

Crystal forms of a 9-aminomethyl substituted tetracycline compound and a preparation method thereof

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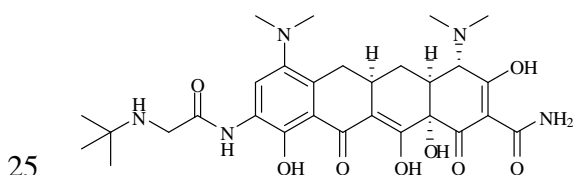
Technical Field

The present invention relates to crystal forms of a 9-aminomethyl substituted tetracycline compound and a preparation method thereof, and use of crystal forms of the compound in manufacture of a medicament for treating and/or preventing a disease caused by
10 tetracycline-sensitive bacteria and/or tetracycline-resistant bacteria.

Background Art

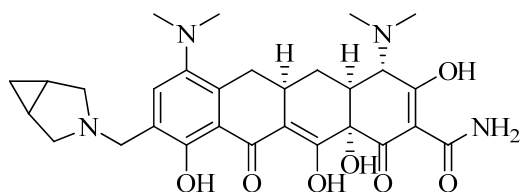
Tetracycline antibiotics are a kind of broad-spectrum antibiotics for oral use, which are generated by Actinomycete-Streptomyces fermentation. They have good pharmacological
15 action against rickettsia, many Gram-positive and Gram-negative bacteria, lymphogranuloma venereum pathogens, inclusion conjunctivitis pathogens and psittacosis pathogens.

In the early 1990s, a class of new tetracycline drugs (named as glycylines) was
20 developed, and its representative drug was tigecycline (GAR-936), which had broad antibacterial spectrum. Tigecycline not only has the same antibacterial activity as the previous tetracyclines, but also has an antibacterial activity to the pathogens that have been resistant to tetracyclines due to efflux mechanism and ribosomal protection mechanisms. Up to now, no oral tigecycline drug can be available in the market.



Tigecycline

In addition, WO2013013505 A1 discloses a compound represented by the following formula (I),



Formula (1)

Its chemical name is

5 (4*S*,4*aS*,5*aR*,12*aS*)-9-(3-azabicyclo[3.1.0]hexan-3-ylmethyl)-4,7-bis(dimethylamino)-3,10,12,12*a*-tetrahydroxy-1,11-dioxo-1,4,4*a*,5,5*a*,6,11,12*a*-octahydrotetracene-2-carboxamide.

This compound has a broad antibacterial spectrum and a high antibacterial activity.

10 WO2013013505 A1 further discloses a preparation process for the compound represented by formula (1). Said process can produce an amorphous form of the compound represented by formula (1) (Fig. 13), but cannot produce any crystal form of the compound represented by formula (1).

Summary of the Invention

15 In the process of studying and developing the compound represented by formula (1), it is found that the compound represented by formula (1) is prone to form an unstable solvate, resulting in an unsatisfactory purity, content and stability. In order to obtain crystal forms with high purity, high content and good stability, the present inventors have made a deep study on crystal forms of the compound represented by formula (1), and finally found
20 crystal forms of the compound represented by formula (1).

An object of the present invention is to provide crystal forms of the compound represented by formula (1).

25 Another object of the present invention is to provide pharmaceutically acceptable crystal forms of the compound represented by formula (1).

Another object of the present invention is to provide a method for preparing crystal forms of the compound represented by formula (1) and a method for converting any one of
30 crystal forms into another crystal form.

Another object of the present invention is to provide use of crystal forms of the compound

represented by formula (1) in a medicament for preventing and/or treating a disease caused by tetracycline-sensitive bacteria and/or tetracycline-resistant bacteria, wherein said disease caused by tetracycline-sensitive bacteria and/or tetracycline-resistant bacteria is for example infection, cancer, diabetes and other diseases that have been found to be
5 treatable and/or preventable by other tetracycline compounds.

The present inventors have made a deep study on crystal forms of the compound represented by formula (1) and found:

10 (1) Amorphous form

The preparation process as described in WO2013013505 A1 produces amorphous form of the compound represented by formula (1), which has an XRPD spectrum as shown in Fig. 13.

15 Amorphous form of the compound represented by formula (1) has a lower content and is not easy to be purified. In the process as described in Example 1, a first purification by column chromatography of the crude product results in a content of 84.8%, a second purification results in a content of 87.7%, and the content after several purifications still cannot satisfy the requirement of the pharmaceutical manufacture.

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It is also found in the study that amorphous form of the compound represented by formula (1) has a poor stability, as shown in table 1, the content after 14 days at a high temperature of 60°C reduces by 6.6%, the content after 14 days at a high humidity condition of 40°C/75%±5%RH reduces by 7.5%, and the content after 14 days under an
25 illumination condition of 4500lx±500lx reduces by 12.1%. Amorphous form of the compound represented by formula (1) itself has a lower content in its preparation, and has poor stabilities at a high temperature, at high humidity and under an illumination condition. Therefore, amorphous form of the compound represented by formula (1) is not suitable for the pharmaceutical manufacture.

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In summary, amorphous form of the compound represented by formula (1) cannot satisfy the requirement of the pharmaceutical manufacture, and there is an urgent need to find a pharmaceutical acceptable crystal form having a better purity, content and stability.

(2) Crystal forms

The present inventors have further made a vast of research on crystal forms of the compound represented by formula (1), and found crystal forms I, II, III, IV, V, VI, VII, VIII of the compound represented by formula (1). It is necessary to particularly point out, these eight different crystal forms cannot be predicted according to the chemical formula of the compound represented by formula (1), and the structure or property of any of these crystal forms cannot be predicated either.

Crystal forms of the compound represented by formula (1) have X-ray powder diffraction patterns comprising the following characteristic peaks expressed by 2θ degree, when measured using Cu-K α radiation:

- Crystal form I: $10.6^{\circ}\pm 0.2^{\circ}$, $13.3^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $24.0^{\circ}\pm 0.2^{\circ}$;
- Crystal form II: $10.2^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $17.9^{\circ}\pm 0.2^{\circ}$, $24.1^{\circ}\pm 0.2^{\circ}$;
- Crystal form III: $11.7^{\circ}\pm 0.2^{\circ}$, $16.6^{\circ}\pm 0.2^{\circ}$, $20.5^{\circ}\pm 0.2^{\circ}$, $27.3^{\circ}\pm 0.2^{\circ}$;
- Crystal form IV: $6.8^{\circ}\pm 0.2^{\circ}$, $10.0^{\circ}\pm 0.2^{\circ}$, $11.1^{\circ}\pm 0.2^{\circ}$, $21.5^{\circ}\pm 0.2^{\circ}$;
- Crystal form V: $9.7^{\circ}\pm 0.2^{\circ}$, $17.9^{\circ}\pm 0.2^{\circ}$, $19.2^{\circ}\pm 0.2^{\circ}$, $23.8^{\circ}\pm 0.2^{\circ}$;
- Crystal form VI: $7.7^{\circ}\pm 0.2^{\circ}$, $15.5^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $19.5^{\circ}\pm 0.2^{\circ}$;
- Crystal form VII: $11.7^{\circ}\pm 0.2^{\circ}$, $15.1^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $17.9^{\circ}\pm 0.2^{\circ}$;
- Crystal form VIII: $4.8^{\circ}\pm 0.2^{\circ}$, $9.7^{\circ}\pm 0.2^{\circ}$, $19.6^{\circ}\pm 0.2^{\circ}$.

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Said crystal forms of the compound represented by formula (1) have X-ray powder diffraction patterns comprising the following characteristic peaks expressed by 2θ degree, when measured using Cu-K α radiation:

- Crystal form I: $9.0^{\circ}\pm 0.2^{\circ}$, $10.6^{\circ}\pm 0.2^{\circ}$, $13.3^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $23.6^{\circ}\pm 0.2^{\circ}$, $24.0^{\circ}\pm 0.2^{\circ}$;
- Crystal form II: $9.3^{\circ}\pm 0.2^{\circ}$, $10.2^{\circ}\pm 0.2^{\circ}$, $14.0^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $17.9^{\circ}\pm 0.2^{\circ}$, $24.1^{\circ}\pm 0.2^{\circ}$;
- Crystal form III: $9.5^{\circ}\pm 0.2^{\circ}$, $11.7^{\circ}\pm 0.2^{\circ}$, $16.6^{\circ}\pm 0.2^{\circ}$, $20.5^{\circ}\pm 0.2^{\circ}$, $22.1^{\circ}\pm 0.2^{\circ}$, $27.3^{\circ}\pm 0.2^{\circ}$;
- Crystal form IV: $6.8^{\circ}\pm 0.2^{\circ}$, $10.0^{\circ}\pm 0.2^{\circ}$, $11.1^{\circ}\pm 0.2^{\circ}$, $20.1^{\circ}\pm 0.2^{\circ}$, $20.5^{\circ}\pm 0.2^{\circ}$, $21.5^{\circ}\pm 0.2^{\circ}$;
- Crystal form V: $9.7^{\circ}\pm 0.2^{\circ}$, $11.8^{\circ}\pm 0.2^{\circ}$, $17.9^{\circ}\pm 0.2^{\circ}$, $19.2^{\circ}\pm 0.2^{\circ}$, $22.1^{\circ}\pm 0.2^{\circ}$, $23.8^{\circ}\pm 0.2^{\circ}$;
- Crystal form VI: $7.7^{\circ}\pm 0.2^{\circ}$, $15.5^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $17.2^{\circ}\pm 0.2^{\circ}$, $19.5^{\circ}\pm 0.2^{\circ}$, $21.2^{\circ}\pm 0.2^{\circ}$;
- Crystal form VII: $11.7^{\circ}\pm 0.2^{\circ}$, $15.1^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $17.9^{\circ}\pm 0.2^{\circ}$, $20.1^{\circ}\pm 0.2^{\circ}$, $21.8^{\circ}\pm 0.2^{\circ}$;
- Crystal form VIII: $4.8^{\circ}\pm 0.2^{\circ}$, $9.7^{\circ}\pm 0.2^{\circ}$, $14.6^{\circ}\pm 0.2^{\circ}$, $19.6^{\circ}\pm 0.2^{\circ}$, $22.0^{\circ}\pm 0.2^{\circ}$, $24.5^{\circ}\pm 0.2^{\circ}$.

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Said crystal forms of the compound represented by formula (1) have X-ray powder diffraction patterns comprising the following characteristic peaks expressed by 2θ degree,

when measured using Cu-K α radiation:

Crystal form I: $9.0^{\circ}\pm0.2^{\circ}$, $10.6^{\circ}\pm0.2^{\circ}$, $13.3^{\circ}\pm0.2^{\circ}$, $14.3^{\circ}\pm0.2^{\circ}$, $15.9^{\circ}\pm0.2^{\circ}$, $18.0^{\circ}\pm0.2^{\circ}$, $20.0^{\circ}\pm0.2^{\circ}$, $21.3^{\circ}\pm0.2^{\circ}$, $23.6^{\circ}\pm0.2^{\circ}$, $24.0^{\circ}\pm0.2^{\circ}$;

Crystal form II: $9.3^{\circ}\pm0.2^{\circ}$, $10.2^{\circ}\pm0.2^{\circ}$, $14.0^{\circ}\pm0.2^{\circ}$, $15.9^{\circ}\pm0.2^{\circ}$, $17.9^{\circ}\pm0.2^{\circ}$, $20.8^{\circ}\pm0.2^{\circ}$,
5 $23.0^{\circ}\pm0.2^{\circ}$, $24.1^{\circ}\pm0.2^{\circ}$, $24.8^{\circ}\pm0.2^{\circ}$, $27.7^{\circ}\pm0.2^{\circ}$;

Crystal form III: $9.5^{\circ}\pm0.2^{\circ}$, $11.7^{\circ}\pm0.2^{\circ}$, $12.7^{\circ}\pm0.2^{\circ}$, $13.5^{\circ}\pm0.2^{\circ}$, $16.6^{\circ}\pm0.2^{\circ}$, $19.8^{\circ}\pm0.2^{\circ}$, $20.5^{\circ}\pm0.2^{\circ}$, $22.1^{\circ}\pm0.2^{\circ}$, $23.5^{\circ}\pm0.2^{\circ}$, $27.3^{\circ}\pm0.2^{\circ}$, $27.7^{\circ}\pm0.2^{\circ}$;

Crystal form IV: $6.8^{\circ}\pm0.2^{\circ}$, $10.0^{\circ}\pm0.2^{\circ}$, $11.1^{\circ}\pm0.2^{\circ}$, $11.8^{\circ}\pm0.2^{\circ}$, $13.9^{\circ}\pm0.2^{\circ}$, $14.9^{\circ}\pm0.2^{\circ}$, $15.5^{\circ}\pm0.2^{\circ}$, $20.1^{\circ}\pm0.2^{\circ}$, $20.5^{\circ}\pm0.2^{\circ}$, $21.5^{\circ}\pm0.2^{\circ}$;

10 Crystal form V: $7.1^{\circ}\pm0.2^{\circ}$, $9.7^{\circ}\pm0.2^{\circ}$, $11.8^{\circ}\pm0.2^{\circ}$, $16.5^{\circ}\pm0.2^{\circ}$, $17.9^{\circ}\pm0.2^{\circ}$, $19.2^{\circ}\pm0.2^{\circ}$, $22.1^{\circ}\pm0.2^{\circ}$, $23.1^{\circ}\pm0.2^{\circ}$, $23.8^{\circ}\pm0.2^{\circ}$, $24.9^{\circ}\pm0.2^{\circ}$;

Crystal form VI: $7.7^{\circ}\pm0.2^{\circ}$, $15.5^{\circ}\pm0.2^{\circ}$, $15.9^{\circ}\pm0.2^{\circ}$, $17.2^{\circ}\pm0.2^{\circ}$, $18.0^{\circ}\pm0.2^{\circ}$, $19.5^{\circ}\pm0.2^{\circ}$, $20.6^{\circ}\pm0.2^{\circ}$, $21.2^{\circ}\pm0.2^{\circ}$, $22.0^{\circ}\pm0.2^{\circ}$, $29.5^{\circ}\pm0.2^{\circ}$;

Crystal form VII: $11.0^{\circ}\pm0.2^{\circ}$, $11.7^{\circ}\pm0.2^{\circ}$, $13.8^{\circ}\pm0.2^{\circ}$, $14.3^{\circ}\pm0.2^{\circ}$, $15.1^{\circ}\pm0.2^{\circ}$, $15.9^{\circ}\pm0.2^{\circ}$,
15 $17.9^{\circ}\pm0.2^{\circ}$, $20.1^{\circ}\pm0.2^{\circ}$, $21.8^{\circ}\pm0.2^{\circ}$, $25.6^{\circ}\pm0.2^{\circ}$;

Crystal form VIII: $4.8^{\circ}\pm0.2^{\circ}$, $9.7^{\circ}\pm0.2^{\circ}$, $14.6^{\circ}\pm0.2^{\circ}$, $19.6^{\circ}\pm0.2^{\circ}$, $22.0^{\circ}\pm0.2^{\circ}$, $24.5^{\circ}\pm0.2^{\circ}$.

Among crystal forms of the compound represented by formula (1),

Crystal form I has an endothermic peak in the range of 180-220°C in its differential
20 scanning calorimetry curve;

Crystal form II has an endothermic peak in the range of 195-215°C in its differential scanning calorimetry curve;

Crystal form III has an endothermic peak in the range of 150-190°C in its differential scanning calorimetry curve;

25 Crystal form VII has an endothermic peak in the range of 165-205°C in its differential scanning calorimetry curve.

Crystal forms of the compound represented by formula (1), which are characterized respectively in that,

30 Crystal form I has an X-ray powder diffraction pattern as shown in Figure 1;

Crystal form II has an X-ray powder diffraction pattern as shown in Figure 3;

Crystal form III has an X-ray powder diffraction pattern as shown in Figure 5;

Crystal form IV has an X-ray powder diffraction pattern as shown in Figure 7;

Crystal form V has an X-ray powder diffraction pattern as shown in Figure 8;

Crystal form VI has an X-ray powder diffraction pattern as shown in Figure 9;
Crystal form VII has an X-ray powder diffraction pattern as shown in Figure 10;
Crystal form VIII has an X-ray powder diffraction pattern as shown in Figure 12.

- 5 Preparation method for crystal form I of the compound represented by formula (1): the compound represented by formula (1) is placed in anhydrous acetonitrile for slurry-washing or in tetrahydrofuran for stirring, a solid separates from the mixture, and crystal form I is obtained through filtration.
- 10 Preparation method for crystal form II of the compound represented by formula (1): the compound represented by formula (1) is placed in a lower alcohol, ethyl acetate, acetone, or a mixed solution of methanol and water (1:1-9:1, v/v) for slurry-washing, or dissolved in tetrahydrofuran under an atmosphere of isopropanol or n-heptane, a solid separates from the mixture, and crystal form II is obtained through filtration.
- 15 Preparation method for crystal form III of the compound represented by formula (1): the compound represented by formula (1) is placed in a mixed solution of acetonitrile and water in a ratio of 1:1-4:1 for slurry-washing at 0-70°C, and crystal form III is obtained through filtration, as acetonitrile solvate.
- 20 Preparation method for crystal form IV of the compound represented by formula (1): the compound represented by formula (1) is placed in a mixed solution of acetonitrile and water in a ratio of 9:1 for slurry-washing at 70-90°C to produce crystal form IV.
- 25 Preparation method for crystal form V of the compound represented by formula (1): the compound represented by formula (1) is placed in a mixed solution of tetrahydrofuran and isopropyl acetate for slow volatilization; or the compound represented by formula (1) is dissolved in tetrahydrofuran, then isopropyl acetate is added dropwise, a solid separates from the mixture, and crystal form V is obtained through filtration, as
- 30 isopropyl acetate solvate.

