# METABOLIC PRODUCTS OF MICROORGANISMS. 240[†] URDAMYCINS, NEW ANGUCYCLINE ANTIBIOTICS FROM *STREPTOMYCES FRADIAE*

## II. STRUCTURAL STUDIES OF URDAMYCINS B TO F

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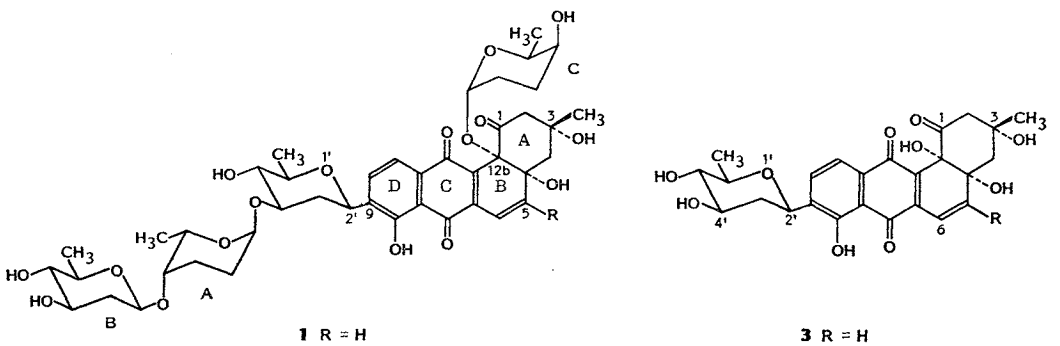
The structures of the angucycline antibiotics urdamycin B (**5**), E (**2**) and F (**9**) were established by comparing of their spectra with those of urdamycin A (**1**). The structures of urdamycins C and D, the largest compounds of this series, are still incomplete (**10** and **11**). The aglycones urdamycinone C, D and E can be liberated by methanolysis of the corresponding urdamycins. The liberation of urdamycinone B (**6**) requires an alcohol-free medium, to prevent its rearrangement to the naphthacenequinone **7** or **8**. The urdamycins differ from other *O*-glycoside series in their variety of aglycones.

The colored urdamycins are new angucycline antibiotics produced by *Streptomyces fradiae* strain Tü 2717[2]. They are biologically active aginst Gram-positive bacteria and stem cells of murine L1210 leukemia. The isolation and characterization of the urdamycins A to F have been described in a previous paper where the group term "angucycline/angucyclinone" has been defined[2]. In this study we shall give additional structural information for the urdamycins together with the full NMR data, which for reasons of space were omitted in the first paper.

### Urdamycins A and E

The structure of urdamycin A (**1**) was deduced by chemical and spectroscopic methods in connection with an X-ray analysis[2,3]. **1** consists of the aglycone aquayamycin (**3**) and three *O*-glycosidically bonded deoxyhexoses, one $\beta$-D-olivose (sugar B) and two $\alpha$-L-rhodinoses (sugars A and C). The $^1$H NMR data (Table 1) were given in acetone-$d_6$, because all urdamycins were soluble in this solvent allowing the spectra to be compared in view of structural differences. The $^{13}$C NMR data for

Scheme 1.




**1** R = H
**2** R = $SCH_3$

**3** R = H
**4** R = $SCH_3$

[†] See ref 1.

urdamycin A (Table 2) were evaluated by comparison with aglycone **3**[4] and other glycosides[5,6]. There was a striking agreement with the data of kerriamycin B[7,8]; thus we assume that both antibiotics are identical although there is given a different configuration for sugar B in the kerriamycin formula.

The minor component urdamycin E (**2**) is the first sulfur-containing angucycline. In the molecular formula urdamycin E differs from A (**1**) by $CH_2S$. The sulfur atom is conjugated with the chro-

Table 1. $^1H$ NMR signals of urdamycins A, B, E and F at 200 MHz in acetone-$d_6$ ($\delta$ in ppm relative to internal TMS, $J$ in Hz).

