Synthesis of Deoxyiodo Sugars from Unstable Triflates. A 100-mL round-bottom flask containing 3.00 mmol of the partially protected carbohydrate, 6.00 mmol of tetrabutylammonium iodide, 6.5 mmol of pyridine, and 50 mL of dichloromethane was cooled to −78 °C and maintained there with stirring during the dropwise addition of a solution of 6.00 mmol of triflic anhydride in 20 mL of dichloromethane from a pressure-equalizing dropping funnel. The entire system was closed before cooling. After the triflic anhydride addition, the reaction mixture was allowed to warm to room temperature over the period of 1 h and then it was extracted with 150-mL portions of water, 5% sodium bisulfite, 5% sodium bicarbonate, and water. The organic phase was dried over sodium sulfate and the solvent removed in vacuo to produce the dark colored deoxyiodo sugar. This material was purified by passing it through a 2.5 × 10 cm column of 200–325-mesh silica gel slurry packed in 1:1 ether–hexane and eluted with 250 mL of this solvent mixture. Product yields and reference to independent syntheses of **23** and **24** used to obtain authentic samples are given in Table IV. The ^{1}H NMR spectra are given in Table II and the mass spectra in Table III.

Registry No. **1**, 582-52-5; **2**, 4064-06-6; **3**, 40269-01-0; **4**, 20880-92-6; **5**, 2595-05-3; **6**, 14686-89-6; **7**, 4099-85-8; **8**, 13100-46-4; **9**, 55951-93-4; **10**, 71001-09-7; **11**, 74925-14-7; **12**, 74925-15-8; **13**, 55951-90-1; **14**, 74925-16-9; **17**, 67337-61-5; **18**, 4026-28-2; **19**, 71732-12-2; **20**, 38084-03-6; **21**, 14260-27-6; **22**, 74958-55-7; **23**, 38838-06-1; **24**, 7468-48-6; **25**, 74925-17-0; **26**, 74958-56-8; **27**, 74925-18-1; **28**, 38838-08-3; **29**, 13454-63-2; **30**, 14260-29-8; **31**, 32785-94-7; **32**, 2774-28-9; tetrabutylammonium iodide, 311-28-4; tetrabutylammonium bromide, 1643-19-2; tetrabutylammonium chloride, 1112-67-0; triflic anhydride, 358-23-6; tresyl chloride, 1648-99-3.

Total Synthesis of Steroid Hormones. Efficient Stereocontrolled Synthesis of 17-Methoxy-6-oxo-*D*-homo-18-nor-5β-androsta-2,13,15,17-tetraene[1]

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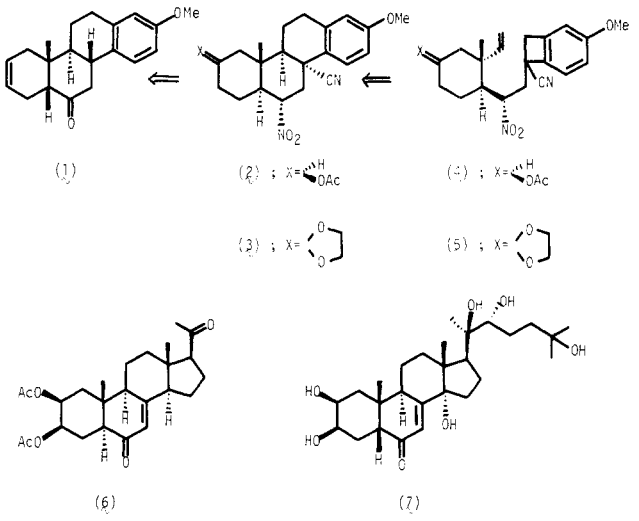
A stereoselective synthesis of 17-methoxy-6-oxo-*D*-homo-18-nor-5β-androsta-2,13,15,17-tetraene (**1**) has been achieved through the key step of thermolysis of 5-acetoxy-2-[2-(1-cyano-4-methoxybenzocyclobutenyl)-1-nitroethyl]-1-ethenyl-1-methylcyclohexane (**4**) and 2-[2-(1-cyano-4-methoxybenzocyclobutenyl)-1-nitroethyl]-ethenyl-5,5-(ethylenedioxy)-1-methylcyclohexane (**5**). An alternative synthesis of **1**, starting from 3,3-(ethylenedioxy)-17-methoxy-*D*-homo-18-nor-androsta-5,8,13,15,17-pentaene (**33**), was carried out to confirm its structure.

