DESCRIPTION

METHODS AND COMPOSITIONS FOR TREATMENT FOR CORONARY AND ARTERIAL ANEURYSMAL SUBARACHNOID HEMORRHAGE

RELATED APPLICATION INFORMATION

This patent application is based on and claims priority to U.S. Provisional Patent Application Serial No. 61/025,170, filed January 31, 2008, the entire contents of which are herein incorporated by reference.

TECHNICAL FIELD

The presently disclosed subject matter relates to the treatment of Aneurysmal Subarachnoid Hemorrhage (SAH), complications associated with SAH (including vasospasm), and vasospasm associated with atherosclerosis, including but not limited to that associated with corornary arterial disease.

BACKGROUND

Aneurysmal Subarachnoid Hemorrhage (SAH) is one of the leading causes of morbidity and mortality associated with stroke worldwide. SAH is a neurological emergency characterized by extravasations of blood into spaces covering the central nervous system that are filled with cerebrospinal fluid. Several complications such as hydrocephalus, rebleeding, cerebral vasospasm, seizures, myocardial injury, and pulmonary edema can result from SAH.

SAH is a major concern throughout the world, with varying incidences of between about 1 and 96 incidents per 100,000 person/year (Batista da Costa Jr. *et al.* (2004) *Arq Neuro-Psiquiatr* (Sao Paulo) 62:245-249), with a worldwide incidence of about 10 per 100,000 person/year (Batista da Costa Jr. *et al.* (2004) *Arq Neuro-Psiquiatr* (Sao Paulo) 62:245-249). According to Suarez *et al.*, SAH affects 21,000-33,000 people per year in the United States, and represents about 2-5% of all new strokes (Suarez *et al.* (2006) *N Engl J Med* 354:387-396). About 80% of cases of SAH result from rupture of an intracranial aneurysm, which itself is associated with significant risk of complications, including death. The peak age of incidence is 55-60 years, and about 20% occurs between the ages of 15 and 45 years. There is a gender difference in

SAH, with a female preponderance characterized by a ratio of female to male patients ranging from 1.6-4.16:1. The incidence of SAH is also higher in African-Americans than in Caucasians.

Recent statistics indicate that about 30% of SAH patients die within the first 24 hours, and another 25-30% die within the following 4 weeks (Flett *et al.* (2005) *AJNR Am J Neuroradiol* 26:367-372). Besides the initial risks associated with SAH, a significant percentage of patients who have suffered SAH suffer from long-term cognitive impairment (Suarez *et al.* (2006) *N Engl J Med* 354:387-396), and thus SAH is associated with substantial impacts on health care resources.

While symptom management plays a major role in the treatment of SAH, there continues to be a long felt need for treatment strategies that address the underlying physiological bases for the development of secondary complications of SAH.

SUMMARY

The presently disclosed subject matter provides methods and compositions for treating SAH and/or associated complications in a subject. In some embodiments, an effective amount of a nitric oxide precursor is administered to a subject suffering from SAH and/or associated complications and/or at risk for suffering complications associated with SAH (*e.g.*, vasospasm). In some embodiments, the nitric oxide precursor comprises at least one of citrulline, a precursor that generates citrulline *in vivo*, a pharmaceutically acceptable salt thereof, and combinations thereof. In some embodiments, the nitric oxide precursor, such as citrulline, is administered orally. In some embodiments, the nitric oxide precursor, such as citrulline, is administered intravenously. In some embodiments, the subject to be treated is a subject suffering from vasospasm. In some embodiments, the subject to be treated is a subject suffering from an acute condition associated with vasospasm.

The presently disclosed subject matter also provides methods and compositions for treating vasospasm. In some embodiments, the subject to be treated suffers from vasospasm associated with SAH. In some embodiments,

the subject to be treated has suffered trauma that results in vasospasm (*e.g.*, trauma that results in SAH). The methods can comprise administering to a subject in need thereof an effective amount of a nitric oxide precursor. In some embodiments, the nitric oxide precursor comprises at least one of citrulline, a precursor that generates citrulline *in vivo*, a pharmaceutically acceptable salt thereof, and combinations thereof. In some embodiments, the subject to be treated is suffering from vasospasm associated with SAH. In some embodiments, the nitric oxide precursor, such as citrulline, is administered orally. In some embodiments, the nitric oxide precursor, such as citrulline, is administered intravenously.

