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(54) Title: USE OF URIDINE TRIPHOSPHATES AND RELATED COMPOUNDS FOR THE PREVENTION AND TREATMENT OF PNEUMONIA IN IMMOBILIZED PATIENTS		
(57) Abstract A method of promoting drainage of mucous secretions in the congested airways of a bedridden/immobilized patient or an intubated/mechanically-ventilated patient is disclosed. The method comprises administering to the airways of the patient a uridine phosphate such as uridine 5'-triphosphate (UTP) or P1,P4-di(uridine-5')tetraphosphate, an analog of UTP, or any other analog, in an amount effective to promote drainage of fluid in the congested airways, including sinuses, to increase the ciliary beat frequency of cilia on the surface lumina epithelia cells, to increase the secretions of mucous by goblet cells and to promote the clearance of retained secretions by hydrating mucous secretions, by stimulating ciliary beat frequency in the airways and by stimulating surfactant production. Pharmaceutical formulations and methods of making the same are also disclosed. Methods of administering the same would include any liquid suspension (including nasal drops or eye drops or spray), oral form (liquid or pill), aerosol inhalation, powder form, topical, injected, intra-operative instillation or or suppository form.		

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USE OF URIDINE TRIPHOSPHATES AND RELATED COMPOUNDS FOR THE PREVENTION AND TREATMENT OF PNEUMONIA IN IMMOBILIZED PATIENTS**5 Technical Field**

This invention relates to a method of removing or preventing the accumulation of retained mucous secretions from the lungs and bronchi of immobilized or bedridden patients, including those whose breathing is assisted by mechanical ventilation.

Background of the Invention

10 Bedrest or immobility can result from a variety of health problems, both acute and chronic in nature. A primary concern in caring for persons who are immobilized or placed on bedrest is that of prevention of pneumonia and other respiratory problems. Once pneumonia develops in these patients, morbidity and mortality can be significant. Because of the immobility it may be difficult for patients to cough and mobilize secretions. Immobile patients include patients
15 confined to either beds or wheelchairs. In addition to complications arising from the immobility, the underlying health problem may place patients at increased risk for infection. Factors or disease states which predispose for high risk for pneumonia development include: altered consciousness (from head injury, anesthesia, drug overdose or other serious illness), tracheal intubation (via endotracheal, nasotracheal, or tracheostomy tubes), mechanical ventilation, and other procedures or
20 treatments including intra-aortic balloon pump, hemo- or ultrafiltration, chronic disease states such as cancer, progressive neuromuscular disorders (multiple sclerosis, amyotrophic lateral sclerosis, etc.), heart disease, diabetes mellitus, acute neurological disorders (stroke, seizures, Guillain-Barre' syndrome, spinal cord injury), and rehabilitation from injuries or surgeries (bedrest, traction, etc.).
(p. 502 "Medical-Surgical Nursing: Assessment and Management of Clinical Problems" by S. Lewis and I. Collier, 2nd ed. 1987, McGraw-Hill, New York).

25

Mechanical ventilation is indicated for respiratory failure or compromise resulting

from a variety of pulmonary disorders and complications. It has been estimated that over 100,000 patients require mechanical ventilation in the U.S. every year (I. Kappstein, et al., *Eur. J. Clin. Microbiol. Infect. Dis.* 11(6), 504-8 (1992)). Morbidity and mortality from the underlying disorders can be high, and the addition of mechanical ventilation further increases risk. Complications resulting from mechanical ventilation may include: ventilator-associated pneumonia (VAP), pneumothorax, pulmonary embolus, right mainstem bronchus intubation, accidental extubation, aspiration of gastric contents, sepsis, fluid overload/heart failure, hypotension, and death (B. deBoisblanc, et al., *Chest* 103, 1543-7 (1993)). One of the most common complications is VAP, with an incidence conservatively estimated at 25%, with greater than 12,000 deaths per year due to VAP (D. Craven, et al., *Am. Rev. Respir. Dis.* 133, 792-6 (1986)). Increased vigilance by nursing or other health care professionals, invasive monitoring, use of vasoactive medications, and frequent overall assessments greatly increase the cost of care for mechanically ventilated patients. A conservative estimate for total cost of these mechanically ventilated patients approaches \$1.5 billion per year in the U.S. alone (I. Kappstein, *supra*).

Patients who are intubated and on mechanical ventilation are at several-fold higher risk for developing pneumonia and other pulmonary complications than non-intubated patients, due to the impairment or absence of several aspects of the normal pulmonary defense mechanisms (T. Inglis, *J. Hosp. Infect.* 30, 409-13 (1995)). Normal defense mechanisms consist of: 1) filtration, warming, and humidification of air; 2) epiglottis closure over the trachea; 3) cough reflex; 4) mucociliary escalator system; 5) immunoglobulins A and G; and 6) activity of alveolar macrophages. Airways distal to the larynx are normally sterile, but with intubation, the cough reflex is impaired and closure of the epiglottis cannot occur, allowing contamination of the lower airways. Because clinical practice guidelines generally do not advocate the maintenance of a complete airway seal in the trachea by the endotracheal cuff, some leakage of nasopharyngeal secretions below the epiglottis may occur, therefore increasing risk for infection in the lower airways (P. Mahul, et al., *Intensive*

Care Med. 18, 20-5 (1992)).

The leading cause of VAP is thought to be aspiration of colonized gastric secretions via the incompletely closed glottis (P. Mahul, et al., supra). Colonization of the lower respiratory tract, especially with gram-negative bacteria is an early stage in the development of VAP. In addition, the use of suction catheters via the endotracheal tube to clear lower airway secretions, as well as other manipulations of the ventilatory system, significantly increase the chance for nosocomial infection, especially pneumonia. The normal warming, humidification, and filtration mechanisms for distal airways are non-functional for intubated patients, and the underlying conditions of the patient, i.e., malnutrition, fluid and/or electrolyte imbalance, and infections, may further complicate a patient's prognosis.

Mucociliary transport velocity has been shown to be impaired in patients who are intubated and receiving mechanical ventilation (F. Konrad, et al., Intensive Care Med. 21, 482-89 (1995); F. Konrad, et al., Chest 105(1), 237-41 (1994); F. Konrad, et al., Chest 102(5), 1377-83 (1992)). Because movement and clearance of secretions is an important lung defense mechanism, any impairment of this function, in addition to the introduction of artificial airways, mechanical ventilation, and the underlying disease state, can severely compromise the pulmonary host defense mechanisms.

Agents that can obviate the need for intubation and mechanical ventilation, or reduce time on mechanical ventilation, thereby decreasing the incidence of complications such as VAP, would certainly have a significant impact in the critical care setting, both in terms of the health of the patient and the costs associated with treatment. Applicants have discovered that uridine 5'-triphosphate (UTP) and related nucleotide compounds modulate specific activities of human airway epithelial cells that are components of the mucociliary escalator. Transport of foreign particles out of the lungs via the mucociliary escalator relies on the integrated action of: 1) mucus secretion by goblet cells and submucosal glands which traps foreign particles; 2) cilia to propel the

mucus out of the lungs; and 3) epithelial ion transport systems which maintain the ionic milieu of, and hence the viscosity of, airway surface liquid to allow effective ciliary beating. Application of extracellular UTP to the apical surface of normal human nasal epithelial cells in primary culture causes increased Cl⁻ secretion in a concentration-dependent manner (S. Mason, et al., Br. J. Pharmacol. 103, 1649-56 (1991); M. Knowles, et al., N. Engl. J. Med. 325, 533-8 (1991)). This response was also observed in cultured nasal epithelial cells from cystic fibrosis (CF) patients (R. Benali, et al., Am. J. Respir. Cell Mol. Biol. 10, 363-8 (1994)). This increased Cl⁻ transport has been associated with increased fluid transport across the epithelium (C. Jiang, et al., Science 262, 424-7 (1993)). In addition to these effects on Cl⁻ and fluid transport, UTP has been shown to produce an increase in cilia beat frequency in cultured human epithelial cells from normal adult humans and CF patients (D. Drutz, et al., Drug Dev Research 1996; 37(3):185 "Uridine 5' Triphosphate (UTP) Regulates Mucociliary Clearance Via Purinergic Receptor Activation", presented at "Purines '96" conference held in Milan, Italy, July 6-9, 1996). These actions of UTP have been associated with an increase in intracellular calcium ion (Ca⁺⁺) due to stimulation of phospholipase C by the P₂Y₂ receptor (H. Brown, et al., Mol. Pharmacol. 40, 648-55 (1991)). UTP has also been shown to increase the rate and total amount of mucin secretion by goblet cells in human airway epithelial explants (M. Lethem, et al., Am. J. Respir. Cell Mol. Biol. 9, 315-22 (1993)). These effects were observed in tissues from both healthy individuals and patients with CF.

