Tacrolimus Capsules

Type of Posting	Revision Bulletin
Posting Date	27–Jul–2018
Official Date	01–Aug–2018
Expert Committee	Chemical Medicines Monographs 1
Reason for Revision	Compliance

In accordance with the Rules and Procedures of the 2015–2020 Council of Experts, the Chemical Medicines Monographs 1 Expert Committee has revised the Tacrolimus Capsules monograph. The purpose of the revision is to add *Dissolution Test 6* to accommodate FDA-approved drug products with different tolerances than the existing dissolution tests.

- *Dissolution Test 6* was validated using the Xterra RP-18 brand of L1 column. The typical retention time for tacrolimus 19-epimer is about 6.5 min and about 8.4 min for tacrolimus.

The Tacrolimus Capsules Revision Bulletin supersedes the currently official monograph.

Should you have any questions, please contact Praveen Pabba, Scientific Liaison (301-816-8540 or pkp@usp.org).

Tacrolimus Capsules

DEFINITION

Tacrolimus Capsules contain NLT 93.0% and NMT 105.0% of the labeled amount of tacrolimus ($C_{44}H_{69}NO_{12}$).

IDENTIFICATION

- **A.** The retention time of the major peak of the *Sample solution* corresponds to that of the *Standard solution*, as obtained in the *Assay*.
- **B.** The UV absorption spectrum of the major peak of the *Sample solution* and that of the *Standard solution* exhibit maxima and minima at the same wavelengths, as obtained in the *Assay*.

ASSAY

- **PROCEDURE**

Allow the *Standard solution* and *Sample solution* to stand for 3 h at ambient temperature before use. Protect solutions containing tacrolimus from light.

Solution A: 6 mM phosphoric acid

Solution B: 50 g/L of polyoxyethylene (23) lauryl ether. [NOTE—Polyoxyethylene (23) lauryl ether is also called Brij-35.]

Solution C: Acetonitrile and *Solution B* (7:3)

Mobile phase: Acetonitrile, *tert*-butyl methyl ether, and *Solution A* (335:55:600)

Standard solution: 50 µg/mL of USP Tacrolimus RS in *Solution C*

Sample solution: Equivalent to 50 µg/mL of tacrolimus from NLT 10 Capsules in *Solution C*. [NOTE—Sonicate, and stir with a magnetic stirrer.]

Chromatographic system

(See *Chromatography* ⟨621⟩, *System Suitability*.)

Mode: LC

Detector: UV 205 nm. When this procedure is used for *Identification* test *B*, use a diode array detector set at 200–400 nm.

Column: 4.0-mm × 5.5-cm; 3-µm packing L1

Column temperature: 60°

Flow rate: 1 mL/min

Injection volume: 5 µL

System suitability

Sample: *Standard solution*

[NOTE—The relative retention times for tacrolimus 19-epimer and tacrolimus are 0.67 and 1.0, respectively.]

Suitability requirements

Tailing factor: NMT 2.0

Relative standard deviation: NMT 3.0% for the sum of the tacrolimus and tacrolimus 19-epimer peaks

Analysis

Samples: *Standard solution* and *Sample solution*

Calculate the percentage of the labeled amount of tacrolimus ($C_{44}H_{69}NO_{12}$) in the portion of Capsules taken:

$$\text{Result} = (r_U/r_S) \times (C_S/C_U) \times 100$$

r_U = sum of the peak responses of tacrolimus and tacrolimus 19-epimer from the *Sample solution*

r_S = sum of the peak responses of tacrolimus and tacrolimus 19-epimer from the *Standard solution*

C_S = concentration of USP Tacrolimus RS in the *Standard solution* (mg/mL)

C_U = nominal concentration of the *Sample solution* (mg/mL)

Acceptance criteria: 93.0%–105.0%

PERFORMANCE TESTS

Change to read:

- **DISSOLUTION ⟨711⟩**

Test 1

Medium: Hydroxypropylcellulose in water ($1:2 \times 10^4$), adjusted with 6% phosphoric acid to a pH of 4.5; 900 mL

Apparatus 2: 50 rpm with sinker (see *Dissolution* ⟨711⟩, *Figure 2a*)

Time: 90 min

Mobile phase: Acetonitrile, methanol, water, and 6% phosphoric acid (46: 18: 36: 0.1)

Standard stock solution: (*L*/360) mg/mL in acetonitrile, where *L* is the Capsule label claim in mg

Standard solution: To 20.0 mL of the *Standard stock solution* add 50.0 mL of *Medium*, and mix to obtain solutions with known concentrations as indicated in *Table 1*. Allow the solution to stand for NLT 6 h at 25° before use.

Sample solution: Pass 10 mL of the solution under test through a G4 glass filter. To 5.0 mL of the filtrate add 2.0 mL of acetonitrile, and mix. Allow the solution to stand for NLT 1 h at 25° before use.

Table 1

Capsule Strength (mg)	Final Concentration (µg/mL)
0.5	0.4
1	0.8
5	4

Chromatographic system

(See *Chromatography* ⟨621⟩, *System Suitability*.)

