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DITERPENOID TOTAL SYNTHESIS—XXI[1]

THE SYNTHESIS OF 4,4-BISNORGRAYANOTOXIN SKELETON BY PHOTOCHEMICAL REARRANGEMENT OF CROSS-CONJUGATED CYCLOHEXADIENONES

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Abstract—The 4,4-bisnorgrayanotoxin skeleton was synthesized from the formylated cross-conjugated cyclohexadienones (**5** and **5'**) by a photochemical rearrangement. The nonformylated cyclohexadienone (**2**) gave the spiro compound (**7**) and the phenols (**8** and **9**) on photolysis in aqueous acetic acid.

Our continuing efforts in the syntheses of biologically active diterpenes resulted in the total syntheses of (±) - kaur - 16 - en - 19 - oic acid,[2] (±)-gibberellins A_2, A_4, A_9 and A_{10},[3] (±)-steviol[4] and other polycyclic natural products. Our attention has been also focused on grayanotoxins† obtained from *Leucothoe grayana* Max. in view of their insecticidal[6] activity. Grayanotoxins have the same skeleton as the lyoniatoxins (lyoniols), asebotoxins (pieristoxins) and rhodojaponins,‡ and these highly oxygenated tetracyclic diterpenoids (*e.g.* grayanotoxin-I) remain as one of the difficult synthetic objectives. In this paper we describe in detail the synthesis of 4,4-bisnorgrayanotoxin skeleton by a photochemical rearrangement.[7]

(±) - 3,14 - Dioxo - 16β - hydroxy - 18,19 - bisnorkaurane (**1**)[1] synthesized from naphthalene was oxidized with 2,3 - dichloro - 5,6 - dicyano benzoquinone (DDQ)[8] in dry dioxane to give the cross-conjugated dienone (**2**).§

Photochemical rearrangement of santonin having a 6/6-fused cross-conjugated dienone in a protic solvent was reported by Barton[9] to afford a 5/7-fused enone. Later Kropp[10] suggested that the substituents on α or α' carbon of a ketone group in a cross-conjugated dienone influence whether a 5/7-fused enone or a spiro compound is formed. Cain *et al.* investigated these effects and succeeded in the total synthesis of (±)-opropanone[11] and (−)-cyclocololenone.[12]

With these facts in mind we expected, as shown in Scheme 1, that both the 5/7-fused 4,4-bisnorgrayanotoxin skeleton (**A**) and the spiro compound (**B**) might be obtained in the photochemical rearrangement of **2** (route a and b).[10,13] However, irradiation of **2** in aqueous acetic acid with a high pressure mercury lamp gave the spiro compound (**7**), m.p. 156–157°, the phenols (**8** and **9**), which were formed by a dienonephenol rearrangement.[14] Thus, the C-2 formyl dienone became a plausible starting material for the 5/7-fused ring system.[15] The Birch reduction of **2** with Li-liq. NH_3 gave a mixture of the enones **3** and **3'**, (*ca* 1:2), which were stereoisomeric at the C-14 position. This fact was confirmed by the Jones oxidation of the above mixture, which afforded a single product (**10**), m.p. 194–196°, in quantitative yield. A change in a quantity of lithium resulted in producing a mixture of many products due to different reductive stages of the two carbonyl groups and the double bonds. The configuration of **3** and **3'** at C-14 was easily established by examining the NMR coupling mode. The C-14 proton of **3** revealed a doublet ($J_{C\text{-}14\,H,\,C\text{-}13\,H}$ = 4·5 Hz) at δ 4·07 (in pyridine-d_5) after addition of D_2O, while that of **3'** showed a singlet at δ 4·61 (in pyridine-d_5 + D_2O), which corresponds to the dihedral angle between the C-14 and C-13 hydrogens of **3'** (approximately 90°) in a

