

Description

This invention relates to recombinant human granulocyte-macrophage colony-stimulating factor (r-h-GM-CSF), and in particular to a crystalline form thereof.

Colony-stimulating factors represent a family of proteins that are required *in vitro* for the survival, proliferation and differentiation of hematopoietic progenitor cells of myeloid and erythroid lineage: Metcalf, D., *The Hemopoietic Colony Stimulating Factors*, Elsevier, Amsterdam (1984); Metcalf, D., *Science* 229, 16-22 (1985); Metcalf, D., *Blood* 67, 257-267 (1986); and Clark, S.C., et al., *Science* 236, 1229-1237 (1987). Granulocyte-macrophage colony-stimulating factor (GM-CSF) stimulates the production of colonies of granulocytes and macrophages from their precursor cells and also promotes the growth and differentiation of pluripotent progenitor cells.

In addition, GM-CSF can enhance a variety of the functional activities of mature effector cells [as reviewed by Morstyn, G., et al., *Cancer Res.* 48, 5624-5637 (1988)] and promote the differentiation of myeloid leukemic cells [Tomonaga, M., et al., *Blood* 67, 31-36 (1986)]. Although human GM-CSF has been purified from natural sources [Gasson, J.C., et al., *Science* 226, 1339-1342 (1984)], the low quantities produced have not permitted detailed characterization of its physiochemical and biological properties. The cloning of the complementary DNA encoding human GM-CSF and its expression in bacterial and mammalian cell hosts has enabled the preparation of large quantities of purified recombinant protein [Greenberg, R., et al., *Curr. Micro.* 17, 321-332 (1988); Burgess, A.W., et al., *Blood* 69, 43-51 (1987); and Lee, F., et al., *Proc. Natl. Acad. Sci. (USA)* 83, 3101-3105 (1985)].

Based on *in vitro* biology and the activity of GM-CSF in animal models [Mayer, P., et al., *Blood* 70, 206-213 (1987), and Donahue, R.E., et al., *Nature* 321, 872-875 (1986)], phase I/II clinical trials on recombinant GM-CSF have been initiated in myelodysplastic syndromes [Vadhan-Raj, S., et al., *N. Engl. J. Med.* 317, 1545-1551 (1987)], acquired immunodeficiency syndrome [Groopman, J.E., et al., *N. Engl. J. Med.* 317, 593-598 (1987), and Baldwin G.C., et al., *Proc. Natl. Acad. Sci. (USA)* 85, 2763-2766 (1988)], and cancer [Brandt, S.J., et al., *N. Engl. J. Med.* 318, 869-876 (1988)].

The mature protein sequence of human GM-CSF consists of 127 amino acids, including four cysteine residues that form two disulfide linkages [Lee, F., et al., *Proc. Natl. Acad. Sci. (USA)* 83, 3101-3105 (1985), Cantrell, M.A., et al., *Proc. Natl. Acad. Sci. (USA)* 82, 6250-6254 (1985), and Schrimsher, J.L. et al., *Biochem. J.* 247, 195-199 (1987)]. Physical studies have suggested that human GM-CSF is a compact globular protein containing both alpha helical and beta sheet structures [Wingfield, P., et al., *Eur. J. Biochem.* 173, 65-72 (1988)].

We have now obtained crystalline, human, recombinant GM-CSF. The crystalline GM-CSF of the invention is mature, human, recombinant GM-CSF lacking an N-terminal methionine and having a methionine at position 80. We have demonstrated that the crystalline r-h-GM-CSF retains its full activity, i.e., upon redissolution in an aqueous system it possesses essentially the same activity as the r-h-GM-CSF starting material used in preparing the crystals. We have also characterized the crystals by X-ray crystallographic analysis. Preferably, the crystalline GM-CSF is non-glycosylated and is derived from *E. coli*. In a preferred embodiment, the r-h-GM-CSF used in the present invention, has the following complete amino acid sequence:

(H) Ala Pro Ala Arg Ser Pro Ser Pro Ser Thr(10)
 Gln Pro Trp Glu His Val Asn Ala Ile Gln(20) Glu Ala
 Arg Arg Leu Leu Asn Leu Ser Arg(30) Asp Thr Ala
 Ala Glu Met Asn Glu Thr Val(40) Glu Val Ile Ser Glu
 Met Phe Asp Leu Gln(50) Glu Pro Thr Cys Leu Gln
 Thr Arg Leu Glu(60) Leu Tyr Lys Gln Gly Leu Arg
 Gly Ser Leu(70) Thr Lys Leu Lys Gly Pro Leu Thr
 Met Met(80) Ala Ser His Tyr Lys Gln His Cys Pro
 Pro(90) Thr Pro Glu Thr Ser Cys Ala Thr Gln
 Ile(100) Ile Thr Phe Glu Ser Phe Lys Glu Asn
 Leu(110) Lys Asp Phe Leu Leu Val Ile Pro Phe
 Asp(120) Cys Trp Glu Pro Val Gln Glu (OH).