Mode: LC

Detector: UV 210 nm

Column: 4.6-mm × 15-cm; 5-µm packing L7

Column temperature: 50°

Flow rate: Adjust the flow rate so that the retention time of tacrolimus is approximately 14 min.

Injection volume: See *Table 2*.

Table 2

Capsule Strength (mg)	Injection Volume (µL)
0.5	800
1	400
5	80

[NOTE—For products with strengths other than those listed in *Table 2*, adjust the *Injection volume* to deliver an equivalent amount of tacrolimus into the column.]

System suitability

Sample: *Standard solution*

Suitability requirements

Resolution: NLT 1.5 between tacrolimus 19-epimer and tacrolimus

Tailing factor: NMT 1.5

Relative standard deviation: NMT 1.5%

Analysis

Samples: *Standard solution* and *Sample solution*

Calculate the percentage of the labeled amount of tacrolimus ($C_{44}H_{69}NO_{12}$) dissolved:

$$\text{Result} = (r_U/r_S) \times C_S \times D \times V \times (100/L)$$

r_U = peak response of tacrolimus from the *Sample solution*
r_S = peak response of tacrolimus from the *Standard solution*
C_S = concentration of USP Tacrolimus RS in the *Standard solution* (mg/mL)
D = dilution factor of the *Sample solution*
V = volume of *Medium*, 900 mL
L = label claim (mg/Capsule)

Tolerances: NLT 80% (Q) of the labeled amount of tacrolimus ($C_{44}H_{69}NO_{12}$) is dissolved.

Test 2: If the product complies with this test, the labeling indicates that it meets USP *Dissolution Test 2*.
[NOTE—Allow the *Standard solution* to stand for 3 h at ambient temperature before use. Protect solutions containing tacrolimus from light.]
Buffer: Dissolve 6 g of sodium dodecyl sulfate and 8.28 g of monobasic sodium phosphate in 6000 mL of water. Adjust with 2 N sodium hydroxide to a pH of 7.0.
Medium: *Buffer*; 900 mL
Apparatus 2: 50 rpm, with sinkers
Time: 60 min
Standard stock solution: 0.2 mg/mL of USP Tacrolimus RS in alcohol and *Medium* (3:7). [NOTE—Dissolve USP Tacrolimus RS in alcohol using 30% of the final volume. Sonicate until dissolved, and dilute with *Medium* to volume.]
Standard solution: Dilute the *Standard stock solution* with *Medium* to obtain a final concentration of 5 µg/mL.
Sample solution: Pass a portion of the solution under test through a suitable filter.
Solution A: 6 mM phosphoric acid
Mobile phase: Acetonitrile, *tert*-butyl methyl ether, and *Solution A* (335:50:600)
Chromatographic system
(See *Chromatography* ⟨621⟩, *System Suitability*.)
Mode: LC
Detector: UV 205 nm
Column: 4.0-mm × 5.5-cm; 3-µm packing L1
Column temperature: 60°
Flow rate: 1.2 mL/min
Injection volume: 100 µL
System suitability
Sample: *Standard solution*
[NOTE—The relative retention times for tacrolimus 19-epimer and tacrolimus are 0.67 and 1.0, respectively.]
Suitability requirements
Tailing factor: NMT 2.0
Relative standard deviation: NMT 5.0% for the sum of the areas of tacrolimus and tacrolimus 19-epimer
Analysis
Samples: *Standard solution* and *Sample solution*
Calculate the percentage of the labeled amount of tacrolimus ($C_{44}H_{69}NO_{12}$) dissolved:

$$\text{Result} = (r_U/r_S) \times (C_S/L) \times V \times 100$$

r_U = sum of the peak responses of tacrolimus and tacrolimus 19-epimer from the *Sample solution*
r_S = sum of the peak responses of tacrolimus and tacrolimus 19-epimer from the *Standard solution*
C_S = concentration of the *Standard solution* (mg/mL)
L = label claim (mg/Capsule)
V = volume of *Medium*, 900 mL

Tolerances: NLT 80% (Q) of the labeled amount of tacrolimus ($C_{44}H_{69}NO_{12}$) is dissolved.

Test 3: If the product complies with this test, the labeling indicates that it meets USP *Dissolution Test 3*.
Medium: 50 mg/L of hydroxypropylcellulose in water. Adjust with phosphoric acid to a pH of 4.5; 900 mL.
Apparatus 2 (without sinker) and **Time:** Proceed as directed in *Test 1*.
Buffer: 3.6 g/L of monobasic potassium phosphate in water. Adjust with diluted phosphoric acid to a pH of 2.5.
Mobile phase: *Buffer* and acetonitrile (1:1)
Standard stock solution: 0.1 mg/mL of USP Tacrolimus RS in acetonitrile
Standard solution: Dilute the *Standard stock solution* with *Medium* to obtain a final concentration of (L/900) mg/mL, where L is the Capsule label claim in mg.
Sample solution: Pass a portion of the solution under test through a suitable filter.
Chromatographic system
(See *Chromatography* ⟨621⟩, *System Suitability*.)
Mode: LC
Detector: UV 210 nm
Column: 4.6-mm × 10-cm; 5-µm packing L1
Column temperature: 60°
Flow rate: 1.3 mL/min
Injection volume: 100 µL
System suitability
Sample: *Standard solution*
[NOTE—The relative retention times for tacrolimus 19-epimer, tacrolimus open ring, and tacrolimus are 0.67, 0.79, and 1.0, respectively.]
Suitability requirements
Tailing factor: NMT 2.0
Relative standard deviation: NMT 2.0%
Analysis
Samples: *Standard solution* and *Sample solution*
Calculate the percentage of the labeled amount of tacrolimus ($C_{44}H_{69}NO_{12}$) dissolved:

$$\text{Result} = (r_U/r_S) \times (C_S/L) \times V \times 100$$

r_U = sum of the peak responses of tacrolimus, tacrolimus 19-epimer, and tacrolimus open ring from the *Sample solution*
r_S = sum of the peak responses of tacrolimus, tacrolimus 19-epimer, and tacrolimus open ring from the *Standard solution*
C_S = concentration of the *Standard solution* (mg/mL)
L = label claim (mg/Capsule)
V = volume of *Medium*, 900 mL

Tolerances: NLT 75% (Q) of the labeled amount of tacrolimus ($C_{44}H_{69}NO_{12}$) is dissolved.

Test 4: If the product complies with this test, the labeling indicates that it meets USP *Dissolution Test 4*.
Medium: Hydroxypropylcellulose in water (1 in 20,000), adjusted with phosphoric acid to a pH of 4.5. See *Table 3* for the volume.

Table 3

Capsule Strength (mg)	Volume of Medium (mL)
0.5	500
1	900
5	900

Apparatus 2: 50 rpm, with sinkers
Time: 120 min
Diluent: 1 mg/mL of hydroxypropylcellulose in water. Sonicate as needed to dissolve.
Buffer: To a solution of 1 g/L of sodium 1-hexanesulfonate in water add 0.1 mL/L of trifluoroacetic acid.
Mobile phase: Acetonitrile, methanol, and *Buffer* (550:50:400)
Standard stock solution: Dissolve USP Tacrolimus RS in acetonitrile. See *Table 4* for the concentrations (*L* is the Capsule label claim in mg).

Table 4

Capsule Strength (mg)	Concentration (mg/mL)
0.5	*L*/25
1	*L*/45
5	*L*/45

Standard solution: Dilute the *Standard stock solution* with *Diluent*. See *Table 5* for the concentrations (*L* is the Capsule label claim in mg).

Table 5

Capsule Strength (mg)	Concentration (mg/mL)
0.5	*L*/500
1	*L*/900
5	*L*/900

Sample solution: Pass a portion of the solution under test through a suitable filter.
Chromatographic system
(See *Chromatography* ⟨621⟩, *System Suitability*.)
Mode: LC
Detector: UV 210 nm
Column: 4.6-mm × 15-cm; 5-µm packing L1
Column temperature: 60°
Flow rate: 1 mL/min
Injection volume: 100 µL
System suitability
Sample: *Standard solution*
Suitability requirements
Tailing factor: NMT 2.0
Relative standard deviation: NMT 3.0%
Analysis
Samples: *Standard solution* and *Sample solution*
Calculate the percentage of the labeled amount of tacrolimus ($C_{44}H_{69}NO_{12}$) dissolved:

$$\text{Result} = (r_U/r_S) \times (C_S/L) \times V \times 100$$

r_U = peak response from the *Sample solution*
r_S = peak response from the *Standard solution*
C_S = concentration of USP Tacrolimus RS in the *Standard solution* (mg/mL)
L = label claim (mg/Capsule)
V = volume of *Medium* (mL) (see *Table 3*)

Tolerances: NLT 75% (*Q*) of the labeled amount of tacrolimus ($C_{44}H_{69}NO_{12}$) is dissolved.

Test 5: If the product complies with this test, the labeling indicates that it meets USP *Dissolution Test 5*.
Medium: 0.05 g/L hydroxypropylcellulose in water. Adjust with phosphoric acid to a pH of 4.5; 900 mL.
Apparatus 2: 50 rpm, with sinkers
Time: 90 min
Solution A: 0.1 mL/L of trifluoroacetic acid in water
Mobile phase: Acetonitrile and *Solution A* (50:50)
Standard stock solution: 0.22 mg/mL of USP Tacrolimus RS in acetonitrile
Standard solution: (*L*/900) mg/mL of USP Tacrolimus RS from the *Standard stock solution* in *Medium*, where *L* is the label claim in mg/Capsule
Sample solution: Centrifuge a portion of the solution under test. Use the supernatant.
Chromatographic system
(See *Chromatography* ⟨621⟩, *System Suitability*.)
Mode: LC
Detector: UV 205 nm
Column: 2.1-mm × 15-cm; 3.5-µm packing L7
Column temperature: 60°
Flow rate: 0.8 mL/min
Injection volume: 750 µL
System suitability
Sample: *Standard solution*
[NOTE—The relative retention times for tacrolimus 19-epimer (tautomer 1), tacrolimus open-ring (tautomer 2), and tacrolimus are 0.55, 0.79, and 1.0, respectively.]
Suitability requirements
Tailing factor: NMT 1.5
Relative standard deviation: NMT 4.0% for the peaks due to tautomer 1, tautomer 2, and tacrolimus.
Analysis
Samples: *Standard solution* and *Sample solution*
Calculate the percentage of the labeled amount of tacrolimus ($C_{44}H_{69}NO_{12}$) dissolved:

$$\text{Result} = (r_U/r_S) \times (C_S/L) \times V \times 100$$

r_U = sum of the peak responses of tacrolimus, tacrolimus open-ring, and tacrolimus 19-epimer from the *Sample solution*
r_S = sum of the peak responses of tacrolimus, tacrolimus open-ring, and tacrolimus 19-epimer from the *Standard solution*
C_S = concentration of USP Tacrolimus RS in the *Standard solution* (mg/mL)
L = label claim (mg/Capsule)
V = volume of *Medium*, 900 mL

Tolerances: NLT 75% (*Q*) of the labeled amount of tacrolimus ($C_{44}H_{69}NO_{12}$) is dissolved.

▲**Test 6:** If the product complies with this test, the labeling indicates that it meets USP *Dissolution Test 6*.
Dilute phosphoric acid: Transfer 7.1 mL of phosphoric acid to a 100 mL volumetric flask, and dilute with water to volume.
Medium: 50 mg/L of hydroxypropyl cellulose in water. Adjust with *Dilute phosphoric acid* to a pH of 4.5; 900 mL.
Apparatus 2: 50 rpm
Time: 60 min

Buffer: 3.6 g/L of monobasic potassium phosphate in water. Adjust with *Dilute phosphoric acid* to a pH of 2.5.
Mobile phase: Acetonitrile and *Buffer* (1:1)
Standard stock solution: 0.11 mg/mL of USP Tacrolimus RS in acetonitrile
Standard solution: Dilute the *Standard stock solution* with *Medium* to obtain a final concentration of (*L*/900) mg/mL, where *L* is the label claim in mg/Capsule.
Sample solution: Centrifuge a portion of the solution under test. Use the supernatant.
Chromatographic system
(See *Chromatography* ⟨621⟩, *System Suitability*.)
Mode: LC
Detector: UV 210 nm
Column: 4.6-mm × 10-cm; 5-µm packing L1
Column temperature: 60°
Flow rate: 1.3 mL/min
Injection volume: 100 µL
System suitability
Sample: *Standard solution*
[NOTE—The relative retention times for tacrolimus 19-epimer, tacrolimus open ring, and tacrolimus are 0.77, 0.89, and 1.0, respectively.]
Suitability requirements
Tailing factor: NMT 2.0 for tacrolimus
Relative standard deviation: NMT 2.0% for the sum of tacrolimus 19-epimer, tacrolimus open ring, and tacrolimus
Analysis
Samples: *Standard solution* and *Sample solution*
Calculate the percentage of the labeled amount of tacrolimus ($C_{44}H_{69}NO_{12}$) dissolved:

$$\text{Result} = (r_U/r_S) \times (C_S/L) \times V \times 100$$

r_U = sum of the peak responses of tacrolimus, tacrolimus 19-epimer, and tacrolimus open ring from the *Sample solution*
r_S = sum of the peak responses of tacrolimus, tacrolimus 19-epimer, and tacrolimus open ring from the *Standard solution*
C_S = concentration of USP Tacrolimus RS in the *Standard solution* (mg/mL)
L = label claim (mg/Capsule)
V = volume of *Medium*, 900 mL

Tolerances: NLT 80% (*Q*) of the labeled amount of tacrolimus ($C_{44}H_{69}NO_{12}$) is dissolved. ▲ (RB 1-Aug-2018)