| Proton | Urdamycin | | | |
|---|---|---|---|---|
| | A (**1**) | B[a] (**5**) | E (**2**) | F (**9**) |
| 2-$H_{ax}$ | 2.90 d (13) | 3.24 d (17) | 2.92 d (13) | 2.77 d (13) |
| 2-$H_{eq}$ | 2.56 dd (13, 2) | 3.08 dd (17, 2) | 2.60 dd (13) | 2.47 dd (13, 2) |
| 3-$CH_3$ | 1.17 s | 1.35 s | 1.17 s | 1.14 s |
| 4-$H_{ax}$ | 2.04 d (15) | 3.07 d (15) | 1.9~2.2 (complex) | 2.77 d (15) |
| 4-$H_{eq}$ | 1.95 dd (15, 2) | 2.74 dd (15, 2) | 1.9~2.2 (complex) | 1.90 dd (15, 2) |
| 5-H | 6.53 d (10) | 7.57 d (8) | 5-$SCH_3$: 2.54 s | 5-$H_{ax}$: 2.65 dd (14, 6)<br>5-$H_{eq}$: 2.47 d (14) |
| 6-H | 6.93 d (10) | 7.89 d (8) | 6.49 s | 5.29 dd (8, 6)[b] |
| 10-H | 7.99 d (8, 1) | 8.26 d (8) | 7.93 d (8) | 7.95 d (8) |
| 11-H | 7.68 d (8) | 7.76 d (8) | 7.61 d (8) | 7.66 d (8) |
| 2′-H | 4.93 dd (10, 2) | 4.83 dd (10, 2) | 4.90 dd (10, 1) | 4.92 dd (10, 1) |
| 3′-$H_{eq}$[c] | 2.20 ddd (13, 5, 2) | 2.46 ddd (13, 5, 2) | 2.18 ddd (13, 5, 2) | 2.19 ddd (13, 5, 2) |
| 4′-H | 3.82 ddd (12, 9, 5) | 3.70 ddd (12, 9, 5) | 3.80 ddd (12, 9, 5) | 3.80 ddd (12, 9, 5) |
| 5′-H | 2.94 ddd (9, 9, 4[d]) | 3.07 dd[e] | 2.92 dd (9, 9) | 2.90 dd (9, 5, 9)[f] |
| 6′-H | 3.53 dq (9, 6) | *ca.* 3.4 complex | 3.51 dq (9, 6) | *ca.* 3.5 m |
| 6′-$CH_3$ | 1.38 d (6) | 1.29 d (6) | 1.37 d (6) | 1.37 d (6) |
| Sugar signals[c] | | | | |
| 1A-H | 5.02 br s | 4.90 br s | 4.99 br s | 4.99 br s |
| 4A-H | 3.58 br s | 3.45 br s | 3.56 br s | 3.56 br s |
| 5A-H | 4.24 dq (2, 6.5) | 4.17 dq (2, 6.5) | 4.21 dq (1.5, 6.5) | 4.22 dq (1.5, 6.5) |
| 5A-$CH_3$ | 1.16 d (6.5) | 1.04 d (6.5) | 1.15 d (6.5) | 1.15 d (6.5) |
| 1B-H | 4.64 dd (10, 2) | 4.49 dd (10, 2) | 4.60 dd (10, 1.5) | 4.60 dd (10, 1.5) |
| 2B-$H_{eq}$[c] | 2.55 ddd (13, 5, 2) | 2.72[e] | 2.54[e] | 2.54 ddd (13, 5, 2) |
| 3B-H | 3.56 m | *ca.* 3.4 m | *ca.* 3.5 m | *ca.* 3.5 m |
| 4B-H | 3.19 ddd (9, 9, 4) | 3.12 dd (9, 9) | 3.16 dd (9, 9) | 3.17 dd (9, 9) |
| 5B-H | 3.27 dq (9, 6) | *ca.* 3.1 m | *ca.* 3.2 m | 3.22 dq (9, 6) |
| 5B-$CH_3$ | 1.24 d (6) | 1.14 d (6) | 1.23 d (6) | 1.23 d (6) |
| 1C-H | 5.33 br s | | 5.32 br s | 5.37 s |
| 4C-H | 3.28 br s | | 3.32 br s | 3.42 br s |
| 5C-H | 3.68 dq (2, 6.5) | | 3.4~3.7 (complex) | 3.4~3.6 (complex) |
| 5C-$CH_3$ | 0.51 d (6.5) | | 0.53 d (6.5) | 0.46 d (6.5) |
| OH signals[g] | | | | |
| | 3.81 s, 4.03 (5), 4.09 d (5), 4.42 s, 4.63 d (4), 5.32 d (3), 12.38 s (8-OH) | 4.85 d (5), 4.92 d (5), 5.04 s (3-OH), 5.13 d (5) | 3.98 s, 4.04 s, 4.35 s, 12.38 br s (8-OH) | 3.42 s, 3.82 s, 4.11 br s, 4.52 s, 4.57 d (4), 4.63 s, 4.89 s, 12.42 s (8-OH) |

[a] In DMSO-$d_6$.
[b] After exchange with $D_2O$; d (6).
[c] 3′-$H_{ax}$, 2A-$H_2$, 3A-$H_2$, 2B-$H_{ax}$, 2C-$H_2$, 3C-$H_2$; 1.0~2.2 (complex or obscured).
[d] After exchange with $D_2O$; dd (9, 9).
[e] Partially obscured.
[f] Better observability after exchange with $D_2O$.
[g] Exchangeable with $D_2O$.

Table 2. $^{13}C$ NMR signals of urdamycins at 50.3 MHz ($\delta$ values in ppm relative to internal TMS; A and B in DMSO-$d_6$, C to F in acetone-$d_6$).