Preparation method for crystal form VI of the compound represented by formula (1): the compound represented by formula (1) is placed in chloroform solution for slow volatilization; or the compound represented by formula (1) is dissolved in chloroform,

placed in an atmosphere of isopropanol or n-heptane, and a solid separates from the mixture; or the compound represented by formula (1) is dissolved in chloroform, under the induction of polyvinyl acetate, polyphenylene sulfide, 1,3-dimethylimidazoline mesylate or 1,3-dimethylimidazoline perchlorate, chloroform is volatilized, a solid
5 separates from the mixture to produce crystal form VI as chloroform solvate.

Preparation method for crystal form VII of the compound represented by formula (1): the compound represented by formula (1) is placed in a mixed solution of acetonitrile and water in a ratio of 1:1-9:1 (v/v) for slurry-washing, filtered, and dried in vacuum to
10 produce crystal form VII. Alternatively, crystal form III of the compound represented by formula (1) is dried in vacuum to produce crystal form VII.

Preparation method for crystal form VIII of the compound represented by formula (1): the compound represented by formula (1) is placed in isopropyl acetate for slurry-washing,
15 and filtered to produce crystal form VIII as isopropyl acetate solvate.

It is found in a further study that, the above crystal forms III, V, VI and VIII are solvates, and respectively contain non-pharmaceutically acceptable organic solvents, acetonitrile (Class 2 solvent, concentration limit: 410 ppm), chloroform (Class 2 solvent,
20 concentration limit: 60 ppm), and isopropyl acetate (Class 3 solvent, the amount of residual solvent is not more than 0.5%). By measurement, crystal forms III, V, VI and VIII have the residual solvent concentration beyond the pharmaceutically acceptable limits and do not conform to the pharmaceutical requirement.

25 In order to further measure the stability of the amorphous form in conformity with the pharmaceutical acceptable content, it is necessary to prepare the amorphous form having a high content. According to the present invention, the amorphous form having a high pharmaceutical acceptable content (the content is 97.1%) is prepared from the crystal form of the compound represented by formula (1) having a high content as the starting
30 material, and it is found that the content of the amorphous form is reduced in the conversion process (as shown in Example 1).

It is also found in the study that not all of crystal forms I, II, III, IV, V, VI, VII and VIII of the compound represented by formula (1) have better stability than the amorphous form.

Specifically, in the investigation of the stability of crystal form III, the content of the compound is reduced by about 10% after being placed in a high humidity condition of 40°C/75%±5%RH for 14 days. It can be seen that in a high humidity condition, crystal form III has worse stability than the amorphous form. In addition, in the investigation of the stability of crystal form IV, the content is reduced by 23.1% after being placed in an illumination condition of 4500Lx±500Lx for 15 days, and additionally the content is reduced by nearly 10% after being placed at a high temperature of 60°C for 15 days. The above test results show that crystal form IV has worse stability than the amorphous form in the illumination condition or the high temperature condition.

Therefore, not all of crystal forms I, II, III, IV, V, VI, VII and VIII of the compound represented by formula (1) can satisfy the pharmaceutical requirements.

(3) Pharmaceutically acceptable crystal forms

Based on the above study, the present invention provides the stable crystal form I, the stable crystal form II and the stable crystal form VII of the compound represented by formula (1).

The preferable technical solutions of the present invention are as follows:

Crystal forms of the compound represented by formula (1) (4*S*,4*aS*,5*aR*,12*aS*)-9-(3-azabicyclo[3.1.0]hexan-3-ylmethyl)-4,7-bis(dimethylamino)-3,10,12,12*a*-tetrahydroxy-1,11-dioxo-1,4,4*a*,5,5*a*,6,11,12*a*-octahydrotetracene-2-carboxamide, have X-ray powder diffraction patterns comprising the following characteristic peaks expressed by 2θ degree, when measured using Cu-Kα radiation:

Crystal form I: 10.6°±0.2°, 13.3°±0.2°, 15.9°±0.2°, 24.0°±0.2°;

Crystal form II: 10.2°±0.2°, 15.9°±0.2°, 17.9°±0.2°, 24.1°±0.2°;

Crystal form VII: 11.7°±0.2°, 15.1°±0.2°, 15.9°±0.2°, 17.9°±0.2°.

Crystal forms of the compound represented by formula (1) have X-ray powder diffraction patterns comprising the following characteristic peaks expressed by 2θ degree, when measured using Cu-Kα radiation:

Crystal form I: 9.0°±0.2°, 10.6°±0.2°, 13.3°±0.2°, 15.9°±0.2°, 23.6°±0.2°, 24.0°±0.2°;

Crystal form II: 9.3°±0.2°, 10.2°±0.2°, 14.0°±0.2°, 15.9°±0.2°, 17.9°±0.2°, 24.1°±0.2°;

Crystal form VII: 11.7°±0.2°, 15.1°±0.2°, 15.9°±0.2°, 17.9°±0.2°, 20.1°±0.2°, 21.8°±0.2°.

Crystal forms of the compound represented by formula (1) have X-ray powder diffraction patterns comprising the following characteristic peaks expressed by 2θ degree, when measured using Cu-K α radiation:

- 5 Crystal form I: $9.0^{\circ}\pm 0.2^{\circ}$, $10.6^{\circ}\pm 0.2^{\circ}$, $13.3^{\circ}\pm 0.2^{\circ}$, $14.3^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $18.0^{\circ}\pm 0.2^{\circ}$, $20.0^{\circ}\pm 0.2^{\circ}$, $21.3^{\circ}\pm 0.2^{\circ}$, $23.6^{\circ}\pm 0.2^{\circ}$, $24.0^{\circ}\pm 0.2^{\circ}$;
Crystal form II: $9.3^{\circ}\pm 0.2^{\circ}$, $10.2^{\circ}\pm 0.2^{\circ}$, $14.0^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $17.9^{\circ}\pm 0.2^{\circ}$, $20.8^{\circ}\pm 0.2^{\circ}$, $23.0^{\circ}\pm 0.2^{\circ}$, $24.1^{\circ}\pm 0.2^{\circ}$, $24.8^{\circ}\pm 0.2^{\circ}$, $27.7^{\circ}\pm 0.2^{\circ}$;
Crystal form VII: $11.0^{\circ}\pm 0.2^{\circ}$, $11.7^{\circ}\pm 0.2^{\circ}$, $13.8^{\circ}\pm 0.2^{\circ}$, $14.3^{\circ}\pm 0.2^{\circ}$, $15.1^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$,
10 $17.9^{\circ}\pm 0.2^{\circ}$, $20.1^{\circ}\pm 0.2^{\circ}$, $21.8^{\circ}\pm 0.2^{\circ}$, $25.6^{\circ}\pm 0.2^{\circ}$.

Among crystal forms of the compound represented by formula (1),

Crystal form I has an endothermic peak in the range of 180-220°C in its differential scanning calorimetry curve;

- 15 Crystal form II has an endothermic peak in the range of 195-215°C in its differential scanning calorimetry curve;

Crystal form VII has an endothermic peak in the range of 165-205°C in its differential scanning calorimetry curve.

- 20 Crystal forms of the compound represented by formula (1), which are characterized respectively in that,

Crystal form I has an X-ray powder diffraction pattern as shown in Figure 1;

Crystal form II has an X-ray powder diffraction pattern as shown in Figure 3;

Crystal form VII has an X-ray powder diffraction pattern as shown in Figure 10.

25

The present invention further provides a pharmaceutical composition, said pharmaceutical composition contains amorphous or crystal forms of the compound represented by formula (1), and pharmaceutically acceptable carriers, wherein said crystal forms comprise crystal form I, II, VII or a combination thereof.

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In the pharmaceutical composition of the present invention, said crystal form is present in a pure form. Including but not exclusively, the content of crystal form I, II, VII or a combination thereof is not lower than 94.5% or 95% or 96% or 98% or 99%, for example, less than about 5.5%, less than about 5%, less than about 4%, less than about 2% or less

than about 1% of the impurities are present. The impurities include but are not limited to degradation products, oxidation products, epimers, solvents and/or other undesirable impurities.

