995) Interferon-gamma and tumor necrosis factor-alpha protect mice from invasive aspergillosis. J Infect Dis 172:1554–1560
47. Kawakami K (2004) Regulation by innate immune T lymphocytes in the host defense against pulmonary infection with *Cryptococcus neoformans*. Jpn J Infect Dis 57:137–145
48. Decken K, Kohler G, Palmer-Lehmann K et al (1998) Interleukin-12 is essential for protective Th1 response in mice infected with *Cryptococcus neoformans*. Infect Immun 66:4994–5000
49. Aguirre K, Havell EA, Gibson GW (1995) Role of tumor necrosis factor and gamma interferon in acquired resistance to *Cryptococcus neoformans* in the central nervous system of mice. Infect Immun 63:1725–1731
50. Vecchiarelli A, Retini C, Monari C et al (1996) Purified capsular polysaccharide of *Cryptococcus neoformans* induces interleukin-10 secretion by human monocytes. Infect Immun 64:2846–2849

51. Vecchiarelli A, Retini C, Pietrella D et al (1995) Downregulation by cryptococcal polysaccharide of tumor necrosis factor alpha and interleukin-1β secretion from human monocytes. Infect Immun 63:2919–2923
52. Rudner X, Happel K, Young E et al (2007) Interleukin-23 (IL-23)-IL-17 cytokine axis in murine *Pneumocystis carinii* infection. Infect Immun 75:3055–3061
53. Zelante T, De Luca A, Bonifazi P et al (2007) IL-23 and the Th17 pathway promote inflammation and impair antifungal immune resistance. Eur J Immunol 37:2695–2706
54. Rogers PD, Pearson MM, Cleary JD et al (2002) Differential expression of genes encoding immunomodulatory proteins in response to amphotericin B in human mononuclear cells identified by cDNA microarray analysis. J Antimicrob Chemotherap 50:811–817
55. Razonable RR, Henault M, Lee LN et al (2005) Secretion of proinflammatory cytokines and chemokines during amphotericin B exposure is mediated by coactivation of toll-like receptors 1 and 2. Antimicrob Ag Chemother 4:1617–1621
56. Shadkchan Y, Keisari Y, Segal E (2004) Cytokines in mice treated with amphotericin B-intralipid. Med Mycol 42:123–128
57. Hohl T, Feldmesser M, Perlin D et al (2007) Caspofungin modulates inflammatory responses to *Aspergillus fumgiatus* through stage-specific effects on fungal β-glucan exposure. Annual meeting of the Infectious Diseases Society of America, 4–7 October, San Diego, CA
58. Wheeler RT, Fink GR (2006) A drug-sensitive genetic network masks fungi from the immune system. PLOS Pathogens 2:328–339
59. Lortholary O, Sitbon K, Dromer F et al (2005) Evidence for HIV and *Cryptococcus neoformans* interactions on the pro- and antiinflammatory responses in blood during AIDS-associated cryptococcosis. Clin Microbiol Infect 11:296–300
60. Singh N, Lortholary O, Alexander BD et al (2005) An "immune reconstitution syndrome"-like entity associated with *Cryptococcus neoformans* infections in organ transplant recipients. Clin Infect Dis 40:1756–1761
61. Breton G, Adle-Biassette H, Therby A et al (2006) Immune reconstitution inflammatory syndrome in HIV-infected patients with disseminated histoplasmosis. AIDS 20:119–121
62. Cheng VCC, Yuen KY, Chan WM et al (2000) Immunorestitution disease involving the innate and adaptive response. Clin Infect Dis 30:882–892
63. Miceli M, Maertens J, Buve K et al (2007) Immune reconstitution inflammatory syndrome in cancer patients with pulmonary aspergillosis recovering from neutropenia: proof of principle, description, and clinical and research implications. Cancer 110:112–120
64. Tang Q, Bluestone J (2006) Regulatory T-cell physiology and application to treat autoimmunity. Immunol Rev 212:217–237
65. Tarbell K, Petit L, Zuo X et al (2007) Dendritic cell-expanded, islet-specific CD4+CD25+CD62L+regulatory T cells restore normoglycemia in diabetic NOD mice. J Exp Med 204:191–201
66. Tarbell K, Yamazaki S, Olson K et al (2004) CD25+CD4+ T cells, expanded with dendritic cells presenting a single autoantigenic peptide, suppress autoimmune diabetes. J Exp Med 199: 1467–1477
67. Ingram P, Howman R, Leahy M et al (2007) Cryptococcal immune reconstitution inflammatory syndrome following alemtuzumab therapy. Clin Infect Dis 12:115–117