| Carbon | Urdamycin | | | | | |
|---|---|---|---|---|---|---|
| | A (1)[a] | B (5)[a] | C (10)[b] | D (11)[b] | E (2)[a] | F (9)[b] |
| 1 | 202.6 s | 196.7 s | 203.8 s | 203.9 s | 202.2 s | 202.4 s |
| 2 | 53.4 t | 53.1 t | 54.6 t | 54.7 t | 54.7 t | 54.9 t |
| 3 | 75.7 s | 71.5 s | 74.9 s | 74.8 s | 75.7 s | 75.2 s |
| 4 | 43.2 t | 43.4 t | 44.0 t | 44.1 t | 45.6 t | 45.0 t |
| 4a | 80.6 s | 149.3 s | 82.2 s | 82.3 s | 82.3 s | 78.4 s |
| 5 | 145.6 d | 134.1 d | 138.8 d | 138.3 d | 164.8 s | 40.0 t |
| 6 | 115.9 d | 128.5 d | 118.6 d | 118.8 d | 105.3 d | 62.7 d |
| 6a | 113.9 s | 132.7 s | 112.6 s | 112.9 s | 114.8 s | 115.4 s |
| 7 | 188.4 s | 187.3 s | 187.5 s | 187.5 s | 190.0 s | 192.1 s |
| 7a | 130.7 s | 114.7 s | 125.2 t | 123.9 s | 132.0 s | 131.7 s |
| 8 | 156.3 s | 157.1 s | 156.6 s | 156.7 s | 158.0 s | 158.1 s |
| 9 | 140.3 s | 136.4 s | 143.7 s | 143.1 s | 137.6 s | 143.6 s |
| 10 | 133.0 d | 133.4 d | | | 134.0 d | 134.2 d |
| 11 | 118.9 d | 118.4 d | Not assigned | | 119.4 d | 120.2 d |
| 11a | 136.2 s | 133.7 s | (see below) | | 135.0 s | 138.9 s |
| 12 | 182.2 s | 182.5 s | | | 182.2 s | 183.5 s |
| 12a | 137.1 s | 135.4 s | | | 138.0 s | 145.5 s |
| 12b | 81.1 s | 135.5 s | 83.1 s | 83.3 s | 84.2 s | 79.7 s |
| 3-$CH_3$ | 29.3 q | 29.6 q | 29.4 q[c] | 29.5 q[d] | 28~32[e] | 28~32[e] |
| $SCH_3$ | | | | | 14.3 q | |
| 2′ | 70.3 d | 70.3 d | 72.1 d | 72.2 d | 71.9 d | 72.2 d |
| 3′ | 38~41[e] | 38~41[e] | 40.3 t | 40.4 t | 40.2 t | 40.4 t |
| 4′ | 76.0 d | 76.1 d | 78.3 d | 78.4 d | 78.2 d | 79.2 d |
| 5′ | 76.7 d | 76.7 d | 79.2 d | 79.3 d | 79.0 d | 79.9 d |
| 6′ | 71.4 d | 71.5 d | 72.5 d | 72.6 d | 72.4 d | 72.6 d |
| 7′ | 18.3 q | 18.4 q | 18.6 q | 18.6 q | 18.6 q | 18.8 q |
| 1A | 91.8 d | 91.9 d | 95.8 d | 95.8 d | 94.9 d | 94.6 d |
| 2A | 24.0 t | 24.0 t | 25.5 t | 25.5 t | 25.3 t | 25.5 t |
| 3A | 24.0 t | 24.0 t | 25.1 t | 25.2 t | 25.0 t | 25.2 t |
| 4A | 74.4 d | 74.3 d | 76.4 d | 76.5 d | 76.3 d | 76.5 d |
| 5A | 65.3 d | 65.2 d | 67.4 d | 67.5 d | 67.2 d | 67.4 d |
| 6A | 16.9 q | 16.9 q | 17.4 q | 17.4 q | 17.2 q | 17.4 q |
| 1B | 100.9 d | 101.0 d | 102.3 d | 102.3 d | 102.1 d | 102.3 d |
| 2B | 36.1 t | 36.0 t | 37.7 t | 38.0 t | 37.1 t | 37.8 t |
| 3B | 74.4 d | 74.6 d | 76.4 d | 76.5 d | 76.3 d | 76.5 d |
| 4B | 75.2 d | 75.3 d | 76.9 d | 77.0 d | 76.9 d | 77.1 d |
| 5B | 70.2 d | 70.2 d | 71.8 d | 71.7 d | 71.5 d | 71.7 d |
| 6B | 18.1 q | 18.1 q | 18.4 q | 18.4 q | 18.2 q | 18.4 q |
| 1C | 93.0 d | — | 95.8 d | 95.9 d | 95.6 d | 95.8 d |
| 2C | 25.2 t | — | 26.3 t | 26.4 t | 26.1 t | 26.2 t |
| 3C | 23.1 t | — | 24.2 t | 24.2 t | 23.5 t | 23.7 t |
| 4C | 65.1 d | — | 67.0 d | 67.0 d | 66.9 d | 67.1 d |
| 5C | 66.4 d | — | 67.5 d | 67.5 d | 67.7 d | 67.6 d |
| 6C | 16.3 q | — | 16.9 q | 16.9 q | 16.9 q | 17.0 q |

[a] Assignment by attached proton test (ATP).
[b] Assignment by distortionless enhancement by polarization transfer (DEPT).
[c] From a spectrum in $CD_3CN$.
[d] From a spectrum in DMSO-$d_6$.
[e] Obscured by solvent.