As for secondary pharmacological effects, aerosol administration of UTP (10⁻² M and 10⁻¹ M in nebulizer) to anesthetized and ventilated dogs had no significant effects on peak inspiratory airway pressure, mean pulmonary artery pressure, heart rate, cardiac output, thoracic aortic pressure, electrocardiogram, or arterial blood gases (S. Mason, et al., Am. Rev. Respir. Dis. 147, A27 (1993)). To test the effect of intravenous administration, sequential doses of intravenous UTP (0.1, 1, 3 and 5 mmoles/kg) were infused into anesthetized, ventilated dogs over 10 minutes produced no significant changes in mean pulmonary artery pressure, heart rate, cardiac output, or

mean arterial pressure. Id.

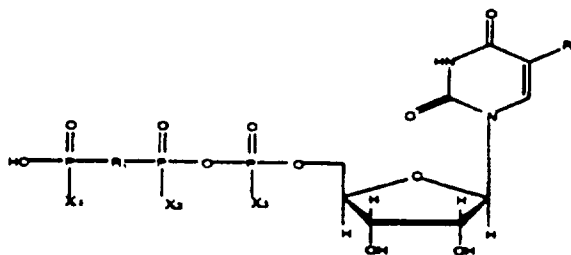
Because UTP has been shown to acutely improve mucociliary clearance (MCC) by 2.5-fold in normal volunteers without significant effects (D. Drutz, supra), it is thought that MCC improvement in mechanically ventilated patients would prevent the pooling of secretions, the plugging of mucus, and the resulting infections and atelectasis. In addition, removal of pulmonary secretions by coughing or suctioning may be enhanced by hydrating and thinning mucus secretions. UTP may, therefore, provide a safe adjunct or alternative to beta-adrenergic agonists for enhancing the removal of lung secretions in mechanically ventilated patients. Additionally, the improvement in MCC will enhance the patient's pulmonary host defense mechanisms, thus preventing ventilator-associated pneumonia (VAP) and other pulmonary complications, such as atelectasis. In addition, by acting on receptors in Type II alveolar cells, UTP may enhance surfactant production and therefore help maintain optimal gas exchange and airway epithelium function in terminal small airways.

Applicant postulates that MCC in mechanically-ventilated patients can be improved by administering UTP and its related compounds as well as other nucleoside phosphates such as: P₁,P₄-di(uridine-5') tetraphosphate (U₂P₄); adenosine 5'-triphosphate (ATP); 1,N₆-ethenoadenosine 5'-triphosphate; adenosine 1-oxide 5'-triphosphate; 3,N₄-ethenocytidine 5'-triphosphate; or P₁,P₄-di(adenosine-5') tetraphosphate (A₂P₄) to the site of fluid congestion. UTP and U₂P₄ are the preferred embodiments of the present invention. By administering UTP or U₂P₄ prior to or soon after intubation, VAP and other associated complications of mechanical ventilation may be avoided. The method of the present invention may also be used to treat chronic bronchitis patients who develop respiratory distress that requires intubation. Finally, the method of the present invention may also be used to promote the drainage of retained mucous secretions in immobilized or bedridden patients.

Summary of the Invention

A method of preventing or treating pneumonia, including ventilator-associated pneumonia (VAP), in a subject in need of such treatment is disclosed. The method of the present invention may also be used to promote the drainage and clearance of retained mucous secretions in immobilized or bedridden patients to prevent pneumonia. The method comprises administering to the patient a compound of Formula I, or a pharmaceutically acceptable salt thereof, in an amount effective to hydrate mucous secretions and stimulate ciliary beat frequency in the luminal epithelial cells of the airway passages:

Formula I



10

15 wherein:

X_1 , X_2 , and X_3 are each independently either O- or S-. Preferably, X_2 and X_3 are O-.

R_1 is O, imido, methylene, or dihalomethylene (e.g., dichloromethylene, difluoromethylene). Preferably, R_1 is oxygen or difluoromethylene.

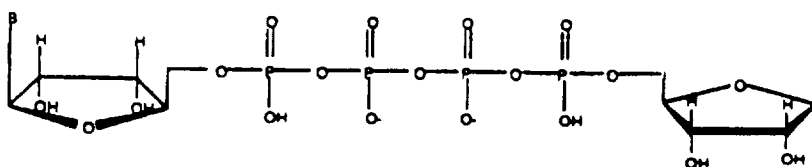
20 R_2 is H or Br. Preferably, R_2 is H. Particularly preferred compounds of Formula I are uridine 5'-triphosphate [UTP] and uridine 5'-O-(3-thiotriphosphate) [UTP γ S].

In addition to Formula I, Formula II, i.e., P1,P4-di(uridine-5') tetraphosphate [U2P4] is also a preferred embodiment of the invention. Another compound of Formula II is P1,P4-di(adenosine-5') tetraphosphate [A_2P_4]. The method of the present invention can also include
25 administering a compound of Formula III (adenosine 5' triphosphate [ATP] or 1,N6-ethenoadenosine

5'-triphosphate or adenosine 1-oxide 5'-triphosphate), or Formula IV (3,N4-ethenocytidine 5'-triphosphate).

Formula II

5



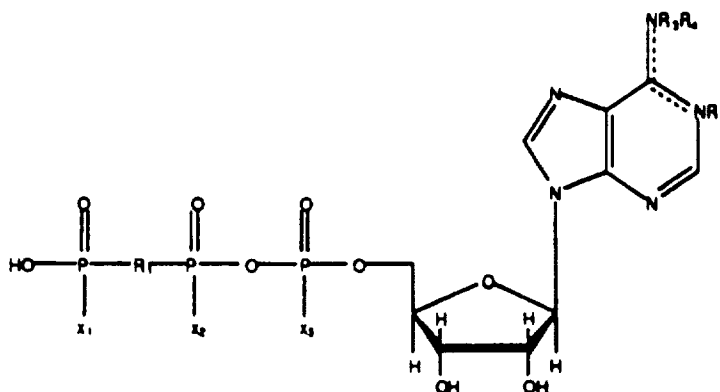
wherein:

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B is uracil or adenine, attached as in Formulae I and III.

Formula III

15



20

wherein:

R₁, X₁, X₂, and X₃ are defined as in Formula I.

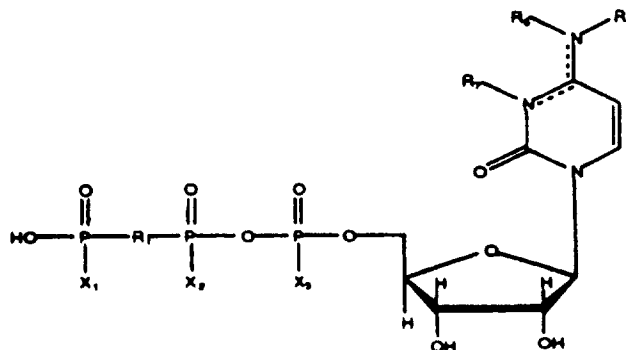
R₃ and R₄ are H while R₂ is nothing and there is a double bond between N-1 and C-6 (adenine), or

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R₃ and R₄ are H while R₂ is O and there is a double bond between N-1 and C-6 (adenine 1-oxide), or

R_3 , R_4 and R_2 taken together are $-\text{CH}=\text{CH}-$, forming a ring from N-6 to N-1 with a double bond between N-6 and C-6 (1,N6-ethenoadenine).

Formula IV



wherein:

10 R_1 , X_1 , X_2 , and X_3 are defined as in Formula I.

R_5 and R_6 are H while R_7 is nothing and there is a double bond between N-3 and C-4 (cytosine), or,

R_5 , R_6 and R_7 taken together are $-\text{CH}=\text{CH}-$, forming a ring from N-3 to N-4 with a double bond between N-4 and C-4 (3,N4-ethenocytosine).

15 A second aspect of the present invention is a pharmaceutical formulation containing the compound of Formula I, II, III or IV in an amount effective to promote or enhance clearance of secretions, hydrate mucous secretions and stimulate ciliary beat frequency in the luminal epithelial cells of the airway passages in a patient in need of such treatment.