• **UNIFORMITY OF DOSAGE UNITS ⟨905⟩:** Meet the requirements

IMPURITIES

• **ORGANIC IMPURITIES, PROCEDURE 1**
Use *Organic Impurities, Procedure 1* when the impurity profile includes tacrolimus diene and tacrolimus regioisomer. It is suggested that new columns be conditioned with about 500 mL of ethanol before use to meet the resolution criterion.
Mobile phase: Hexane, *n*-butyl chloride, and acetonitrile (7:2:1). Add *n*-butyl chloride to hexane, and mix well before adding acetonitrile. After adding acetonitrile, mix the *Mobile phase* for 2 h to get a clear solution. Any deviations from the ratio of components in the *Mobile phase* and the order of mixing will result in a two-phase solution.
System suitability solution: 0.1 mg/mL each of USP Tacrolimus RS and USP Tacrolimus Related Compound A RS in *Mobile phase*
Sample solution: Transfer the contents of a suitable number of Capsules (equivalent to about 5 mg of tacrolimus for 0.5-mg Capsules or 10 mg of tacrolimus for 1-mg and 5-mg Capsules) into a centrifuge tube. Add 1.5 mL of a mixture of *n*-butyl chloride and acetonitrile (2:1), sonicate in an ultrasonic bath for 2 min, add 3.5 mL of *n*-hexane, and mix. Centrifuge this solution, and collect the supernatant or pass the solution through a 0.5-µm membrane filter. Use the solution within 30 min of preparation.
Chromatographic system
(See *Chromatography* ⟨621⟩, *System Suitability*.)
Mode: LC
Detector: UV 225 nm
Columns: Two 4.6-mm × 25-cm columns; 5-µm packing L20
Column temperature: 28 ± 2°
Flow rate: 1.5 mL/min. Adjust the *Flow rate* so that the retention time of tacrolimus is approximately 15 min.
Injection volume: 20 µL
Run time: 3 times the retention time of tacrolimus
System suitability
Sample: *System suitability solution*
Suitability requirements
Resolution: NLT 1.1 between tacrolimus and tacrolimus related compound A
Tailing factor: NMT 1.5
Relative standard deviation: NMT 2.0%
Analysis
Sample: *Sample solution*
Calculate the percentage of each impurity in the portion of Capsules taken:

$$\text{Result} = (r_U/F_i) \times \{1/[r_T + \Sigma(r_U/F_i)]\} \times 100$$

r_U = peak response of each impurity from the *Sample solution*
F_i = relative response factor for each corresponding impurity (see *Table 6*)
r_T = peak response of tacrolimus from the *Sample solution*

Acceptance criteria: See *Table 6*. Disregard peaks due to the solvent.

Table 6

Name	Relative Retention Time	Relative Response Factor	Acceptance Criteria, NMT (%)
Tacrolimus diene[a]	0.79	2.2	0.3
Tacrolimus regioisomer[b]	0.88	1.0	0.5
Tacrolimus impurity 1[c]	0.96	1.0	0.3
Tacrolimus related compound A[d]	0.96	—	—
Tacrolimus	1.0	—	—
Tacrolimus 19-epimer[e, f]	1.1	—	—
Tacrolimus open ring[e, g]	1.3	—	—
Any individual unspecified impurity	—	1.0	0.2

Table 6 *(continued)*

Name	Relative Retention Time	Relative Response Factor	Acceptance Criteria, NMT (%)
Total impurities	—	—	1.0

[a] (14*E*,18*E*)-17-Allyl-1-hydroxy-12-[(*E*)-2-(4-hydroxy-3-methoxycyclohexyl)-1-methylvinyl]-23,25-dimethoxy-13,19,21,27-tetramethyl-11,28-dioxa-4-azatricyclo[22.3.1.0^{4,9}] octacosa-14,18-diene-2,3,10,16-tetrone.
[b] (4*E*,11*E*)-10-Allyl-7,8,10,13,14,15,16,17,18,19,20,21,26,22,28,28a-hexadecahydro-7,21-dihydroxy-3-(4-hydroxy-3-methoxycyclohexyl)-16,18-dimethoxy-4,6,12,14,20-pentamethyl-17,21-epoxy-3*H*-pyrido[2,1-*c*][1,4]oxaazacyclopentacosine-1,9,22,23(6*H*,25*H*)-tetrone.
[c] Tacrolimus impurity 1 is a specified, unidentified impurity.
[d] Tacrolimus related compound A is listed here to indicate the relative retention time of this compound. It is used in the procedure to evaluate system suitability and is not to be reported. It is not to be included in total impurities.
[e] Tacrolimus open ring and tacrolimus 19-epimer are isomers of tacrolimus, which are present in equilibrium with the active ingredient. They are not to be reported as degradation products and are not included in total impurities.
[f] (3*S*,4*R*,5*S*,8*R*,9*E*,12*S*,14*S*,15*R*,16*S*,18*R*,19*S*,26a*S*)-8-Allyl-5,6,8,11,12,13,14,15,16,17,18,19,24,25,26,26a-hexadecahydro-5,19-dihydroxy-3-{(*E*)-2-[(1*R*,3*R*,4*R*)-4-hydroxy-3-methoxycyclohexyl]-1-methylvinyl}-14,16-dimethoxy-4,10,12,18-tetramethyl-15,19-epoxy-3*H*-pyrido[2,1-*c*][1,4]oxaazacyclotricosine-1,7,20,21(4*H*,23*H*)-tetrone.
[g] (3*S*,4*R*,5*S*,8*R*,12*S*,14*S*,15*R*,16*S*,18*R*,26a*S*,*E*)-8-Allyl-5,6,11,12,13,14,15,16,17,18,24,25,26,26a-tetradecahydro-5,15,20,20-tetrahydroxy-3-{(*E*)-2-[(1*R*,3*R*,4*R*)-4-hydroxy-3-methoxycyclohexyl]-1-methylvinyl}-14,16-dimethoxy-4,10,12,18-tetramethyl-3*H*-pyrido[2,1-*c*][1,4]oxaazacyclotricosine-1,7,19,21(4*H*,8*H*,20*H*,23*H*)-tetrone.

