(54) Method of treating IBD/Crohn's disease and related conditions wherein drug metabolite levels in host blood cells determine subsequent dosage

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( ) Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: 09/288,344
(22) Filed: Apr. 8, 1999

Related U.S. Application Data
(60) Provisional application No. 60/101,714, filed on Sep. 24, 1998.

(51) Int. Cl. 731/370

(52) U.S. Cl. 514/45; 514/47; 514/48; 514/262; 514/391; 514/395

(58) Field of Search 514/45, 47, 48, 514/262, 391, 395

(56) References Cited
U.S. PATENT DOCUMENTS
FOREIGN PATENT DOCUMENTS
WO 96/30021 10/1996

OTHER PUBLICATIONS

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ABSTRACT
The present invention provides a method of optimizing therapeutic efficacy and reducing toxicity associated with 6-mercaptopurine drug treatment of an immune-mediated gastrointestinal disorder such as inflammatory bowel disease. The method of the invention includes the step of determining the level of one or more 6-mercaptopurine metabolites in the patient having an immune-mediated gastrointestinal disorder.

54 Claims, 3 Drawing Sheets
OTHER PUBLICATIONS


* cited by examiner.
FIG. 3
METHOD OF TREATING IBD/CROHN'S DISEASE AND RELATED CONDITIONS WHEREIN DRUG METABOLITE LEVELS IN HOST BLOOD CELLS DETERMINE SUBSEQUENT DOSAGE

This application claims the benefit of priority of provisional application Ser. No. 60/101,714, filed Sep. 24, 1998, which is incorporated herein by reference now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates generally to autoimmunity and immune-mediated gastrointestinal disorders such as inflammatory bowel disease and more specifically to methods for optimizing treatment of immune-mediated gastrointestinal disorders.

BACKGROUND INFORMATION

Immune-mediated gastrointestinal disorders encompass a wide range of debilitating gastrointestinal diseases of various etiologies. One such immune-mediated gastrointestinal disorder, inflammatory bowel disease (IBD), is the collective term used to describe two gastrointestinal disorders of unknown etiology: Crohn's disease (CD) and ulcerative colitis (UC). The course and prognosis of IBD, which occurs world-wide and is reported to affect as many as two million people, varies widely. Onset of IBD is predominantly in young adulthood with diarrhea, abdominal pain, and fever being the three most common presenting symptoms. The diarrhea may range from mild to severe and in ulcerative colitis offers is accompanied by bleeding. Anemia and weight loss are additional common signs of IBD. Ten percent to fifteen percent of all patients with IBD will require surgery over a ten year period. In addition, patients with IBD are at increased risk for the development of intestinal cancer. Reports of an increasing occurrence of psychological problems, including anxiety and depression, are perhaps not surprising symptoms of what is often a debilitating disease that strikes people in the prime of life.

6-Mercaptopurine (6-MP) and azathioprine (AZA), a prodrug that is non-enzymatically converted to 6-mercaptopurine (6-MP), are 6-MP drugs that can be used as an effective treatment for inflammatory bowel diseases such as Crohn's disease and ulcerative colitis (Kirschner Gastroenterology 115:813–821 (1998)). 6-MP can be enzymatically converted to various 6-MP metabolites, including 6-methyl-mercaptopurine (6-MMP) and 6-thioguanine (6-TG) and their nucleotides. 6-TG nucleotides are thought to be the active metabolite in mediating many of the effects of 6-MP drug treatment.

Thiopurine methyltransferase (TPMT) is a cytoplasmic enzyme that preferentially catalyzes the S-methylation of 6-MP and 6-TG to form S-methylated metabolites such as 6-MMP and 6-methylthioguanine (6-MTG), respectively. TPMT exhibits genetic polymorphism, with 89% of Caucasians and African Americans having high activity, 11% intermediate activity and 1 in 300 TPMT deficient. Clinical studies with AZA and 6-MP have shown an inverse relationship between TPMT activity and 6-TGN accumulation. Patients who less efficiently methylate these thiopurines have more extensive conversion to 6-TGN, which can lead to potentially fatal hematopoietic toxicity. Therefore, patients who have less active TPMT can be more susceptible to toxic side effects of 6-MP therapy.

Although drugs such as 6-MP and AZA have been used for treating IBD, non-responsiveness and drug toxicity unfortunately complicate treatment in some patients. Complications associated with 6-MP drug treatment include allergic reactions, neoplasia, opportunistic infections, hepatitis, bone marrow suppression, and pancreatitis. Therefore, many physicians are reluctant to treat patients with AZA because of its potential side effects, especially infection and neoplasia.

Thus, there exists a need to develop methods to optimize the dose of 6-mercaptopurine drugs and assess biotransformation in individual patients to optimize the therapeutic efficacy of 6-mercaptopurine drugs while minimizing toxic side effects. The present invention satisfies this need and provides related advantages as well.

SUMMARY OF THE INVENTION

The present invention provides a method of optimizing therapeutic efficacy of 6-mercaptopurine drug treatment of an immune-mediated gastrointestinal disorder. The method includes the steps of administering a 6-mercaptopurine drug to a subject having an immune-mediated gastrointestinal disorder; and determining a level of 6-thioguanine in the subject having the immune-mediated gastrointestinal disorder, where a level of 6-thioguanine less than a level corresponding to about 230 pmol per 8x10^6 red blood cells indicates a need to increase the amount of 6-mercaptopurine drug subsequently administered to the subject and where a level of 6-thioguanine greater than a level corresponding to about 400 pmol per 8x10^6 red blood cells indicates a need to decrease the amount of 6-mercaptopurine drug subsequently administered to the subject. The methods are directed to treating immune-mediated gastrointestinal disorders, including inflammatory bowel diseases (IBD) such as Crohn’s disease and ulcerative colitis, lymphocytic colitis, microscopic colitis, collagenous colitis, autoimmune enteropathy, allergic gastrointestinal disease and eosinophilic gastrointestinal disease. In a method of optimizing therapeutic efficacy of 6-mercaptopurine treatment of IBD, the subject having IBD can be, for example, a pediatric subject. The level of 6-thioguanine can be determined, for example, in red blood cells using high pressure liquid chromatography.

The present invention also provides a method of reducing toxicity associated with 6-mercaptopurine drug treatment of an immune-mediated gastrointestinal disorder. The method of reducing toxicity associated with an immune-mediated gastrointestinal disorder includes the steps of administering a 6-mercaptopurine drug to a subject having the immune-mediated gastrointestinal disorder; and determining a level of a 6-mercaptopurine metabolite in the subject having the immune-mediated gastrointestinal disorder, where a level of the 6-mercaptopurine metabolite greater than a predetermined toxic level of the 6-mercaptopurine metabolite indicates a need to decrease the amount of 6-mercaptopurine drug subsequently administered to the subject, thereby reducing toxicity associated with 6-mercaptopurine drug treatment of the immune-mediated gastrointestinal disorder.

In a method of the invention, the 6-mercaptopurine metabolite can be, for example, 6-thioguanine and the predetermined toxic level of 6-thioguanine can correspond, for example, to a level of about 400 pmol per 8x10^6 red blood cells. Where the elevated 6-mercaptopurine metabolite is 6-thioguanine, the toxicity associated with 6-mercaptopurine treatment can be, for example, hematologic toxicity. The 6-mercaptopurine metabolite also can be a metabolite such as 6-methyl-mercaptopurine and the predetermined toxic level of 6-methyl-mercaptopurine can correspond, for example, to a level of about 7000 pmol per
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8x10^6 red blood cells. Where the elevated 6-mercaptopurine metabolite is 6-methyl-mercaptopurine, the toxicity associated with 6-mercaptopurine treatment can be, for example, hepatic toxicity.

Further provided by the invention is a method of optimizing therapeutic efficacy and reducing toxicity associated with 6-mercaptopurine drug treatment of an immune-mediated gastrointestinal disorder. The method includes the steps of administering a 6-mercaptopurine drug to a subject having an immune-mediated gastrointestinal disorder; determining a level of 6-thioguanine in the subject having the immune-mediated gastrointestinal disorder; and determining a level of 6-thioguanine less than a predetermined minimal therapeutic level indicates a need to increase the amount of 6-mercaptopurine drug subsequently administered to the subject, thereby increasing therapeutic efficacy; where a level of 6-thioguanine greater than a predetermined toxic level of 6-thioguanine indicates a need to decrease the amount of 6-mercaptopurine drug subsequently administered to the subject, thereby reducing toxicity associated with 6-mercaptopurine treatment of the immune-mediated gastrointestinal disorder.