It is therefore an object of the presently disclosed subject matter to provide for treatment for SAH, vasospasm, and/or associated complications in a subject.

An object of the presently disclosed subject matter having been stated hereinabove, other objects will become evident as the description proceeds, when taken in connection with the accompanying drawings and examples as best described hereinbelow.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic of the urea cycle.

DETAILED DESCRIPTION

A considerable number of people worldwide are afflicted with Aneurysmal Subarachnoid Hemorrhage (SAH). The mortality rate for this condition is quite high, and even patients who survive SAH frequently experience dramatic reductions in their qualities of life. Current therapies in use can often prevent the death of a person who has experienced SAH if begun within an appropriate timeframe, but even successfully preventing that patient's death does not address the development of serious secondary complications. Therapies aimed at preventing secondary complications such as vasospasm and its sequelae, for example, are provided in accordance with aspects of the presently disclosed subject matter.

I. GENERAL CONSIDERATIONS

The *in vivo* synthetic pathway for arginine commences with ornithine. Ornithine is combined with carbamyl phosphate to produce citrulline, which in turn is combined with aspartate, in the presence of adenosine triphosphate (ATP), to produce argininosuccinate. In the final step, fumarate is split from argininosuccinate, to produce arginine. The degradative pathway for arginine is by the hydrolytic action of arginase, to produce ornithine and urea. These reactions form the urea cycle. The urea cycle serves as the primary pathway for removing waste nitrogen produced by the metabolism of endogenous and exogenous proteins, and is shown schematically in Fig.1. In addition to its role in nitrogen clearance, the urea cycle is the body's intrinsic source of arginine which acts as a precursor of nitric oxide (NO), a potent vasodilator.

SAH typically results from rupture of a cranial aneurysm which results in leakage of blood into compartments of the nervous system that contain cerebrospinal fluid. Primary symptomology typically includes sudden onset of headache, which is usually very severe, nausea, vomiting, neck pain, photophobia, and loss of consciousness (Suarez *et al.* (2006) *N Engl J Med* 354:387-396), which is frequently associated with neurological deficits that become apparent on physical exam (Suarez *et al.* (2006) *N Engl J Med* 354:387-396). Hydrocephalus (20%), rebleeding (7%), cerebral vasospasm (46%), seizures (30%), hyponatremia (28%), myocardial injury (35%), and pulmonary edema (23%) occur in a significant percentage of patients, even if the damage to the underlying vessel(s) is repaired. These events also frequently lead to additional secondary complications, including seizures, pulmonary edema, cardiac arrhythmias, electrolyte disturbances, and neuropsychological complications such as problems with memory, mood, and neuropsychological function.

While the causes of the various sequelae of SAH are multifactorial, certain observations have been made. For example, decreased availability of nitric oxide in cerebral vessels has been observed, as has increased synthesis of endothelin or increase sensitivity of the arteries to this factor. Alterations in smooth muscle cells that promote a contracted state and activation of signal transduction mechanisms that can alter calcium sensitivity have also been

reported. Additionally, increased thrombogenicity of the endothelium and/or platelet adhesion contributing to arterial dysfunction can occur, as can disruption of the blood brain barrier, inflammation, vasoconstriction, and injury to cerebral vessels of all sizes.

Given its devastating impact on patients, rapid diagnosis and treatment of SAH is critical. Typically, patients presenting with symptoms suggestive of SAH are subjected to head CT, which can detect the presence of SAH. If a subarachnoid hemorrhage is detected, FT angiography and/or cerebral angiography can locate an aneurysm, which is then repaired. If, however, the angiography is normal, CT angiography is typically repeated 1-3 weeks subsequent to initial presentation, optionally followed by brain, brain stem, and/or spinal cord imaging. In those cases where heat CT does not detect a subarachnoid hemorrhage, testing of cerebrospinal fluid obtained by lumbar puncture can also provide indicators of SAH, which then can be confirmed by angiography.