Intramolecular cycloaddition of *o*-quinodimethanes has proven to be one of the most promising methods for the synthesis of polycyclic natural products, including A-ring aromatic steroids. Several groups, including our own,[2-6] have reported the successful application of the method for the synthesis of physiologically active target molecules, and we have recently extended it to achieve the stereoselective synthesis of D-ring aromatic steroids.[1,7] Our conversion of the latter to pregnane-type steroids has provided a new synthetic entry in this field. D-ring aromatic steroids with Δ^2 and 6-oxo groups are considered to be general intermediates for the synthesis of insect molting hormones, connecting with our D-ring transformation[8] and the conversion of pregnane-type steroid **6** into β-ecdysone (**7**).[9] Here we report a stereoselective total synthesis of 17-methoxy-6-oxo-*D*-homo-18-nor-5β-androsta-2,13,15,17-tetraene (**1**), via **2** and **3**, by thermolysis of benzocyclobutenes **4** and **5** (Scheme I).

Scheme I



As a preliminary experiment, synthesis of the olefinic benzocyclobutene **4** was carried out as follows. To olefinic ester **9** [prepared by 1,4-addition of vinylmagnesium bromide to Hagemann's ester (**8**)[10] in the presence of cuprous iodide] was converted into the tosylate **13**, via the diol **11** and the hydroxy tosylate **12**, by successive reduction with lithium aluminum hydride in tetrahydrofuran, tosy-

(1) A part of this research has been reported as a communication: T. Kametani and H. Nemoto, *Tetrahedron Lett.*, 3309 (1979).
(2) For a recent review of intramolecular cycloaddition reactions of *o*-quinodimethanes, see W. Oppolzer, *Synthesis*, 793 (1978).
(3) T. Kametani, H. Nemoto, M. Tsubuki, and M. Nishiuchi, *Tetrahedron Lett.*, 27 (1979).
(4) T. Kametani, H. Nemoto, M. Tsubuki, G.-E. Purvaneckas, M. Aizawa, and M. Nishiuchi, *J. Chem. Soc., Perkin Trans. 1*, 2830 (1979).
(5) W. Oppolzer, D. A. Roberts, and T. G. C. Bird, *Helv. Chim. Acta*, **62**, 2017 (1979).
(6) K. C. Nicolaou and W. E. Barnette, *J. Chem. Soc., Chem. Commun.*, 1119 (1979).
(7) T. Kametani, K. Suzuki, and H. Nemoto, *J. Chem. Soc., Chem. Commun.*, 1127 (1979).
(8) T. Kametani, K. Suzuki, and H. Nemoto, *Tetrahedron Lett.*, 1469 (1980).
(9) U. Kerb, R. Wiechert, A. Furlenmeir, and A. Furst, *Tetrahedron Lett.*, 4277 (1968).
(10) L. I. Smith and G. F. Rouault, *J. Am. Chem. Soc.*, **65**, 631 (1943).