• ORGANIC IMPURITIES, PROCEDURE 2

Use *Organic Impurities, Procedure 2* when the impurity profile includes tacrolimus hydroxy acid and tacrolimus 8-epimer. It is suggested to equilibrate the column overnight with a mixture of *Solution C* and *Solution D* (17:3) before performing this procedure. Allow the *System suitability solution*, *Standard solution*, and *Sample solution* to stand for 3 h at ambient temperature before use. Protect solutions containing tacrolimus from light.

Solution A: 6 mM phosphoric acid

Solution B: Acetonitrile and *tert*-butyl methyl ether (81:19). [NOTE—The ratio of acetonitrile to *tert*-butyl methyl ether is critical.]

Solution C: *Solution A* and *Solution B* (4:1)

Solution D: *Solution A* and *Solution B* (1:4)

Mobile phase: See *Table 7*.

Table 7

Time (min)	Solution C (%)	Solution D (%)
0	74	26
45	74	26
60	15	85
75	15	85
76	74	26
85	74	26

Solution E: 50 g/L of polyoxyethylene (23) lauryl ether in *Solution A*. [NOTE—Polyoxyethylene (23) lauryl ether is also called Brij-35.]

Diluent: Acetonitrile and *Solution E* (7:3)

System suitability solution: 1.5 mg/mL of USP Tacrolimus System Suitability Mixture RS in *Diluent*

Standard solution: 7.5 µg/mL of USP Tacrolimus RS in *Diluent*

Sensitivity solution: 1.5 µg/mL of USP Tacrolimus RS in *Diluent* from *Standard solution*

Peak identification solution 1: 10 µg/mL of USP Tacrolimus 8-epimer RS in *Diluent*

Peak identification solution 2: 10 µg/mL of USP Tacrolimus 8-propyl Analog RS in *Diluent*

Sample solution: Equivalent to 1.5 mg/mL of tacrolimus in *Diluent*. [NOTE—Shake the mixture on a mechanical shaker for 30 min, and pass through a suitable filter.]

Chromatographic system

(See *Chromatography* ⟨621⟩*, System Suitability*.)

Mode: LC

Detector: UV 220 nm

Column: 4.6-mm × 15-cm; 3-µm packing L1

Column temperature: 60°

Flow rate: 1.5 mL/min

Injection volume: 40 µL

System suitability

Samples: *System suitability solution*, *Standard solution*, and *Sensitivity solution*

Suitability requirements

Resolution: NLT 3.0 between tacrolimus and ascomycin, *System suitability solution*

Relative standard deviation: NMT 10.0% for the sum of the responses of tacrolimus and tacrolimus 19-epimer, *Standard solution*

Signal-to-noise ratio: NLT 10.0, *Sensitivity solution*

Analysis

Samples: *Standard solution*, *Peak identification solution 1*, *Peak identification solution 2*, and *Sample solution*

Calculate the percentage of each impurity in the portion of Capsules taken:

$$\text{Result} = (r_U/r_S) \times (C_S/C_U) \times P \times (1/F) \times 100$$

r_U = peak response of each impurity from the *Sample solution*

r_S = sum of the peak responses of tacrolimus 19-epimer and tacrolimus from the *Standard solution*

C_S = concentration of USP Tacrolimus RS in the *Standard solution* (mg/mL)

C_U = nominal concentration of tacrolimus in the *Sample solution* (mg/mL)

P = potency of tacrolimus in USP Tacrolimus RS (mg/mg)

F = relative response factor (see *Table 8*)

Acceptance criteria: See *Table 8*. Identify tacrolimus 8-epimer and tacrolimus 8-propyl analog using *Peak identification solution 1* and *Peak identification solution 2*. Disregard peaks that are smaller than the tacrolimus peak in the *Sensitivity solution*.

Table 8

Name	Relative Retention Time	Relative Response Factor	Acceptance Criteria, NMT (%)
Tacrolimus hydroxy acid[a]	0.18	1.5	0.5
Tacrolimus open ring[b, c]	0.49	—	—
Ascomycin 19-epimer[d, e]	0.52	—	—
Tacrolimus 19-epimer[b, f]	0.62	—	—
Ascomycin[e, g]	0.84	—	—
Desmethyl tacrolimus[e, h]	0.91	—	—
Tacrolimus	1.0	—	—

Table 8 *(continued)*

Name	Relative Retention Time	Relative Response Factor	Acceptance Criteria, NMT (%)
Tacrolimus 8-epimer[i]	1.28	1.0	0.5
Tacrolimus 8-propyl analog[e, j]	1.30	—	—
Any individual unspecified impurity	—	1.0	0.2
Total impurities	—	—	1.5

[a] (3*S*,4*R*,5*S*,8*R*,12*S*,14*S*,15*R*,16*S*,18*R*,25a*S*,*E*)-8-Allyl-5,15,19-trihydroxy-3-{(*E*)-1-[(1*R*,3*R*,4*R*)-4-hydroxy-3-methoxycyclohexyl]prop-1-en-2-yl}-14,16-dimethoxy-4,10,12,18-tetramethyl-1,7,20-trioxo-1,3,4,5,6,7,8,11,12,13,14,15,16,17,18,19,20,22,23,24,25,25a-docosahydropyrido[2,1-*c*][1]oxa[4]azacyclodocosine-19-carboxylic acid.