In such a method of optimizing therapeutic efficacy and reducing toxicity associated with 6-mercaptopurine drug treatment of an immune-mediated gastrointestinal disorder, the level of the minimal therapeutic level of 6-thioguanine can be, for example, a level corresponding to about 230 pmol per 8x10^6 red blood cells; the predetermined toxic level of 6-thioguanine can be, for example, a level corresponding to about 400 pmol per 8x10^6 red blood cells; and the predetermined toxic level of 6-methyl-mercaptopurine can be, for example, a level corresponding to about 700 pmol per 8x10^6 red blood cells. The level of 6-thioguanine and 6-methyl-mercaptopurine each can be conveniently determined, for example, in red blood cells using high pressure liquid chromatography (HPLC). The invention further provides methods to optimize the therapeutic efficacy of 6-mercaptopurine drug treatment of a non-IBD autoimmune disease.

**BRIEF DESCRIPTION OF THE DRAWINGS**

**FIG. 1** shows mercaptopurine metabolism and the structures of 6-mercaptopurine (6-MP) metabolites. The initial metabolism of 6-MP is catalyzed by thiopurine methyltransferase (TPMT), xanthine oxidase (XO), and hypoxanthine phosphoribosyltransferase (HPRT). Further metabolism of the thionucleotide is catalyzed by inosine monophosphate dehydrogenase (IMPD) and guanosine monophosphate synthetase (GMPS). The breakdown of azathioprine to 6-mercaptopurine is nonenzymatic.

**FIG. 2** shows 6-mercaptopurine (6-MP) metabolism and the 6-MP metabolites that are measured as 6-MP, 6-thioguanine (6-TG) and 6-methyl-mercaptopurine (6-MMP) (indicated as “MP”, “TG” and “MMP” inside the base). 6-TG mono-phosphate is converted to the di- and tri-phosphate by monophosphate kinase (MPK) and diphosphate kinase (DPK), respectively. The ribonucleoside diphosphate is converted to deoxyribonucleoside diphosphate by ribonucleotide reductase (RR).

**FIG. 3** shows ranges of 6-thioguanine in IBD patients treated with a 6-MP drug.

**DETAILED DESCRIPTION OF THE INVENTION**

The present invention provides a method of optimizing therapeutic efficacy of 6-mercaptopurine (6-MP) drug treatment of an immune-mediated gastrointestinal disorder. The method includes the steps of administering a 6-MP drug to a subject having an immune-mediated gastrointestinal disorder; and determining a level of 6-thioguanine (6-TG) in the subject having the immune-mediated gastrointestinal disorder, where a level of 6-TG less than a level corresponding to about 230 pmol per 8x10^6 red blood cells indicates a need to increase the amount of 6-MP drug subsequently administered to the subject and where a level of 6-TG greater than a level corresponding to about 400 pmol per 8x10^6 red blood cells indicates a need to decrease the amount of 6-MP drug subsequently administered to the subject. The methods are directed to treating immune-mediated gastrointestinal disorders, including inflammatory bowel diseases (IBD) such as Crohn’s disease and ulcerative colitis, lymphocytic colitis, microscopic colitis, collaginous colitis, autoimmune enteropathy, allergic gastrointestinal disease and eosinophilic gastrointestinal disease. In a method of optimizing therapeutic efficacy of 6-MP treatment of IBD, the subject having IBD can be, for example, a pediatric subject. The level of 6-TG can be determined, for example, in red blood cells using high pressure liquid chromatography (HPLC).

The invention provides methods of optimizing therapeutic efficacy of 6-MP drug treatment of an immune-mediated gastrointestinal disorder. The methods of the invention are particularly useful for treating an immune-mediated gastrointestinal disorder such as IBD, including Crohn’s disease and ulcerative colitis and subtypes thereof. The methods of the invention allow the clinician to provide an individually optimized dosage of a 6-MP drug so as to achieve a target level of a 6-MP metabolite in a particular patient having an immune-mediated gastrointestinal disorder, thereby optimizing the effectiveness of 6-MP drug therapy in the patient. The methods of the invention for optimizing therapeutic efficacy of 6-MP drug treatment involve determining the level of 6-TG in a patient having an immune-mediated gastrointestinal disorder. As disclosed herein, the level of 6-TG measured in a patient treated with a 6-MP drug was an indicator of the effectiveness of drug treatment. A level of at least 230 pmol 6-TG/8x10^6 red blood cells (RBC) was found in responders to drug therapy (see Examples I and II). These results indicate that determining the level of 6-TG can be used to assess whether a patient has a level of 6-TG that is sufficient to alleviate symptoms of an immune-mediated gastrointestinal disorder such as IBD, thus optimizing therapeutic efficacy.

As used herein, the term “6-mercaptopurine drug” or “6-MP drug” refers to any drug that can be metabolized to an active 6-mercaptopurine metabolite that has therapeutic efficacy such as 6-TG. Exemplary 6-mercaptopurine drugs as defined herein include 6-mercaptopurine (6-MP) and azathioprine (AZA). As illustrated in FIG. 1, both of 6-MP and AZA can be metabolized to 6-mercaptopurine metabolites such as the exemplary 6-mercaptopurine metabolites shown in FIG. 1, including 6-thioguanine (6-TG), 6-methyl-mercaptopurine (6-MMP) and 6-thioctic acid (Lehmarb, Eur. J. Clin. Pharmacol. 43:329—339 (1992)).

Other 6-MP drugs include, for example, 6-methylmercaptopurine riboside and 6-TG (Loo et al., Clin.
The most frequent symptoms of CD are abdominal pain, diarrhea and recurrent fever. CD is commonly associated with intestinal obstruction or fistula, which is an abnormal passage between diseased loops of bowel, for example. Crohn’s disease also includes complications such as inflammation of the eye, joints and skin; liver disease; kidney stones or amyloidosis. In addition, CD is associated with an increased risk of intestinal cancer. Several features are characteristic of the pathology of Crohn’s disease. The inflammation associated with CD, known as transmural inflammation, involves all layers of the bowel wall. Thickening and edema, for example, typically also appear throughout the bowel wall, with fibrosis also present in long-standing disease. The inflammation characteristic of CD also is discontinuous in that segments of inflamed tissue, known as “skip lesions,” are separated by apparently normal intestine. Furthermore, linear ulcerations, edema, and inflammation of the intervening tissue lead to a “cobblestone” appearance of the intestinal mucosa, which is distinctive of CD.

A hallmark of Crohn’s disease is the presence of discrete aggregations of inflammatory cells, known as granulomas, which are generally found in the submucosa. Some Crohn’s disease cases display the typical discrete granulomas, while others show nonspecific transmural inflammation. As a result, the presence of discrete granulomas is indicative of CD, although the absence of granulomas also is consistent with the disease. Thus, transmural or discontinuous inflammation, rather than the presence of granulomas, is a preferred diagnostic indicator of Crohn’s disease (Rubin and Farber, Pathology (Second Edition) Philadelphia: J. B. Lippincott Company (1994)).

Ulcerative colitis (UC) is a disease of the large intestine characterized by chronic diarrhea with cramping abdominal pain, rectal bleeding, and loose discharges of blood, pus and mucus. The manifestations of ulcerative colitis vary widely. A pattern of exacerbations and remissions typifies the clinical course of most UC patients (70%), although continuous symptoms without remission are present in some patients with UC. Local and systemic complications of UC include arthritis, eye inflammation such as uveitis, skin ulcers and liver disease. In addition, ulcerative colitis and especially long-standing, extensive disease is associated with an increased risk of colon carcinoma.

Several pathologic features characterize UC in distinction to other inflammatory bowel diseases. Ulcerative colitis is a diffuse disease that usually extends from the most distal part of the rectum for a variable distance proximally. The term left-sided colitis describes an inflammation that involves the distal portion of the colon, extending as far as the splenic flexure. Sparing of the rectum or involvement of the right side (proximal portion) of the colon alone is unusual in ulcerative colitis. The inflammatory process of ulcerative colitis is limited to the colon and does not involve, for example, the small intestine, stomach or esophagus. In addition, ulcerative colitis is distinguished by a superficial inflammation of the mucosa that generally spares the deeper layers of the bowel wall. Crypt abscesses, in which degenerated intestinal crypts are filled with neutrophils, also are typical of ulcerative colitis (Rubin and Farber, supra, 1994).

In comparison with Crohn’s disease, which is a patchy disease with frequent sparing of the rectum, ulcerative colitis is characterized by a continuous inflammation of the colon that usually is more severe distally than proximally. The inflammation in ulcerative colitis is superficial in that it is usually limited to the mucosal layer and is characterized by
an acute inflammatory infiltrate with neutrophils and crypt abscesses. In contrast, Crohn’s disease affects the entire thickness of the bowel wall with granulomas often, although not always, present. Disease that terminates at the ileocecal valve, or in the colon distal to it, is indicative of ulcerative colitis, while involvement of the terminal ileum, a cobblestone-like appearance, discrete ulcers or fistulas suggest Crohn’s disease.

In addition to IBD, immune-mediated GI disorders also include other gastrointestinal diseases such as lymphocytic colitis; microscopic colitis; collagenous colitis; autoimmune enteropathy, including autoimmune enteritis and autoimmune enterocolitis; allergic gastrointestinal disease; and eosinophilic gastrointestinal disease, including eosinophilic gastroenteritis and eosinophilic enteropathy.