Once SAH is diagnosed, treatment generally includes securing of the aneurysm by neurosurgical clipping or endovascular coiling. Treatment of associated symptoms including, but not limited to hypertension, hyperthermia, hyperglycemia, and ischemia are performed as needed. Given that complications associated with SAH typically develop over the course of several weeks, a subject generally remains hospitalized for extended periods in order to provide continuous monitoring of the subject's condition.

II. THERAPEUTIC METHODS

The presently disclosed subject matter provides methods for treating SAH and/or associated complications in a subject. In some embodiments, an effective amount of a nitric oxide precursor is administered to a subject suffering from SAH and/or associated complications and/or at risk for suffering complications associated with SAH. Representative examples of such complications are disclosed herein above.

In some embodiments, the nitric oxide precursor comprises at least one of citrulline, a precursor that generates citrulline *in vivo*, a pharmaceutically acceptable salt thereof, and combinations thereof. See Figure 1. In some

embodiments, the nitric oxide precursor is selected from the group including, but not limited to, citrulline, arginine, or combinations thereof. In some embodiments, the nitric oxide precursor, such as citrulline, is administered orally. In some embodiments, the nitric oxide precursor, such as citrulline, is administered intravenously. In some embodiments, the subject to be treated is a subject suffering from vasospasm. In some embodiments, the subject to be treated is a subject suffering from an acute condition associated with vasospasm. Representative examples of such conditions are disclosed herein above.

In some embodiments, the subject suffering from a complication, such as vasospasm, suffers from relative hypocitrullinemia. The term "relative hypocitrullinemia" refers to a state in which the subject suffering from a complication has reduced plasma citrulline as compared to a subject not suffering from a complication.

In some embodiments, the subject suffers from hypocitrullinemia. In some embodiments the hypocitrullinemia is characterized by plasma citrulline levels of ≤ 37 μmol/liter, in some embodiments, ≤ 25 μmol/liter, in some embodiments, ≤ 20 μmol/liter, in some embodiments, ≤ 10 μmol/liter, in some embodiments, ≤ 5 μmol/liter.

The presently disclosed subject matter also provides methods and compositions for treating vasospasm. In some embodiments, the subject to be treated suffers from vasospasm associated with SAH. In some embodiments, the subject to be treated has suffered trauma that results in vasospasm (*e.g.*, trauma that results in SAH). In some embodiments the vasospasm is associated with atherosclerosis in the subject. In some embodiments the atherosclerosis is associated with coronary artery disease in the subject, with carotid arterial disease in the subject, with peripheral arterial disease in the subject, and combinations thereof.

In some embodiments, the nitric oxide precursor comprises at least one of citrulline, a precursor that generates citrulline *in vivo*, a pharmaceutically acceptable salt thereof, and combinations thereof. See Figure 1. In some embodiments, the nitric oxide precursor is selected from the group including, but not limited to, citrulline, arginine, or combinations thereof. In some

embodiments, the nitric oxide precursor, such as citrulline, is administered orally. In some embodiments, the nitric oxide precursor, such as citrulline, is administered intravenously. In some embodiments, the subject to be treated is a subject suffering from vasospasm. In some embodiments, the subject to be treated is a subject suffering from an acute condition associated with vasospasm (e.g. ischemia and/or angina in coronary arterial disease).

In some embodiments, the subject suffering from a complication, sucha as vasospasm, suffers from relative hypocitrullinemia. The term "relative hypocitrullinemia" refers to a state in which the subject suffering from a complication has reduced plasma citrulline as compared to a subject not suffering from a complication.

As used herein, the phrase "treating" refers to both intervention designed to ameliorate a condition in a subject (*e.g.*, after initiation of a disease process or after an injury) as well as to interventions that are designed to prevent the condition from occurring in the subject. Stated another way, the terms "treating" and grammatical variants thereof are intended to be interpreted broadly to encompass meanings that refer to reducing the severity of and/or to curing a condition, as well as meanings that refer to prophylaxis. In this latter respect, "treating" can refer to "preventing" to any degree, or otherwise enhancing the ability of the subject to resist the process of the condition, such as a subject at risk to suffer the condition.