20 A third aspect of the present invention is the stimulation of surfactant production in Type II alveolar cells.

A fourth aspect of the present invention is the use of the active compounds disclosed herein for the manufacture of a medicament for the therapeutic hydration of mucous secretions and stimulation of ciliary beat frequency in the luminal epithelial cells of the airway passages in a patient in need of such treatment.

25

Brief Description of the Drawings

Figure 1 represents the results of the studies described in Example 2 showing the effects of UTP on tracheal mucous velocity.

5 Figure 2 represents the results of the studies described in Example 2 showing the effects of U_2P_4 on tracheal mucous velocity.

Figure 3 represents the results of studies described in Example 2 showing a bar graph of the TMV post dose for varying concentrations of UTP and U_2P_4 .

Figure 4 represents the results of the studies described in Example 3 showing the effects of UTP and U_2P_4 in mucociliary clearance of adult ewes

10 Description of the Specific Embodiments

The method of the present invention may be used to prevent or treat pneumonia, including ventilator-associated pneumonia (VAP), by hydrating retained mucous secretions, stimulating ciliary beat frequency and promoting clearing of mucous in the airways of a subject in need of such treatment. The method of the present invention may also be used to prevent or treat

15 sinusitis in nasally intubated patients, and to improve mucociliary clearance (MCC) thereby preventing pneumonia in chronically immobilized or bedridden patients. The present invention increases mucociliary clearance (MCC) in three ways: (1) by increasing the ciliary beat frequency of cilia on the surface of luminal epithelia cells, (2) by increasing the secretions of mucins by goblet cells, and (3) by increasing the chloride ion secretion and simultaneously increasing the secretion

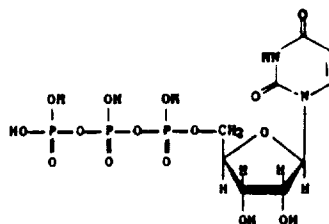
20 of water into the periciliary liquid layer by luminal epithelial cells, consequently lowering the viscosity of the mucus. The mucins secreted by goblet cells form a layer on top of the cilia and capture foreign particles, including viruses and bacteria; the mucin layer is transported by the wave-like action of cilia; and the movement of cilia is facilitated by the hydration of the periciliary liquid layer surrounding the cilia. Further, the method of the present invention may be used with

25 the compounds disclosed to influence agonist activity on P_2Y_2 receptors thereby stimulating

surfactant production.

Compounds illustrative of the compounds of Formula I above include: (a) uridine 5'-triphosphate (UTP); (b) uridine 5'-O-(3-thiotriphosphate) (UTP γ S); and (c) 5-bromo-uridine 5'-triphosphate (5-BrUTP). These compounds are known or may be made in accordance with known procedures, or variations thereof which will be apparent to those skilled in the art. For example, UTP may be made in the manner described in Kenner, et al., *J. Chem. Soc.* 1954, 2288. Following this well-known methodology, UTP can be synthesized by condensing 2':3'-di-O-acetyl- or 2':3'-O-isopropylidene-uridine-5' benzyl phosphorochloridate with a salt of tribenzyl pyrophosphate and then removing the benzyl and other protecting groups. UTP has also been synthesized by treating at room temperature a mixture of UMP and 85% orthophosphoric acid with excess DCC in aqueous pyridine. Hall and Khorana, *J. Am. Chem. Soc.* 76, 5056 (1954).

The Merck Index, Monograph No. 9795 (11th Ed. 1989) gives the chemical structure of UTP:



S-2-carbamoyl ethyl thiophosphate can be used for the chemical synthesis of thiophosphate compounds such as UTP γ S which has a sulfur at its terminal phosphorus atom. S. Goody and F. Eckstein, *J. Am. Chem. Soc.* 93, 6252 (1971).

For simplicity, Formulae I-IV herein illustrate the active compounds in the naturally occurring D-configuration, but the present invention also encompasses compounds in the L-configuration, and mixtures of compounds in the D- and L- configurations, unless otherwise specified. The naturally occurring D-configuration is preferred.

Compounds illustrative of the compounds of Formula II include (P₁,P₄-di(adenosine-5')) tetrphosphate (A₂P₄) or P₁,P₄-di(uridine-5') tetrphosphate (U₂P₄). These

compounds can be made in accordance with known procedures, or variations thereof. For example, A_2P_4 was synthetically prepared by activating ADP with carbonyldiimidazole. E. Rapaport, et al., *Proc. Natl. Acad. Sci. USA* 72(2), 838-42 (1981). Treating aqueous solutions of adenosine-5'-mono-, di-, or triphosphate with carbodiimide results in diadenosine-5'-5'-polyphosphate (including A_2P_4).

5 K. Ng and L. E. Orgel, *Nucleic Acids Res.* 15 (8), 3572-80 (1987). U_2P_4 can be synthesized through the reaction of uridine 5'-phosphoromorpholidate (0.54 mmol) with triethylamine salt of pyrophosphate (0.35 mmol) in a medium of anhydrous pyridine (10 ml). C. Vallejo, et al., *Biochem. Biophys. Acta* 438, 304-09 (1976).

Compounds illustrative of the compounds of Formula III above include (a) adenosine

10 5'-triphosphate (ATP) and (b) 1,N6-ethenoadenosine 5'-triphosphate. Compounds illustrative of the compounds of Formula IV above include (a) cytidine 5'-triphosphate and (b) 3,N4-ethenocytidine 5'-triphosphate. These compounds can be made in accordance with known procedures, or variations thereof which will be apparent to those skilled in the art. For example, nucleoside triphosphates can be synthesized by the reaction of the phosphorimidazolidate formed from a nucleotide and 1,1'-

15 carbonyldiimidazole with inorganic pyrophosphate. D. Hoard and D. Ott, *J. Am. Chem. Soc.* 87, 1785-1788 (1965). Another general method involves adding a 2',3'-iso-propylidene nucleoside to a cold mixture of trialkyl phosphate and phosphoryl chloride with stirring. The mixture is converted into the corresponding 5'-phosphorodichloridate. 5'nucleotide is obtained by rapid hydrolysis of the chloridate group followed by removal of the isopropylidene group at 70°C. M. Yoshikawa, et al.,

20 *Tetrahedron Lett.* 5065-68 (1967) and *idem.*, *Bull. Chem. Soc. (Jpn)* 42, 3505-08 (1969).

Nucleoside-5' phosphoramidates may be used as an improved method for the preparation of nucleoside-5' polyphosphates. J. Moffatt and H. Khorana, *J. Am. Chem. Soc.* 83, 649-59 (1961); and B. Fischer, et al., *J. Med. Chem.* 36, 3937-46 (1993).

Etheno derivatives of cytidine and adenosine are prepared by known methods. For

25 example, a reaction using chloroacetaldehyde and the nucleosides adenosine and cytidine is well

known. Chloroacetaldehyde reacts with 9-N-methyladenine and I-N-methylcytosine in weakly acidic aqueous solutions to form ethenoderivatives of cytidine and adenosine. N. Kotchetkov, et al., *Tetrahedron Lett.* 1993 (1971); J. Barrio, et al., *Biochem. Biophys. Res. Commun.* 46, 597 (1972); J. Secrist, et al., *Biochemistry* 11, 3499 (1972); J. Bierndt, et al., *Nucleic Acids Res.* 5, 789 (1978);
5 K. Koyasuga-Mikado, et al., *Chem. Pharm. Bull. (Tokyo)* 28, 932 (1980).

Derivatives with alpha, beta and gamma thiophosphorus groups can be derived by the following or by adapting the following methods: 2-Chloro-4H-1,3,2-benzodioxaphosphorin-4-one can be used to phosphitylate the 5'-hydroxy group of a nucleoside to form an intermediate, which on a subsequent reaction with pyrophosphate forms, in a double displacement process a P²,P³-dioxo-
10 P'-5'-nucleosidylcyclo triphophite. Oxidation with sulfur forms a nucleoside 5'-(1-thiocyclotriphosphate), which is hydrolyzed to the diastereomeric mixture of a nucleoside 5'-O-(1-thiotriphosphate). Alternatively, P²,P³-dioxo-P'-5'-nucleosidylcyclo triphophite can be oxidized with iodine/water to yield nucleoside 5'-triphosphates. This reagent can also be used for the synthesis of nucleoside 2',3'-cyclic phosphorothioates. J. Ludwig and F. Eckstein, *J. Org. Chem.* 54, 631-35
15 (1989).