[b] Tacrolimus open ring and tacrolimus 19-epimer are isomers of tacrolimus, which are present in equilibrium with the active ingredient. They are not to be reported as degradation products and are not included in total impurities.

[c] (3*S*,4*R*,5*S*,8*R*,12*S*,14*S*,15*R*,16*S*,18*R*,26a*S*,*E*)-8-Allyl-5,6,11,12,13,14,15,16,17,18,24,25,26,26a-tetradecahydro-5,15,20,20-tetrahydroxy-3-{(*E*)-2-[(1*R*,3*R*,4*R*)-4-hydroxy-3-methoxycyclohexyl]-1-methylvinyl}-14,16-dimethoxy-4,10,12,18-tetramethyl-3*H*-pyrido[2,1-*c*][1,4]oxaazacyclotricosine-1,7,19,21(4*H*,8*H*,20*H*,23*H*)-tetrone.

[d] (3*S*,4*R*,5*S*,8*R*,9*E*,12*S*,14*S*,15*R*,16*S*,18*R*,19*S*,26a*S*)-8-Ethyl-5,6,8,11,12,13,14,15,16,17,18,19,24,25,26,26a-hexadecahydro-5,19-dihydroxy-3-[(*E*)-2-[(1*R*,3*R*,4*R*)-4-hydroxy-3-methoxycyclohexyl]-1-methylvinyl]-14,16-dimethoxy-4,10,12,18-tetramethyl-15,19-epoxy-3*H*-pyrido[2,1-*c*][1,4]oxaazacyclotricosine-1,7,20,21-(4*H*,23*H*)-tetrone.

[e] These are process impurities that are controlled in the drug substance. They are not to be reported in the drug product.

[f] (3*S*,4*R*,5*S*,8*R*,9*E*,12*S*,14*S*,15*R*,16*S*,18*R*,19*S*,26a*S*)-8-Allyl-5,6,8,11,12,13,14,15,16,17,18,19,24,25,26,26a-hexadecahydro-5,19-dihydroxy-3-{(*E*)-2-[(1*R*,3*R*,4*R*)-4-hydroxy-3-methoxycyclohexyl]-1-methylvinyl}-14,16-dimethoxy-4,10,12,18-tetramethyl-15,19-epoxy-3*H*-pyrido[2,1-*c*][1,4]oxaazacyclotricosine-1,7,20,21(4*H*,23*H*)-tetrone.

[g] (3*S*,4*R*,5*S*,8*R*,9*E*,12*S*,14*S*,15*R*,16*S*,18*R*,19*R*,26a*S*)-8-Ethyl-5,6,8,11,12,13,14,15,16,17,18,19,24,25,26,26a-hexadecahydro-5,19-dihydroxy-3-[(*E*)-2-[(1*R*,3*R*,4*R*)-4-hydroxy-3-methoxycyclohexyl]-1-methylvinyl]-14,16-dimethoxy-4,10,12,18-tetramethyl-15,19-epoxy-3*H*-pyrido[2,1-*c*][1,4]oxaazacyclotricosine-1,7,20,21-(4*H*,23*H*)-tetrone.

[h] (3*S*,4*R*,5*S*,8*R*,9*E*,12*S*,14*S*,15*R*,16*S*,18*R*,19*R*,26a*S*)-8-Allyl-5,6,8,11,12,13,14,15,16,17,18,19,24,25,26,26a-hexadecahydro-5,19-dihydroxy-3-[(*E*)-2-[(1*R*,3*R*,4*R*)-4-hydroxy-3-methoxycyclohexyl]-1-methylvinyl]-14,16-dimethoxy-4,12,18-trimethyl-15,19-epoxy-3*H*-pyrido[2,1-*c*][1,4]oxaazacyclotricosine-1,7,20,21-(4*H*,23*H*)-tetrone.

[i] (3*S*,4*R*,5*S*,8*S*,9*E*,12*S*,14*S*,15*R*,16*S*,18*R*,19*R*,26a*S*)-8-Allyl-5,6,8,11,12,13,14,15,16,17,18,19,24,25,26,26a-hexadecahydro-5,19-dihydroxy-3-{(*E*)-2-[(1*R*,3*R*,4*R*)-4-hydroxy-3-methoxycyclohexyl]-1-methylvinyl}-14,16-dimethoxy-4,10,12,18-tetramethyl-15,19-epoxy-3*H*-pyrido[2,1-*c*][1,4]oxaazacyclotricosine-1,7,20,21(4*H*,23*H*)-tetrone.