Over the past two decades, the histological evaluation of colorectal biopsies obtained by colonoscopy has expanded the spectrum of chronic IBD. A new group of immune-mediated bowel disorders has emerged, characterized by chronic watery diarrhea, minimal or absent endoscopic findings, and inflammatory changes in mucosal biopsies. Lymphocytic colitis, also commonly referred to as microscopic colitis, is a clinicopathological syndrome characterized primarily by lymphocytic infiltration of the epithelium. Collagenous colitis is defined by the presence of a collagenous band below the surface epithelium, accompanied by an increase in inflammatory cell infiltrate (Lazenby et al. Hum. Pathol. 20:18–28 (1989)). These disorders are often associated with other autoimmune diseases such as rheumatoid arthritis, pernicious anemia, thyroiditis, uveitis and type I diabetes mellitus. Clinicians have used immunosuppressive drugs, including 6-MP, to treat these disorders (Deslandres et al. J. Pediatr. Gastroenterol. Nutr. 25:341–346 (1997)).

Autoimmune enteropathy, including autoimmune enteritis and autoimmune enterocolitis, is a syndrome of severe secretory diarrhea and marked enterocolitis, in association with diagnostic circulating antibodies to enterocytes (Scidman et al., J. Pediatr. 117:329–332 (1990)). This syndrome, most often seen in infancy, can be seen in association with other autoimmune diseases. Complete villous atrophy is associated with a severe inflammatory reaction on small bowel biopsies. Although some cases remit after an extended period of time, most patients die without immunosuppressive therapy, which can include 6-MP drug therapy.

Eosinophilic gastrointestinal disease, including eosinophilic gastroenteritis and eosinophilic enteropathy, is characterized by a dense infiltration of eosinophils in one or more areas of the gastrointestinal tract, variable intestinal symptoms, and usually a peripheral eosinophilia (80% of cases). Food allergic, including allergic gastrointestinal disease, and eosinophilic disorders of the gastrointestinal tract are commonly treated by dietary elimination of the offending nutrients. However, both food induced and eosinophilic enteropathies may, in certain circumstances, require corticosteroid and immunosuppressive therapy, including 6-MP (Russo et al., Pediatric Dev. Path. 2:65–71 (1999)).

The methods of the invention relate to optimizing therapeutic efficacy of 6-MP drug treatment of an immune-mediated GI disorder, including IBD such as Crohn’s disease and ulcerative colitis and subtypes thereof. The methods of the invention are particularly useful for treating patients dependent on steroid therapy for maintenance of remission of disease in Crohn’s disease and ulcerative colitis patients. As used herein, the phrase “optimizing therapeutic efficacy of 6-MP drug treatment” refers to adjusting the therapeutic dosage of a 6-MP drug such as 6-MP or azathioprine so that the concentration of a 6-MP metabolite that is correlated with effective treatment is maintained. As set forth above, the methods of the invention allow the clinician to provide an individually optimized dosage of a 6-MP drug so as to achieve a target level of a 6-MP metabolite in a particular patient, thereby optimizing the effectiveness of 6-MP drug therapy in the patient. The therapeutic efficacy generally is indicated by alleviation of one or more signs or symptoms associated with the disease. In the case of immune-mediated GI disorders, in particular IBD, therapeutic efficacy is indicated by alleviation of one or more signs or symptoms associated with the disease, including, for example, joint pain, arthritis, arthralgia, anorexia, growth failure, fistula closure, abdominal pain, diarrhea, recurrent fever, anemia, weight loss, rectal bleeding, inflammation of the intestine, and loose discharges of blood, pus and mucus. Methods for determining therapeutic efficacy, in particular for treating IBD, are disclosed herein in Examples I and II.

Therapeutic efficacy can be readily determined by one skilled in the art as the alleviation of one or more signs or symptoms of the disease being treated. In the case of IBD, patients can be analyzed using a Crohn’s disease activity index (Best et al., Gastroenterology 70:439–444 (1976)). IBD patients can also be analyzed using a Harvey-Bradshaw index (HBD) (Harvey and Bradshaw, Lancet 1:514 (1980)). The Harvey-Bradshaw index provides an analytical method for measuring signs or symptoms of Crohn’s disease, including the signs or symptoms of general well-being, abdominal pain, number of liquid stools per day, abdominal mass, and complications such as arthralgia, uveitis, erythema nodosum, aphthous ulcers, pyoderma gangrenosum, anal fissure, new fistula and abscess. The Harvey-Bradshaw index is particularly useful when evaluating pediatric patients.

Previous studies suggested that measurement of 6-MP metabolite levels can be used to predict clinical efficacy and tolerance to azathioprine or 6-MP (Cuffari et al., Gut 39:401–406 (1996a)). However, it was unknown what concentrations of 6-MP metabolites correlated with optimized therapeutic efficacy or with toxicity (Cuffari et al., supra, 1996a). As disclosed herein, levels of 6-MP metabolites such as 6-TG and 6-MMP were determined and correlated with therapeutic efficacy and toxicity associated with 6-MP drug therapy (see Examples I and II).

The invention is directed to methods of optimizing therapeutic efficacy of 6-MP drug treatment of an immune-mediated GI disorder by monitoring predetermined levels associated with therapeutic efficacy or toxicity and adjusting the 6-MP drug dosage so as to maintain an optimized dose that is efficacious and has reduced toxicity. The methods involve administering a 6-MP drug such as 6-MP or azathioprine to a subject having an immune-mediated GI disorder and determining a level of a 6-MP metabolite in the subject having the immune-mediated GI disorder. The methods of the invention are advantageous in that the dosage of a 6-MP drug can be adjusted to maximize the efficacy of treating an immune-mediated GI disorder such as IBD while minimizing toxicity associated with 6-MP drug treatment.

As used herein, the term “6-mercaptopurine metabolite” refers to a product derived from 6-mercaptopurine in a biological system. Exemplary 6-mercaptopurine metabolites are shown in FIG. 1 and include 6-thioguanine (6-TG), 6-methyl-mercaptopurine (6-MMP) and 6-thiouric acid and analogues thereof. For example, 6-MP metabolites include 6-TG bases such as 6-TG, 6-thioguanosine mono-, di- and
tri-phosphate; 6-MMP bases such as 6-methylmercaptopyrine and 6-methylthiosinosine monophosphate; 6-thiokinosine (6-TX) bases such as 6-thiokinosine mono-phosphate; 6-thiouric acid (6-TUA); and 6-MP bases such as 6-mercaptopurine and 6-thiouric acid phosphate (see FIG. 2). The immunosuppressive properties of 6-MP are believed to be mediated via the intracellular transformation of 6-MP to its active metabolites such as 6-TG and 6-MMP nucleosides. Furthermore, 6-MP metabolites such as 6-TG and 6-MMP were found to correlate with therapeutic efficacy and toxicity associated with 6-MP drug treatment of IBD patients (see Examples I and II).

The level of a 6-MP metabolite can be determined by methods well known in the art including, for example, those described in Lileyman and Lennard, Lancet 343:1188–1190 (1994); Lennard and Singleton, J. Chromatography Biomed. Applications 583:83–90 (1992); Lennard and Singleton, J. Chromatography 661:25–33 (1994); and Cuffari et al., Can. J. Physiol. Pharmacol. 74:580–585 (1996b)). 6-MP metabolites such as 6-TG and 6-MMP can be measured, for example, by collecting red blood cells and extracting thiobases, for example, 6-MP, 6-TG, 6-TX and 6-MMP, which are acrylamide by acid hydrolysis of 6-MMP is converted to a form extractable by phenyl mercury salts (Dervieux and Boulieu, Clin. Chem. 44:2511–2525 (1998); Duchesne et al., Proc. Amer. Soc. Clin. Oncol. 13:137 (1994a); Duchesne et al., Can. J. Physiol. Pharmacol. 72:197 (1994b)). Such an analysis measures the thiobase and its analogues, including ribonucleoside, ribonucleotide, deoxyribonucleoside, deoxyribo nucleotide thiobases as well as mono-, di- and triphosphate analogues, which have been converted to thio bases.

Acid hydrolyzed extracts can be analyzed by resolving 6-MP metabolites and measuring their levels. For example, HPLC such as reverse phase HPLC is a useful method for resolving and measuring the levels of 6-MP metabolites, including 6-MP, 6-TG, and 6-MMP (Lennard and Singleton, supra, 1992). Ultraviolet light (UV) detection can be used to measure the 6-MP metabolites. A particularly useful method of measuring 6-MP metabolites is isocratic reverse phase HPLC with UV detection (Cuffari et al., supra, 1996b).