The subject treated in the presently disclosed subject matter in its many embodiments is desirably a human subject, although it is to be understood that the principles of the presently disclosed subject matter indicate that the presently disclosed subject matter is effective with respect to all vertebrate species, including warm-blooded vertebrates such as mammals and birds, which are intended to be included in the term "subject". In this context, a mammal is understood to include any mammalian species in which treatment is desirable, such as but not limited to agricultural and domestic mammalian species.

Thus, provided is the treatment of mammals such as humans, as well as those mammals of importance due to being endangered (such as Siberian tigers), of economical importance (animals raised on farms for consumption by

humans) and/or social importance (animals kept as pets or in zoos) to humans, for instance, carnivores other than humans (such as cats and dogs), swine (pigs, hogs, and wild boars), ruminants (such as cattle, oxen, sheep, giraffes, deer, goats, bison, and camels), and horses. Also provided is the treatment of birds, including the treatment of those kinds of birds that are endangered, kept in zoos, as well as fowl, and more particularly domesticated fowl, i.e., poultry, such as turkeys, chickens, ducks, geese, guinea fowl, and the like, as they are also of economical importance to humans. Thus, provided is the treatment of livestock, including, but not limited to, domesticated swine (pigs and hogs), ruminants, horses, poultry, and the like.

III. PHARMACEUTICAL COMPOSITIONS

An effective dose of a composition of the presently disclosed subject matter is administered to a subject in need thereof. An "effective amount" is an amount of a composition sufficient to produce a measurable response (*e.g.,* a biologically or clinically relevant response in a subject being treated). Actual dosage levels of active ingredients in the compositions of the presently disclosed subject matter can be varied so as to administer an amount of the active compound(s) that is effective to achieve the desired therapeutic response for a particular subject. The selected dosage level will depend upon the activity of the therapeutic composition, the route of administration, combination with other drugs or treatments, the severity of the condition being treated, and the condition and prior medical history of the subject being treated. By way of example and not limitation, doses of compositions can be started at levels lower than required to achieve the desired therapeutic effect and to gradually increase the dosage until the desired effect is achieved. The potency of a composition can vary, and therefore an "effective amount" can vary.

After review of the disclosure of the presently disclosed subject matter presented herein, one of ordinary skill in the art can tailor the dosages to an individual subject, taking into account the particular formulation, method of administration to be used with the composition, and particular disease treated. Further calculations of dose can consider subject height and weight, gender, severity and stage of symptoms, and the presence of additional deleterious

physical conditions.

By way of additional examples, the amount of active ingredient that may be combined with the carrier materials to produce a single dosage form will vary depending upon the subject to be treated and the particular mode of administration. For example, a formulation intended for administration to humans can contain from 0.5 mg to 5 g of active agent compounded with an appropriate and convenient amount of carrier material which may vary from about 5 to about 95 percent of the total composition. For example, in a human adult, the doses per person per administration are generally between 1 mg and 500 mg up to several times per day. Thus, dosage unit forms will generally contain between from about 1 mg to about 500 mg of an active ingredient, typically 25 mg, 50 mg, 100 mg, 200 mg, 300 mg, 400 mg, 500 mg, 600 mg, 800 mg, or 1000 mg.

The nitric oxide precursor is administered in some embodiments in a dose ranging from about 0.01 mg to about 1,000 mg, in some embodiments in a dose ranging from about 0.5 mg to about 500 mg, and in some embodiments in a dose ranging from about 1.0 mg to about 250 mg. The nitric oxide precursor can also be administered in some embodiments in a dose ranging from about 100 mg to about 30,000 mg, and in some embodiments in a dose ranging from about 250 mg to about 1,000 mg. A representative dose is 3.8 g/m2/day of arginine or citrulline (molar equivalents, MW L-citrulline 175.2, MW L-arginine 174.2).