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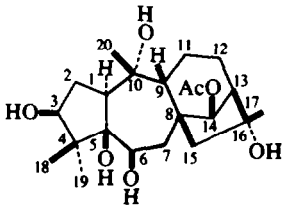
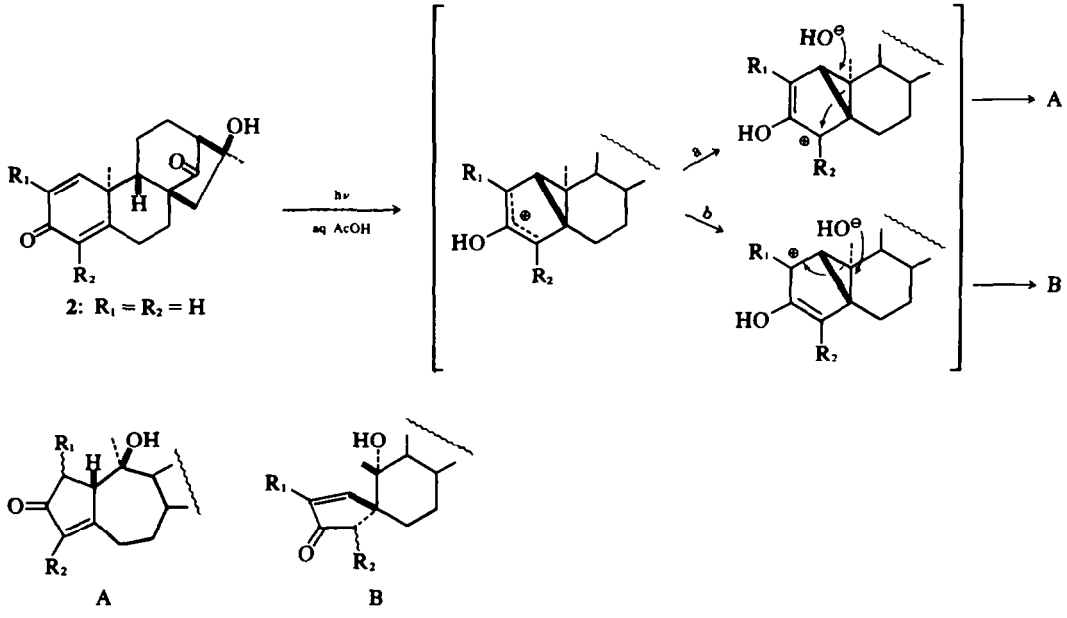
†Another name is andromedotoxin (or andromedol, acetyl andromedol), it was unified for grayanotoxin after *the 4th IUPAC Symposium on the Chemistry of Natural Products*, Kyoto, (1960); X-ray analysis of grayanotoxin—I:[5]

‡The difference of these naming was only derived from the names of species of each plant containing them. There is no common name for this skeleton. In this paper we tenatively use the word of grayanotoxin skeleton.

§Treatment of (**1**) with 1·1 equivs of DDQ afforded the Δ[1]-derivative of (**1**), (±) - 3,14 - *dioxo* - 16β - *hydroxy* - 18,19 - *bisnorkaur* - 1 - *ene* in 65% yield, mp 226–227°, ν_{max}^{Nujol} 3500, 1730, 1655, 955, 785, 778 cm^{-1}, NMR δ ($CDCl_3$) 1·07 (3H, s), 1·28 (3H, s), 5·83 (C-2 H, d, J = 10 Hz), 7·05 (C-1 H, d, J = 10 Hz). (Found: C, 75·26; H, 8·60. Calcd. for $C_{18}H_{24}O_3$: C, 74·97; H, 8·39%).