Additional non-assigned $^{13}C$ NMR signals of the aglycones of urdamycins C and D: Urdamycin C $\delta$ 160.0 s, 159.5 s, 145.0 s, 134.7 d, 134.5 d, 134.5 d, 133.9 s, 132.7 s, 128.9 s, 123.7 s, 116.2 s, 115.9 d, 115.9 d. Urdamycin D $\delta$ 159.5 s, 143.6 s, 137.4 s, 136.1 d, 133.2 d, 130.7 s, 128.4 s, 127.9 s, 127.8 s, 123.5 d, 121.8 d, 121.1 d, 116.8 s, 113.1 d, 109.1 s.

mophoric system as indicated by a significant shift of the UV maxima[2]. The NMR data (Tables 1 and 2) were very similar to those of **1**. One of the olefinic protons in positions 5 and 6 existed only as a singlet ($\delta$ 6.49) and a new methyl group ($\delta_H$ 2.47, $\delta_C$ 14.3) occurred, indicating an *S*-methyl group at C-5. Its position was confirmed by a comparison of the NMR data (5-H/6-H and C-5/C-6 of **1**/**3** and **2**/**4**, respectively, Tables 1~3) in connection with increment calculations. 6-H is shifted by the neighboring sulfur atom 0.44 ppm upfield, C-5 19.2 ppm downfield and C-6 10.6 ppm upfield. The sign and value of these shifts were as expected[9]. Treatment with Raney nickel and analysis on TLC plates demonstrated that urdamycin E (**2**) could be transformed into A (**1**). Hydrolysis of **2** yielded urdamycinone E (**4**).

## Urdamycin B

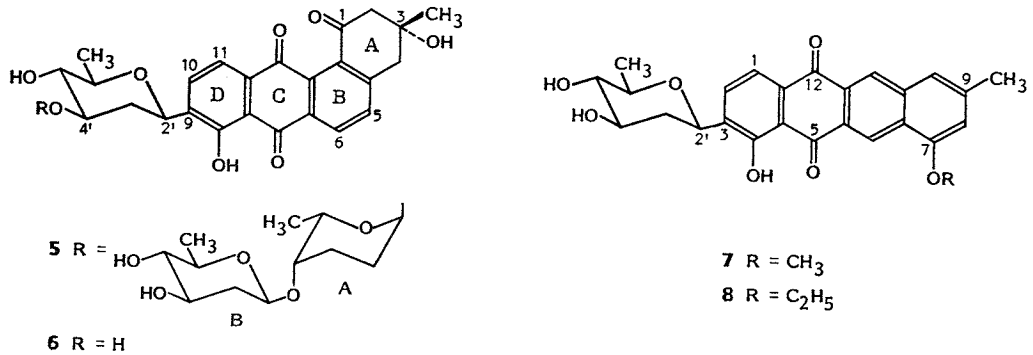
Urdamycin B (**5**) is the smallest molecule of the urdamycin complex. The NMR spectra (Tables 1 and 2) in comparison with **1** show ring B to be aromatic and subsequently lack of the angularly bonded L-rhodinose (sugar C). Sugars A and B are identical with those of **1**.

In the presence of acidic methanol, **5** yielded methyl-$\beta$-D-olivosyl-(1→4)-$\alpha$-L-rhodinoside[2] and the yellow naphthacenequinone **7**. The molecular formula $C_{26}H_{24}O_7$ (MW 448) of **7** was confirmed by high resolution electron impact mass spectra (HREI-MS) and differed from that of the expected urdamycinone B (**6**, $C_{25}H_{24}O_8$). The structure of **7** was deduced by analysis of the $^1$H NMR spectrum taking into account a plausible mechanism of the assumed rearrangement. Striking was the lack of the aliphatic protons of ring A and the aromatic AB-protons of ring B in **5** (Table 1). Instead, four aromatic protons (two broadened 1H-singlets at $\delta$ 7.13 and 7.44; a 2H-singlet at $\delta$ 8.13), one aromatic methyl group ($\delta$ 2.50) and one aromatic methoxyl group ($\delta$ 3.88) were observed. The downfield shift to two aromatic protons could be explained by their peri-position to the quinone carbonyl groups. Thus, the angular frame of the urdamycin B aglycone has changed to a linear one.

The rearrangement from the expected aglycone **6** to **7** is probably initiated as methanol attacks at C-1 (hemiketalization), cleaving the C-1/C-12b bond in a retro Friedel-Crafts reaction. During the cyclization of the open chain methyl ester and the following aromatization to the linear tetracyclic **7**, the methoxyl group is retained. This could be confirmed by repeating this reaction with ethanolic sulfuric acid, yielding **8** as main product. The tendency to rearrange from an angular to a linear molecular frame was first shown in the case of aquayamycin (**3**)[10].

Thus, the aglycone urdamycinone B (**6**) could not be formed in an alcoholic medium but yields of about 50% were possible using tetrahydrofurane as solvent. The spectroscopic data of the aglycone

Scheme 2.