Derivatives with alpha, beta and gamma thiophosphorus groups can also be made by following the protocol recited in F. Eckstein and R. Goody, *Biochemistry* 15, 1685 (1976). [³⁵S]Adenosine 5'-(0-1-thiotriphosphate). [³⁵S]Adenosine 5'-phosphorothioate (7500 A₂₆₀ units, 0.5 mmol) was converted to the pyridinium salt by passage over Merck I ion exchanger (pyridinium
20 form). The solution was evaporated to dryness, tri-*n*-octylamine (0.22 ml, 0.5 mmol) and methanol (ca. 10 ml) were added, and the mixture was stirred until a clear solution was obtained. After evaporation, the residue was evaporated (three times) with dry dimethylformamide using an oil pump. The residue was dissolved in anhydrous dioxane (2 ml) and diphenyl phosphorochloridate (0.15 md, 0.75 mmol) and tri-*n*-butylamine (0.25 ml, 1 mmol) were added. After stirring the mixture
25 at room temperature for 3 h, the solvent was removed by evaporation, and anhydrous ether (10 ml)

and petroleum ether (30 ml) were added to the residue, and the mixture was left at 0 °C for 30 min. The ether was decanted, the remaining material dissolved in anhydrous dioxane (1 ml), and the solution evaporated.

5 Tetrasodium pyrophosphate decahydrate (2.23 g, .5 mmol) was converted to the pyridinium salt by addition of tri-*n*-butylamine (2.43 ml, 10 mmol) and evaporation to dryness to the tri-*n*-butylammonium salt. After repeated evaporation with anhydrous pyridine (three times), the material was dissolved in anhydrous pyridine (3 ml) and added to the activated [³⁵S]adenosine 5'-phosphorothioate described above.

10 After stirring at room temperature for 2 h, ether (10 ml) was added to precipitate the product. The precipitate was dissolved in water and chromatographed on a DE-52 cellulose column (37 x 2.5 cm), with a linear gradient of 1.5 l. Each of 0.05 M and 0.5 M triethylammonium bicarbonate. The product was eluted at ca. 0.33 M buffer, yield 1550 A_{260} units (0.1 mmol, 20%). For further purification this material was rechromatographed on a QAE-A 25 Sephadex column (1.5 x 25 cm) with a linear gradient of 800 ml each of 0.25 M and 0.5 M triethylammonium bicarbonate: 15 yield 1200 A_{260} units (16%). The material was not degraded by snake venom phosphodiesterase but was degraded to AMPS¹ by alkaline phosphatase under conditions described for ATPβS:

20 [³⁵S]Adenosine 5'-(*O*-1-Thiodiphosphate). The synthesis of this compound was carried out as described for [³⁵S]adenosine 5'-(*O*-1-thiotriphosphate) except that phosphate was added to the activated [³⁵S]adenosine 5'-phosphorothioate instead of pyrophosphate: yield 1410 A_{260} units (0.94 mmol, 18%).

25 Adenosine 5'-(*O*-2-thiotriphosphate) (ATPβS) Adenosine 5'-(*O*-2-thiodiphosphate (1.5 mmol; Goody and Eckstein, 1971) was converted to its pyridinium salt by passage over Merck I ion exchanger (pyridinium form) in methanol-water (1:1, v/v), and the solution was evaporated to dryness using a rotary evaporator. Tri-*n*-octylamine (1.3 ml, ca. 3 mmol) and methanol (10 ml) were added to the residue, and the mixture was stirred until solution was obtained (ca. 30 min). After

removal of solvent under reduced pressure, the residue was dissolved in dry pyridine (10 ml) and evaporated to dryness on a rotary evaporator using an oil pump. This process was repeated three times.

5 β -Cyanoethyl phosphate (Ba^{2+} salt, 854 mg, 3 mmol) was converted to its mon(tri-*n*-octylammonium) salt in a similar way to that described above, using 3 mmol of tri-*n*-octylamine. The salt was dried by repeated addition and reevaporation of dry dimethylformamide (10 ml) and then dissolved in dry dioxane (15 ml). Diphenyl phosphorochloridate (0.9 ml, 4.5 mmol) and tri-*n*-butylamine (0.45 ml) were added, and the solution was allowed to stand at room temperature for 3 h. After removal of dioxane under reduced pressure, ether (30 ml) followed by petroleum ether (60 ml; 60-80 °C) was added and, after shaking for a few minutes, the mixture was allowed to stand for 15 min in ice. The ether was then removed by decantation and the residue dissolved in dry dioxane (5 ml) which was then removed by evaporation under reduced pressure, and to the residue was added the ADP β S tri-*n*-octylammonium salt, prepared as described above dissolved in a mixture of dry hexamethyl phosphorotriamidate (4 ml) and dry pyridine (4 ml). The resulting solution was allowed to stand for 3 h at room temperature, and pyridine was then removed under reduced pressure. The remaining mixture was treated with 0.5 N sodium hydroxide (100 ml) for 1 h at room temperature, after which time the solution was neutralized by addition of Merck I ion exchanger (pyridinium form). The neutralized solution was applied to a column of DE-52-cellulose (ca. 50 x 4 cm) which was eluted with a linear gradient of triethylammonium bicarbonate (0.1-0.35 M, 2 X 2 l.). The product was eluted at about 0.25 M: yield 2750 A_{260} units (12%); for ^{31}P NMR spectrum, see Table I. This was slightly contaminated with ADP β S. A further 800 A_{260} units of product were obtained, more heavily contaminated with ADP β S. Pure ADP β S could be obtained by chromatography on DEAE-Sephadex A-25, using a gradient of triethylammonium bicarbonate (0.2-0.5 M) at 4 °C. The product behaved identically with regard to TLC on PEI-cellulose with ATP β S synthesized using pyruvate kinase.

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R. Goody and F. Eckstein, *J. Am. Chem. Soc.* 93, 6252 (1971) describe the synthesis of thiophosphate analogs of nucleoside di- and triphosphates having a sulfur at the terminal phosphorus atom by the use of S-2-carbamoylethyl thiophosphate.

Compounds of Formulas I, III, or IV where R_1 is CCl_2 and CF_2 can be prepared by methods similar to that described in G. Blackburn, et al., *J. Chem. Soc. Perkin Trans. I*, 1119-25 (1984).

Adenosine 5'-(β,γ - μ -Difluoromethylene)triphosphate, AMPPCF₂P (1c).--(a)
Morpholine-4-*N,N'*-dicyclohexylcarboxamidinium adenosine-5'-phosphoromorpholidate (390 mg, 0.5 mmol) was dissolved in anhydrous, amine-free pyridine (5 ml). The solution was evaporated to dryness and the procedure repeated twice more with exclusion of moisture. It was finally dissolved in pyridine (3 ml). Similarly the bis(tri-*n*-butylammonium) salt of difluoromethylenebisphosphonic acid (580 mg, 1.0 mmol) was evaporated repeatedly from its solution in pyridine (3 x 5 ml). Finally, the two pyridine solutions were combined and evaporated to dryness. The residue was kept in anhydrous pyridine (4 ml) for 24 h with magnetic stirring and exclusion of moisture. After this time the solution was evaporated to remove pyridine. The residue was dissolved in deionized water (5 ml), applied to a column of DEAE-Sephadex (3 x 30 cm), and the product eluted with a linear salt gradient (0--0.5M-LiCl). Fractions containing the analogue were combined and evaporated to dryness. The white solid residue was dissolved in a small volume of anhydrous methanol (5 ml) and the nucleotide precipitated out by the addition of acetone (25 ml). The precipitated product was collected by centrifugation and the whole procedure repeated four times. The white pellet was finally redissolved in methanol (10 ml) and evaporated to dryness to yield the white, powdery product as the tetralithium salt (164 MG, 54%), m.p. 225-235 °C (decomp.).

Adenosine 5'-(β,γ - μ -Dichloromethylene)triphosphate, AMPPCCl₂P(1e). Adenosine-5'-phosphoromorpholidate (390 mg, 0.5 mmol) was condensed with the bis(tri-*n*-butylammonium)

salt of dichloro-methylenebisphosphonic acid (613 mg, 1 mmol). The product was chromatographed on DEAE Sephadex using a linear gradient (LiCl, 0--0.5 M, pH 7.0, 2 l). Fractions containing the product were combined and evaporated to dryness and the *product* isolated by repeated dissolution in methanol (5 ml) and precipitation with acetone (25 ml) to give a white powder (24 mg, 75.7%), m.p. 235-245 °C (decomp).