5 The present invention further provides a pharmaceutical acceptable formulation of crystal forms of the compound represented by formula (1) and one or more pharmaceutically acceptable carriers and/or diluents, which can be any pharmaceutical acceptable dosage form. The present invention further provides a pharmaceutical acceptable formulation that can be prepared from crystal forms of the compound represented by formula (1) and one
10 or more pharmaceutically acceptable carriers. Said pharmaceutical formulation refers to conventional formulations in the clinical use, and can be orally or parenterally applied to patients in need of such treatment. For oral administration, they can be made into conventional solid formulations such as tablets, capsules, pills, granules, etc., as well as oral liquid formulations, such as oral solutions, oral suspensions, syrups, etc.. For
15 parenteral administration, they can be made into injections, including injection solution, a sterile powder for injection, concentrated solution for injection and suspension for injection. For rectal administration, they can be made into suppositories and the like. For transpulmonary administration, they can be made into inhalations or aerosols and the like. For topical or percutaneous administration, they can be made into ointments, pastes,
20 creams, lotions, gels, powders, solutions or transdermal stickers and the like. These formulations can be prepared by conventional methods, which comprise a step of adding pharmaceutically acceptable carriers such as excipients, binders, moisturizers, disintegrating agents, thickeners and the like. Said crystal forms comprise crystal form I, II, VII or a combination thereof.

25

The present invention further provides use of crystal forms of the compound represented by formula (1) in manufacture of a medicament for treating and/or preventing a disease caused by tetracycline-sensitive bacteria and/or tetracycline-resistant bacteria, wherein said "disease caused by tetracycline-sensitive bacteria and/or tetracycline-resistant
30 bacteria" is for example infection, cancer, diabetes and other diseases that have been found to be treatable and/or preventable by other tetracycline compounds, wherein said crystal forms include crystal form I, II, VII or a combination thereof.

Crystal forms of the compound represented by formula (1) of the present invention can be

used to treat and/or prevent tetracycline drug-sensitive diseases including infections (e.g. rickettsial infection, lymphogranuloma venereum, inclusion conjunctivitis, psittacosis pathogens infection and other tetracycline compound resistant infections), cancers, diabetes and any other diseases that have been found to be treatable and/or preventable by
5 tetracycline compounds. Crystal forms of the compound represented by formula (1) of the present invention have a broad antibacterial spectrum and strong antibacterial activity against both Gram-positive and-negative bacteria, including aerobic and anaerobic bacteria, and further have good pharmacokinetics.

10 Compared with the closest prior art, crystal forms of the compound represented by formula (1) of the present invention has the following advantages:

(1) crystal form I, II, VII of the compound represented by formula (1) according to the present invention or a combination thereof has good stability, wherein crystal forms I and II have better stability than crystal form VII, and crystal form I has better thermal stability
15 than crystal form II;

(2) crystal form I, II, VII of the compound represented by formula (1) according to the present invention or a combination thereof has a lower amount of residual solvent, and therefore low toxicity and side-effect;

(3) crystal form I, II, VII of the compound represented by formula (1) according to the present invention or a combination thereof has good physicochemical property, stable
20 quality, high content and purity, and stable particle size, and therefore is easy for a large scale of industrial production.

Crystal form I, II, VII of the compound represented by formula (1) according to the present invention or a combination thereof is characterized in that the physical properties,
25 e.g., stability, solubility, hygroscopicity and dissolution rate, appropriate for clinical and therapeutic dosage forms; and also in that the physical properties, e.g., crystal morphology, compressibility, particle sizes and hardness, suitable for manufacture of solid dosage forms. The above properties can be determined with the technologies well
30 known in the art such as X- ray diffraction, microscopy, IR spectroscopy, thermal analysis and hygroscopicity analysis.

Polymorphic forms of the compound are known to affect the solubility, dissolution rate, bioavailability, chemical and physical stability, flowability, fractability, and

compressibility of the compound as well as the safety and efficacy of drug products based on the compound (see, e.g., Knapman, Modern Drug Discovery, 2000, 3(2): 53). Thus, it becomes important to produce and market the pure drug in its most thermodynamically stable polymorph and substantially free of other polymorphs.

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The crystal form of a compound with optimal physical and chemical properties will advance the development of the active compound as pharmaceuticals. The most useful of such physical and chemical properties include: easy and reproducible preparation, crystallinity, non-hygroscopicity, aqueous solubility, stability to visible and ultraviolet
10 light, low rate of degradation under accelerated stability conditions of temperature and humidity, low rate of isomerization between isomeric forms, and safety for long-term administration to humans. Therefore, it is necessary to show the advantages of crystal forms in the examples.

15 Crystal form I, II, VII of the compound represented by formula (1) according to the present invention or a combination thereof has storage stability, suitable crystalline shape (crystal morphology), compressibility, flowability, non-sticking, density, particle size stability, the dissolution property and the like that are advantageous for preparation, formulation, use in the formulation and biological availability of the compound
20 represented by formula (1).

Crystal forms I, II, III, IV, V, VI, VII, VIII and amorphous form of the compound represented by formula (1) described in the present invention can be converted each other in a certain condition, and the present invention further provides a conversion relation
25 among crystal form I, crystal form II, crystal form III, crystal form IV, crystal form V, crystal form VI, crystal form VII, crystal form VIII and amorphous form.

Amorphous form is slurry-washed in anhydrous acetonitrile or recrystallized in tetrahydrofuran to produce crystal form I;

Amorphous form is slurry-washed in methanol to produce crystal form II;

30 Amorphous form is slurry-washed in a mixed solution of acetonitrile and water in a ratio of 1:1-4:1 at 0-70°C to produce crystal form III;

Amorphous form is slurry-washed in a mixed solution of acetonitrile and water in a ratio of 9:1 at 70-90°C to produce crystal form IV;

Amorphous form is slurry-washed in isopropyl acetate to produce crystal form VIII;

Crystal form II is slurry-washed in anhydrous acetonitrile to produce crystal form I;
Crystal form III is dried in vacuum to produce crystal form VII;
Crystal form VII is recrystallized in methanol to produce crystal form II;
Crystal forms V, VI and VIII are dried to produce the amorphous form.

5

Description of the drawings

Figure 1: the XRPD spectrum for crystal form I of the compound represented by formula (1);

Figure 2: the DSC curve for crystal form I of the compound represented by formula (1);

10 Figure 3: the XRPD spectrum for crystal form II of the compound represented by formula (1);

Figure 4: the DSC curve for crystal form II of the compound represented by formula (1);

Figure 5: the XRPD spectrum for crystal form III of the compound represented by formula (1);

15 Figure 6: the DSC curve for crystal form III of the compound represented by formula (1);

Figure 7: the XRPD spectrum for crystal form IV of the compound represented by formula (1);

Figure 8: the XRPD spectrum for crystal form V of the compound represented by formula (1);

20 Figure 9: the XRPD spectrum for crystal form VI of the compound represented by formula (1);

Figure 10: the XRPD spectrum for crystal form VII of the compound represented by formula (1);

25 Figure 11: the DSC curve for crystal form VII of the compound represented by formula (1);

Figure 12: the XRPD spectrum for crystal form VIII of the compound represented by formula (1);

Figure 13: the XRPD spectrum for amorphous form of the compound represented by formula (1);

30 Figure 14: the conversion relation among crystal form I, crystal form II, crystal form III, crystal form IV, crystal form V, crystal form VI, crystal form VII, crystal form VIII and amorphous form of the compound represented by formula (1), wherein:

1. Slurry-washing in methanol or slurry-washing in a mixed solution of methanol and water (1:1-9:1, v/v);

2. Slurry-washing in acetonitrile or tetrahydrofuran;
3. Slurry-washing in a mixed solution of acetonitrile and water in a ratio of 1:1-4:1;
4. Slurry-washing in a mixed solution of acetonitrile and water in a ratio 9:1;
5. Slurry-washing in isopropyl acetate;
- 5 6. Crystallization with slow volatilization of chloroform solution or under the induction of polyvinyl acetate, polyphenylene sulfide, 1,3-dimethylimidazoline mesylate or 1,3-dimethylimidazoline perchlorate in the chloroform solution,
7. Slow volatilization of a mixed solution of tetrahydrofuran and isopropyl acetate (1:1, v/v); and
- 10 8. Drying under heat.

The slurry-washing according to the present invention means washing a large amount of solid with a small amount of solvent under stirring.

- 15 The lower alcohol according to the present invention means an alcohol containing 1-6 carbon atoms, including methanol, ethanol, propanol, isopropanol, butanol, iso-butanol, n-butanol, pentanol, hexanol and the like.

Detailed description of the present invention

- 20 The present invention will be described in details by the following embodiments in form of Examples. However, it should be understood that the scope of the present invention is not limited by the following Examples, and all of the technical solutions accomplished based on the above contents of the present invention belong to the scope of the present invention.