Experimental Procedures

Human GM-CSF was expressed periplasmically in *E. coli* with a secretory vector, pN111ompA2 [Greenberg, R., et al., *Curr. Micro.* 17, 321-332 (1988)]. Other methods for the expression of r-h-GM-CSF can be used; for example that of Lee et al., *Proc. Natl. Acad. Sci. (USA)* 82, 4060-4064 (1985). It was purified by conventional chromatography, as previously described (International Patent Application no. PCT/US 88/02294, Schering Corporation and Trotta, P.P., et al., published 26th January 1989 as WO 89/00579, corresponding to U.S. application serial no. 074,410 filed July 16, 1987), followed by reversed-phase high-performance liquid chromatography (HPLC) on a Rainin Dynamax-300Å C-4 column using a 27-72% gradient of acetonitrile in 0.1% trifluoroacetic acid.

Crystals suitable for X-ray analysis were obtained by vapor-diffusion equilibration using either hanging droplets or sandwiched droplets. For hanging droplets, 20 µl droplets containing 20 mg/ml of protein in 10% polyethylene glycol 8000 (PEG-8000), 16 mM sodium phosphate, pH 8.0, were hung from siliconized coverslips inverted on Linbro plates. These droplets were equilibrated against 1 ml of 20% PEG-8000 in 16 mM sodium phosphate, pH 8.0. After 10-15 days at 4°C, orthorhombic crystals with dimensions up to 2.0 mm x 0.60 mm x 0.10 mm were obtained. Alternatively, for sandwiched droplet vapor-diffusion experiments, 20 µl droplets containing 20 mg/ml of protein in 10% PEG-8000, 16 mM sodium phosphate, pH 8.0, were equilibrated against 1 ml of 20% PEG-8000 in 16 mM sodium phosphate, pH 8.0. After 15-20 days at 4°C, crystals of the same general morphology and size appeared. In each procedure the crystals grew within the pH range of 6.5 to 8.5, preferably 7.0-8.0; we have obtained the best crystals at pH 8.0.

For X-ray studies, crystals were mounted in glass capillaries and were photographed with a precession camera at 22°C using CuKα radiation from a Rigaku RU-300 rotating anode generator operating at 40 kV and 100 mA. A complete native data set was collected on a Nicolet X-100A area detector using the same radiation source.

Several batches of crystals, some prepared by the hanging droplet method and some by the sandwiched droplet method, were subjected to X-ray analysis and gave consistent results as to space group and unit cell size. The results are described below.

The crystalline GM-CSF of the invention can be used in basically the same manner in which prior GM-CSF materials have been used in pharmaceutical preparations, e.g., depot preparations of GM-CSF, which can be designed to administer a daily dose of 0.1 µg/kg to 100 µg/kg of GM-CSF. Such preparations contain a physiologically effective amount of the crystalline GM-CSF in association with a conventional pharmaceutically acceptable carrier.

CHARACTERIZATION**1. BIOASSAY**

5 Individual crystals were extracted from hanging droplets with a syringe, and then resuspended in 100 μ l of wash solution consisting of 20% PEG 8,000, 16 mM sodium phosphate, pH 7.5 at 4°C. The suspension was centrifuged and the wash solution was removed with a Pasteur pipette. The washed crystals were redissolved in 100 μ l of 20 mM sodium phosphate, pH 7.5, 0.15 M sodium chloride, at 25°C.

10 A protein determination and a cell-proliferation assay [Mosmann, T. J., *Journal of Immuno. Methods* 65, 55-63 (1983)] using the KG-1 cell line on the redissolved crystal solution yielded a specific activity of 2.7×10^8 units/mg. This value is the same as that obtained for the original GM-CSF preparation prior to crystallization, within the limits of the precision of the assay (typically within the range 2×10^8 to 3×10^8 units per mg).