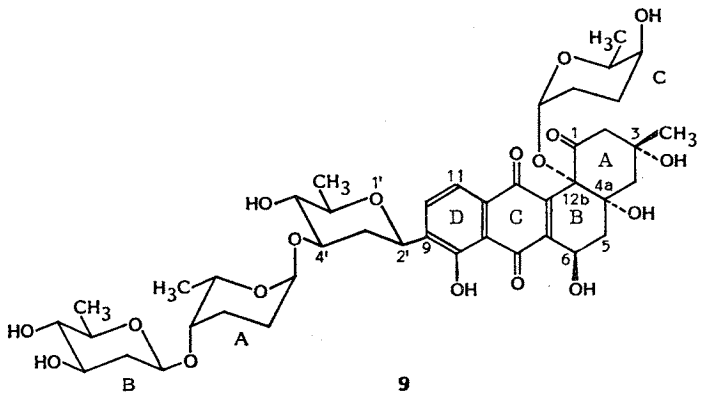


were in agreement with the given formula **6**. The absolute configuration of the chiral center at C-3 is assumed to be identical with that of the corresponding center of **1** because all urdamycins are derived on the same biosynthetic pathway. Urdamycinone B (**6**) is a missing link in the series of angucyclinones with an anthraquinone chromophore[2]. **6** is the first C-9 *C*-glycoside of tetrangomycin.

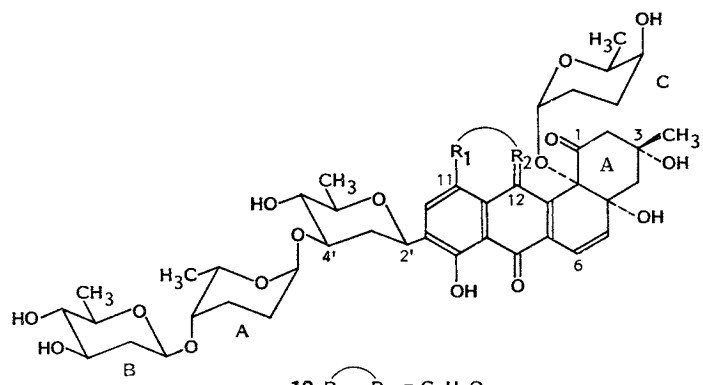
## Urdamycins C and D

Both urdamycin C (red colored) and urdamycin D (blue colored) posses an extended chromophoric system. Comparison of the $^1H$ NMR[2] and the $^{13}C$ NMR data (Table 2) with those for urdamycin A (**1**) and methanolysis of these compounds indicated the sugar pattern and parts of the aglycone, namely the *C*-glycosidic bonded olivose and the complete ring A, are the same. Urdamycins C and D were synthesized by *Streptomyces fradiae* in the late phase of the fermentation process, when urdamycin A (**1**) was already present at a high concentration. We assume that urdamycins C and D have the same $C_{43}$-frame as **1** and differ from **1** by additional structural elements, which are attached to the chromophore (partial formulae **10** and **11**). This is supported by the observation that the aglycones urdamycinone C and D were liberated by methanolysis of the corresponding urdamycins without any change of the UV maxima. Additionally the $^{13}C$ NMR spectra (Table 2 and Experimental) showed the lack of the C-12 quinone carbonyl group and the $^1H$ NMR data showed that the two AB-systems

Scheme 3.




**9**




**10** $R_1 \frown R_2 = C_8H_5O_3$

**11** $R_1 \frown R_2 = C_{10}H_6NO_2$

Table 3. $^1$H NMR data of urdamycinones B, C, D and E at 200 MHz in acetone-$d_6$ ($\delta$ in ppm relative to internal TMS, $J$ in Hz).

| Proton | Urdamycinone | | | |
|---|---|---|---|---|
| | B (6) | C | D | E (4) |
| 2-$H_{ax}$ | 3.33 d (17) | 3.23 d (13) | 3.28 d (12.5) | 3.05 d (13) |
| 2-$H_{eq}$ | 3.21 dd (17, 1) | 2.78 dd (13, 2) | 2.82 dd (12.5, 1.5) | 2.70 dd (13, 3) |
| 3-$CH_3$ | 1.49 s | 1.18 s | 1.20 s | 1.28 s |
| 4-$H_{ax}$ | 3.10 d (14.5) | *ca.* 2.1 | *ca.* 2.1 | 2.42 d (15) |
| 4-$H_{eq}$ | 2.90 dd (14.5, 1.5) | *ca.* 2.1 | *ca.* 2.1 | 2.15 dd (15, 3) |
| 5-H | 7.61 d (8) | 6.14 d (10) | 6.12 d (10) | 2.56 s (5-$SCH_3$) |
| 6-H | 7.95 d (8) | 6.99 d (10) | 7.00 d (10) | 6.43 s |
| 10-H | 7.76 d (8) | Not assigned[a] | Not assigned[b] | 7.58 d (8) |
| 11-H | 8.31 d (8) | | | 7.93 d (8) |
| 2'-H | 4.92 dd (11.5, 1.5) | 4.70 dd (10, 1.5) | 4.72 dd (11, 1.5) | 4.91 dd (10, 2) |
| 3'-$H_{ax}$[c] | 1.23 ddd (13, 11.5, 9.5) | 1.23 ddd (12, 11, 10) | 1.23 ddd (12.5, 11, 9.5) | 1.30 ddd (13, 12, 10) |
| 3'-$H_{eq}$ | 2.46 ddd (13, 5, 2) | 2.41 ddd (12, 5, 2) | 2.42 ddd (12.5, 5, 1.5) | 2.42 ddd (13, 5, 2) |
| 4'-H | 3.76 ddd (12, 9.5, 5) | 3.70 ddd (11, 9, 5) | 3.68 ddd (9.5, 9, 5) | 3.77 ddd (12, 9, 5) |
| 5'-H | 3.11 dd (8.5, 8) | 2.96 dd (10, 9) | 2.85 dd (9.5, 9) | 3.10 dd (9, 9) |
| 6'-H | 3.50 dq (9.5, 6) | 3.41 dq (9, 6) | 3.37 dq (9, 6) | 3.50 dq (9, 6) |
| 6'-$CH_3$ | 1.37 d (6) | 1.21 d (6) | 1.03 d (6) | 1.36 d |
| OH[d] | 3.82 s, 4.22 2×br s | 3.87 s, 4.14 br s | 4.12 2×br s, | 3.40 br s, |
| | | 4.74 s, 4.90 s, | 4.75 s, 4.96 br s, | 4.80 br s, |
| | | 5.26 s, 9.00 br s, | 5.27 s, 12.18 s, | 5.49 br s, |
| | | 13.16 br s | 13.24 s[e] | 12.20 s (8-OH) |