Preparation of guanosine 5'-(β,γ - μ -Difluoromethylenetriphosphate) GMPPCF₂P (2b)--Morpholine-4-*N,N'*-dicyclohexyl-carboxamidinium guanosine-5'-phosphoromorpholidate (390 mg, 0.5 mmol) was dissolved in a mixture of anhydrous pyridine (5 ml) and freshly distilled 2-chlorophenox (4 ml). To this was added the bis(tri-*n*-butylammonium) difluoromethylenebisphosphonate (580 mg, 1 mmol). The solution was stirred for 4 days with exclusion of moisture and light. After this time water (50 ml) was added and the solution extracted with ether (3 x 50 ml). The aqueous phase was evaporated to dryness and the gummy residue redissolved in water (5 ml), applied to a column of DEAE Sephadex, and eluted with a linear salt gradient (LiCl, 0--0.5 M, pH 7.0). Fractions containing the analogue were combined and evaporated to dryness and the product repeatedly precipitated from methanol with acetone. Evaporation to dryness of the final *product* in methanol yielded the title compound as a white powder (136 mg, 42.8%), m.p. 245-255 °C (decomp.).

Guanosine 5'(β,γ - μ -Dichloromethylene)triphosphate GMPPCCl₂P (2d)--In a reaction exactly analogous to that for (2b), morpholine-4-*N,N'*-dicyclohexylcarboxamidinium guanosine-5'-phosphoromorpholidate (144 mg, 0.2 mmol) was combined with the bis(tri-*n*-butylammonium) salt of dichloro-methylenebisphosphonic acid¹⁰ (360 mg, 0.6 mmol) to yield the *product* as a white powder, (81 mg, 62%), m.p. 240-260 °C (decomp).

Compounds of Formula I, II, III where R₁ is CH₂ can be prepared by methods similar to that described in T. Myers, et al., *J. Am. Chem. Soc.* 85, 3292-95 (1963). This methodology demonstrates that the syntehsis of 5'-adenylylmethylene or diphosphonate has been accomplished

by the reaction of adenosine 5'-phosphorimidate with methylenediphosphonic acid and by the condensation of AMP with methylenediphosphonic acid in the presence of excess dicyclohexylcarbodiimide.

In addition, UTP, ATP, CTP, A_2P_4 , 3,N⁴-ethenocytidine triphosphate, 1,N⁶-ethenoadenine 5'-triphosphate, adenosine 1-oxide 5'-triphosphate, ATP γ S, ATP β S, ATP α S, AMPPCH₂P, AMPPNHP, N⁴-ethenocytidine and 1,N⁶-ethenoadenosine are commercially available, for example, from Sigma Chemical Company, PO Box 14508, St. Louis, MO 63178.

The active compounds of Formulae I - IV may be administered by themselves or in the form of their pharmaceutically acceptable salts, e.g., an alkali metal salt such as sodium or potassium, an alkaline earth salt, or an ammonium and tetraalkyl ammonium salts, NX₄⁺ (wherein X is C₁₋₄). Pharmaceutically acceptable salts are salts that retain the desired biological activity of the parent compound and do not impart undesired toxicological effects.

The active compounds disclosed herein may be administered to the lungs, sinuses, ears or eyes by a variety of suitable means, but are preferably administered by administering a liquid/liquid suspension (either a nasal spray of respirable particles which is either inhaled by the subject or administered to the subject by means of nebulization through the mechanical ventilation system, or nasal drops of a liquid formulation, or eye drops of a liquid formulation) comprised of the active compound. Liquid pharmaceutical compositions of the active compound for producing a nasal spray or nasal powder, nasal or eye drops, or a liquid nebulized preparation may be prepared by combining the active compound with a suitable vehicle, such as sterile pyrogen free water or sterile saline by techniques known to those skilled in the art. Further, other methods of administration could be used including, systemic administration and oral forms (liquid or pill), powder inhalation, topical, injectable, intra-operative instillation of a gel, cream, powder, foam, crystals or liquid suspension or suppository form.

The methods described herein are also applicable to veterinary use.

EXPERIMENTAL

Example 1

Treatment of Patients At Risk For Ventilator-Associated Pneumonia (VAP)

Uridine 5'-triphosphate (UTP) or P₁,P₄ di(uridine-5')-tetrphosphate (U₂P₄) is administered to adult patients with acute neurological impairment requiring intubation and mechanical ventilation. UTP is administered in an aerosolized form via an in-line nebulizer, 2-3 times per day, for a total of 5 days. The concentration of UTP is in the range of 10⁻⁷ to 10⁻¹ moles/liter. Treatment with UTP begins within 12 hours of intubation/mechanical ventilation. The length of treatment for each patient is 5 days.

The safety of UTP to prevent or treat VAP is assessed by standard safety measures of vital signs--heart rate, respiratory rate, blood pressure, electrocardiogram and laboratory blood tests (e.g., blood chemistries, complete blood count, hematology), as well as any adverse events observed.

The effectiveness of UTP in preventing VAP is measured by a diminution of symptoms of VAP as determined by periodic physical examinations, and by laboratory and bacteriology evaluations. Another means of measuring effectiveness is a decrease in the total number of days on mechanical ventilation--this is because an improvement in mucociliary clearance would decrease airway ventilating pressures and the need for assisted ventilation.

Example 2

Trachael Mucus Study

The effects of UTP and U₂P₄ on trachael mucus velocity (TMV) were studied using the following procedures: The nasal passages of conscious adult ewes were anesthetized with a 2% lidocaine solution. After local anesthesia was produced, a modified endotracheal tube 7.5 mm was placed such that the cuff was just below the vocal cords (verified by fluoroscopy). Inspired air was warmed and humidified. The cuff of the endotracheal tube was inflated only during administration

of the test compound to minimize possible impairment of TMV by the cuff. Test compounds were administered by nebulization in a volume of 4 mL over a period of 10-12 min.

TMV was measured by fluroscopy. Ten to twenty radiopaque disks (Teflon[®]/bismuth trioxide; 1mm diameter, 0.8 mm thick, weighing 1.8 mg) were introduced into the trachea through a modified suction catheter with a puff of compressed air (3-4 L/min). Velocities of the individual disks were recorded on videotape from a portable image intensifier unit. Individual disk velocities were calculated by measuring the distance traveled by each disk during a 1 min observation period. Values reported are the means of the individual disk velocities. A collar was worn by the sheep which was used as a standard to correct for magnification errors inherent in the fluoroscope.

Both UTP and U_2P_4 produced significant dose-related effects on tracheal mucus velocity. The doses ranged from 4 to 400 μ mole. Both compounds had their maximal effects at a dose of 400 μ mole (4 ml of $10^{-1}M$). UTP produced a maximal effect of 125 ± 7 % of baseline (mean \pm standard error, n=6). U_2P_4 produced a maximal effect of 144 ± 9 % of baseline (n=6). Both compounds produced their maximal effects 15 min after administration. The highest dose of UTP produced significant effects on TMV up to 4 h after administration. The effects of U_2P_4 were significant out to 2 h after administration. Results are shown in Figures 1-3.

Example 3

Mucociliary Clearance Study

In this study healthy adult ewes were given 99 mTc-labeled human serum albumin (99mTc-HSA) via a nebulized aerosol. The 99 mTC-HSA (20mCi) was administered over 5 min through a nasotracheal tube introduced under local anesthesia with 2% lidocaine. After administration of the 99mTc-HSA, the animals were given a test compound: either UTP or U_2P_4 . Test compounds were administered by nebulization in a volume of 4 mL over a period of 10-12 min. The test compounds were given at a dose of 400 μ mole. After the administration of the test compound, the animals were extubated. Clearance of the radiolabeled particles was monitored with

a gamma camera. Measurements were made at 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 76, 90, 105 and 120 min. Initial results (n=2) have shown that both test compounds promote clearance of the radiolabeled particles (compared to the saline control). Results are shown in Figure 4.

The results of the studies in sheep on tracheal mucus velocity (TMV) and whole lung mucociliary clearance (WLC) demonstrated that UTP and U_2P_4 can enhance mucociliary clearance in intubated animals. Intubation is known to have detrimental effects on mucociliary clearance. This was shown in the TMV study by the decline in TMV over the study period in the saline treated animals. Despite this declining baseline, UTP and U_2P_4 were able to produce an enhancement of TMV. Although the intubation period was brief in the WLC study (only during administration of the test compound), impairment of mucociliary clearance is a realistic possibility. UTP and U_2P_4 produced enhanced clearance under these conditions as well. These data strongly suggest that these agents will enhance mucociliary clearance in intubated patients, which may be therapeutically useful in the prevention or treatment of VAP and subjects at risk.