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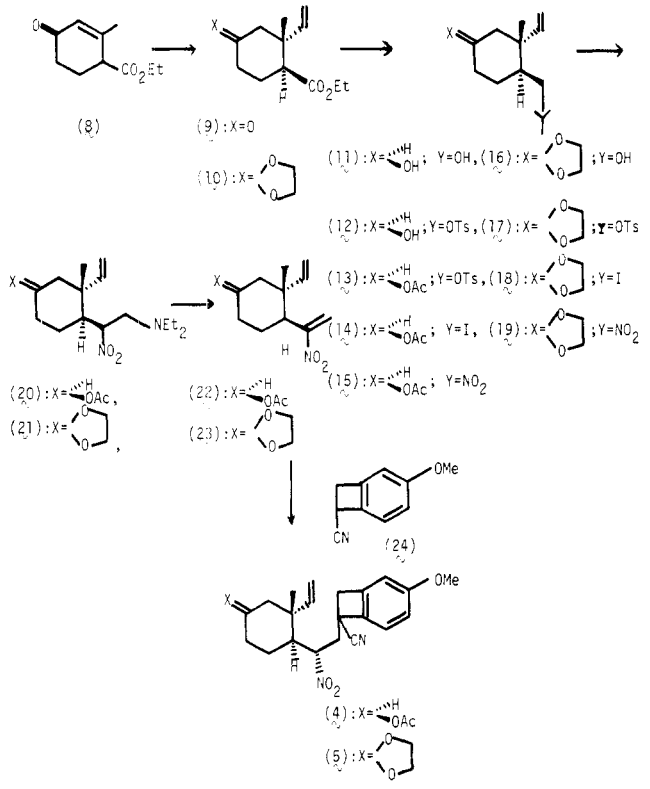
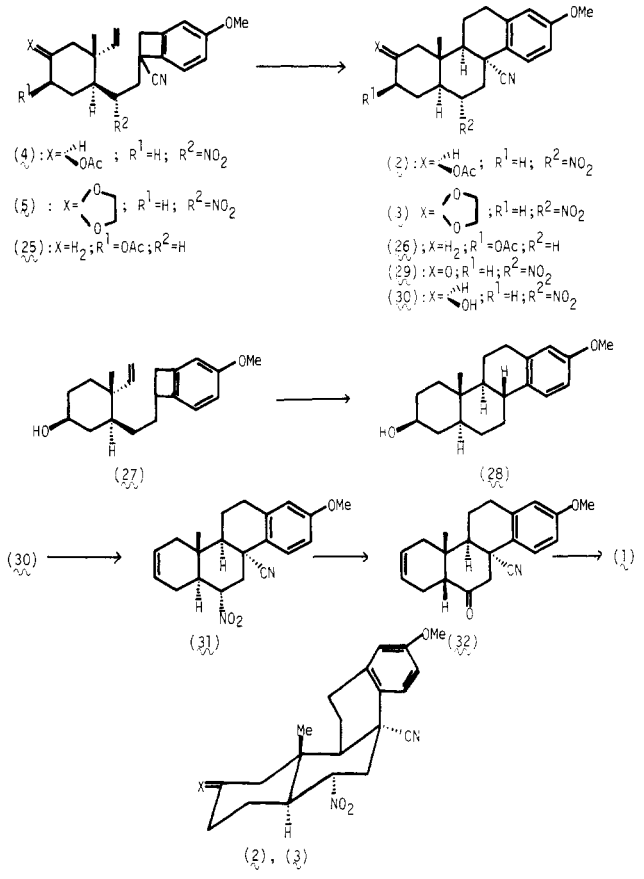
Scheme II