25

Example 1: preparation of an amorphous form of (4*S*,4*aS*,5*aR*,12*aS*)-9-(3-azabicyclo[3.1.0]hexan-3-ylmethyl)-4,7-bis(dimethylamino)-3,10,12,12*a*-tetrahydroxy-1,11-dioxo-1,4,4*a*,5,5*a*,6,11,12*a*-octahydrotetracene-2-carboxamide

- 30 According to the preparation process disclosed in the patent application WO2013013505A1, 8g of (4*S*,4*aS*,5*aR*,12*aS*)-9-(3-azabicyclo[3.1.0]hexan-3-ylmethyl)-4,7-bis(dimethylamino)-3,10,12,12*a*-tetrahydroxy-1,11-dioxo-1,4,4*a*,5,5*a*,6,11,12*a*-octahydrotetracene-2-carboxamide was synthesized. The content of the crude product was 84.8%.

8g of the crude product was dissolved in 1.5L of water. Trifluoroacetic acid was added to adjust the pH to 2-4. After dissolution, ammonia water was added to adjust the pH to 6.5-7.5. After loading, the preparative separation was carried out with (1%TFA/water)/acetonitrile (6%) system. The product-containing fraction was collected. The aqueous phase was adjusted with an aqueous sodium hydroxide solution to the pH of 7.5-8.5. The aqueous phase was kept at a temperature of 25-30°C, and extracted with dichloromethane for three times. The dichloromethane phases were combined. The combined dichloromethane phase was concentrated, and dropwise added to n-heptane. The mixture was cooled to a temperature of 0-5°C, stirred for 10-30min, and filtered by suction to produce 3.17g of the compound (having a content of 87.7% and a purity of 96.2%).

Molecular formula: C₂₉H₃₆N₄O₇

¹H-NMR (CD₃OD, 400 MHz) δ: 8.48(s,1H), 4.54(brs,2H), 4.22(s,1H), 3.65(brs,4H), 3.46(m,1H), 3.35(s,6H), 3.25(m,1H), 3.10(s,3H), 3.05(s,1H), 3.00(s,3H), 2.60(m,1H), 2.37(m,1H), 1.87-1.97(m,2H), 1.68(m, 1H), 1.07(m, 1H), 0.78(m,1H).

In order to prepare the amorphous form of (4*S*,4*aS*,5*aR*,12*aS*)-9-(3-azabicyclo[3.1.0]hexan-3-ylmethyl)-4,7-bis(dimethylamino)-3,10,12,12*a*-tetrahydroxy-1,11-dioxo-1,4,4*a*,5,5*a*,6,11,12*a*-octahydrotetracene-2-carboxamide having a high content, the following processes were attempted:

Crystal form II of the compound represented by formula (1) (having a content of 95.6%) was dissolved in an appropriate amount of dichloromethane, and dropwise added to the n-heptane system at a temperature of 0-5°C. The mixture was stirred for 30min, and filtered by suction. The resulting solid was dried in vacuum to produce the amorphous form of the compound represented by formula (1) (having a content of 93.3%).

Crystal form II of the compound represented by formula (1) (having a content of 97.0%) was dissolved in an appropriate amount of dichloromethane, and dropwise added to the n-heptane system at a temperature of 0-5°C. The mixture was stirred for 30min, and filtered by suction. The resulting solid was dried in vacuum to produce the amorphous form of the compound represented by formula (1) (having a content of 93.9%).

Crystal form II of the compound represented by formula (1) (having a content of 98.4%) was dissolved in an appropriate amount of dichloromethane, and dropwise added to the n-heptane system at a temperature of 0-5°C. The mixture was stirred for 30min, and

filtered by suction. The resulting solid was dried in vacuum to produce the amorphous form of the compound represented by formula (1) (having a content of 97.1%).

The solid was characterized with XPRD as an amorphous form, as shown in Fig. 13.

5

Example 2: Preparation of crystal form I of (4*S*,4*aS*,5*aR*,12*aS*)-9-(3-azabicyclo[3.1.0]hexan-3-ylmethyl)-4,7-bis(dimethylamino)-3,10,12,12*a*-tetrahydroxy-1,11-dioxo-1,4,4*a*,5,5*a*,6,11,12*a*-octahydrotetracene-2-carboxamide

10 0.5g of the amorphous form of the compound represented by formula (1) prepared in Example 1 (having a content of 87.7%, and a purity of 96.2%) was placed in 5mL of acetonitrile or 2mL of THF. The mixture was heated to 55°C and stirred for 0.5h, and filtered. The obtained solid was placed in a vacuum drying oven and dried in vacuum at 50°C for 12h to produce crystal form I having a content of 97.0%, and a purity of 98.2%.

15

Crystal form I had an X-ray powder diffraction (XRPD) spectrum as shown in Figure 1, in which the main parameters were as follows:

2θ angles (°)	d value (Å)	Strength (%)
9.025765	9.79798	38.74
10.586120	8.35704	100.00
13.306510	6.65401	43.61
14.277980	6.20339	31.16
15.716330	5.63875	55.34
15.935210	5.56179	53.43
17.646390	5.02613	19.96
18.039520	4.91747	31.42
19.985140	4.44292	30.34
21.261890	4.17892	28.80
22.452190	3.96000	28.54
23.618520	3.76702	35.07
23.966900	3.71305	58.77
24.727390	3.60055	24.17
26.599820	3.35120	4.21
27.485250	3.24522	6.23
28.370430	3.14595	4.91
31.601690	2.83126	2.64
32.827100	2.72832	6.25
35.731580	2.51293	8.09
36.550010	2.45852	4.56
39.294720	2.29288	6.57

Crystal form I of the compound represented by formula (1) had a DSC curve as shown in Figure 2.

Example 3: Preparation of crystal form II of (4*S*,4*aS*,5*aR*,12*aS*)-9-(3-azabicyclo[3.1.0]hexan-3-ylmethyl)-4,7-bis(dimethylamino)-3,10,12,12a-tetrahydroxy-1,11-dioxo-1,4,4*a*,5,5*a*,6,11,12*a*-octahydrotetracene-2-carboxamide

5

Method 1: 1.0g of the amorphous form of the compound represented by formula (1) prepared in Example 1 (having a content of 87.7%, and a purity of 96.2%) was dissolved in 10mL of methanol. The mixture was stirred at 55°C for 1-2h, and filtered. The obtained solid was placed in a vacuum drying oven, and dried in vacuum at 50°C for 12h to produce crystal form II having a content of 94.5%, and a purity of 96.4%.

Method 2: 1.0g of the amorphous form of the compound represented by formula (1) prepared in Example 1 (having a content of 87.7%, and a purity of 96.2%), after several purifications, was dissolved in 10mL of methanol. The mixture was stirred at 55°C for 1-2h, and filtered. The obtained solid was placed in a vacuum drying oven, and dried in vacuum at 50°C for 12h to produce crystal form II having a content of 98.4%.

Method 3: 15mg of the obtained compound represented by formula (1) was placed in a 3mL vial. The vial was placed in a 20mL carboy. The carboy contains 4mL of methanol. After being placed at room temperature for 10 days, the solid was crystal form II.

Method 4: 15mg of the obtained compound represented by formula (1) was placed in a 3mL vial and dissolved in 0.6mL of THF. The vial was placed in a 20mL carboy. The carboy contains 4mL of n-heptane. After being placed at room temperature for 4 days, a solid separated from the mixture. The mixture was filtered to produce crystal form II.

Crystal form II had an X-ray powder diffraction (XRPD) spectrum as shown in Figure 3, in which the main parameters were as follows:

2θ angles (°)	d value (Å)	Strength (%)
---------------	-------------	--------------

9.260124	9.55053	32.36
10.219830	8.65573	100.00
13.957680	6.34502	30.22
15.906220	5.57186	67.00
17.867450	4.96444	33.45
20.822590	4.26608	21.68
23.047770	3.85900	22.73
24.083840	3.69528	40.93
24.817680	3.58766	14.67
27.666960	3.22432	4.69
34.791430	2.57865	4.46
36.987580	2.43043	2.36

Example 4: Preparation of crystal form III of
(4*S*,4*aS*,5*aR*,12*aS*)-9-(3-azabicyclo[3.1.0]hexan-3-ylmethyl)-4,7-bis(dimethylamino)-3,10
,12,12*a*-tetrahydroxy-1,11-dioxo-1,4,4*a*,5,5*a*,6,11,12*a*-octahydrotetracene-2-carboxamide
5 (as acetonitrile solvate)

Method 1: 500mg of the amorphous form of the compound represented by formula (1)
prepared in Example 1 (having a content of 87.7%, and a purity of 96.2%) was placed in a
mixed solution of acetonitrile and water (1:1). The mixture was stirred at 5°C for 2h, and
10 filtered to produce crystal form III having a content of 90.1%, and a purity of 97.7%. The
data for investigating the stability was mentioned as above.

Method 2: 16.1mg of the amorphous form of the compound represented by formula (1)
prepared in Example 1 (having a content of 97.1%) was placed in a mixed solution of
15 0.15mL of acetonitrile and 0.15mL of water. The mixture was stirred at 5°C for 2h, and
filtered to produce crystal form III.