The subject methods and compounds described herein provide a means for preventing or treating ventilator-associated pneumonia in the intensive care unit setting. The method comprises administering to the airways of the subject a uridine triphosphate such as uridine 5'-triphosphate (UTP) or any analog of UTP, for example U_2P_4 , in an amount effective to hydrate mucous secretions to promote or enhance clearance, or to stimulate ciliary beat frequency in the lungs.

The invention now being fully described, it will be apparent to one of ordinary skill in the art that many changes and modifications can be made thereto without departing from the spirit or scope of the appended claims.

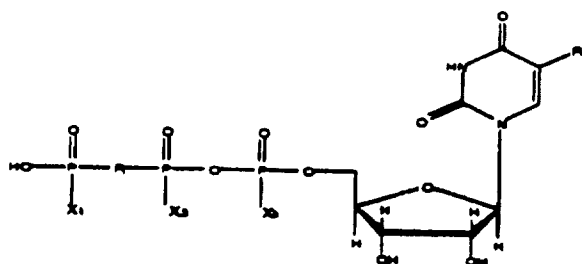
WHAT IS CLAIMED IS:

1. A method of preventing or treating pneumonia, including ventilator-associated pneumonia, in a bedridden or immobilized subject in need of such treatment, said method comprising:

administering to the subject a compound of Formula I, II, III or IV, or a

5 pharmaceutically acceptable salt thereof, in a pharmaceutical carrier having an amount of said compound effective to promote clearance from the airways:

Formula I



wherein:

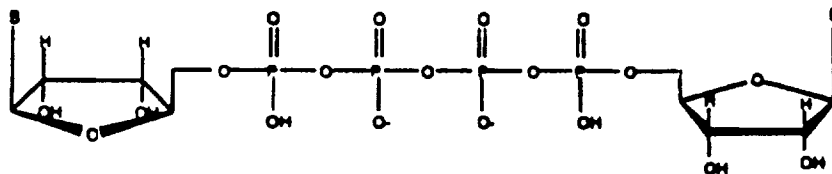
X_1 , X_2 , and X_3 are each independently selected from the group consisting of OH and SH;

10 R_1 is selected from the group consisting of O, imido, methylene, and dihalomethylene;

and

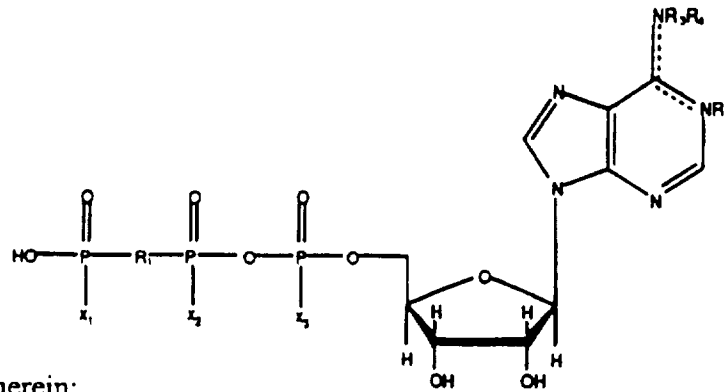
R_2 is selected from the group consisting of H and Br;

Formula II



wherein:

15 B is uracil or adenine, attached as in Formulae I and III;



wherein:

R_1 , X_1 , X_2 , and X_3 are defined as in Formula I,

R_3 and R_4 are H while R_2 is nothing and there is a double bond between N-1 and C-6

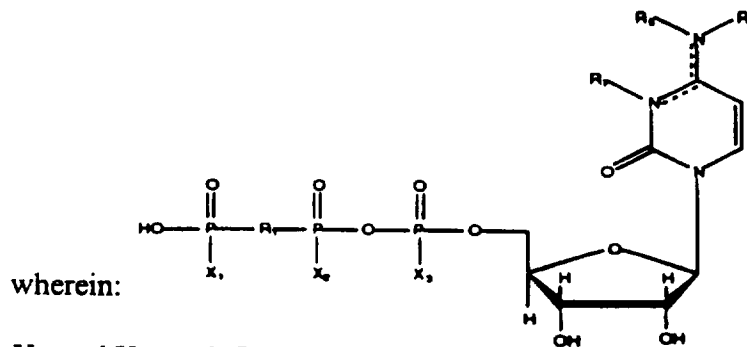
5 (adenine), or

R_3 and R_4 are H while R_2 is O and there is a double bond between N-1 and C-6 (adenine 1-oxide), or

R_3 , R_4 , and R_2 taken together are $-\text{CH}=\text{CH}-$, forming a ring from N-6 to N-1 with a double bond between N-6 and C-6 (1,N6-ethenoadenine);

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Formula IV



wherein:

R_1 , X_1 , X_2 , and X_3 are defined as in Formula I,

R_5 and R_6 are H while R_7 is nothing and there is a double bond between N-3 and C-4 (cytosine), or,

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R_5 , R_6 and R_7 taken together are $-\text{CH}=\text{CH}-$, forming a ring from N-3 to N-4 with a double bond between N-4 and C-4 (3,N4-ethenocytosine).

2. A method according to Claim 1, wherein said compound is delivered by

administering a liquid/liquid suspension, including eye drops of said compound to the eyes, or nasal drops, or spray, of said compound to the nasopharyngeal airways, nasotracheal tube, endotracheal tube, or tracheostomy of said subject, such that a therapeutically effective amount of said compound contacts the airways of said subject either directly or via systemic absorption and circulation.

3. A method according to Claim 1, wherein said compound is delivered by administering an oral form of said compound, such that a therapeutically effective amount of said compound contacts the airways of said subject via systemic absorption and circulation.

4. A method according to Claim 1, wherein said compound is delivered by administering a nebulized aerosol or suspension of said compound to the nasopharyngeal airways, nasotracheal tube, endotracheal tube, or tracheostomy of said subject, such that a therapeutically effective amount of said compound contacts the airways of said subject either directly or via
5 systemic absorption and circulation.

5. A method according to Claim 1, wherein said compound is delivered by administering a topical form of said compound to the airways via the nose, eyes, outer ear or nasopharyngeal airways of said subject, such that a therapeutically effective amount of said compound contacts the airways of said subject.

6. A method according to Claim 1, wherein said compound is delivered by administering an injected form of said compound, such that a therapeutically effective amount of said compound contacts the airways of said subject either directly or via systemic absorption and circulation.

7. A method according to Claim 1, wherein said compound is delivered by administering a suppository form of said compound, such that a therapeutically effective amount of said compound contacts the airways of said subject via systemic absorption and circulation.

8. A method according to Claim 1, wherein said compound is delivered by administering an intra-operative instillation of a gel, cream, powder, foam, crystals or liquid

suspension form of the active compound such that a therapeutically effective amount of said compound contacts the airways either directly or via systemic absorption and circulation.

9. A method according to Claim 1, wherein said compound is delivered by administering a dry-powder aerosolized form of said compound, such that a therapeutically effective amount of said compound contacts the airways of said subject either directly or via systemic absorption and circulation.

10. A method according to Claim 1, wherein said compound is administered in an amount sufficient to achieve concentrations thereof on the surfaces of the airways of said subject to increase the ciliary beat frequency of cilia on the surface of luminal epithelia cells, to increase the secretions of mucous by goblet cells, to increase the chloride ion secretion to stimulate surfactant reduction and to promote the clearance of retained secretions.

11. A method according to Claim 1, wherein said compound is administered in an amount sufficient to achieve concentrations on the surfaces of the airways of said subject of from about 10^{-7} to about 10^{-1} moles/liter.

12. A method according to Claim 1, wherein X_2 and X_3 are OH.

13. A method according to Claim 1, wherein R_1 is oxygen.

14. A method according to Claim 1, wherein R_2 is H.

15. A method according to Claim 1, wherein said compound of Formula I is selected from the group consisting of uridine 5'-triphosphate, uridine 5'-O-(3-thiotriphosphate), 5-bromo-uridine 5' triphosphate and the pharmaceutically acceptable salts thereof.