Other methods for measuring 6-MP metabolites can also be used. For example, ion-pairing HPLC with dual UV-wavelength detection can be used to measure 6-MP metabolites (Zimm and Strong, Anal. Biochem. 160:1–6 (1987)). Additional methods for measuring 6-MP metabolites include, for example, capillary electrophoresis with laser-induced fluorescence detection (Rabel et al., Anal. Biochem. 224:315–322 (1995)); anion exchange chromatography and fluorescent detection (Tidd and Dedhar J. Chromatography 145:237–246 (1978)); lanthanum precipitation, acid hydrolysis, back extraction and fluorometric assay (Fletcher and Maddocks, Brit. J. Clin. Pharmacol. 10:287–292 (1980)); thin layer chromatography (Bennet and Allen, Cancer Res. 31:152–158 (1971)); precolumn derivatization with the thiol-reactive fluorophore monobromobimane, treatment with alkylphosphatase, HPLC resolution and quantification by fluorometry (Warren and Sordal, Anal. Biochem. 215:278–283 (1993)); and enzymatic hydrolysis followed by HPLC separation and UV detection (Gierthuys et al., Ther. Drug Monit. 19:663–668 (1997)). 6-MP metabolites such as 6-TG can also be measured in DNA by degrading DNA to deoxyribonucleosides, derivatizing deoxy-6-TG with a fluorophore and resolving on reverse phase HPLC (Warren et al., Cancer Res. 55:1670–1674 (1995)).

As used herein, the level of a 6-MP metabolite can include the 6-MP metabolite itself, or the level of the 6-MP metabolite and analogues thereof. For example, as described above, acid hydrolysis can be used to release thionucleotides from a sample, resulting in conversion of mono-, di- and tri-phosphates to thiobases. In such an analysis, the level of several analogues of a thionucleotide are measured (see FIG. 2). For example, measuring 6-TG can include 6-thioguanosine 5’-mono-, di-, and tri-phosphate, and 6-thiodeoxyguanosine 5’-di- and tri-phosphate. Measuring 6-MP can include 6-mercaptopurine and 6-thiouricosine 5’-monophosphate. Measuring 6-MMP can include 6-methylmercaptopyrine and 6-methylthiosinosine 5’-monophosphate, and can also include 6-methylthioinosine di- and tri-phosphate, as well as 6-methylthiouricosine.

A particularly useful determination of the level of a 6-MP metabolite is the median level of the 6-MP metabolite since the distribution of 6-MP metabolite values is trimodal. Unless otherwise designated, the levels referred to herein are median levels. A 6-MP metabolite level can also be a mean level, if so desired. Unless otherwise designated, the levels of 6-MP metabolites referred to herein are values per 8×10⁶ RBC, whether reported as mean or median values.

6-MP metabolite levels can be conveniently assayed using red blood cells because such cells are readily available from the patient, lack a nucleus and are easy to manipulate. However, it should be understood that any measurement that allows determination of 6-MP metabolite levels can be used. For example, leukocytes can be used to measure 6-MP metabolite levels, which can be correlated with 6-MP metabolite levels in erythrocytes (Cuffari et al., supra, 1996b).

Regardless of the method employed to measure 6-MP metabolites, one skilled in the art can readily measure 6-MP metabolite levels in a sample, for example, in leukocytes or DNA obtained from a patient, and correlate the level of 6-MP metabolites to the values disclosed herein, which were determined using RBC.

For convenience, levels of 6-MP metabolites disclosed herein are given in terms of an assay with RBC and, therefore, are given as an amount of a 6-MP metabolite in a given number of RBCs. 6-MP metabolites assayed in RBCs can also be determined relative to the amount of hemoglobin. However, it should be understood that one skilled in the art can measure 6-MP metabolite levels in samples other than RBCs and readily correlate such levels with 6-MP metabolite levels in RBCs. For example, one skilled in the art can readily determine levels of a 6-MP metabolite in cells such as leukocytes, or cells from the oral mucosa, and in RBCs by measuring the level of 6-MP metabolites in both types of cells and determining the correspondence between levels of 6-MP metabolites in RBCs and the levels in the other cells. Once a correspondence between 6-MP metabolites in RBCs and in a sample has been determined, one skilled in the art can use that correspondence to measure levels in the other sample and correlate those levels with the levels in RBCs disclosed herein.

As disclosed herein, the level of 6-TG in an IBD patient treated with a 6-MP drug was found to correlate with therapeutic efficacy (see Examples I and II). In particular, a median level of 230 pmol 6-TG per 8×10⁶ RBC can be a minimal therapeutic level of 6-TG for efficaciously treating a patient. Accordingly, a level of 6-TG below about 230 pmol/8×10⁶ RBC indicates a need to increase the amount of a 6-MP drug administered to the patient. A minimal therapeutic level of 6-TG for efficaciously treating a patient can also be for, example, at least
about 240 pmol per 8x10⁵ RBC; at least about 250 pmol per
8x10⁵ RBC; at least about 260 pmol per 8x10⁵ RBC; at least
about 280 pmol per 8x10⁵ RBC or at least about 300 pmol per
8x10⁶ RBC. It is understood that the minimal therapeutic
levels of 6-TG disclosed herein are useful for treating
immune-mediated gastrointestinal disorders, including IBD,
as well as non-IBD autoimmune diseases.

The methods of the invention directed to determining
whether a patient has a minimal therapeutic level of a 6-MP
metabolite such as 6-TG and who also presents as unresponsive to
6-MP drug therapy or having poor responsiveness to 6-MP
drug therapy as measured by minimal or no effect on a sign
or symptom of the disease being treated, one skilled in the
art can determine that the dosage of a 6-MP drug should
be increased. However, if it is determined that a patient has
less than a predetermined minimal therapeutic level of a 6-MP
metabolite but is responsive to 6-MP therapy, the current
dose of 6-MP drug can be maintained. Based on measuring
6-MP metabolite levels and assessing the responsiveness of
the patient to 6-MP therapy, one skilled in the art can
determine whether a 6-MP drug dose should be maintained,
increased, or decreased.

Although 6-MP drugs such as 6-MP and azathioprine
can be used for effective treatment of an immune-mediated GI
disorder, including IBDs such as Crohn’s disease or ulcerative
colitis, administration of such drugs can be associated with
toxic side effects. Toxicities associated with 6-MP drug
administration include pancreatitis, bone marrow
regression, allergic reactions and drug hepatitis as well as
eosinophilic and infectious complications (Present et al.,
Annals Int. Med. 111:641—649 (1989); Cullif et al., supra,
1996a). As disclosed herein, various toxicities associated
with 6-MP drug treatment, including hepatic toxicity, pan-
creatic toxicity and hematologic toxicity, correlate with the
level of 6-MP metabolites in a subject administered a 6-MP
drug (see Examples I and II).

Thus, the present invention also provides a method of
reducing toxicity associated with 6-MP drug treatment of an
immune-mediated GI disorder. The method of the invention
for reducing toxicity associated with 6-MP drug treatment
includes the steps of administering a 6-MP drug to a subject
having an immune-mediated GI disorder; and determining a
level of a 6-MP metabolite in the subject having the
immune-mediated GI disorder, where a level of the 6-MP
metabolite greater than a predetermined toxic level of the
6-MP metabolite indicates a need to decrease the amount of
6-MP drug subsequently administered to the subject, thereby
reducing toxicity associated with 6-MP drug treatment of the
immune-mediated GI disorder. In a method of the invention
where the 6-MP metabolite can be, for example, 6-TG and the
predetermined toxic level of 6-TG can correspond, for
example, to a level of about 400 pmol per 8x10⁵ red blood
cells. Where the elevated 6-MP metabolite is 6-TG, the
toxicity associated with 6-MP treatment can be, for example,
hematologic toxicity, including leukopenia or bone marrow
suppression. The 6-MP metabolite also can be a metabolite
such as 6-MMP, and the predetermined toxic level of 6-MMP
can correspond, for example, to a level of about 7000 pmol per
8x10⁵ red blood cells. Where the elevated 6-MP metabolite
is 6-MMP, the toxicity associated with 6-MP drug treatment
can be, for example, hepatic toxicity.