15 2. HPLC

Analytical high performance reversed-phase liquid chromatography was run on an aliquot of the redissolved-crystal solution on a Rainin Dynamax C8 widepore (4.6 mm x 25 cm) column using a 27% acetonitrile : 0.1% trifluoroacetic acid to 72% acetonitrile : 0.1% trifluoroacetic acid linear gradient over a 30
20 minute period on a Waters analytical HPLC system. A Gilson variable wavelength detector set at 280 nm with a sensitivity of 0.02 absorbance units was used to monitor peaks. The retention times and chromatographic profiles of both the redissolved-crystal solution and the original GM-CSF preparation prior to crystallization were identical.

From 1. and 2. above, there is clearly no reason to suppose that any chemical changes or any
25 denaturing of the protein took place during the crystallization or reconstitution.

3. X-RAY DIFFRACTION ANALYSIS

X-ray diffraction data were initially collected to 2.8 Å resolution using the area detector. Oscillation
30 frames covered 0.25° and were measured for 10 min. A total of 6,797 reflections were measured; these were merged into 3,841 unique reflections. Indexing and integration of intensity data were carried out using XENGEN processing programs [Howard, A.J., et al., *J. Appl. Crystallogr.* 20, 383-387 (1987)]. The R_{sym} value (based on I) for the data to 3.0 Å was 0.087. The data indexed in the orthorhombic system with $a = 126.9 \pm 2$ Å, $b = 47.4 \pm 1$ Å and $c = 59.1 \pm 1$ Å. The space group $P2_12_12_1$ was specified by the systematic
35 absence of reflections $h00$ with $h = 2n+1$, $0k0$ with $k = 2n+1$, and $00l$ with $l = 2n+1$. Subsequent X-ray precession photographs of GM-CSF confirmed the space group and the unit cell dimensions. The crystals are stable to X-rays at room temperature for at least three days and diffract to 2.5 Å resolution or better.

Based on a molecular weight of 14,477 daltons as predicted from the cDNA of the crystalline r-h-GM-CSF used [Lee, F., et al., *Proc. Natl. Acad. Sci. (USA)* 83, 3101-3105 (1985)], the calculated values of V_m -
40 [Matthews, B.W., *J. Mol. Biol.* 33, 491-497 (1968)] for two or three molecules per crystallographic asymmetric unit are 3.07 and 2.05, respectively. Assuming a partial specific volume of 0.724 cm³/g [Wingfield, P., et al., *Eur. J. Biochem.* 173, 65-72 (1988)], these values correspond to solvent volume fractions of 59% and 39%, respectively. The corresponding V_m values for one and four molecules per
45 crystallographic asymmetric unit are 6.14 and 1.53, respectively, which are far outside the limits normally observed for proteins. Therefore, it appears that the protein crystallizes with either two or three molecules in the asymmetric unit. A self-rotation function that was calculated using the native data collected on the area detector did not show a noncrystallographic 2-fold or 3-fold axis.

Claims

50 **Claims for the following Contracting States : AT, BE, CH, DE, DK, ES, FR, GB, IT, LI, LU, NL, SE**

1. Crystalline, human recombinant GM-CSF (granulocyte - macrophage colony - stimulating factor) lacking an N-terminal methionine and having a methionine at position 80.



CHARACTERIZATION

1. BIOASSAY

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40 Based on a molecular weight of 14,477 daltons as predicted from the cDNA of the crystalline r-h-GM-CSF used [Lee, F., et al., *Proc. Natl. Acad. Sci. (USA)* 83, 3101-3105 (1985)], the calculated values of V_m - [Matthews, B.W., *J. Mol. Biol.* 33, 491-497 (1968)] for two or three molecules per crystallographic asymmetric unit are 3.07 and 2.05, respectively. Assuming a partial specific volume of 0.724 cm³/g [Wingfield, P., et al., *Eur. J. Biochem.* 173, 65-72 (1988)], these values correspond to solvent volume fractions of 59% and 39%, respectively. The corresponding V_m values for one and four molecules per crystallographic asymmetric unit are 6.14 and 1.53, respectively, which are far outside the limits normally observed for proteins. Therefore, it appears that the protein crystallizes with either two or three molecules in the asymmetric unit. A self-rotation function that was calculated using the native data collected on the area detector did not show a noncrystallographic 2-fold or 3-fold axis.

Claims

50 Claims for the following Contracting States : AT, BE, CH, DE, DK, ES, FR, GB, IT, LI, LU, NL, SE

1. Crystalline, human recombinant GM-CSF (granulocyte - macrophage colony - stimulating factor) lacking an N-terminal methionine and having a methionine at position 80.