Scheme III



lation with *p*-toluenesulfonyl chloride in pyridine, and acetylation with acetic anhydride in pyridine (Scheme II). The tosylate **13** was transformed into the nitro derivative **15**, through the iodide **14**, by successive treatment with sodium iodide in acetone and sodium nitrite in dimethylformamide. The nitro derivative **15** on reaction with formalin and diethylamine gave the Mannich base **20**, which was treated with hydrogen chloride in boiling benzene to afford the nitro olefin **22**. Michael addition of 1-cyano-4-methoxybenzocyclobutene (**24**)[11] to the nitro olefin **22**, in the presence of sodium amide in liquid ammonia, yielded the key intermediate **4**. In an attempt to obtain a higher overall yield, the olefinic benzocyclobutene **5** was also synthesized by an analogous reaction sequence as follows. The ketal tosylate **17** was prepared from the olefinic ester **9**, via the ketal ester **10** and the alcohol **16**, by successive ketalization with ethylene glycol in the presence of a catalytic amount of *p*-toluenesulfonic acid in benzene, reduction with lithium aluminum hydride in tetrahydrofuran, and tosylation with *p*-toluenesulfonyl chloride in pyridine. The ketal tosylate **17** was converted to the iodide **18** by treatment with sodium iodide in acetone, and **18** was treated with sodium nitrite in dimethylformamide to give the nitro derivative **19**. The nitro derivative **19** on reaction with formalin and diethylamine afforded the Mannich base **21** which was converted into the ketal nitro olefin **23** by treatment with hydrogen chloride in boiling benzene. Michael addition of **24** to the ketal nitro olefin **23**, in the presence of sodium amide in liquid ammonia, furnished the olefinic benzocyclobutene **5**.

Thermolysis of **4** and **5** was carried out by heating in *o*-dichlorobenzene at 180 °C for 2 h under an atmosphere of nitrogen to afford D-ring aromatic steroid **2** [NMR (CCl_4) δ 0.35 (3 H, s, Me), 1.77 (3 H, s, OCOMe), 3.8 (3 H, s, OMe), 4.5 (1 H, distorted t, J = 12 Hz, $CHNO_2$), 5.1 (1 H, s, CHOAc), 6.7–7.5 (3 H, m, Ar H)] and **3** [NMR (CCl_4) δ 0.3 (3 H, s, Me), 3.8 (7 H, s, OCH_2CH_2O and OMe), 4.4 (1 H, distorted t, J = 12 Hz, $CHNO_2$), 6.5–7.3 (3 H, m, Ar H)] in 94% and 96% yields, respectively. The stereochemistry of these two products was determined to be as represented in formulas **2** and **3** by ^{1}H NMR spectral analysis. In particular, the 19-methyl protons of both products were observed to resonate at abnormally high field, indicative of a conformation (Scheme III) in which this group is located over the benzene ring and is shielded by its ring current. The same stereoselectivity was shown in the thermolysis of the analogous olefinic benzocyclobutene **25**,[7] resulting in exclusive formation of the D-ring aromatic steroid **26** [NMR (CCl_4) δ 0.19 (3 H, s, Me), 1.93 (3 H, s, OCOMe), 3.8 (3 H, s, OMe), 6.5–7.4 (3 H, m, Ar H)] in 94% yield. Although the reason for the stereoselectivity in this thermolysis is not clear, this contrasts with thermolysis of **27**, whereby **28** was produced stereoselectively.[7]

The conversion of **3** into **1** was straightforward. Thus, **3** was treated with 10% hydrochloric acid in tetrahydrofuran to give the ketone **29**, which was reduced with sodium borohydride in methanol to afford the alcohol **30**. This product was shown to be identical with a sample prepared by hydrolysis (sodium hydroxide in ethanol) of the acetate **2**. The olefinic ketone **32** was prepared from alcohol **30**, via the olefinic nitro compound **31**, by successive dehydration with thionyl chloride and pyridine in dichloromethane and a modified Neff reaction, as developed by McMurry,[12] with titanium trichloride in the presence of ammonium acetate in water and tetrahydrofuran. Ketone **32** was subjected to reductive decyanation with sodium in liquid ammonia, followed by Jones oxi-