[a] 7.03 (2H, d, $J$=8 Hz), 7.43 (2H, d, $J$=8 Hz), 7.87 (1H, d, $J$=1, 5 Hz).
[b] 7.16 (1H, ddd, $J$=8, 8 and 1.5 Hz), 7.26 (1H, ddd, $J$=8, 8 and 1.5 Hz), 7.60 (2H, dd, $J$=8 and 1.5 Hz), 8.05 (1H, s), 8.20 (1H, d, $J$=1.5 Hz).
[c] Partially obscured.
[d] Exchangeable with $D_2O$.
[e] From a spectrum in DMSO-$d_6$.

of 5-H/6-H and 10-H/11-H in **1** were changed or replaced.

In the fast atom bombardment mass spectrum (FAB-MS) of urdamycinone C the molecule could be seen only as a negative ion at $m/z$ 619. From the NMR data (Tables 2 and 3) it followed that a residue of $C_6H_5$ and three oxygen atoms must be added to the aglycone urdamycinone A (**3**) as a hypothetical precursor in the biosynthesis. Thus, the molecular formulae of urdamycinone C ($C_{33}H_{30}O_{12}$) and urdamycin C ($C_{51}H_{60}O_{19}$) could be deduced and were in agreement with the elemental analysis. The additional residue is highly unsaturated.

Urdamycin D is the only nitrogen containing compound of the urdamycin complex. The NMR analysis indicated that urdamycinone D was larger than **3** by $C_{10}H_6NO_2$. The molecular formula $C_{35}H_{31}NO_{11}$ for urdamycinone D fitted the FAB-MS ($m/z$ 642, negative ion) best and suggested a molecular formula for urdamycin D ($C_{53}H_{61}NO_{18}$). As with urdamycin C, the main difference in the $^1$H NMR spectrum in comparison with **1** concerned the aromatic/olefinic hydrogen atoms. The olefinic AB-system was similar to urdamycin C ($\delta$ 6.16 and 7.06, $J$=10 Hz). Furthermore, an aromatic ABCD-pattern ($\delta$ 7.20, 7.29, 7.62 and 7.63, $J$=7.5 and 1.5 Hz) was seen instead of the simple AB-system in **1**, and a singlet ($\delta$ 8.12) and a doublet ($\delta$ 8.25, $J$=2 Hz) could be detected. Further structure elucidation of **10** and **11** is under progress.

## Urdamycin F

The molecular formula of urdamycin F (**9**) differs from that of **1** by $H_2O$. Comparison of the

NMR spectra (Tables 1 and 2) of urdamycin F with those of **1** showed that the C-5/C-6 double bond of **1** was hydrated. The position of the hydroxyl group at C-6 and the absolute configuration of this center was deduced by analysis of the $^1$H NMR spectrum: The chemical shift of 5-$H_2$ ($\delta$ 2.47 (d) and 2.65 (dd), Table 1) precluded close proximity to 7-CO; the proton assignments were confirmed by double resonance experiments. The overall coupling constant of 6-H ($\delta$ 5.29, $J$=6 Hz, after exchange with $D_2O$) was in agreement with this H-atom in a quasi-equatorial position. The X-ray analysis of urdamycin A (**1**) indicated a $^4C_1$-chair conformation for ring A and a $^{4a}$T-half chair conformation for ring B[3]. Molecular model studies showed that similar conformations of rings A and B are probably in urdamycin F (**9**): $^4C_1$ (ring A) and $^{4a}T_5$ (ring B). These energetically favored conformations agreed with the $^1$H NMR data for ring A (Table 1). The evident deshielding of 4-$H_{ax}$ ($\Delta\delta$ 0.6 ppm in comparison with **1**) could be explained by its close proximity to 6-OH, which led to the (*R*)-configuration at C-6 of **9**.

## Experimental

General

See ref 2. The Rf values of the urdamycinones are given in Table 1 of ref 2.