As disclosed herein, the level of a 6-MP metabolite can be
determined in a subject treated with a 6-MP drug and
compared to a predetermined toxic level of a 6-MP metabo-
lite such as 6-TG or 6-MMP to adjust future 6-MP drug
administration, thereby reducing toxicity in the subject. For
example, as disclosed herein, levels of 6-TG above about
400 pmol/8x10⁵ RBC indicated that a patient was likely to
experience toxicity, in particular hematologic toxicity such as
leukopenia (see Examples I and II). Accordingly, a level
of 6-TG above about 400 pmol/8x10⁵ RBC can be a
determined toxic level of 6-TG, which indicates that the
amount of 6-MP drug subsequently administered should be
decreased. It is understood that, when a patient is determined to have
a level of a 6-MP metabolite such as 6-TG or 6-MMP higher than a
determined toxic level, one skilled in the art can make a
determination as to whether a 6-MP drug dose should be
decreased. For example, if the level of a 6-MP
metabolite such as 6-TG or 6-MMP is higher than a
determined toxic level, one skilled in the art can monitor for
toxic side effects by measuring one or more of the toxicities
associated with 6-MP drug treatment, as disclosed herein. As
disclosed herein, a level of 6-TG greater than about 400
pmol per 8x10⁵ RBCs was associated with increased risk of
leukopenia or bone marrow suppression. Therefore, one
skilled in the art can measure white blood cells (WBC) in a
patient having levels of 6-TG higher than a predetermined
toxic level to determine if the patient is exhibiting signs of
reduced WBC counts. If such a patient exhibits signs of
leukopenia or bone marrow suppression, the 6-MP drug
can be reduced. However, if it is determined that a patient
has levels of a 6-MP metabolite higher than a predetermined
toxic level but does not exhibit signs of leukopenia or other
6-MP drug toxicities, one skilled in the art can determine
that the current 6-MP drug dose can be maintained. Based on
measuring 6-MP metabolite levels and determining signs or
symptoms of toxicities associated with 6-MP drug treatment,
one skilled in the art can determine whether a 6-MP drug
dose should be maintained or decreased. As such, a level of
a 6-MP metabolite higher than a predetermined toxic level
can indicate a need to measure a toxicity associated with
6-MP drug treatment such as measuring WBCs or any of the
other signs or symptoms of toxicities associated with 6-MP
drug treatment to determine if the 6-MP drug dose should be
adjusted.

Furthermore, it is understood that, when decreasing the
6-MP drug dose, one skilled in the art will know or can readily
determine whether the 6-MP drug dose should be
decreased to a lower dose or whether 6-MP drug
administration should be stopped for some period of time, or
terminated. For example, if the clinician determines that
6-MP drug therapy should be stopped for some period of
time due to levels of a 6-MP metabolite exceeding a level
predetermined to be toxic, the levels of 6-MP metabolites
can be monitored after stopping 6-MP drug therapy until the
level of the toxic 6-MP metabolite returns to a safe, non-
toxic level. At that time, the clinician can resume 6-MP drug
therapy, if desired.

The methods of the invention for reducing toxicity associ-
ated with 6-MP drug treatment of a disease involve compar-
ing a level of a 6-MP metabolite to a predetermined toxic
level of a 6-MP metabolite. In general, a “predetermined
toxic level” of a 6-MP metabolite means a level of a 6-MP
metabolite that has been correlated with one or more toxic-
ities associated with 6-MP drug treatment. As disclosed
herein, a predetermined toxic level of 6-TG can be about
400 pmol per 8x10⁵ RBC. A predetermined toxic level of 6-TG
also can be about 350 pmol per 8x10⁵ RBC; 370 pmol per
8x10⁵ RBC; 390 pmol per 8x10⁵ RBC; 425 pmol per 8x10⁵
RBC; or 450 pmol per 8x10^10 RBC. It is understood that the predetermined toxic levels of 6-TG disclosed herein are useful for treating immune-mediated GI disorders, including IBD, as well as non-IBD autoimmune diseases. Another 6-MP metabolite useful for predicting the likelihood of toxicity is 6-methyl-mercaptopyrimidine (6-MMP). As disclosed herein, a level of greater than about 7000 pmol 6-MMP/8x10^10 in patients administered a 6-MP drug was associated with toxicity, in particular hepatotoxicity (see Examples I and II). These results indicate that the level of 6-MMP can be used to predict toxicity in a patient treated with a 6-MP drug. As disclosed herein, a predetermined toxic level of 6-MMP can be about 7000 pmol per 8x10^10 RBC. A predetermined toxic level of 6-MMP also can be about 6000 pmol per 8x10^10 RBC; 5000 pmol per 8x10^10 RBC; 7500 pmol per 8x10^10 RBC; or 8000 pmol per 8x10^10 RBC. It is understood that the predetermined toxic levels of 6-MMP disclosed herein are useful for treating immune-mediated GI disorders, including IBD, as well as non-IBD autoimmune diseases. According to a method of the invention, if the level of 6-MMP is above a predetermined toxic level, the subsequent administration of a 6-MP drug can be decreased to minimize toxicity.

Further provided by the invention is a method of optimizing therapeutic efficacy and reducing toxicity associated with 6-MP drug treatment of an immune-mediated GI disorder such as IBD. The method includes the steps of administering a 6-MP drug to a subject having an immune-mediated GI disorder; determining a level of 6-TG in the subject having the immune-mediated GI disorder; and determining a level of 6-MMP in the subject having the immune-mediated GI disorder, where a level of 6-TG less than a predetermined minimal therapeutic level indicates a need to increase the amount of 6-MP drug subsequently administered to the subject, thereby increasing therapeutic efficacy; where a level of 6-TG greater than a predetermined toxic level of 6-TG indicates a need to decrease the amount of 6-MP drug subsequently administered to the subject, thereby reducing toxicity associated with 6-MP treatment of the immune-mediated GI disorder; and where a level of 6-MMP greater than a predetermined toxic level of 6-MMP indicates a need to decrease the amount of 6-MP drug subsequently administered to the subject, thereby reducing toxicity associated with 6-MP drug treatment of the immune-mediated GI disorder.

In such a method of optimizing therapeutic efficacy and reducing toxicity associated with 6-MP drug treatment of an immune-mediated GI disorder such as IBD, the predetermined minimal therapeutic level of 6-TG can be, for example, a level corresponding to about 230 pmol per 8x10^10 red blood cells; the predetermined toxic level of 6-TG can be, for example, a level corresponding to about 400 pmol per 8x10^10 red blood cells; and the predetermined toxic level of 6-MMP can be, for example, a level corresponding to about 7000 pmol per 8x10^10 red blood cells. In a method of the invention, the subject having an immune-mediated GI disorder such as IBD can be, for example, a pediatric subject. The level of 6-TG and 6-MMP each can be conveniently determined, for example, in red blood cells using HPLC.

The methods of the invention are useful for optimizing the amount of a 6-MP drug to be administered to a patient with an immune-mediated GI disorder such as IBD. By measuring the levels of 6-MP metabolites such as 6-MMP and 6-TG, one skilled in the art can determine the 6-MP drug dosage that will result in optimized therapeutic efficacy and reduced toxicity when administered to a patient. As disclosed herein, gender and age differences were observed in pediatric patients treated with 6-MP drug therapy (see Example III). Very little change in 6-MP metabolite levels of 6-TG and 6-MMP was seen for girls who had gone through puberty (older than age 12). However, boys who had gone through puberty (older than age 14) had a marked decrease in the level of 6-MMP, suggesting that hormonal changes occurring during puberty can affect the metabolism of a 6-MP drug. Therefore, the methods of the invention can additionally be used to monitor 6-MP metabolite levels in adolescents, particularly those going through puberty, in order to optimize therapeutic efficacy or minimize toxic side effects associated with 6-MP therapy.

As disclosed herein, TPMT genotyping is useful for predicting the effectiveness of 6-MP therapy in an IBD patient (see Example IV). Heterozygote patients are expected to have lower TPMT activity and should therefore be monitored for high levels of 6-TG for possible toxic levels associated with leukopenia or bone marrow suppression. 6-MP drug doses can be reduced accordingly. Wild type homozygous patients are expected to have high TPMT activity and should therefore be monitored to maintain an effective therapeutic level of 6-TG and to determine if patients develop toxic levels of 6-MMP. Homozygous patients deficient in TPMT activity can be treated with lower doses of a 6-MP drug provided that patients are closely monitored for toxicity such as leukopenia. Therefore, TPMT genotyping can be used to predict patient responsiveness to and potential toxicities associated with 6-MP drug therapy. Furthermore, TPMT genotyping can be combined with other methods of the invention to both determine TPMT genotype and to monitor 6-MP metabolites. TPMT genotyping can be particularly valuable when determining a starting dose of 6-MP drug therapy but can also be useful when adjusting 6-MP drug doses after therapy has begun.

The invention additionally provides a method of optimizing therapeutic efficacy of 6-MP drug treatment of a non-IBD autoimmune disease. The method includes the steps of administering a 6-MP drug to a subject having a non-IBD autoimmune disease; and determining a level of 6-thioguanine (6-TG) in the subject having the non-IBD autoimmune disease, where a level of 6-TG less than a minimal therapeutic level indicates a need to increase the amount of 6-MP drug subsequently administered to the subject and where a level of 6-TG greater than a predetermined toxic level indicates a need to decrease the amount of 6-MP drug subsequently administered to the subject. The level of 6-MMP can also be monitored in a patient having a non-IBD autoimmune disease to determine if the level is higher than a predetermined toxic level of 6-MMP.