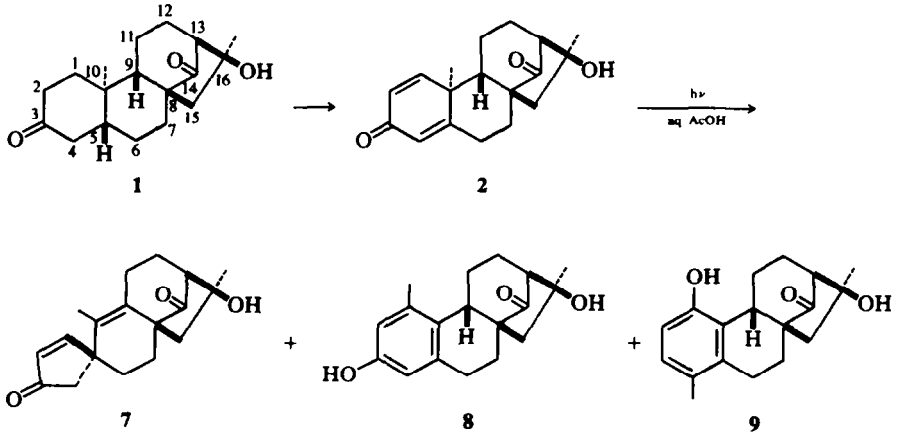
grayanotoxin-I



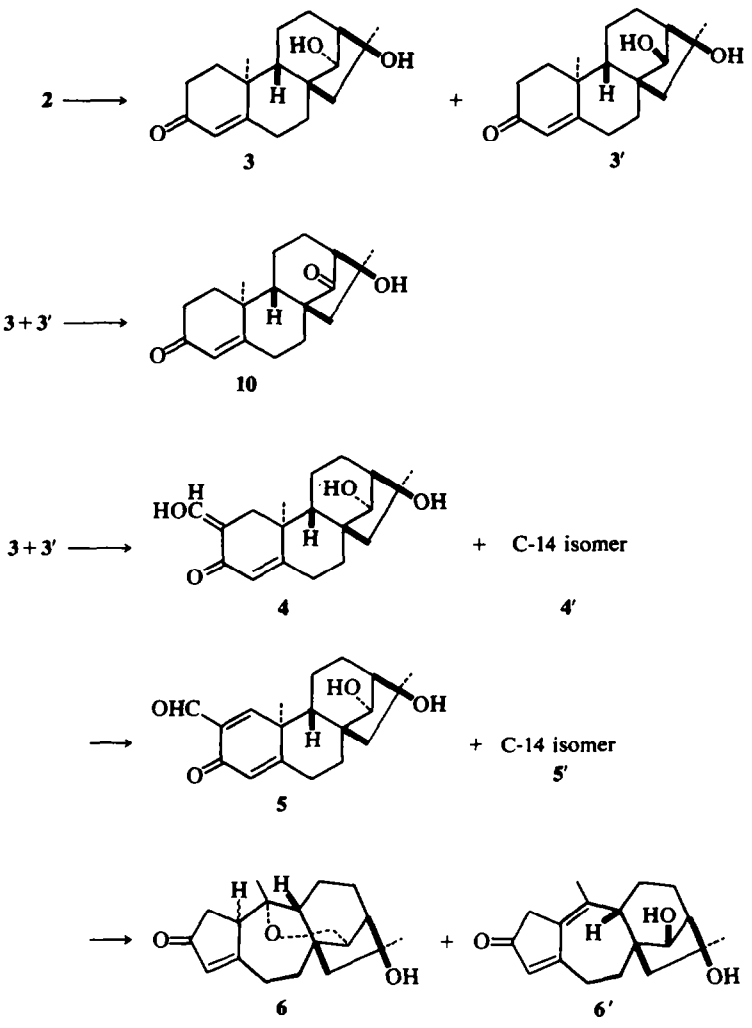
SCHEME 1.

molecular model. In fact natural grayanotoxins have a coupling constant of almost zero for the C-14 and C-13 protons.[16]

The formylation of the enone (**10**) with ethyl formate and sodium methoxide in dry benzene–tetrahydrofuran furnished no usable product because of a retro-aldol reaction in the D ring or other side reactions. Subsequently the mixture of **3** and **3'** was treated with ethyl formate and sodium methoxide to produce the C-2 hydroxymethylene derivatives



SCHEME 2.



SCHEME 3.