2. The crystalline GM-CSF of claim 1 which has the amino acid sequence:

(H) Ala Pro Ala Arg Ser Pro Ser Pro Ser Thr Gln Pro
 Trp Glu His Val Asn Ala Ile Gln Glu Ala Arg Arg Leu
 Leu Asn Leu Ser Arg Asp Thr Ala Ala Glu Met Asn
 Glu Thr Val Glu Val Ile Ser Glu Met Phe Asp Leu Gln
 Glu Pro Thr Cys Leu Gln Thr Arg Leu Glu Leu Tyr
 Lys Gln Gly Leu Arg Gly Ser Leu Thr Lys Leu Lys Gly
 Pro Leu Thr Met Met Ala Ser His Tyr Lys Gln His
 Cys Pro Pro Thr Pro Glu Thr Ser Cys Ala Thr Gln Ile
 Ile Thr Phe Glu Ser Phe Lys Glu Asn Leu Lys Asp
 Phe Leu Leu Val Ile Pro Phe Asp Cys Trp Glu Pro
 Val Gln Glu (OH).

3. A pharmaceutical composition comprising crystalline, human recombinant GM-CSF as claimed in claim 1 or Claim 2 and pharmaceutically acceptable carrier.

Claims for the following Contracting State : GR

1. Use of crystalline, human recombinant GM-CSF (granulocyte - macrophage colony - stimulating factor) lacking an N-terminal methionine and having a methionine at position 80 in the manufacture of a medicament.
2. Use according to Claim 1 of crystalline GM-CSF having the following amino acid sequence:-

(H) Ala Pro Ala Arg Ser Pro Ser Pro Ser Thr Gln Pro
 Trp Glu His Val Asn Ala Ile Gln Glu Ala Arg Arg Leu
 Leu Asn Leu Ser Arg Asp Thr Ala Ala Glu Met Asn
 Glu Thr Val Glu Val Ile Ser Glu Met Phe Asp Leu Gln
 Glu Pro Thr Cys Leu Gln Thr Arg Leu Glu Leu Tyr
 Lys Gln Gly Leu Arg Gly Ser Leu Thr Lys Leu Lys Gly
 Pro Leu Thr Met Met Ala Ser His Tyr Lys Gln His
 Cys Pro Pro Thr Pro Glu Thr Ser Cys Ala Thr Gln Ile
 Ile Thr Phe Glu Ser Phe Lys Glu Asn Leu Lys Asp
 Phe Leu Leu Val Ile Pro Phe Asp Cys Trp Glu Pro
 Val Gln Glu (OH).

**Patentansprüche**

Patentansprüche für folgende Vertragsstaaten : AT, BE, CH, DE, DK, ES, FR, GB, IT, LI, LU, NL, SE

- 5 1. Kristalliner, rekombinanter Human-GM-CSF (das Koloniewachstum von Human-Granulozyten-Makrophagen stimulierender Faktor), dem ein N-terminales Methionin fehlt und der ein Methionin in Position 80 besitzt.
2. Kristalliner GM-CSF von Anspruch 1, der die Aminosäuresequenz

10 (H) Ala Pro Ala Arg Ser Pro Ser Pro Ser Thr Gln Pro
 Trp Glu His Val Asn Ala Ile Gln Glu Ala Arg Arg Leu
 15 Leu Asn Leu Ser Arg Asp Thr Ala Ala Glu Met Asn
 Glu Thr Val Glu Val Ile Ser Glu Met Phe Asp Leu Gln
 Glu Pro Thr Cys Leu Gln Thr Arg Leu Glu Leu Tyr
 Lys Gln Gly Leu Arg Gly Ser Leu Thr Lys Leu Lys Gly
 20 Pro Leu Thr Met Met Ala Ser His Tyr Lys Gln His
 Cys Pro Pro Thr Pro Glu Thr Ser Cys Ala Thr Gln Ile
 Ile Thr Phe Glu Ser Phe Lys Glu Asn Leu Lys Asp
 25 Phe Leu Leu Val Ile Pro Phe Asp Cys Trp Glu Pro
 Val Gln Glu (OH)

besitzt.

- 30 3. Pharmazeutische Zusammensetzung umfassend in Anspruch 1 oder Anspruch 2 beanspruchten kristallinen Human rekombinanten GM-CSF und einen pharmazeutisch annehmbaren Träger.