Crystal form III had an X-ray powder diffraction (XRPD) spectrum as shown in Figure 5,
and a DSC curve as shown in Figure 6, in which the main parameters were as follows:

2θ angles (°)	d value (Å)	Strength (%)
---------------	-------------	--------------

8.687313	10.17893	27.52
9.534775	9.27603	57.43
10.907640	8.11142	39.04
11.659660	7.58989	100.00
12.693860	6.97375	48.44
13.549430	6.53526	43.82
14.368000	6.16473	17.17
15.326080	5.78144	21.57
16.603930	5.33926	64.78
18.088170	4.90436	18.77
19.776820	4.48924	44.02
20.496670	4.33318	76.31
22.142080	4.01475	53.89
23.105800	3.84944	27.66
23.494860	3.78657	41.85
23.965170	3.71331	21.43
24.828240	3.58615	5.35
25.543780	3.48730	27.49
26.341220	3.38351	24.53
27.295890	3.26730	51.68
27.651590	3.22607	47.77
30.106550	2.96837	11.96
32.005070	2.79649	17.76
33.610130	2.66653	8.05
35.313900	2.54169	18.90
36.611660	2.45452	14.25
37.342910	2.40812	15.87

Example 5: Preparation of crystal form IV of
(4*S*,4*aS*,5*aR*,12*aS*)-9-(3-azabicyclo[3.1.0]hexan-3-ylmethyl)-4,7-bis(dimethylamino)-3,10
,12,12a-tetrahydroxy-1,11-dioxo-1,4,4*a*,5,5*a*,6,11,12*a*-octahydrotetracene-2-carboxamide

5

15mg of the amorphous form of the compound represented by formula (1) prepared in Example 1 was placed in a mixed solution of 0.9mL of acetonitrile and 0.1mL of water. The mixture was stirred at 80°C for 2h, and filtered to produce crystal form IV. Crystal form IV was unstable, resulting in a bad repeatability.

10

Crystal form IV had an X-ray powder diffraction (XRPD) spectrum as shown in Figure 7, in which the main parameters were as follows:

2θ angles (°)	d value (Å)	Strength (%)
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6.822	12.94699	100.0
7.168	12.32169	6.5
9.013	9.80423	8.3
9.995	8.84303	31.0
11.112	7.95586	39.2
11.779	7.50736	16.7
12.338	7.16824	9.3
13.037	6.78547	5.3
13.887	6.37191	16.8
14.859	5.95719	13.8
15.143	5.84613	7.1
15.535	5.69940	14.6
16.580	5.34236	7.8
17.601	5.03492	3.9
18.177	4.87656	12.4
18.867	4.69985	7.8
19.100	4.64303	6.7
19.843	4.47079	13.6
20.082	4.41808	20.8
20.453	4.33877	18.9
20.862	4.25457	4.9
21.472	4.13512	25.6
22.332	3.97776	7.1
22.592	3.93260	9.6
22.887	3.88253	8.9
23.369	3.80350	7.3
23.770	3.74034	8.1
24.069	3.69447	7.8
24.488	3.63213	7.0
25.576	3.48007	4.4
26.576	3.35140	7.0
27.561	3.23374	5.7
28.205	3.16138	4.6
28.526	3.12656	5.2
29.936	2.98239	7.5
30.269	2.95039	5.8
30.752	2.90511	4.9
31.668	2.82316	4.5
32.258	2.77281	4.7
32.645	2.74087	4.2
33.946	2.63876	4.7
35.371	2.53563	4.4
38.014	2.36515	4.7
39.120	2.30080	4.3
40.111	2.24622	4.6
43.500	2.07876	4.9
44.106	2.05161	4.1

Example 6: Preparation of crystal form V of
(4*S*,4*aS*,5*aR*,12*aS*)-9-(3-azabicyclo[3.1.0]hexan-3-ylmethyl)-4,7-bis(dimethylamino)-3,10
,12,12*a*-tetrahydroxy-1,11-dioxo-1,4,4*a*,5,5*a*,6,11,12*a*-octahydrotetracene-2-carboxamide
5 (as isopropyl acetate solvate)

Method 1: 14.8mg of the compound represented by formula (1) prepared in Example 1 was dissolved in 0.7mL of THF and 0.7mL of isopropyl acetate. The solvent slowly

volatilized at 5°C or at room temperature, and a solid separated from the mixture. The mixture was filtered to produce crystal form V.

Method 2: 15mg of the compound represented by formula (1) prepared in Example 1 was dissolved in 1.0mL of THF. Then 4mL of isopropyl acetate was dropwise added, and a solid separated from the mixture. The mixture was filtered to produce the crystal form.

Crystal form V had an X-ray powder diffraction (XRPD) spectrum as shown in Figure 8, in which the main parameters were as follows:

2θ angles (°)	d value (Å)	Strength (%)
4.727485	18.69238	4.86
7.095715	12.45813	16.14
9.727849	9.09236	100.00
11.846180	7.47080	17.17
16.491390	5.37545	14.44
17.883960	4.95989	56.77
19.183180	4.62681	53.32
22.061500	4.02924	39.42
23.092320	3.85166	15.52
23.754860	3.74571	45.79
24.895740	3.57658	11.30
37.480630	2.39958	4.29

Example 7: Preparation of crystal form VI of (4*S*,4*aS*,5*aR*,12*aS*)-9-(3-azabicyclo[3.1.0]hexan-3-ylmethyl)-4,7-bis(dimethylamino)-3,10,12,12*a*-tetrahydroxy-1,11-dioxo-1,4,4*a*,5,5*a*,6,11,12*a*-octahydrotetracene-2-carboxamide (as chloroform solvate)

Method 1: 15mg of the compound represented by formula (1) prepared in Example 1 was dissolved in 0.5mL of chloroform. The solvent slowly volatilized at room temperature, and a solid separated from the mixture to produce crystal form VI.

Method 2: 16.1mg of the compound represented by formula (1) prepared in Example 1 was placed in a 3mL vial, and dissolved in 0.8mL of chloroform. The vial was placed in a 20mL carboy, and the carboy contained 4mL of isopropanol or n-heptane. The mixture was placed at room temperature for 4 days. A solid separated from the mixture to produce crystal form VI.

Method 3: 15mg of crystal form II of the compound represented by formula (1) prepared

in the example was placed in a 3mL vial, and the vial was placed in a 20mL carboy. The carboy contained 4mL of chloroform. The mixture was placed at room temperature for 10 days, and the resulting solid was crystal form VI.

- 5 Method 4: 15mg of the compound represented by formula (1) was placed in a 3mL vial. 0.5mL of chloroform was added until dissolved. Then 2.98mg of polyphenylene sulfide was added. The solvent slowly volatilized at room temperature, and a solid separated from the mixture to produce crystal form VI.
- 10 Method 5: 15mg of the compound represented by formula (1) was placed in a 3mL vial. 0.5mL of chloroform was added until dissolved. Then 3mg of 1,3-dimethylimidazoline mesylate was added. The solvent slowly volatilized at room temperature, and a solid separated from the mixture to produce crystal form VI.
- 15 Crystal form VI had an X-ray powder diffraction (XRPD) spectrum as shown in Figure 9, in which the main parameters were as follows:

2θ angles (°)	d value (Å)	Strength (%)
7.692313	11.49320	58.12
15.457590	5.73255	100.00
15.909050	5.57087	43.32
17.196630	5.15655	34.40
17.976590	4.93454	29.91
19.542360	4.54257	56.79
20.646680	4.30203	32.34
21.224630	4.18618	40.47
21.974070	4.04507	28.99
29.474920	3.03053	13.31

- Example 8: Preparation of crystal form VII of
(4*S*,4*aS*,5*aR*,12*aS*)-9-(3-azabicyclo[3.1.0]hexan-3-ylmethyl)-4,7-bis(dimethylamino)-3,10
,12,12a-tetrahydroxy-1,11-dioxo-1,4,4*a*,5,5*a*,6,11,12a-octahydrotetracene-2-carboxamide

- Method 1: 16.1mg of the amorphous form of the compound represented by formula (1) prepared in Example 1 was placed in a mixed solution of 0.15mL of acetonitrile and 0.15mL of water. The mixture was stirred at 5°C for 2h, filtered, and dried in vacuum to
 25 produce crystal form VII.

Method 2: 15mg of crystal form II of the compound represented by formula (1) prepared

in the Examples was placed in a mixed solution of 0.8mL of acetonitrile and 0.2mL of water (ACN/H₂O,V/V,4:1). The mixture was reacted at room temperature, filtered, dried in vacuum at 50°C for 2h to produce a solid as crystal form VII.

- 5 Method 3: crystal form III of the compound represented by formula (1) prepared in the Examples was dried in vacuum to produce crystal form VII.