16. A method according to Claim 1, wherein said compound of Formula II is selected from the group consisting of P1,P4-di(uridine-5') tetraphosphate (U_2P_4) and P1,P4-di(adenosine-5') tetraphosphate (A_2P_4) and substituted derivatives and the pharmaceutically acceptable salts thereof.

17. A method according to Claim 1, wherein said compound of Formula III is

selected from the group consisting of adenosine 5'-triphosphate, 1,N6-ethenoadenosine 5'-triphosphate, adenosine 1-oxide 5'-triphosphate and the pharmaceutically acceptable salts thereof.

18. A method according to Claim 1, wherein said compound of Formula IV is selected from the group consisting of cytidine 5'-triphosphate (CTP), 3,N4-ethenocytidine 5'-triphosphate and the pharmaceutically acceptable salts thereof.

19. A method of preventing or treating sinusitis in a nasally-intubated patient, said method comprising:

administering to the subject a compound of Formula I, II, III or IV, or a pharmaceutically acceptable salt thereof, in a pharmaceutical carrier having an amount of said compound effective to promote mucociliary clearance from the sinuses.

20. A method of preventing or treating retained mucous secretions in a bedridden or immobilized patient, said method comprising:

administering to the subject a compound of Formula I, II, III or IV, or a pharmaceutically acceptable salt thereof, in a pharmaceutical carrier having an amount of said compound effective to promote mucociliary clearance from the airways.

21. A method according to Claim 20, wherein the subject is placed in a lateral rotation therapeutic bed which rotates the subject to further loosen mucous secretions.