Reactions of Urdamycin B

a: 45 mg of **5** were dissolved in 50 ml of MeOH and treated with 10 drops of conc $H_2SO_4$ at room temperature. After all starting material had reacted (2.5 hours, TLC control, system: $CHCl_3$ - MeOH, 4:1) the solution was poured into ice-water and extracted three times with 50 ml of $CHCl_3$. The collected organic layers were evaporated to dryness, dissolved again in MeOH and purified by chromatography on Sephadex LH-20 (column 100×2.5 cm, MeOH). The main yellow zone contained 12 mg of the 3-(2′,3′,7′-trideoxy-$\beta$-D-arabinohexopyranos-2′-yl)-4-hydroxy-7-methoxy-9-methylnaphthacene-5,12-quinone (**7**), which was precipitated by pouring a saturated $CH_2Cl_2$ solution into *n*-pentane: Rf 0.66 ($CHCl_3$ - MeOH, 4:1), 0.57 ($CH_2Cl_2$ - EtOH, 9:1); IR (KBr) cm$^{-1}$ 3440, 1670, 1627; UV $\lambda_{max}$ (MeOH and MeOH - HCl) nm ($\varepsilon$) 410 (7,300), 305 (31,500), 243 (sh, 29,200), 225 (42,500); (MeOH - NaOH) 500 (6,400), 293 (31,700), 243 (30,100) 219 (33,700); $^1$H NMR (200 MHz, DMSO-$d_6$, see formula **7** for numbering scheme) $\delta$ 1.26 (3H, d, $J$=6 Hz, 6′-$CH_3$), 1.29 (1H, ddd, $J$=12, 12 and 12 Hz, 3′-$H_{ax}$), 2.24 (1H, ddd, $J$=12, 5 and 2 Hz, 3′-$H_{eq}$), 2.50 (3H, s, 9-$CH_3$), 2.89 (1H, dd, $J$=9 and 9 Hz, 5′-H), 3.34 (1H, dq, $J$=9 and 6 Hz, 6′-H), 3.54 (1H, ddd, $J$=12, 9 and 5 Hz, 4′-H), 3.88 (3H, s, 7-$OCH_3$), 4.79 (1H, dd, $J$=9 and 1.5 Hz, 2′-H), 4.97 and 5.05 (2H, 2×d, $J$=4 Hz, respectively, 4′-OH and 5′-OH, exchangeable with $D_2O$), 7.13 (1H, s, 8-H), 7.44 (1H, s, 10-H), 7.53 (1H, d, $J$=8 Hz, 2-H), 7.83 (1H, d, $J$=8 Hz, 1-H), 8.13 (2H, s, 6-H and 11-H), 12.42 (1H, br s, 4-OH, exchangeable with $D_2O$); MS (70 eV) *m/z* (abundance) 448 (72%, $M^+$, high resolution calcd for $C_{26}H_{24}O_7$ and found 448.1521), 373 (27%), 355 (31%), 345 (85%), 327 (100%), 318 (30%), 60 (23%), 43 (47%).

b: Rearrangement in ethanol, 5 mg of the 3-(2′,3′,7′-trideoxy-$\beta$-D-arabinohexopyranos-2′-yl)-4-hydroxy-7-ethoxy-9-methylnaphthacene-5,12-quinone (**8**) were obtained from 20 mg **5**: $^1$H NMR (80 MHz, acetone-$d_6$) $\delta$ 1.35 (3H, d, $J$=6 Hz, 6′-$CH_3$), 1.35 (1H, ddd, $J$=3×12 Hz, 3′-$H_{ax}$), 1.43 (3H, t, $J$=6.5 Hz, ethoxy-$CH_3$), 2.35 (1H, ddd, $J$=12, 5 and 2 Hz, 3′-$H_{eq}$), 2.50 (3H, s, 9-$CH_3$), 3.05 (1H, dd, $J$=9 and 9 Hz, 5′-H), 3.40 (1H, dq, $J$=9 and 6 Hz, 6′-H), 3.75 (1H, ddd, $J$=12, 9 and 5 Hz, 4′-H), 4.18 (2H, q, $J$=6.5 Hz, ethoxy-$OCH_2$), 4.87 (1H, dd, $J$=10 and 2 Hz, 2′-H), 7.02 (1H, s, 8-H), 7.32 (1H, s, 10-H), 7.47 (1H, d, $J$=8 Hz, 2-H), 7.85 (1H, d, $J$=8 Hz, 1-H), 8.02 and 8.06 (2H, 2×s, 6-H and 11-H).

c: 20 mg **5** was dissolved in 10 ml THF and treated with three drops of conc $H_2SO_4$. After stirring the solution for 48 hours at room temperature, it was poured into ice-water and extracted three times with 50 ml of $CHCl_3$. The evaporated organic layers were chromatographed on silica gel (plates 20×20 cm, $CH_2Cl_2$ - MeOH, 85:15) and Sephadex LH-20 (column 50×2.5 cm, MeOH), to yield 8 mg of urdamycinone B (**6**): IR (KBr) cm$^{-1}$ 3410, 1704, 1673, 1635, 1592; $^1$H NMR, see Table

3; MS (70 eV) *m/z* (abundance) 434 (4%, M−$H_2O$, high resolution calcd for $C_{25}H_{22}O_7$ and found 434.1366), 330 (4%), 97 (4%), 85 (14%), 71 (8%), 57 (13%), 44 (100%); CD $\lambda_{extreme}$ (MeOH) nm ($[\theta]^{25}$) 495 (−2,000), 410 (+3,000), 325 (+2,000), 264 (−23,000).