Crystal form VII had an X-ray powder diffraction (XRPD) spectrum as shown in Figure 10, in which the main parameters were as follows:

10

2θ angles (°)	d value (Å)	Strength (%)
11.008970	8.03698	20.09
11.728880	7.54525	62.33
13.794880	6.41953	30.30
14.308280	6.19032	30.51
15.145890	5.84981	69.50
15.873440	5.58329	47.53
17.911120	4.95243	100.00
20.133590	4.41049	32.48
21.828890	4.07164	34.86
24.512310	3.63165	12.97
25.622960	3.47670	14.08
26.747930	3.33298	13.74
37.385250	2.40549	4.92

Example 9: Preparation of crystal form VIII of
(4*S*,4*aS*,5*aR*,12*aS*)-9-(3-azabicyclo[3.1.0]hexan-3-ylmethyl)-4,7-bis(dimethylamino)-3,10
,12,12*a*-tetrahydroxy-1,11-dioxo-1,4,4*a*,5,5*a*,6,11,12*a*-octahydrotetracene-2-carboxamide
 15 (as isopropyl acetate solvate)

15mg of the amorphous form of the compound represented by formula (1) prepared in Example 1 was placed in 1mL of isopropyl acetate. The mixture was stirred at 5°C for 2h, filtered to produce a solid as crystal form VIII.

20

Crystal form VIII had an X-ray powder diffraction (XRPD) spectrum as shown in Figure 12, in which the main parameters were as follows:

2θ angles (°)	d value (Å)	Strength (%)
---------------	-------------	--------------

4.819580	18.33540	11.85
9.734293	9.08635	100.00
14.642940	6.04959	2.19
19.602850	4.52869	6.36
21.998290	4.04067	0.70
24.522330	3.63019	0.51

Hereinafter, the beneficial effects of the present compound will be further discussed through the stability assays of the amorphous form and the crystal forms. However, it should not be understood that the present compound only has the following beneficial effects.

Assay 1: Stability for amorphous form and crystal forms of the present compound

Tested sample: amorphous form, crystal form I, crystal form II, and crystal form VII of the compound represented by formula (1) were prepared according to Examples;

Test conditions for investigating the influencing factors:

High temperature tests: amorphous form, crystal form I, crystal form II, and crystal form VII of the compound represented by formula (1) were laid on a dry and clean watch glass, and kept at $60^{\circ}\text{C} \pm 5^{\circ}\text{C}$ for 14 days. Samples were taken respectively on Day 7 and Day 14. The content and the purity of the compound represented by formula (1) were measured, and compared with those of the sample taken on Day 0.

High humidity test: amorphous form, crystal form I, crystal form II, and crystal form VII of the compound represented by formula (1) were laid on a dry and clean watch glass, and kept at $25^{\circ}\text{C} \pm 2^{\circ}\text{C}$, $\text{RH}75\% \pm 5\%$, $40^{\circ}\text{C} \pm 2^{\circ}\text{C}$, $\text{RH}75\% \pm 5\%$ for 14 days. Samples were taken respectively on Day 7 and Day 14. The content and the purity of the compound represented by formula (1) were measured, and compared with those of the sample taken on Day 0.

Illumination test: amorphous form, crystal form I, crystal form II, and crystal form VII of the compound represented by formula (1) were laid on a dry and clean watch glass, and kept at an illuminance of $4500\text{Lx} \pm 500\text{Lx}$ in an illumination box for 14 days. Samples were taken respectively on Day 7 and Day 14. The content and the purity of the compound represented by formula (1) were measured, and compared with those of the sample taken

on Day 0.

Content: it was measured by using an external standard method in accordance with the
High Performance Liquid Chromatography in Chinese Pharmacopoeia, Appendix V D,
5 Edition 2010.

Purity: it was measured by using an area normalization method in accordance with the
High Performance Liquid Chromatography in Chinese Pharmacopoeia, Appendix V D,
Edition 2010.

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Table 1: The investigation results of the influencing factor tests for amorphous form and crystal forms of the compound represented by formula (1)

Test conditions	Test Day	Amorphous form		Crystal form I		Crystal form II		Crystal form VII	
		Purity (%)	Content (%)	Purity (%)	Content (%)	Purity (%)	Content (%)	Purity (%)	Content (%)
High temperature 60°C	Day 0	98.0	97.1	98.2	97.0	96.4	94.5	97.4	95.8
	Day 7	95.8	94.5	97.9	97.7	96.1	95.8	96.8	95.2
	Day 14	94.3	90.5	97.7	97.3	96.0	96.0	96.2	93.6
25°C/75%±5%RH	Day 7	97.1	98.7	98.1	97.2	96.3	95.9	97.1	96.1
	Day 14	96.7	93.3	98.1	98.2	96.2	96.1	97.2	95.8
40°C/75%±5%RH	Day 7	94.9	94.7	98.0	97.4	96.2	96.5	96.4	94.6
	Day 14	92.9	89.6	97.8	97.5	96.1	96.1	95.7	94.5
Illumination 4500lx±500lx	Day 14	92.9	85.0	98.1	97.8	96.2	96.1	96.6	95.7

It could be clear from the investigation results that the content and the purity of amorphous form of the compound represented by formula (1) changed very much at the conditions of high temperature, high humidity and illumination, showing the amorphous form of the compound represented by formula (1) was unstable. However, the content and the purity of crystal forms I, II, VII of the compound represented by formula (1) changed very little at the conditions of high temperature, high humidity and illumination, showing crystal forms I, II, VII of the compound represented by formula (1) had a relatively high stability that was suitable for drug manufacture, storage and transport and was favorable for ensuring the validity and the safety in the drug use.

Assay 2: Stability for crystal form II and crystal form IV of the present compound

Tested sample: crystal form II and crystal form IV of the compound represented by formula (1) were prepared according to Examples;

Test conditions for investigating the influencing factors:

High temperature tests: crystal form II and crystal form IV of the compound represented by formula (1) were laid on a dry and clean watch glass, and kept at 60°C± 5°C for 15 days. Samples were taken respectively on Day 5 and Day 15. The content and the purity of the compound represented by formula (1) were measured, and compared with those of the sample taken on Day 0.

High humidity test: crystal form II and crystal form IV of the compound represented by formula (1) were laid on a dry and clean watch glass, and kept at 25°C± 2°C, RH92.5% ±

5%, 25°C± 2°C, RH75% ± 5%, 40°C± 2°C, RH75% ± 5% for 15 days. Samples were taken respectively on Day 5 and Day 15. The content and the purity of the compound represented by formula (1) were measured, and compared with those of the sample taken on Day 0.

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Illumination test: crystal form II and crystal form IV of the compound represented by formula (1) were laid on a dry and clean watch glass, and kept at an illuminance of 4500Lx±500Lx in an illumination box for 15 days. Samples were taken respectively on Day 5 and Day 15. The content and the purity of the compound represented by formula (1) were measured, and compared with those of the sample taken on Day 0.

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Content: it was measured by using an external standard method in accordance with the High Performance Liquid Chromatography in Chinese Pharmacopoeia, Appendix V D, Edition 2010.

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Purity: it was measured by using an area normalization method in accordance with the High Performance Liquid Chromatography in Chinese Pharmacopoeia, Appendix V D, Edition 2010.

20 Test results were shown in Table 2.

Table 2: The investigation results of the influencing factor tests for crystal forms of the compound represented by formula (1)

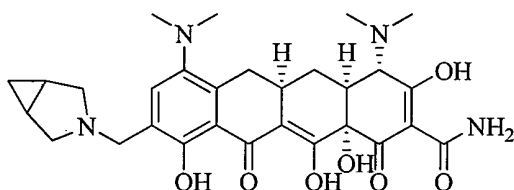
Test conditions	Day	Crystal form II	Crystal form IV
		Content %	Content %
/	0	98.4	97.0
60°C	15	97.0	88.6
4500Lx±500Lx	15	97.8	74.6
25°C/ RH 75%±5%	15	98.3	93.1
25°C/ RH 92.5%±5%	15	96.7	90.3
40°C/ RH 75%±5%	15	98.0	74.6

25 It could be clear from the investigation results that the content of the compound represented by formula (1) changed very much, when crystal form IV of the compound

represented by formula (1) was in the conditions of high temperature, high humidity and illumination, while the content of the compound represented by formula (1) changed very little, when crystal form II of the compound represented by formula (1) was in the conditions of high temperature, high humidity and illumination, showing crystal form II
5 of the compound represented by formula (1) had higher stability than crystal form IV, and it was suitable for drug manufacture, storage and transport and favorable for ensuring the validity and the safety in the drug use.