The methods of the invention can be used to optimize therapeutic efficacy of 6-MP drug treatment of a non-IBD autoimmune disease. Such a non-IBD autoimmune disease can be any non-IBD autoimmune disease treatable by a 6-MP drug such as 6-MP or azathioprine and, in particular, can be a disease such as rheumatoid arthritis, systemic lupus erythematosus, autoimmune hepatitis (chronic active hepatitis) or pemphigus vulgaris.

As used herein, the term “non-IBD autoimmune disease” means a disease resulting from an immune response against a self tissue or tissue component, including both self antibody responses and cell-mediated responses. The term non-IBD autoimmune disease encompasses organ-specific non-IBD autoimmune diseases, in which an autoimmune response is directed against a single tissue, including myasthenia gravis, vitiligo, Graves’ disease, Hashimoto’s disease, Addison’s disease, autoimmune gastritis, and Type I diabetes mellitus. The term non-IBD autoimmune disease
also encompasses non-organ specific autoimmune diseases, in which an autoimmune response is directed against a component present in several or many organs throughout the body. Non-organ specific autoimmune diseases include, for example, systemic lupus erythematosus, progressive systemic sclerosis and variants, polymyositis and dermatomyositis, and rheumatoid disease. Additional non-IBD autoimmune diseases include pernicious anemia, primary biliary cirrhosis, autoimmune thrombocytopenia, and Sjögren’s syndrome. One skilled in the art understands that the methods of the invention can be applied to these or other non-IBD autoimmune diseases treatable by a 6-MP drug such as 6-MP or azathioprine, or other 6-MP drugs, as desired. Specifically excluded from the term “non-IBD autoimmune disease” are diseases resulting from a graft versus host response and inflammatory bowel diseases such as Crohn’s disease or ulcerative colitis.

The methods of the invention are also useful for treating a non-immune-mediated GI disorder autoimmune disease. As used herein, the term “non-immune-mediated GI disorder autoimmune disease” is a non-IBD autoimmune disease and specifically excludes immune-mediated GI disorders.

The methods of the invention can be particularly useful for optimizing therapeutic efficacy of 6-MP drug treatment of rheumatoid arthritis. Rheumatoid arthritis is a chronic systemic disease primarily of the joints, usually polyarticular, marked by inflammatory changes in the synovial membranes and articular structures and by muscle atrophy and rarefaction of the bones.

The methods of the invention also can be particularly valuable for optimizing therapeutic efficacy of 6-MP drug treatment of lupus erythematosus and, in particular, systemic lupus erythematosus (SLE). Systemic lupus erythematosus is a chronic, remitting, relapsing inflammatory, and sometimes febrile multisystemic disorder of connective tissue. SLE can be acute or insidious at onset and is characterized principally by involvement of the skin, joints, kidneys and serosal membranes.

Autoimmune hepatitis, also called chronic active hepatitis, also can be treated with a 6-MP drug and the dose optimized using the methods of the invention. Autoimmune hepatitis is a chronic inflammation of the liver occurring as a sequel to hepatitis B or non-A, non-B hepatitis and is characterized by infiltration of portal areas by plasma cells and macrophages, piecemeal necrosis, and fibrosis.

The methods of the invention also can be useful for treating pemphigus vulgaris, the most common and severe form of pemphigus, which is a chronic, relapsing and sometimes fatal skin disease characterized clinically by the development of successive crops of vesicles and bullae treated by azathioprine. This disorder is characterized histologically by acantholysis, and immunologically by serum autoantibodies against antigens in the intracellular zones of the epidermis.

The methods of the invention can also be used to optimize the therapeutic efficacy of 6-MP drug treatment of graft versus host disease, which can occur in transplant patients. Graft versus host disease occurs when a transplant patient has an immune reaction to the non-self transplant organ or tissue. The methods of the invention for optimizing the therapeutic efficacy of 6-MP drug treatment is particularly useful for treating heart, kidney and liver transplant recipients. The methods of the invention can be used to optimize therapeutic efficacy and/or minimize toxicity associated with 6-MP drug treatment of a transplant patient.

The following examples are intended to illustrate but not limit the present invention.

EXAMPLE 1

6-Mercaptopurine Metabolic Levels Predict Clinical Efficacy and Drug Toxicity in Pediatric IBD

This example describes measuring 6-MP metabolite levels and correlation with the response of IBD patients treated with a 6-MP drug.

The levels of the 6-MP metabolites 6-TG and 6-MMP were measured in IBD patients to whom 6-MP pro-drug was administered, and the relationship of 6-MP metabolites to clinical disease activity and drug toxicity was determined. Briefly, blood was sampled (n=89) prior to daily administration of 6-MP in 55 IBD patients (CD n=51, UC n=4) receiving 1–1.5 mg/kg/day over at least a 4 month period (3±4 mo). When AZA was administered, a conversion factor of 2.07 was used to convert to the equivalent 6-MP dose. Twice as much AZA is administered relative to 6-MP to have an equivalent dose of 6-MP.

Erythrocyte 6-TG, 6-MMP and 6-MP thiobases were measured (pmol/8×10^8 RBC) using reverse phase HPLC. Briefly, blood samples were collected in EDTA (ethylene diamine tetraacetic acid) as anticoagulant. Cells were centrifuged and washed three times with an equal volume of 0.9% saline. Washed packed cells were stored at ~70° C until analysis was performed.

For acid hydrolysis, 500 μl deionized H₂O, 50 μl thawed red blood cells, 40 μl of the appropriate standard or control, 500 μl 3.0 N H₂SO₄, and 300 μl 10 mM dithiobis (2-nitrobenzoic acid) (DTNB) was added to an 8 ml glass screw cap tube. The capped tubes were placed in a heating block preheated to 100° C and hydrolyzed. For 6-MMP, hydrolysis was carried out for 5 hours. For 6-MP and 6-TG, hydrolysis was carried out for 1 hour. After the incubation, tubes were cooled in a room temperature water bath. To tubes hydrolyzed for 5 hours (6-MMP), 400 μl 3.4 N NaOH and 1.0 ml 2 M Tris buffer, pH 9.0 was added. To tubes hydrolyzed for 1 hour (6-MP/6-TG), 450 μl 3.4 N NaOH and 500 μl 2 M Tris base was added. A volume of 4 ml 8% phenylmercuric chloride in methylene chloride was added to each tube. The tubes were capped and lightly agitated on a bi-directional rotator (15 min for 6-MMP and 30 min for 6-MP/6-TG). The contents were transferred to a 15 ml polypropylene centrifuge tube and centrifuged at 3500 rpm for 5 min at 10° C. The aqueous phase (top layer) was discarded, and 3.0 ml of the organic phase (bottom layer) was transferred to a clean 15 ml polypropylene centrifuge tube. The analytes in the organic phase were back extracted by adding 225 μl 0.1 N HCl and lightly mixing on an orbital rotator for 5 min. Following vortexing for 30 seconds, the tubes were centrifuged at 3500 rpm for 5 min at 10° C.

For 6-MMP analysis, 50 μl analyte was analyzed on a C18 reverse phase column with the mobile phase containing 1 mM DTT, 2.078% triethanol and 4% methanol, adjusted to pH 3.2 with concentrated H₃PO₄. For 6-MP and 6-TG analysis, 100 μl analyte was analyzed on a C18 reverse phase column using 0.1 M H₃PO₄ and 1 mM DTT in H₂O as the mobile phase.

Hepatic, pancreatic and hematological tests were obtained every 3 months. Clinical remission was defined as a Harvey Bradshaw Index<5 in those patients off corticosteroids or weaned to a level of prednisone ≤0.4 mg/kg/od (administered every other day). Treatment failures were defined as non-responders (HBI>5 or steroid dependence) or cessation of 6-MP due to side effects.

As shown in Table 1, a 6-TG level of >225 pmol per 8×10⁸ RBC was associated with remission. The median
values shown in the tables represent pmoL of the indicated 6-MP metabolite per 8x10^10 RBC. Excessive 6-TG and 6-MMP levels were associated with leukopenia and hepatotoxicity, respectively. Negligible metabolite levels detected non-compliance as a cause of treatment failure in 2/31 cases. These results indicate that 6-MP metabolite levels predict both clinical responsiveness and drug-related toxicity.