(4 and 4'). The mixture ratio at the C-14 position was about 1 to 2 according to NMR measurement. A small part of this mixture was separated by column chromatography on silica gel to give pure 4, m.p. 217–222°, NMR δ (DMSO-d_6) 3·62 (C-14 H, d, $J_{C\text{-}14\,H,\,C\text{-}13\,H} = 4$ Hz), and 4', m.p. 208–211°, NMR δ (DMSO-d_6) 4·12 (C-14 H, s). Dehydrogenation of this mixture 4 and 4' (*ca* 1:2) with 1·1 equivs of DDQ as described by Edwards *et al.*[17] resulted in the C-2 formylated cross-conjugated dienones 5 and 5' (ratio: *ca* 3:1). During this oxidation reaction the mixture ratio at the C-14 position changed from 1:2 to 3:1, which was easily determined by NMR. This reveals that the yield of the dehydrogenation of 4 is higher than that of 4'. The reason for this difference is not clear at the present time. The formyl dienone (5) showed a doublet at δ 4·07 (C-14 H, J = 4·5 Hz) and a singlet at δ 10·60 (C-2 formyl hydrogen) in its NMR spectrum (pyridine-d_5 + D_2O), whereas the isomer (5') revealed a singlet at δ 4·61 (C-14 H) and a singlet at δ 10·57 (C-2 formyl hydrogen). Finally, this stereoisomeric mixture at C-14 (5 and 5'), in a 3:1 ratio was irradiated with a high pressure mercury UV lamp (Hanovia, 450 W) under N_2. Treatment of the photo-products with aqueous sodium carbonate to remove the formyl group gave two compounds after chromatography on silica gel. One of them, m.p. 225–226°, had one OH group, ν_{max}^{Nujol} 3300 cm^{-1} and a β-disubstituted cyclopentenone system, ν_{max}^{Nujol} 1695, 1620 cm^{-1}, λ_{max}^{EtOH} 232 nm, and showed an ABC coupling pattern between the C-1 proton and C-2 methylene protons in its NMR spectrum: δ (pyridine-d_5) 3·01 (C-1 H, dd, J = 6·0, 4·8, 1·8 Hz), 2·59 (C-2 H, dd, J = 6·0, 18·0 Hz), 2·06 (C-2 H, dd, J = 4·8, 18·0 Hz). These data suggest that the product would be the 5/7-fused 4,4-bisnorgrayanotoxin derivative (6), which has an ether bond between C-14 and C-10, originat-

ing from the compound **5**. The structure of **6** was further confirmed by 100 MHz NMR decoupling experiments. The C-1 proton couples with the C-4 olefinic proton at δ 5·94 (J = 1·8 Hz), and the C-14 proton at δ 4·42 couples with the C-13 proton (J = 5·0 Hz). The mass spectrum and elemental analysis also agreed well with the structure **6**. The configuration of C-1 hydrogen of **6** was not determined by NMR because the relative dihedral angles between C-1 hydrogen and C-2 methylene in a molecular model are almost same. From the reaction mechanism, the β-configuration is more possible than the α-configuration, because the C-14 OH group might attack the C-10 position from α-side with elimination of the C-10 β-hydroxy substituent produced during photochemical rearrangement, or add to the C_1–C_{10} double bond formed by dehydration of photo-product (*cf* **6'**). However, the mixture was treated with aqueous sodium carbonate in order to remove the formyl group, which gives rise to the possibility of changing the configuration at the C-1 hydrogen due to activation by an enone system.

The other compound, m.p. 250–252·5° (dec), showed two OH groups in the IR and NMR spectrum, and had a longer conjugated system than **6**, *i.e.* λ_{max}^{EtOH} 306·5 nm. The NMR spectrum showed a Me signal at δ 2·07 which would be allylic, and the hydrogen at the C-1 position was not observed. From these data the second photochemical product can be concluded to be **6'**, which would be derived from **5'**. This product (**6'**) has the opposite configuration at the C-14 position as compared to **6**; accordingly etherification between C-14 and C-10 is not possible.

Thus the first synthesis of a 4,4-bisnorgrayanotoxin skeleton was accomplished.

EXPERIMENTAL

All m.ps are uncorrected. NMR spectra were taken on a 100 MHz spectrometer (unless otherwise indicated) using TMS as internal standard.

(±) - 3,14 - *Dioxo* - 16β - *hydroxy* - 18,19 - *bisnorkaur* - 1,4 - *diene* (**2**). A soln of **1**[1] (2·90 g) and 2,3 - dichloro - 5,6 - dicyano - 1,4 - benzoquinone (DDQ) (6·50 g) in dry dioxane (80 ml) was refluxed for 20 h. After evaporation *in vacuo* to remove dioxane from the mixture, the residue was chromatographed on neutral alumina (Woelm, 8% water content) (150 g) with acetone (500 ml) elution. Evaporation of acetone eluate gave crude crystals (**2**) which were triturated with benzene and collected (1·26 g) by filtration. The filtrate was concentrated and purified by dry column chromatography using silica gel to give further quantity of **2** (total yield, 1·55 g, 52·7%), m.p. 175–176°: ν max (nujol) 3430, 1742, 1662, 1631, 1604, 882 cm^{-1}; λ max (EtOH) 239·5 nm (ϵ = 15,500); δ ($CDCl_3$) 1·21 (3H, s), 1·29 (3H, s), 6·08 (C-4 h, m), 6·17 (C-2 H, dd, J = 2, 10 Hz), 7·05 (C-1 H, d, J = 10 Hz). (Found: C, 75·62; H, 7·49. Calcd. for $C_{18}H_{22}O_3$: C, 75·40; H, 7·74%).