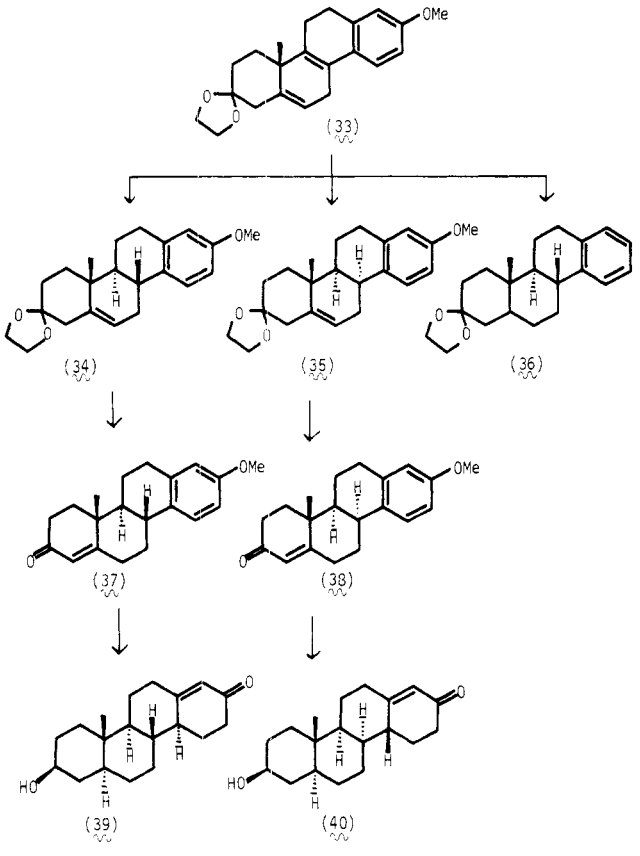
(11) T. Kametani, Y. Kato, T. Honda, and K. Fukumoto, *J. Am. Chem. Soc.*, **98**, 8185 (1976).

(12) J. E. McMurry and J. Melton, *J. Org. Chem.*, **38**, 4367 (1973).

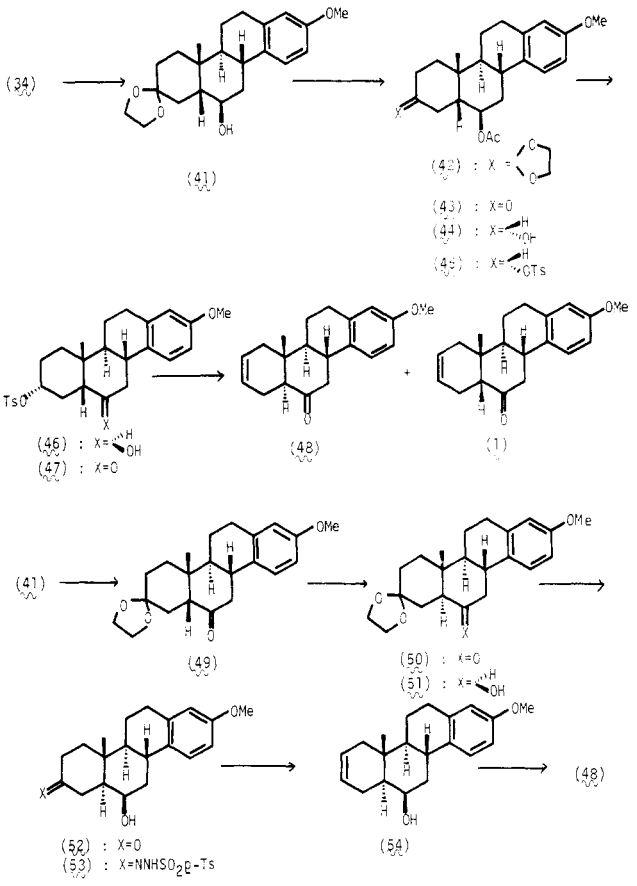
Table I

conditions	product yield, % 34	35	36
K, liquid NH_3, absolute EtOH	20		22
Li, liquid NH_3, absolute EtOH	6		
Na, liquid NH_3, absolute EtOH	18 (34 + 35)		
Na, liquid NH_3, absolute EtOH	59	35	

Scheme IV



Scheme V



dation of the crude reaction product to furnish the target molecule 1. The 19-methyl group resonance in the ^1H NMR spectrum of **32** was observed at 0.75 ppm, suggesting that epimerization at C_5 had occurred in the transformation of **31** to **32**. The D-ring aromatic steroidal compound **1** thus obtained was shown to be identical with a sample synthesized by an alternative route.