**TABLE 1**

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>median 6-TG</th>
<th>6-TG &gt;225</th>
<th>median 6-MMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responders</td>
<td>58</td>
<td>295</td>
<td>45/58 (78%)</td>
<td>3004</td>
</tr>
<tr>
<td>Non-responders</td>
<td>31</td>
<td>184*</td>
<td>8/31 (26%)</td>
<td>2048</td>
</tr>
<tr>
<td>Hepatic toxicity</td>
<td>7</td>
<td>258</td>
<td>5/7</td>
<td>9211**</td>
</tr>
<tr>
<td>Pancreatic toxicity</td>
<td>6</td>
<td>211</td>
<td>2/6</td>
<td>2342</td>
</tr>
<tr>
<td>Hematologic toxicity</td>
<td>6</td>
<td>414*</td>
<td>5/5</td>
<td>7042</td>
</tr>
</tbody>
</table>

p Values
- *p<0.001
- **p<0.001

**TABLE 2**

<table>
<thead>
<tr>
<th>Clinical evaluation point</th>
<th>Median 6-TG</th>
<th>Median 6-MMP</th>
<th>Median dose (mg/kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remission</td>
<td>106</td>
<td>309*</td>
<td>2600</td>
</tr>
<tr>
<td>Relapse</td>
<td>72</td>
<td>197</td>
<td>1002</td>
</tr>
</tbody>
</table>

p value: *p<0.001

Toxicity in the IBD patients treated with a 6-MP drug was also evaluated. Toxicity was measured essentially as described previously (Cuffari et al., supra, 1996a). Thirty-six patients (39%) experienced an adverse event. Hepatotoxicity was observed in 17% of patients, measured as the serum level of alanine aminotransferase (ALT) or aspartate aminotransferase (AST) (ALT, AST; exceeding or greater than 2× upper limit of normal). Leukopenia was observed in 14% of patients (white blood cell [WBC]<4000). Pancreatic toxicity was observed in 7% of patients (lipase/amylase>2×N). High 6-MMP levels correlated significantly with hepatotoxicity (54/63 with hepatotoxicity versus 2177 without hepatotoxicity; p<0.04). Leukopenia was observed in only 8% (8/106) of samples from patients in remission, with significantly higher 6-TG levels observed in these patients (mean value of 490 in patients with leukopenia versus mean value of 323 without leukopenia; p<0.04; median values were 342 versus 307, respectively). Therefore, leukopenia did not correlate with therapeutic efficacy. Furthermore, drug dose (per kg) did not correlate with therapeutic efficacy (see Table 2). However, those patients who do develop leukopenia have a higher 6-TG level than the rest of the responder group. These results indicate that 6-TG levels should be monitored to avoid potential clinical bone marrow suppression in responder patients who have high levels of 6-TG.

These results demonstrate a significant correlation between erythrocyte 6-TG levels and the therapeutic response to 6-MP drug treatment in IBD patients. The induction and maintenance of remission was found to be optimal at 6-TG levels>230 pmol/8x10^10 RBC. Therefore, monitoring 6-MP metabolite levels, in particular 6-TG, is useful for determining that a therapeutically effective concentration of 6-MP metabolites is maintained while treating IBD patients with a 6-MP drug. Monitoring 6-MP metabolite levels, in particular 6-TG and 6-MMP, is also useful for minimizing 6-MP drug related toxicity.

**EXAMPLE III**

Gender and Age Differences in Metabolism of a 6-MP Drug

This example describes gender and age differences observed in pediatric patients treated with 6-MP drug therapy. Pediatric IBD patients undergoing 6-MP drug therapy were assessed for levels of 6-MP metabolites. These patients were wild type for TPMT. Patients were assessed based on gender and age as it relates to puberty. Puberty is established at 12 years of age in girls and 14 years of age in boys.
As shown in Table 3, the 6-MMP values are much lower in boys after puberty (greater than 14 years). Since the total amount of thiomethylolines is lower, this indicates that either lower doses of 6-MP are used or that there is a difference in the bioavailability of 6-MP after puberty in males.

**TABLE 3**

<table>
<thead>
<tr>
<th>Number Observed</th>
<th>6-TG level (pmol per 8 x 10^8 RBC)</th>
<th>6-MMP level (pmol per 8 x 10^8 RBC)</th>
<th>Ratio 6-MMP/6-TG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girls (0-12 y)</td>
<td>39</td>
<td>182.2</td>
<td>447.0</td>
</tr>
<tr>
<td>Girls (&gt;12 y)</td>
<td>116</td>
<td>217.2</td>
<td>3304.5</td>
</tr>
<tr>
<td>Boys (0-14 y)</td>
<td>51</td>
<td>238.0</td>
<td>3681.6</td>
</tr>
<tr>
<td>Boys (&gt;14 y)</td>
<td>104</td>
<td>222.5</td>
<td>1662.3*</td>
</tr>
</tbody>
</table>

*p < 0.001

These results demonstrate that gender and age can affect the metabolism of 6-MP in pediatric IBD patients undergoing 6-MP drug therapy.

**EXAMPLE IV**

Thiopurine Methyltransferase (TPMT) Genotyping and Responsiveness to 6-MP Drug Therapy

This example describes TPMT genotyping of IBD patients treated with 6-MP drug therapy.

The genotype of TPMT was determined in IBD patients that were responders and non-responders. Genotyping of TPMT was measured essentially as described previously (Baccichet et al., Leuk. Res. 21:817–823 (1997); Zielkeiwicz et al., Gene 205:161–171 (1997)). The data shown in Table 4 indicate that patients heterozygous for the TPMT mutation had significantly higher 6-TG levels compared to those patients without the mutation. All heterozygote patients were responders to 6-MP.

**TABLE 4**

<table>
<thead>
<tr>
<th>TPMT Genotyping of IBD Patients</th>
<th>Heterozygote</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responder</td>
<td>100%</td>
<td>55%</td>
</tr>
<tr>
<td>Non responder</td>
<td>0%</td>
<td>45%</td>
</tr>
<tr>
<td>mean 6-TG</td>
<td>589*</td>
<td>247</td>
</tr>
</tbody>
</table>

*p value *less than 0.0001

TPMT genotyping revealed that 8 of 93 (9%) of patients were heterozygotes. No homozygous TPMT deficient patients were detected. All 8 heterozygotes responded to 6-MP and had 6-TG levels > 230 pmol/8 x 10^8 RBC.

These results demonstrate that TPMT genotyping is useful for predicting the effectiveness of 6-MP therapy in an IBD patient. Heterozygote patients are expected to have lower TPMT activity and should therefore be monitored for high levels of 6-TG for possible toxic levels associated with leukopenia or bone marrow suppression. 6-MP drug doses can be reduced accordingly. Wild-type homozygous patients are expected to have higher TPMT activity and should therefore be monitored to maintain an effective therapeutic level of 6-TG and to determine if patients develop toxic levels of 6-MMP. Homozygous patients deficient in TPMT activity can be treated with lower doses of a 6-MP drug provided that patients are closely monitored for toxicity such as leukopenia.

Although the invention has been described with reference to the examples provided above, it should be understood that various modifications can be made without departing from the spirit of the invention. Accordingly, the invention is limited only by the claims.

We claim:

1. A method of optimizing therapeutic efficacy for treatment of an immune-mediated gastrointestinal disorder, comprising:
   (a) administering a drug providing 6-thioguanine to a subject having said immune-mediated gastrointestinal disorder; and
   (b) determining the level of 6-thioguanine in said subject having said immune-mediated gastrointestinal disorder, wherein the level of 6-thioguanine less than about 230 pmol per 8x10^8 red blood cells indicates a need to increase the amount of said drug subsequently administered to said subject and wherein the level of 6-thioguanine greater than about 400 pmol per 8x10^8 red blood cells indicates a need to decrease the amount of said drug subsequently administered to said subject.

2. The method of claim 1, wherein said immune-mediated gastrointestinal disorder is inflammatory bowel disease (IBD).

3. The method of claim 2, wherein said subject having IBD is a pediatric subject.

4. The method of claim 1, wherein said immune-mediated gastrointestinal disorder is selected from the group consisting of lymphocytic colitis, microscopic colitis, collagenous colitis, autoimmune enteropathy, allergic gastrointestinal disease and eosinophilic gastrointestinal disease.

5. The method of claim 1, wherein said level of 6-thioguanine is determined in red blood cells.

6. The method of claim 5, wherein said level is determined using high pressure liquid chromatography.

7. A method of reducing toxicity associated with treatment of an immune-mediated gastrointestinal disorder, comprising:
   (a) administering a drug providing 6-thioguanine to a subject having said immune-mediated gastrointestinal disorder;
   (b) determining the level of 6-thioguanine in said subject having said immune-mediated gastrointestinal disorder; and
   (c) determining the level of 6-methylmercapturine in said subject having said immune-mediated gastrointestinal disorder, wherein the level of 6-thioguanine greater than about 400 pmol per 8x10^8 red blood cells or the level of 6-methylmercapturine greater than about 7000 pmol per 8x10^8 red blood cells indicates a need to decrease the amount of said drug subsequently administered to said subject.