The Birch reduction of **2**[18]. *Mixture of* (±) - 3 - *oxo* - 14α,16β - *dihydroxy* - 18,19 - *bisnorkaur* - 4 - *ene* (**3**) *and* (±) - 3 - *oxo* - 14β,16β - *dihydroxy* - 18,19 - *bisnorkaur* - 4 - *ene* (**3'**). To a stirred soln of liq. NH_3 (140 ml) and Li (460 mg) **2** (2·0 g) in dry THF (140 ml) was added at −65 ~ −60°. Stirring was continued for 45 min at this temp. To the mixture powdered NH_4Cl (3·4 g) was added slowly. During this time the color of the soln turned from deep-blue to yellow-green and finally to white. Then, liq. NH_3 was evaporated at room temp, sat NH_4Cl aq (80 ml) was added, and the mixture extracted with ether. The ether extract was washed with brine and dried ($MgSO_4$). Evaporation of ether gave crude crystals which were washed with a small amount of ether to give a mixture of **3** and **3'**; ν max (nujol) 3360 (broad), 1646, 1614 cm^{-1}. The ratio of **3** to **3'** is about 1 to 2 from NMR: **3**, δ (pyridine-d_5) 1·54 (C-10 CH_3, s), 1·73 (C-16 CH_3, s) 4·07 (C-14 H, m, coupling with C-14 OH and C-13 H, this changes into a doublet on addition of D_2O, J = 4·5 Hz), 5·64 (C-16 OH, broad s), 5·89 (C-4 H, s), 6·59 (C-14 OH, d, J = 4 Hz); **3'**, δ (pyridine-d_5) 1·20 (C-10 CH_3, s), 2·00(C-16 CH_3, s), 4·61 (C-14 H, d, J = 4 Hz, coupling with C-14 OH, this collapses to a singlet on D_2O exchange), 5·86 (C-4 H, s), 6·06 (C-14 OH, d, J = 4 Hz). This mixture was employed for the next reaction without further purification.

(±) - 3,14 - *Dioxo* - 16β - *hydroxy* - 18,19 - *bisnorkaur* - 4 - *ene* (**10**). The above mixture of diols (**3** and **3'**; 90 mg) in acetone (30 ml) was treated with Jones reagent (0·15 ml) at 0° for 30 min. To the mixture was added a few drops of MeOH to destroy the excess Jones reagent. This mixture was poured into water and extracted with EtOAc. The organic layer was washed with water and dried ($MgSO_4$). Evaporation of the solvent gave **10**, (90 mg), quantitatively. An analytical sample was recrystallized from EtOAc-n-hexane to give prisms, m.p. 194–196°, ν max (nujol) 3400, 1738, 1658, 1617 cm^{-1}, δ ($CDCl_3$, 60 MHz) 1·20 (3H, s), 1·30 (3H, s), 5·76 (C-4 H, d, J = 1·6 Hz, coupling with C-6 H), (Found: C, 74·84; H, 8·51. Calcd. for $C_{18}H_{24}O_3$: C, 74·97; H, 8·39%).