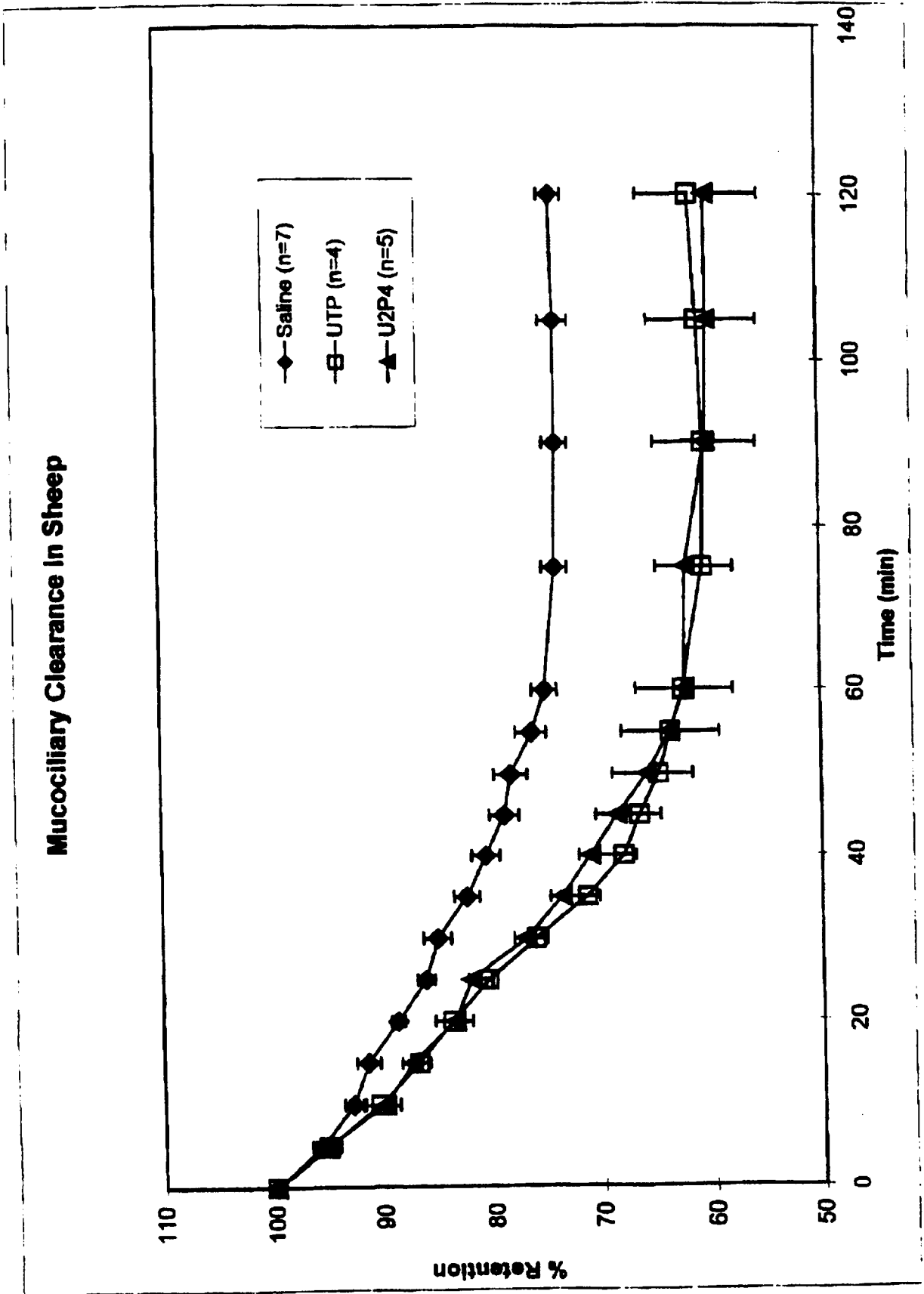


FIGURE 4

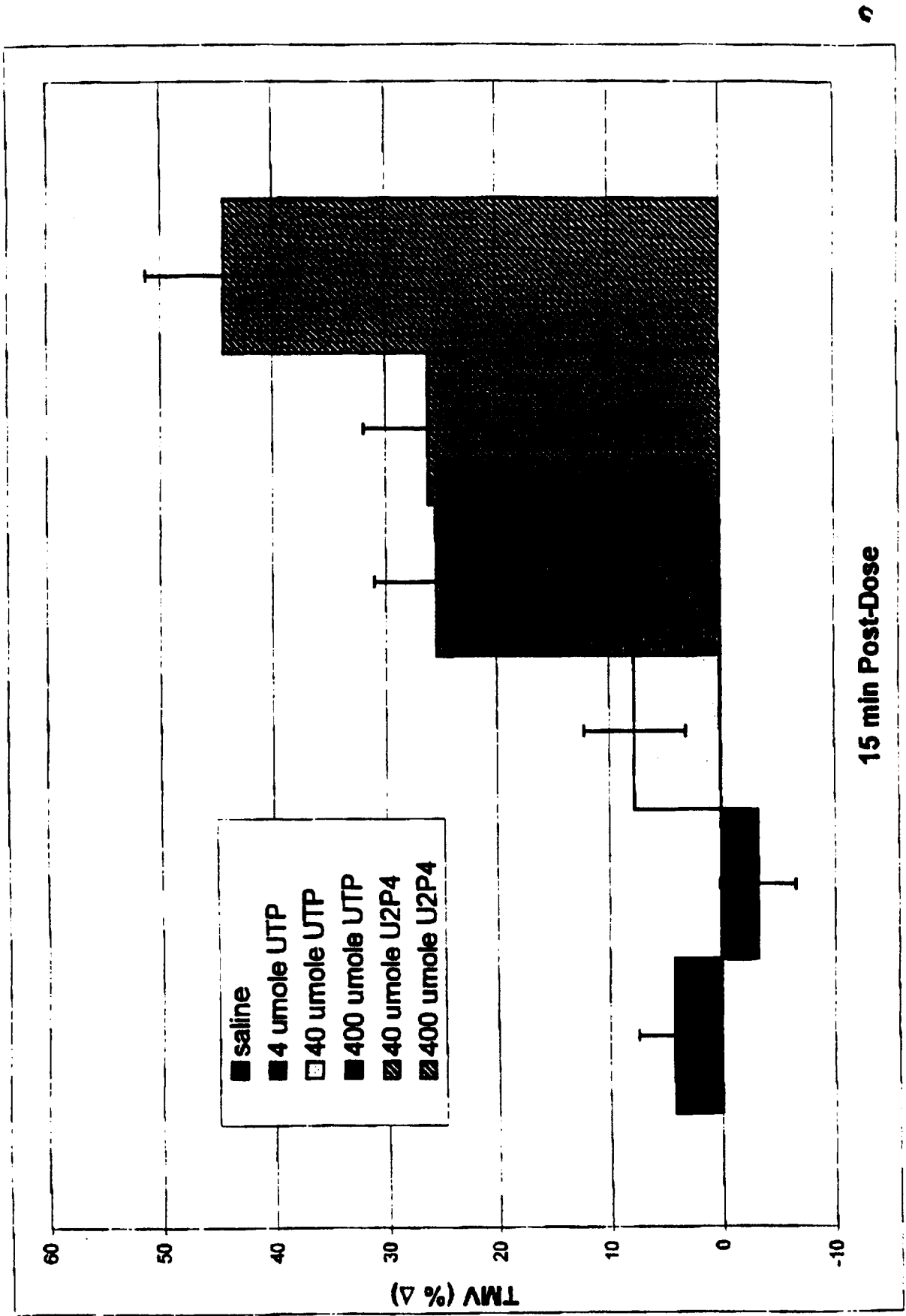


FIGURE 3

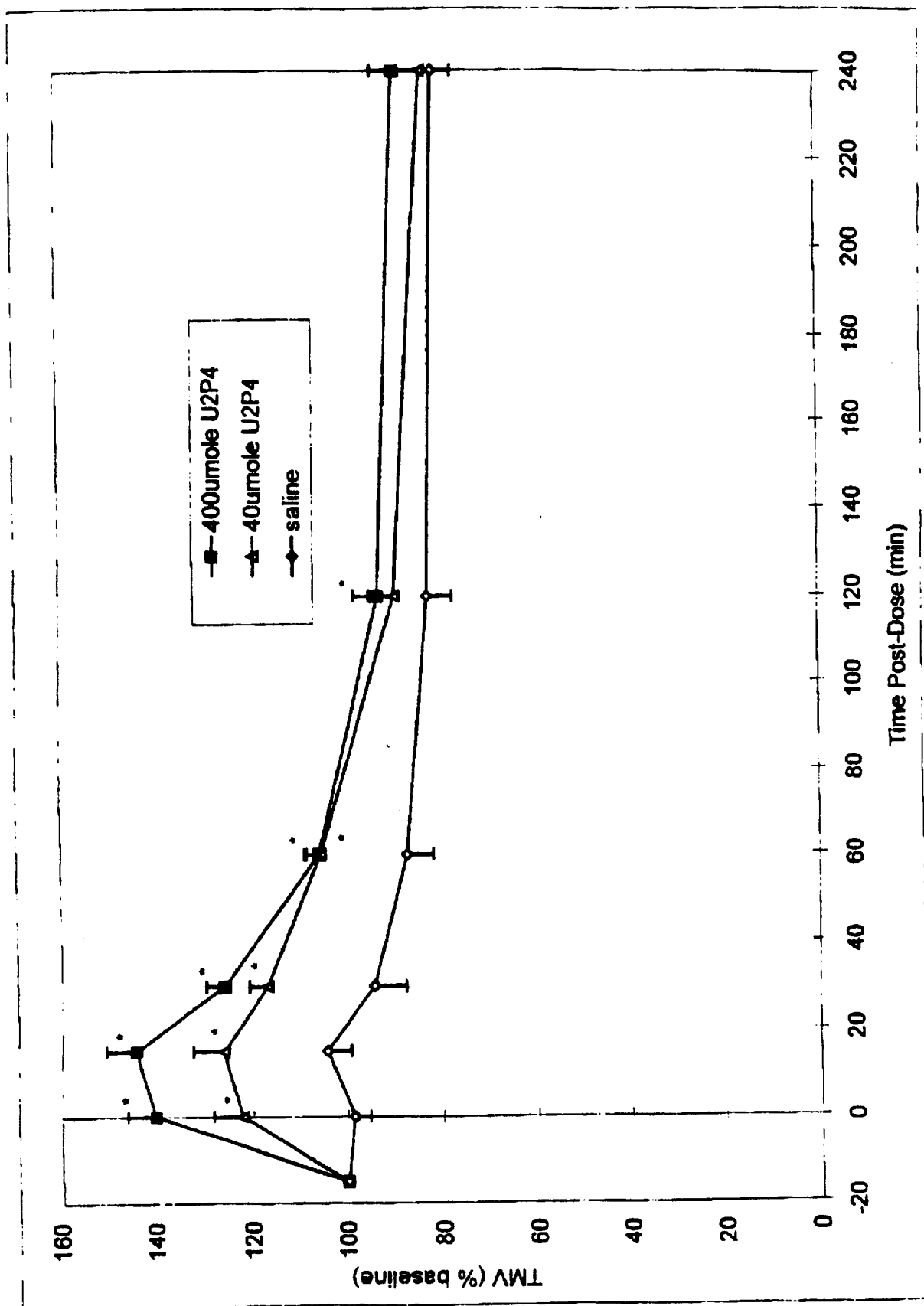


FIGURE 2

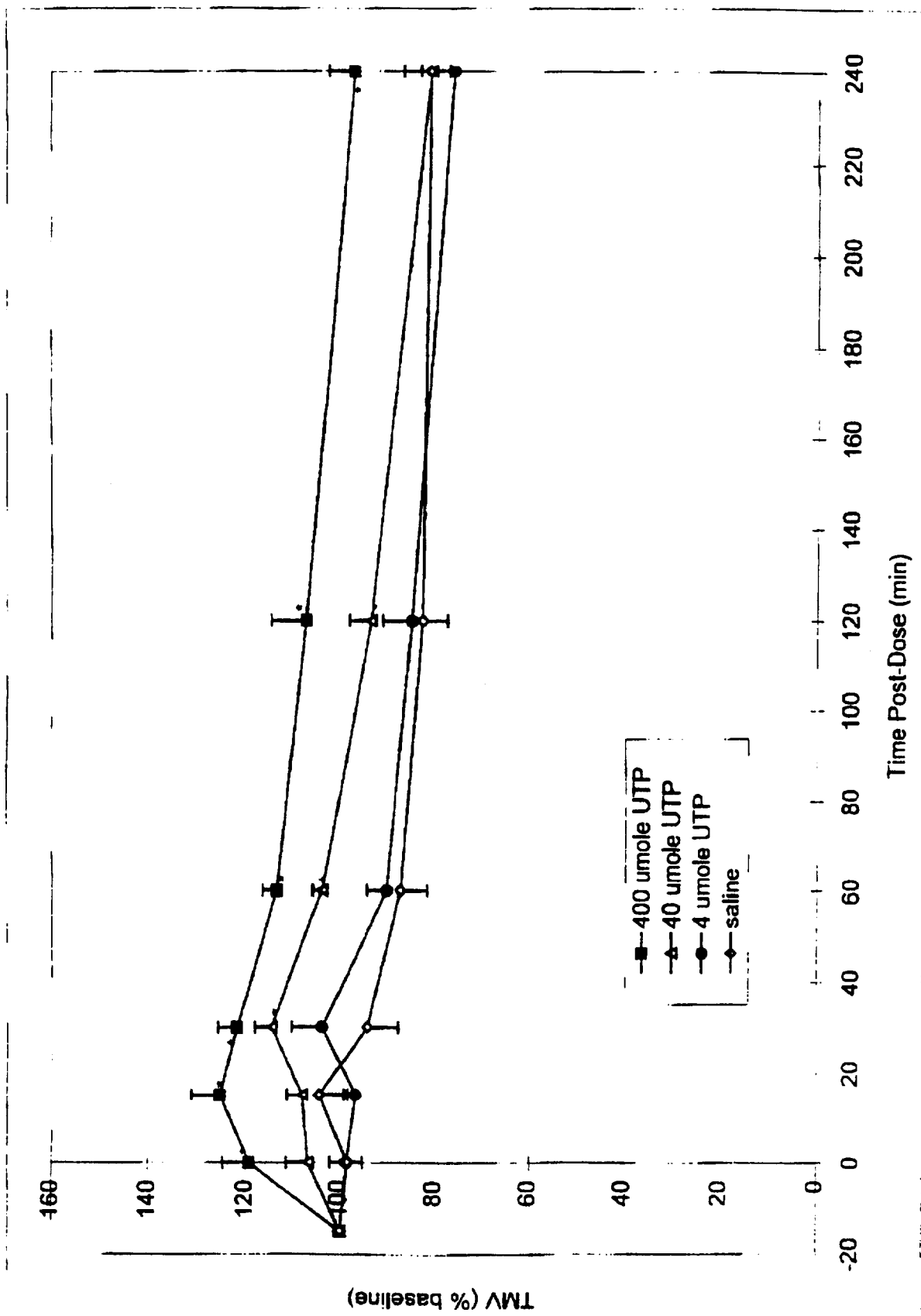


FIGURE 1