Patentansprüche für folgenden Vertragsstaat : GR

- 35 1. Verwendung von kristallinem, rekombinantem Human-GM-CSF (das Koloniewachstum von Human-Granulozyten-Makrophagen stimulierender Faktor), dem ein N-terminales Methionin fehlt und der ein Methionin in Position 80 besitzt, bei der Herstellung eines Arzneimittels.



2. Verwendung des kristallinen GM-CSF, der die folgende Aminosäuresequenz besitzt

(H) Ala Pro Ala Arg Ser Pro Ser Pro Ser Thr Gln Pro
 Trp Glu His Val Asn Ala Ile Gln Glu Ala Arg Arg Leu
 Leu Asn Leu Ser Arg Asp Thr Ala Ala Glu Met Asn
 Glu Thr Val Glu Val Ile Ser Glu Met Phe Asp Leu Gln
 Glu Pro Thr Cys Leu Gln Thr Arg Leu Glu Leu Tyr
 Lys Gln Gly Leu Arg Gly Ser Leu Thr Lys Leu Lys Gly
 Pro Leu Thr Met Met Ala Ser His Tyr Lys Gln His
 Cys Pro Pro Thr Pro Glu Thr Ser Cys Ala Thr Gln Ile
 Ile Thr Phe Glu Ser Phe Lys Glu Asn Leu Lys Asp
 Phe Leu Leu Val Ile Pro Phe Asp Cys Trp Glu Pro
 Val Gln Glu (OH)

gemäß Anspruch 1.

Revendications

25 **Revendications pour les Etats contractants suivants : AT, BE, CH, DE, DK, ES, FR, GB, IT, LI, LU, NL, SE**

1. GM-CSF (facteur stimulant les colonies de granulocytes et macrophages) cristallin recombinant humain manquant d'une méthionine N-terminale et ayant une méthionine à la position 80.
2. GM-CSF cristallin de la revendication 1 qui a la séquence d'acides aminés :

(H) Ala Pro Ala Arg Ser Pro Ser Pro Ser Thr Gln Pro
 Trp Glu His Val Asn Ala Ile Gln Glu Ala Arg Arg Leu
 Leu Asn Leu Ser Arg Asp Thr Ala Ala Glu Met Asn
 Glu Thr Val Glu Val Ile Ser Glu Met Phe Asp Leu Gln
 Glu Pro Thr Cys Leu Gln Thr Arg Leu Glu Leu Tyr
 Lys Gln Gly Leu Arg Gly Ser Leu Thr Lys Leu Lys Gly
 Pro Leu Thr Met Met Ala Ser His Tyr Lys Gln His
 Cys Pro Pro Thr Pro Glu Thr Ser Cys Ala Thr Gln Ile
 Ile Thr Phe Glu Ser Phe Lys Glu Asn Leu Lys Asp
 Phe Leu Leu Val Ile Pro Phe Asp Cys Trp Glu Pro
 Val Gln Glu (OH).

3. Composition pharmaceutique comprenant GM-CSF cristallin recombinant humain selon la revendication 1 ou la revendication 2 et un support acceptable en pharmacie.

**Revendications pour l'Etat contractant suivant : GR**

1. Utilisation d'un GM-CSF (facteur stimulant les colonies de granulocytes et macrophages) cristallin recombinant humain manquant d'une méthionine N-terminale et ayant une méthionine à la position 80.
2. Utilisation selon la revendication 1 de GM-CSF cristallin ayant la séquence d'acides aminés suivante :

(H) Ala Pro Ala Arg Ser Pro Ser Pro Ser Thr Gln Pro
Trp Glu His Val Asn Ala Ile Gln Glu Ala Arg Arg Leu
Leu Asn Leu Ser Arg Asp Thr Ala Ala Glu Met Asn
Glu Thr Val Glu Val Ile Ser Glu Met Phe Asp Leu Gln
Glu Pro Thr Cys Leu Gln Thr Arg Leu Glu Leu Tyr
Lys Gln Gly Leu Arg Gly Ser Leu Thr Lys Leu Lys Gly
Pro Leu Thr Met Met Ala Ser His Tyr Lys Gln His
Cys Pro Pro Thr Pro Glu Thr Ser Cys Ala Thr Gln Ile
Ile Thr Phe Glu Ser Phe Lys Glu Asn Leu Lys Asp
Phe Leu Leu Val Ile Pro Phe Asp Cys Trp Glu Pro
Val Gln Glu (OH).