Claims

1. Crystal forms of a compound represented by formula (1),
(4*S*,4*aS*,5*aR*,12*aS*)-9-(3-azabicyclo[3.1.0]hexan-3-ylmethyl)-4,7-bis(dimethylamino)-3,10
5 ,12,12*a*-tetrahydroxy-1,11-dioxo-1,4,4*a*,5,5*a*,6,11,12*a*-octahydrotetracene-2-carboxamide,



Formula (1)

which are characterized by having X-ray powder diffraction patterns comprising the following characteristic peaks expressed by 2θ degree, when measured using Cu-K α radiation:

- 10 Crystal form I: $10.6^{\circ}\pm 0.2^{\circ}$, $13.3^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $24.0^{\circ}\pm 0.2^{\circ}$;
Crystal form II: $10.2^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $17.9^{\circ}\pm 0.2^{\circ}$, $24.1^{\circ}\pm 0.2^{\circ}$;
Crystal form VII: $11.7^{\circ}\pm 0.2^{\circ}$, $15.1^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $17.9^{\circ}\pm 0.2^{\circ}$.

2. Crystal forms of the compound represented by formula (1) of claim 1, which are
15 characterized by having X-ray powder diffraction patterns comprising the following characteristic peaks expressed by 2θ degree, when measured using Cu-K α radiation:
Crystal form I: $9.0^{\circ}\pm 0.2^{\circ}$, $10.6^{\circ}\pm 0.2^{\circ}$, $13.3^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $23.6^{\circ}\pm 0.2^{\circ}$, $24.0^{\circ}\pm 0.2^{\circ}$;
Crystal form II: $9.3^{\circ}\pm 0.2^{\circ}$, $10.2^{\circ}\pm 0.2^{\circ}$, $14.0^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $17.9^{\circ}\pm 0.2^{\circ}$, $24.1^{\circ}\pm 0.2^{\circ}$;
Crystal form VII: $11.7^{\circ}\pm 0.2^{\circ}$, $15.1^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $17.9^{\circ}\pm 0.2^{\circ}$, $20.1^{\circ}\pm 0.2^{\circ}$, $21.8^{\circ}\pm 0.2^{\circ}$.

20

3. Crystal forms of the compound represented by formula (1) of claim 1, which are characterized by having X-ray powder diffraction patterns comprising the following characteristic peaks expressed by 2θ degree, when measured using Cu-K α radiation:

- Crystal form I: $9.0^{\circ}\pm 0.2^{\circ}$, $10.6^{\circ}\pm 0.2^{\circ}$, $13.3^{\circ}\pm 0.2^{\circ}$, $14.3^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $18.0^{\circ}\pm 0.2^{\circ}$,
25 $20.0^{\circ}\pm 0.2^{\circ}$, $21.3^{\circ}\pm 0.2^{\circ}$, $23.6^{\circ}\pm 0.2^{\circ}$, $24.0^{\circ}\pm 0.2^{\circ}$;
Crystal form II: $9.3^{\circ}\pm 0.2^{\circ}$, $10.2^{\circ}\pm 0.2^{\circ}$, $14.0^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $17.9^{\circ}\pm 0.2^{\circ}$, $20.8^{\circ}\pm 0.2^{\circ}$,
 $23.0^{\circ}\pm 0.2^{\circ}$, $24.1^{\circ}\pm 0.2^{\circ}$, $24.8^{\circ}\pm 0.2^{\circ}$, $27.7^{\circ}\pm 0.2^{\circ}$;
Crystal form VII: $11.0^{\circ}\pm 0.2^{\circ}$, $11.7^{\circ}\pm 0.2^{\circ}$, $13.8^{\circ}\pm 0.2^{\circ}$, $14.3^{\circ}\pm 0.2^{\circ}$, $15.1^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$,
 $17.9^{\circ}\pm 0.2^{\circ}$, $20.1^{\circ}\pm 0.2^{\circ}$, $21.8^{\circ}\pm 0.2^{\circ}$, $25.6^{\circ}\pm 0.2^{\circ}$.

30

4. Crystal forms of the compound represented by formula (1) of claim 2, which are characterized by having X-ray powder diffraction patterns comprising the following characteristic peaks expressed by 2θ degree, when measured using Cu-K α radiation:

Crystal form I: $9.0^{\circ}\pm 0.2^{\circ}$, $10.6^{\circ}\pm 0.2^{\circ}$, $13.3^{\circ}\pm 0.2^{\circ}$, $14.3^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $18.0^{\circ}\pm 0.2^{\circ}$,
5 $20.0^{\circ}\pm 0.2^{\circ}$, $21.3^{\circ}\pm 0.2^{\circ}$, $23.6^{\circ}\pm 0.2^{\circ}$, $24.0^{\circ}\pm 0.2^{\circ}$;

Crystal form II: $9.3^{\circ}\pm 0.2^{\circ}$, $10.2^{\circ}\pm 0.2^{\circ}$, $14.0^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$, $17.9^{\circ}\pm 0.2^{\circ}$, $20.8^{\circ}\pm 0.2^{\circ}$,
 $23.0^{\circ}\pm 0.2^{\circ}$, $24.1^{\circ}\pm 0.2^{\circ}$, $24.8^{\circ}\pm 0.2^{\circ}$, $27.7^{\circ}\pm 0.2^{\circ}$;

Crystal form VII: $11.0^{\circ}\pm 0.2^{\circ}$, $11.7^{\circ}\pm 0.2^{\circ}$, $13.8^{\circ}\pm 0.2^{\circ}$, $14.3^{\circ}\pm 0.2^{\circ}$, $15.1^{\circ}\pm 0.2^{\circ}$, $15.9^{\circ}\pm 0.2^{\circ}$,
10 $17.9^{\circ}\pm 0.2^{\circ}$, $20.1^{\circ}\pm 0.2^{\circ}$, $21.8^{\circ}\pm 0.2^{\circ}$, $25.6^{\circ}\pm 0.2^{\circ}$.

5. Crystal forms of the compound represented by formula (1) according to any of claims 1-4, which are characterized in that

Crystal form I has an X-ray powder diffraction pattern substantially as shown in Figure 1;

Crystal form II has an X-ray powder diffraction pattern substantially as shown in Figure
15 3;

Crystal form VII has an X-ray powder diffraction pattern substantially as shown in Figure
10.

6. Crystal forms of the compound represented by formula (1) according to any of claims
20 1-4, which are characterized in that,

Crystal form I has an endothermic peak in the range of 180-220°C in its differential scanning calorimetry curve;

Crystal form II has an endothermic peak in the range of 195-215°C in its differential scanning calorimetry curve;

25 Crystal form VII has an endothermic peak in the range of 165-205°C in its differential scanning calorimetry curve.

7. Crystal forms of the compound represented by formula (1) according to claim 5, which are characterized in that,

Crystal form I has an endothermic peak in the range of 180-220°C in its differential scanning calorimetry curve;

5 Crystal form II has an endothermic peak in the range of 195-215°C in its differential scanning calorimetry curve;

Crystal form VII has an endothermic peak in the range of 165-205°C in its differential scanning calorimetry curve.

10 8. A process for preparing crystal forms I, II, and VII of the compound represented by formula (1) according to any of claims 1-7, which are characterized respectively in that, the compound represented by formula (1) is placed in anhydrous acetonitrile for slurry-washing or in tetrahydrofuran for stirring, a solid separates from the mixture, and crystal form I is obtained through filtration;

15 the compound represented by formula (1) is placed in a lower alcohol, ethyl acetate, acetone, or a mixed solution of methanol and water in a ratio of 1:1-9:1 (v/v) for slurry-washing, or dissolved in tetrahydrofuran under an atmosphere of isopropanol or n-heptane, a solid separates from the mixture, and crystal form II is obtained through filtration;

20 the compound represented by formula (1) is placed in a mixed solution of acetonitrile and water in a ratio of 1:1-9:1 (v/v) for slurry-washing, filtered, and dried in vacuum to produce crystal form VII.

9. A pharmaceutical composition, which is characterized in that said pharmaceutical
25 composition contains crystal form I, II, VII of the compound represented by formula (1) according to any of claims 1-7 or a combination thereof, and pharmaceutically acceptable carrier(s).

10. The pharmaceutical composition of claim 9, wherein said crystal form has a content
30 of not lower than 94.5%.

11. A pharmaceutical formulation containing crystal form I, II, VII of the compound represented by formula (1) according to any of claims 1-7 or a combination thereof, and one or more pharmaceutically acceptable carriers and/or diluents, which is in any pharmaceutically acceptable dosage form.

5

12. Use of crystal forms of the compound represented by formula (1) according to any of claims 1-7 or a combination thereof in manufacture of a medicament for treating and/or preventing a disease caused by tetracycline-sensitive bacteria and/or tetracycline-resistant bacteria, wherein said disease caused by tetracycline-sensitive bacteria and/or
10 tetracycline-resistant bacteria is selected from infection, cancer, diabetes and other diseases that have been found to be treatable and/or preventable by other tetracycline compounds.