Representative intravenous citrulline solutions can comprise a 100 mg/ml (10%) solution. Representative intravenous citrulline dosages can comprise 200 mg/kg, 400 mg/kg, 600 mg/kg, and 800 mg/kg. In some embodiments, for example but not limited to a 600 or 800 mg/kg dosage, the dose can be decreased by an amount ranging from 50 mg/kg and 100 mg/kg to mitigate observed undesired effects on systemic blood pressure. In some embodiments, doses can be administered one or more times during a given period of time, such as a day.

In some embodiments a pharmaceutical composition comprises an amount of citrulline effective to raise plasma citrulline level to treat a complication as disclosed herein in a subject. In some embodiments, the level

is determined by comparing plasma citrulline levels in a subject to be treated to that observed in a subject not suffering from the complication. In some embodiments, the amount of citrulline is effective to raise plasma citrulline level in a subject to at least 5 μmol/liter, optionally at least 10 μmol/liter, optionally at least 20 μmol/liter, optionally at least 25 μmol/liter, and optionally about 37 μmol/liter.

In some embodiments, the presently disclosed subject matter provides pharmaceutical compositions comprising a nitric oxide precursor and a pharmaceutically acceptable carrier, such as a pharmaceutically acceptable carrier in humans. In some embodiments, the presently disclosed subject matter provides pharmaceutical compositions comprising citrulline or arginine in dosages as described above.

A composition of the presently disclosed subject matter is typically administered orally or parenterally in dosage unit formulations containing standard nontoxic pharmaceutically acceptable carriers, adjuvants, and vehicles as desired. The term "parenteral" as used herein includes intravenous, intra-muscular, intra-arterial injection, or infusion techniques.

Injectable preparations, for example sterile injectable aqueous or oleaginous suspensions, are formulated according to the known art using suitable dispersing or wetting agents and suspending agents. The sterile injectable preparation can also be a sterile injectable solution or suspension in a nontoxic acceptable diluent or solvent, for example, as a solution in 1,3-butanediol.

Among the acceptable vehicles and solvents that can be employed are water, Ringer's solution, and isotonic sodium chloride solution. In addition, sterile, fixed oils are conventionally employed as a solvent or suspending medium. For this purpose any bland fixed oil can be employed including synthetic mono- or diglycerides. In addition, fatty acids such as oleic acid find use in the preparation of injectables. Exemplary carriers include neutral saline solutions buffered with phosphate, lactate, Tris, and the like.

In a representative embodiment doses can be administered to a subject several times during a relevant treatment period, including but not limited to 1, 2, 3, 4, 5, 6 or more dosages.

It will be understood, however, that the specific dose level for any particular subject will depend upon a variety of factors including the age, body weight, general health, sex, diet, time of administration, route of administration, rate of excretion, drug combination and the severity of the particular disease undergoing therapy.

EXAMPLES

The following Examples have been included to illustrate representavtive modes of the presently disclosed subject matter. In light of the present disclosure and the general level of skill in the art, those of skill will appreciate that the following Examples are intended to be exemplary only in that numerous changes, modification, and alterations can be employed without departing from the spirit and scope of the presently disclosed subject matter.

OVERVIEW OF EXAMPLES

While symptom management plays a major role in the treatment of SAH, there continues to be a long felt need for treatment strategies that address the underlying physiological bases for the development of secondary complications of SAH. For example, one of the key pathological mechanisms following aneurismal SAH is decreased availability of nitric oxide in cerebral vessels resulting in contraction of smooth muscles or vasospasm. By comparing plasma from patients with and without vasospasm it has been determined by the instant co-inventors there is a significant difference in citrulline levels such that patients with vasospasm have lower levels of citrulline as compared to patients without vasospasm. While it is not desired to be bound by any particular theory of operation, these results suggest that citrulline acting as a NO precursor can be a treatment for both SAH and coronary arterial disease through a similar mechanism of supporting vascular relaxation through restoring an adequate supply of citrulline which can act as a nitric oxide precursor amongst other actions.

Examples 1 and 2 present the results of assaying plasma levels of citrulline, ornithine, arginine, and nitric oxide in subjects with and without vasospasm. The samples were separated by 24 hours in time from collection.