Urdamycinone C

A stirred solution of 40 mg urdamycin C in 25 ml MeOH - $H_2O$ (2:1) was treated with 20 drops of conc $H_2SO_4$. After 24 hours, the mixture was poured into ice-water and extracted several times with EtOAc. The product was purified chromatographically on silica gel (plate 40×20 cm, $CH_2Cl_2$ - MeOH, 9:1) and Sephadex LH-20 (column 100×2.5 cm, MeOH). The red dye was precipitated by pouring its concentrated acetone solution into *n*-hexane, yielding 20 mg urdamycinone C: MP >350°C; IR (KBr) $cm^{-1}$ 3420, 1726, 1708 (sh), 1640, 1604; $^1H$ NMR, see Table 3; $^{13}C$ NMR (200 MHz, acetone-$d_6$) $\delta$ 18.5 (q, C-7'), 29.6 (q, C-13)*, 40.7 (t, C-3'), 44.7 (t, C-4), 52.8 (t, C-2), 71.9 (d, C-2'), 73.1 (d, C-6'), 75.9 (s, C-3), 76.9 (d, C-4'), 78.4 (d, C-5'), 79.0 (s, C-4a), 81.2 (s, C-12b), 112.4 (s, C-6a), 115.9 (d), 115.9 (d), 116.7 (s), 118.8 (d, C-6), 123.8 (s), 125.4 (s, C-7a), 129.5 (s), 132.8 (s), 133.9 (s), 134.3 (d), 134.3 (d), 134.5 (d), 138.5 (d, C-5), 142.0 (s, C-9), 145.2 (s), 156.7 (s, C-8), 159.5 (s), 160.2 (s), 187.6 (s), *ca.* 204 (s, C-1); negative-FAB-MS *m/z* 619 (100%); CD $\lambda_{extreme}$ (MeOH) nm ($[\theta]^{24}$) 520 (+6,000), 420 (±0), 340 (+10,000), 314 (−6,000), 295 (±0), 275 (−6,000), 246 (+9,000), 239 (+7,000), 221 (+38,000).

*Anal* Calcd for $C_{33}H_{30}O_{12}$: C 64.08, H 4.89.
Found: C 63.64, H 5.52.

Urdamycinone D

40 mg of urdamycin D were dissolved in 25 ml MeOH and treated with approximately 20 drops of conc $H_2SO_4$. After stirring for 24 hours, the solution was poured into ice-water, and the product was extracted several times with EtOAc. The evaporated organic layer was chromatographed on silica gel (plate 40×20 cm, $CH_2Cl_2$ - MeOH, 85:15) and Sephadex LH-20 (column 100×2.5 cm, MeOH), to yield 20 mg of urdamycinone D, which could be precipitated by pouring its concentrated acetone solution into *n*-hexane: IR (KBr) $cm^{-1}$ 3400, 1726, 1638, 1614, 1591; $^1H$ NMR, see Table 3; $^{13}C$ NMR (50.3 MHz, acetone-$d_6$) $\delta$ 18.43 (q, C-7'), *ca.* 30 (q, C-13, obscure by solvent), 41.01 (t, C-3'), 44.73 (t, C-4), 52.86 (t, C-2), 71.87 (d, C-2'), 73.26 (d, C-6'), 75.97 (s, C-3), 76.92 (d, C-4'), 78.50 (d, C-5'), 79.03 (s, C-4a), 81.34 (s, C-12b), 109.15 (s), 112.79 (s, C-6a), 112.96 (d), 117.23 (s), 119.03 (d, C-6), 121.22 (d), 121.76 (d), 123.49 (s), 124.16 (s, C-7a), 127.78 (s), 127.99 (s), 129.13 (s), 130.91 (s), 132.93 (d), 135.88 (d), 137.40 (s), 137.86 (d, C-5a), 141.39 (s), 143.81 (s, C-9), 156.70 (s, C-8), 159.54 (s), 187.56 (s, C-7), *ca.* 205 (obscure, C-1); negative-FAB-MS *m/z* 642 (100%); CD $\lambda_{extreme}$ (MeOH) nm ($[\theta]^{24}$) 490 (−2,300), 430 (sh, 0), 350 (+13,300), 318 (−3,400), 290 (+3,800), 267 (−13,000), 224 (+53,300).

Urdamycinone E (4)

30 mg urdamycin E (**2**) were dissolved in 20 ml MeOH - $H_2O$ (2:1) and treated with 10 drops of conc $H_2SO_4$. After stirring 1 hour at room temperature, the solution was poured into ice-water. The product was extracted several times with EtOAc, the evaporated organic layer was purified chromatographically on silica gel (plate 20×20 cm, $CH_2Cl_2$ - EtOH, 9:1) and Sephadex LH-20 (column 30×0.5 cm, MeOH), to yield 18 mg urdamycinone E (**4**) as red amorphous powder: IR (KBr) $cm^{-1}$ 3420, 1721, 1679, 1634, 1605 (sh), 1580 (sh); $^1H$ NMR, see Table 3; CD $\lambda_{extreme}$ (MeOH) nm ($[\theta]^{25}$) 500 (−5,000), 360 (+2,000), 315 (+300), 292 (+11,000), 276 (+6,000), 250 (+26,000).

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* From DMSO-$d_6$ spectrum.

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