Mixture of (±) - 2 - *hydroxymethylene* - 3 - *oxo* - 14α,16β - *dihydroxy* - 18,19 - *bisnorkaur* - 4 - *ene* (**4**) *and* (±) - 2 - *hydroxymethylene* - 3 - *oxo* - 14β,16β - *dihydroxy* - 18,19 - *bisnorkaur* - 4 - *ene* (**4'**). The mixture of **3** and **3'**, (*ca* 1:2), (760 mg) in dry THF (20 ml) and dry benzene (13 ml) was treated with ethyl formate (7·5 ml) and NaOMe (750 mg) with ice-cooling under N_2 for 30 min, then stirring was continued overnight at room temp. Half of the solvent was removed *in vacuo* from the mixture which was then poured into ice-water and washed with ether to remove neutral compounds. The water-layer was acidified with dil HCl (conc HCl/H_2O = 1/7) and extracted with EtOAc which was washed with brine and dried ($MgSO_4$). After decolorization with a small amount of activated charcoal, the solvent was evaporated to give crude crystals (**4** and **4'**) which were triturated with ether and collected by filtration (650 mg. The filtrate was concentrated and chromatographed on silica gel. Elution with EtOAc–benzene (1:9) gave further quantity of crystals. A total amount of a mixture of **4** and **4'**, (*ca* 1:2), weighed 730 mg (87%): ν max (nujol) 3400 (broad), 1640, 1555 cm^{-1}. This mixture was employed for the next reaction without further purification. A small part of the mixture was separated by chromatography on silica gel to give **4**, m.p. 217–222°, δ (DMSO-d_6) 1·26 (3H, s), 1·45 (3H, s), 3·62 (C-14 H, d, J = 4 Hz, coupling with C-13 H at δ *ca* 1·65), 5·60 (C-4 H, d, J = 1·5 Hz, coupling with C-6 H), 7·58 (C-2  , broad s), and **4'**, m.p. 208–211°, δ (DMSO-d_6) 1·06 (3H, s), 1·43 (3H, s), 4·12

(C-14 H, s), 5·64 (C-4 H, s), 7·62 (C-2=  , s). (Found: C, 71·73; H, 8·36. Calcd. for $C_{19}H_{26}O_4$: C, 71·67; H, 8·23%).

Mixture of (±) - 2 - *formyl* - 3 - *oxo* - 14α,16β - *dihydroxy* - 18,19 - *bisnorkaur* - 1,4 - *diene* (**5**) *and* (±) - 2 - *formyl* - 3 - *oxo* - 14β,16β - *dihydroxy* - 18,19 - *bisnorkaur*-1,4 - *diene* (**5'**) A mixture of **4** and **4'**, (*ca* 1:2, 230 mg) in dry dioxane (4 ml) was teated with DDQ (200 mg) at room temp for 5 min with stirring. The mixture was diluted with CH_2Cl_2 (150 ml), and then the soln was washed with 2% NaOH aq (30 ml × 3), water and brine, and dried ($MgSO_4$). Evaporation of the solvent gave crystals which were washed with a small amount of ether to give a mixture of **5** and **5'**, (*ca* 3:1; 110 mg) in 46% yield. This mixture showed m.p. 210–220° and ν max (nujol) 3325 (broad), 1708, 1659, 1620, 1600 (sh) cm^{-1}, and was employed for the next reaction without further purification. NMR of **5** showed peaks at δ (pyridine-d_5) 1·52 (3H, s), 1·75 (3H, s), 3·43 (C-6 α H ddt, $J_{c\text{-}6\alpha\,H,C\text{-}4\,H}$ = 1·3, $J_{c\text{-}6\alpha\,H,c\text{-}7\alpha\,H}$ = 5·0, $J_{c\text{-}6\alpha\,H,c\text{-}6\beta\,H}$ = 13·0, $J_{c\text{-}6\alpha\,H,c\text{-}7\beta\,H}$ = 13·0 Hz), 4·07 (C-14 H, m, coupling with C-14 OH and C-13 H at δ *ca* 2·1; this changes into a doublet on addition of D_2O, J = 4·5 Hz), 6·25 (C-4 H, d, J = 1·3 Hz), 8·03 (C-1 H, s), 10·60 (C-2 CHO, s); and that of **5'** showed peaks at δ (pyridine-d_5) 1·28 (3H, s), 1·72 (3H, s), 4·61 (C-14 H, s), 6·25 (C-4 H, d, J = 1·3 Hz, coupling with C-6 H), 7·91 (C-1 H, s), 10·57 (C-2 CHO, s).