In Example 1, levels were assayed after early collection, and in Example 2, levels were assayed after late collection.

EXAMPLE 1

COMPARISON OF PLASMA (EARLY COLLECTION) IN PATIENTS WITHOUT AND WITH VASOSPASM

Parameter	Without vasospasm[1]	With vasospasm[1]	*p*-value
Citrulline (nM/ml)	9.12 ± 1.2	5.66 ± 1.2	0.08
Ornithine (nM/ml)	31.66 ± 5.7	16.46 ± 3.4	0.04
Arginine (nM/ml)	34.88 ± 9.7	22.54 ± 4.3	0.14
Nitric Oxide (μM)	27.36 ± 4.8	30.72 ± 9.6	0.38

[1] n = 5; data expressed as mean ± standard error

EXAMPLE 2

COMPARISON OF PLASMA (LATE COLLECTION) IN PATIENTS WITHOUT AND WITH VASOSPASM

Parameter	Without vasospasm	With vasospasm[1]	*p*-value
Citrulline (nM/ml)	8.62 ± 1.2	4.81 ± 1.6	0.12
Ornithine (nM/ml)	42.60 ± 4.9	25.22 ± 6.5	0.06
Arginine (nM/ml)	47.76 ± 16	26.52 ± 9.0	0.14
Nitric Oxide (μM)	58.85 ± 39	48.01 ± 30	0.41

[1] n = 5; data expressed as mean ± standard error

REFERENCES

The references listed below as well as all references cited in the specification are incorporated herein by reference to the extent that they supplement, explain, provide a background for or teach methodology, techniques and/or compositions employed herein.

Batista da Costa Jr. *et al.* (2004) *Arq Neuro-Psiquiatr* (Sao Paulo) 62:245-249.

Suarez *et al.* (2006) *N Engl J Med* 354:387-396.

Flett *et al.* (2005) *AJNR Am J Neuroradiol* 26:367-372.

Published U.S. Patent Application Number US-2004-0235953-A1, published November 25, 2004.

PCT International Patent Application Publication No. WO 2005/082042, published September 9, 2005.

U.S. Patent No. 6,343,382.

U.S. Patent No.6,743,823.

It will be understood that various details of the presently disclosed subject matter may be changed without departing from the scope of the presently disclosed subject matter. Furthermore, the foregoing description is for the purpose of illustration only, and not for the purpose of limitation.

CLAIMS

1. Use of citrulline in the manufacture of a medicament suitable for intravenously administering into a subject suffering from relative hypocitrullinemia for treating vasospasms.

2. The use of claim 1, wherein the vasospasm is associated with aneurysmal subarachnoid hemorrhage in the subject.

3. The use of any one of claims 1-2, wherein the subject has suffered trauma that results in vasospasm.

4. The use of any one of claims 1-3, wherein the vasospasm is associated with atherosclerosis in the subject.

5. The use of claim 4, wherein the atherosclerosis is associated with coronary arterial disease, with carotid arterial disease, with peripheral arterial disease, or combinations thereof.

6. The use of any one of claims 1-5, wherein the citrulline is a pharmaceutically acceptable salt thereof.

7. The use of any one of claims 1-6, wherein the administering is in a dose ranging from about 100 mg to about 30,000 mg.

8. The use of any one of claims 1-7, wherein the administering is in a dose ranging from about 250 mg to about 1,000 mg.

9. A medicament comprising a pharmaceutically acceptable carrier and an amount of citrulline effective to raise plasma citrulline level to treat a complication associated with aneurysmal subarachnoid hemorrhage (SAH) in a subject suffering from relative hypocitrullinemia, wherein the medicament is adapted for intravenous administration, and wherein the level is determined by comparing plasma citrulline levels in a subject to be treated to that observed in a subject not suffering from a complication associated with aneurysmal subarachnoid hemorrhage (SAH).

10. The medicament of claim 9, wherein the amount of citrulline effective to raise plasma citrulline level in a subject to at least 5 μmol/liter, optionally at least 10 μmol/liter, optionally at least 20 μmol/liter, optionally at least 25 μmol/liter, and optionally about 37 μmol/liter.