8. The method of claim 7, wherein said immune-mediated gastrointestinal disorder is IBD.

9. The method of claim 8, wherein said subject having IBD is a pediatric subject.

10. The method of claim 7, wherein said immune-mediated gastrointestinal disorder is selected from the group consisting of lymphocytic colitis, microscopic colitis, collagenous colitis, autoimmune enteropathy, allergic gastrointestinal disease and eosinophilic gastrointestinal disease.
11. The method of claim 7, wherein said toxicity associated with said drug treatment is hematologic toxicity.
12. The method of claim 7, wherein said toxicity associated with said drug treatment is hepatic toxicity.
13. The method of claim 7, wherein said level of 6-thioguanine and said level of 6-methylmercaptopurine each is determined in red blood cells.
14. The method of claim 13, wherein said level is determined using high pressure liquid chromatography.
15. A method of optimizing therapeutic efficacy and reducing toxicity associated with treatment of an immune-mediated gastrointestinal disorder, comprising:
   (a) administering a drug providing 6-thioguanine to a subject having said immune-mediated gastrointestinal disorder;
   (b) determining the level of 6-thioguanine in said subject having said immune-mediated gastrointestinal disorder; and
   (c) determining the level of 6-methylmercaptopurine in said subject having said immune-mediated gastrointestinal disorder,
      wherein the level of 6-thioguanine less than about 230 pmol per 8x10^6 red blood cells indicates a need to increase the amount of said drug subsequently administered to said subject,
      wherein the level of 6-thioguanine greater than about 400 pmol per 8x10^6 red blood cells indicates a need to decrease the amount of said drug subsequently administered to said subject, and
      wherein the level of 6-methylmercaptopurine greater than about 7000 pmol per 8x10^6 red blood cells indicates a need to decrease the amount of said drug subsequently administered to said subject.
16. The method of claim 15, wherein said immune-mediated gastrointestinal disorder is IBD.
17. The method of claim 16, wherein said subject having IBD is a pediatric subject.
18. The method of claim 15, wherein said immune-mediated gastrointestinal disorder is selected from the group consisting of lymphocytic colitis, microscopic colitis, collagenous colitis, autoimmune enteropathy, allergic gastrointestinal disease and eosinophilic gastrointestinal disease.
19. The method of claim 15, wherein said level of 6-thioguanine and said level of 6-methylmercaptopurine each is determined in red blood cells.
20. The method of claim 19, wherein said level is determined using high pressure liquid chromatography.
21. The method of claim 15, wherein said toxicity associated with said drug treatment is selected from the group consisting of hepatic toxicity and hematologic toxicity.
22. A method of optimizing therapeutic efficacy of treatment of a non-IBD autoimmune disease, comprising:
   (a) administering a drug providing 6-thioguanine to a subject having said non-IBD autoimmune disease; and
   (b) determining the level of 6-thioguanine in said subject having said non-IBD autoimmune disease,
      wherein the level of 6-thioguanine less than about 230 pmol per 8x10^6 red blood cells indicates a need to increase the amount of 6-methylmercaptopurine drug subsequently administered to said subject and
      wherein the level of 6-thioguanine greater than about 400 pmol per 8x10^6 red blood cells indicates a need to decrease the amount of 6-methylmercaptopurine drug subsequently administered to said subject.
23. The method of claim 22, wherein said level of 6-thioguanine metabolite is determined in red blood cells.
24. The method of claim 23, wherein said level is determined using high pressure liquid chromatography.
25. A method of optimizing therapeutic efficacy and reducing toxicity associated with treatment of an immune-mediated gastrointestinal disorder, comprising:
   (a) administering a drug providing 6-thioguanine to a subject having said immune-mediated gastrointestinal disorder;
   (b) determining the level of 6-thioguanine in said subject having said immune-mediated gastrointestinal disorder; and
   (c) determining the level of 6-methylmercaptopurine in said subject having said immune-mediated gastrointestinal disorder,
      wherein the level of 6-thioguanine less than about 230 pmol per 8x10^6 red blood cells indicates a need to increase the amount of said drug subsequently administered to said subject, and
      wherein the level of 6-thioguanine greater than about 400 pmol per 8x10^6 red blood cells or a level of 6-methylmercaptopurine greater than about 7000 pmol per 8x10^6 red blood cells indicates a need to decrease the amount of said drug subsequently administered to said subject.
26. The method of claim 25, wherein said immune-mediated gastrointestinal disorder is IBD.
27. The method of claim 26, wherein said subject having IBD is a pediatric subject.
28. The method of claim 25, wherein said immune-mediated gastrointestinal disorder is selected from the group consisting of lymphocytic colitis, microscopic colitis, collagenous colitis, autoimmune enteropathy, allergic gastrointestinal disease and eosinophilic gastrointestinal disease.
29. The method of claim 25, wherein said level of 6-thioguanine and said level of 6-methylmercaptopurine each is determined in red blood cells.
30. The method of claim 29, wherein said level is determined using high pressure liquid chromatography.
31. The method of claim 25, wherein said toxicity associated with said drug treatment is selected from the group consisting of hepatic toxicity and hematologic toxicity.
32. The method of claim 1, wherein said drug is selected from the group consisting of 6-mercaptopurine, azathioprine, 6-thioguanine, and 6-methylmercaptopurine riboside.
33. The method of claim 7, wherein said drug is selected from the group consisting of 6-mercaptopurine, azathioprine, 6-thioguanine, and 6-methylmercaptopurine riboside.
34. The method of claim 15, wherein said drug is selected from the group consisting of 6-mercaptopurine, azathioprine, 6-thioguanine, and 6-methylmercaptopurine riboside.
35. The method of claim 22, wherein said drug is selected from the group consisting of 6-mercaptopurine, azathioprine, 6-thioguanine, and 6-methylmercaptopurine riboside.
36. The method of claim 25, wherein said drug is selected from the group consisting of 6-mercaptopurine, azathioprine, 6-thioguanine, and 6-methylmercaptopurine riboside.
37. A method of optimizing therapeutic efficacy and reducing toxicity associated with treatment of an immune-mediated gastrointestinal disorder, comprising:
(a) administering a drug selected from the group consisting of 6-mercaptopurine, azathioprine, 6-thioguanine, and 6-methylmercaptopurine in a subject having said immune-mediated gastrointestinal disorder; and
(b) determining the level of 6-thioguanine or 6-methylmercaptopurine in said subject having said immune-mediated gastrointestinal disorder;
wherein the level of 6-thioguanine less than about 230 pmol per 8x10⁸ red blood cells indicates a need to increase the amount of said drug subsequently administered to said subject, and
wherein the level of 6-thioguanine greater than about 400 pmol per 8x10⁸ red blood cells or a level of 6-methylmercaptopurine greater than about 7000 pmol per 8x10⁸ red blood cells indicates a need to decrease the amount of said drug subsequently administered to said subject.

38. The method of claim 37, wherein said drug is 6-mercaptopurine.
39. The method of claim 37, wherein said drug is azathioprine.
40. The method of claim 37, wherein said immune-mediated gastrointestinal disorder is inflammatory bowel disease (IBD).
41. The method of claim 40, wherein said subject having IBD is a pediatric subject.
42. The method of claim 37, wherein said immune-mediated gastrointestinal disorder is selected from the group consisting of lymphocytic colitis, microscopic colitis, collagenous colitis, autoimmune enteropathy, allergic gastrointestinal disease and eosinophilic gastrointestinal disease.
43. The method of claim 37, wherein said level of 6-thioguanine and said level of 6-methylmercaptopurine each is determined in red blood cells.
44. The method of claim 43, wherein said level is determined using high pressure liquid chromatography.
45. The method of claim 37, wherein said toxicity associated with said drug treatment is selected from the group consisting of hepatic toxicity and hematologic toxicity.
46. A method of optimizing therapeutic efficacy and reducing toxicity associated with treatment of an immune-mediated gastrointestinal disorder, comprising:

(a) determining the level of 6-thioguanine or 6-methylmercaptopurine in a subject administered a drug selected from the group consisting of 6-mercaptopurine, azathioprine, 6-thioguanine, and 6-methylmercaptopurine, said subject having said immune-mediated gastrointestinal disorder;
wherein the level of 6-thioguanine less than about 230 pmol per 8x10⁸ red blood cells indicates a need to increase the amount of said drug subsequently administered to said subject, and
wherein the level of 6-thioguanine greater than about 400 pmol per 8x10⁸ red blood cells or a level of 6-methylmercaptopurine greater than about 7000 pmol per 8x10⁸ red blood cells indicates a need to decrease the amount of said drug subsequently administered to said subject.
47. The method of claim 46, wherein said drug is 6-mercaptopurine.
48. The method of claim 46, wherein said drug is azathioprine.
49. The method of claim 46, wherein said immune-mediated gastrointestinal disorder is IBD.
50. The method of claim 47, wherein said subject having IBD is a pediatric subject.
51. The method of claim 46, wherein said immune-mediated gastrointestinal disorder is selected from the group consisting of lymphocytic colitis, microscopic colitis, collagenous colitis, autoimmune enteropathy, allergic gastrointestinal disease and eosinophilic gastrointestinal disease.
52. The method of claim 46, wherein said level of 6-thioguanine and said level of 6-methylmercaptopurine each is determined in red blood cells.
53. The method of claim 52, wherein said level is determined using high pressure liquid chromatography.
54. The method of claim 46, wherein said toxicity associated with said drug treatment is selected from the group consisting of hepatic toxicity and hematologic toxicity.

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