Photochemical rearrangement of a mixture of **5** *and* **5'**

(±) - 3 - *Oxo* - 16β - *hydroxy* - 10^{14} - *oxa* - 1ξ - 4,4 - *bis* - *norgrayanotoxin* - 4 - *ene* (**6**) *and* (±) - 3 - *oxo* - 14β,16β - *dihydroxy* - 4,4 - *bisnorgrayanotoxin* - 4,10^1 - *diene* (**6'**). The above mixture of **5** and **5'**, (150 mg) in 60 ml of 45% AcOH solution was irradiated with a high pressure mercury UV lamp (Hanovia, type 679A, 450W) through a pyrex filter with water cooling for 75 min. while N_2 was passed through the soln. The soln was evaporated *in vacuo* to give an oil which was refluxed for 10 h in 1% Na_2CO_3 aq (20 ml) to remove formyl group. The mixture was extracted with ether and the extract was washed with water and dried ($MgSO_4$). Evaporation of ether gave crude crystals (80 mg) which were chromatographed on thick layer silica gel (Kieselgel F 254, 20 × 20 cm, 2 mm thickness) by development with EtOAc–benzene (1:1); the UV sensitive broad middle reagion was collected. The weight of crystals was 45 mg, NMR data showed that this was not a single product, but a mixture of **6** and **6'** which had two types of olefinic protons (the ratio, *ca* 3:1) and four Me signals. Fractional recrystallization of this mixture from THF–EtOAc–EtOH soln (10:10:0·5) was repeated a few times to give 4 mg of pure yellowish **6'**, m.p. 250–252·5° (dec), ν max (KBr) 3380, 3320, 1656, 1623, 1564 cm^{-1}, λ max (EtOH) 306·5 nm (ε = 17,900), *m/e* 288 (M^+), δ (pyridine-d_5) 1·86 (C-16 CH_3, s), 2·07 (C-10 CH_3, s), 3·90 (C-14 H, d, J = 3 Hz, coupling with C-14 OH, this collapsed to a singlet on D_2O exchange), 5·56 (C-16 OH, broad), 5·98 (C-14 OH, d, J = 3 Hz), 6·02 (C-4 H, this peak overlapped with C-14 OH signal and changes into a doublet on D_2O exchange, J ≤ 1, coupling with C-6 H at δ *ca* 2·64), (Found: C, 75·18; H, 8·44. Calcd. for $C_{18}H_{24}O_3$: C, 74·97; H, 8·39%).

Another crystalline product (**6**) was recrystallized from ether to give white, light needles, m.p. 225–226°, ν max (nujol) 3300, 1695, 1620, 1058 cm^{-1}, λ max (EtOH) 232 nm (ε 14,100), *m/e* 288 (M^+), δ (pyridine-d_5) 1·45 (3H, s), 1·48 (3H, s), 2·06 (C-2 Ha, dd, J = 4·8, 18 Hz), 2·59 (C-2 Hb, dd, J = 6, 18 Hz), 3·01 (C-1 H, ddd, J = 6, 4·8, 1·8 Hz) 4·42 (C-14 H, d, J = 5 Hz, coupling with C-13 H at δ 2·05), 5·85 (C-16 OH, broad, s) 5·94 (C-4 H, d, J = 1·8 Hz). (Found: C, 74·52; H, 8·37. Calcd for $C_{18}H_{24}O_3$; C, 74·97; H, 8·39%).

Photochemical rearrangement of dienone (**2**)