[j] (3*S*,4*R*,5*S*,8*R*,9*E*,12*S*,14*S*,15*R*,16*S*,18*R*,19*R*,26a*S*)-5,6,8,11,12,13,14,15,16,17,18,19,24,25,26,26a-Hexadecahydro-5,19-dihydroxy-3-{(*E*)-2-[(1*R*,3*R*,4*R*)-4-hydroxy-3-methoxycyclohexyl]-1-methylvinyl}-14,16-dimethoxy-4,10,12,18-tetramethyl-15,19-epoxy-8-propyl-3*H*-pyrido[2,1-*c*][1,4]oxaazacyclotricosine-1,7,20,21(4*H*,23*H*)-tetrone.

ADDITIONAL REQUIREMENTS

- **PACKAGING AND STORAGE:** Preserve in tight containers. Store at controlled room temperature.
- **LABELING:** If a test for *Organic Impurities* other than *Procedure 1* is used, then the labeling states with which test for *Organic Impurities* the article complies. When more than one *Dissolution* test is given, the labeling states the *Dissolution* test used only if *Test 1* is not used.
- **USP REFERENCE STANDARDS ⟨11⟩**

USP Tacrolimus RS

USP Tacrolimus Related Compound A RS
(*E*)-8-Ethyl-5,6,8,11,12,13,14,15,16,17,18,19,24,25,26,26a-hexadecahydro-5,19-dihydroxy-3-[(*E*)-2-(4-hydroxy-3-methoxycyclohexyl)-1-methylvinyl]-14,16-dimethoxy-4,10,12,18-tetramethyl-15,19-epoxy-3*H*-pyrido[2,1-*c*][1,4]oxaazacyclotricosine-1,7,20,21-(4*H*,23*H*)-tetrone.
$C_{43}H_{69}NO_{12}$ 792.01

USP Tacrolimus 8-epimer RS
(3*S*,4*R*,5*S*,8*S*,9*E*,12*S*,14*S*,15*R*,16*S*,18*R*,19*R*,26a*S*)-8-Allyl-5,6,8,11,12,13,14,15,16,17,18,19,24,25,26,26a-hexadecahydro-5,19-dihydroxy-3-{(*E*)-2-[(1*R*,3*R*,4*R*)-4-hydroxy-3-methoxycyclohexyl]-1-methylvinyl}-14,16-dimethoxy-4,10,12,18-tetramethyl-15,19-epoxy-3*H*-pyrido[2,1-*c*][1,4]oxaazacyclotricosine-1,7,20,21(4*H*,23*H*)-tetrone.
$C_{44}H_{69}NO_{12}$ 804.02

USP Tacrolimus 8-propyl Analog RS
(3*S*,4*R*,5*S*,8*R*,9*E*,12*S*,14*S*,15*R*,16*S*,18*R*,19*R*,26a*S*)-5,6,8,11,12,13,14,15,16,17,18,19,24,25,26,26a-Hexadecahydro-5,19-dihydroxy-3-{(*E*)-2-[(1*R*,3*R*,4*R*)-4-hydroxy-3-methoxycyclohexyl]-1-methylvinyl}-14,16-dimethoxy-4,10,12,18-tetramethyl-15,19-epoxy-8-propyl-3*H*-pyrido[2,1-*c*][1,4]oxaazacyclotricosine-1,7,20,21(4*H*,23*H*)-tetrone.
$C_{44}H_{71}NO_{12}$ 806.03

USP Tacrolimus System Suitability Mixture RS
It contains tacrolimus, ascomycin
(3*S*,4*R*,5*S*,8*R*,9*E*,12*S*,14*S*,15*R*,16*S*,18*R*,19*R*,26a*S*)-8-Ethyl-5,6,8,11,12,13,14,15,16,17,18,19,24,25,26,26a-hexadecahydro-5,19-dihydroxy-3-[(*E*)-2-[(1*R*,3*R*,4*R*)-4-hydroxy-3-methoxycyclohexyl]-1-methylvinyl]-14,16-dimethoxy-4,10,12,18-tetramethyl-15,19-epoxy-3*H*-pyrido[2,1-*c*][1,4]oxaazacyclotricosine-1,7,20,21-(4*H*,23*H*)-tetrone.
$C_{43}H_{69}NO_{12}$ 792.01
and tacrolimus 8-propyl analog
(3*S*,4*R*,5*S*,8*R*,9*E*,12*S*,14*S*,15*R*,16*S*,18*R*,19*R*,26a*S*)-5,6,8,11,12,13,14,15,16,17,18,19,24,25,26,26a-Hexadecahydro-5,19-dihydroxy-3-{(*E*)-2-[(1*R*,3*R*,4*R*)-4-hydroxy-3-methoxycyclohexyl]-1-methylvinyl}-14,16-dimethoxy-4,10,12,18-tetramethyl-15,19-epoxy-8-propyl-3*H*-pyrido[2,1-*c*][1,4]oxaazacyclotricosine-1,7,20,21-(4*H*,23*H*)-tetrone.
$C_{44}H_{71}NO_{12}$ 806.03