The cross-conjugated dienone **2** (580 mg) in 45% AcOH soln (140 ml) was irradiated with a high pressure mercury lamp (Ohosawa U.V. Industry Co., 400 W) through a pyrex filter under N_2 vigorous bubbling at 20° for 1 h. Evaporation of the solvent gave an oil which was chromatographed on alumina (18 g). Eluate (No. 1-3) with EtOAc–benzene (1:1) (10 ml × 3) gave an oil which was not investigated further. Eluate (No. 4-8) with EtOAc–benzene (1:1) (20 ml × 5) afforded crystals which were recrystallized from benzene–EtOAc–EtOH to give prisms (52 mg) of **7**, m.p. 156–157°, ν max (nujol) 3460, 1740, 1700, 1670, 1640 (sh), 1580, 1140, 942, 842, 793 cm^{-1}, δ ($CDCl_3$) 1·33 (3H, s), 1·45 (3H, s), 6·16 (1H, d, J = 5 Hz), 7·42 (1H, d, J = 5 Hz). (Found: C, 75·68; H, 7·66. Calcd. for $C_{18}H_{22}O_3$: C, 75·49; H, 7·74%). Eluate (No. 9) with EtOAc–MeOH (4:1) (300 ml) gave an oil which was rechromatographed on silica gel (18 g). Eluate (No.1-4) with benzene–EtOAc (9:1) (100 ml) was an oil which was discarded, and eluate (No. 5-6) gave phenolic crystals which were recrystallized from ether to give prisms of **8**, (116 mg), m.p. 181–183·5°, ν max (nujol) 3560, 3400, 1730, 1614, 1602, 942, 848 cm^{-1}, δ ($CDCl_3$) 1·41 (3H, s), 2·29 (3H, s), 6·45 (aromatic H, d, J = 2 Hz), 6·52 (aromatic H, d, J = 2 Hz). (Found: C, 75·40; H, 7·54. Calcd. for $C_{18}H_{22}O_3$: C, 75·49; H, 7·74%). Eluate (No. 7-8) was another phenolic compound (**9**) which was recrystallized from EtOAc to afford needles of **9** as mono-hydrate, m.p. 239–241°, ν max (nujol) 3400, 1730, 1660 (w, H_2O), 1593, 1193, 800 cm^{-1}, δ (DMSO-d_6) 1·12 (3H, s), 1·98 (3H, s), 6·55 (aromatic H, d, J = 8 Hz), 6·86 (aromatic H, d, J = 8 Hz). (Found: C, 71·46; H, 7·76. Calcd. for $C_{18}H_{22}O_3 + H_2O$: C, 71·02; H, 7·95%).

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REFERENCES

[1]Part XX: M. Shiozaki, K. Mori and M. Matsui, *Agr. Biol. Chem.* **36**, 2539 (1972)
[2]K. Mori and M. Matsui, *Tetrahedron* **24**, 3095 (1968)
[3]K. Mori, M. Shiozaki, N. Itaya, M. Matsui and Y. Sumiki, *Ibid.* **25**, 1293 (1969)
[4a]K. Mori, Y. Nakahara and M. Matsui, *Ibid.* **28**, 3217 (1972); [b]Y. Nakahara, K. Mori and M. Matsui, *Agr. Biol. Chem.* **35**, 918 (1971)
[5]P. Narayanan, M. Röhrl, K. Zechmeister and W. Hoppe, *Tetrahedron Letters* 3943 (1970)
[6]S. Miyajima and S. Takei, *J. Agr. Chem. Soc. Japan* **10**, 1093 (1934)
[7]A preliminary result was reported: M. Shiozaki, K. Mori, M. Matsui and T. Hiraoka, *Tetrahedron Letters* 657 (1972)
[8]D. Walker and J. D. Hiebert, *Chem. Rev.* **67**, 153 (1967)
[9]D. H. R. Barton, *Helv. Chim. Acta* **42**, 2604 (1959)
[10]P. J. Kropp, *J. Am. Chem. Soc.* **87**, 3914 (1965)
[11]D. Cain and F. N. Tuller, *J. Org. Chem.* **38**, 3663 (1973)

[12]D. Cain and P. F. Ingwalson, *Ibid.* 37, 3751 (1972)
[13]P. J. Wagner and G. S. Hammond, *Advances in Photochemistry* (Edited by W. A. Noyes, Jr., G. S. Hammond and J. N. Pitts, Jr.) Vol. 5, p. 112. Interscience, New York, London, Sydney (1968)
[14]R. S. Shapiro, *Steroid Reactions* (Edited by C. Djerassi) p. 373–379. Holden-Day, San Francisco (1963)
[15]D. Cain and J. F. DeBardeleben, Jr. *Tetrahedron Letters* 4585 (1965)
[16]T. Kozima, K. Nakanishi, M. Yanai and H. Kakisawa, *Ibia.* 1329 (1964)
[17]J. A. Edwards, M. C. Calzada, L. C. Ibáñez, M. E. Cabezas Rivera, R. Urquiza, L. Cardona, J. C. Orr and A. Bowers, *J. Org. Chem.* 29, 3481 (1964)
[18a]R. E. Schaub and M. J. Weiss, *Chem. & Ind.* 2003 (9161); [b]E. Shapiro, T. Legatt, L. Weber, M. Steinberg and E. P. Oliveto, *Ibid.* 300 (1962); [c]*cf* P. Wieland und G. Anner, *Helv. Chim. Acta* 51 1698 (1968)