Although the structure of **1** was deduced from the spectroscopic data, we have undertaken an alternative synthesis of **1**, through a completely different reaction sequence, in order to confirm the structure unambigously.

First, Birch reduction of 3,3-(ethylenedioxy)-17-methoxy-*D*-homo-18-norandrosta-5,8,13,15,17-pentaene (**33**)[13,14] was examined under various conditions,[15] and the results are summarized in Table I. The structures of products **34** and **35** were confirmed by their transformation, via enones **37** and **38**, to the known compounds **39** and **40**,[14] respectively, by acid treatment followed by Birch reduction. The trans-BC ring structure **36** (Scheme IV) was assigned to the other Birch reduction product [*m/e* 310 (M^+)] on the basis of NMR spectral data; namely, the appearance of the methyl group resonance for **36** at 1.07 ppm is closely similar to that for the proven trans-BC compound **34**, at 1.04 ppm, whereas that for the cis-BC compound **35** appeared at 1.26 ppm.

Compound **34**, obtained as the main product of Birch reduction of **33** with sodium in liquid ammonia and ethanol, was converted[16,17] into the ketal alcohol **41** by hydroboration followed by oxidation (Scheme V). The diol monoacetate **44**, obtained from **41** through **42** and **43** by successive treatment with acetic anhydride in pyridine, 2 N hydrochloric acid in tetrahydrofuran, and sodium borohydride in methanol, was tosylated with *p*-toluenesulfonyl chloride in pyridine to give the compound **45**. Partial hydrolysis, with potassium carbonate in methanol, and Jones oxidation of the resulting alcohol tosylate **46** afforded the ketone tosylate **47**. Treatment of **47** with lithium bromide and lithium carbonate in dimethylformamide at 150 °C for 6 h gave a 1:1 mixture of compounds **48** and **1**. The structures of **48** and **1** were determined from the spectroscopic data, and the latter compound **1** was identical with the product obtained via an intramolecular cycloaddition reaction as described before. However, as epimerization at C_5 had occurred during the final olefin

(13) W. Nagata, S. Hirai, T. Terasawa, I. Kikkawa, and K. Takeda, *Chem. Pharm. Bull.*, **9**, 756 (1961).
(14) W. Nagata, S. Hirai, T. Terasawa, and K. Takeda, *Chem. Pharm. Bull.*, **9**, 769 (1961).
(15) The same type of Birch reduction of the 17a-methoxy analogue of **1**, using lithium in liquid ammonia and ethanol, has been reported: W. S. Johnson, E. R. Rogier, J. Szmuszkovicz, H. I. Hadler, J. Ackerman, B. K. Bhattacharyya, B. M. Bloom, L. Stalmann, R. A. Clement, B. Bannister, and H. Wynberg, *J. Am. Chem. Soc.*, **78**, 6289 (1956).
(16) D. N. Kirk and D. R. A. Leonard, *J. Chem. Soc., Perkin Trans. 1*, 1836 (1973).
(17) G. Cooley and A. E. Kellie, *J. Chem. Soc., Perkin Trans. 1*, 452 (1976).
(18) J. E. Bridgeman, P. C. Cherry, A. S. Clegg, J. M. Evans, E. R. H. Jones, A. Kasal, V. Kumar, G. D. Meakins, Y. Morisawa, E. E. Richard, and P. D. Woodgate, *J. Chem. Soc. C*, 250 (1970).

formation reaction, this structure determination could not be considered completely unambigous. Another reaction sequence was therefore carried out as follows. The ketal alcohol **41**, which is believed[16,17] to have a cis-AB ring junction was oxidized with Jones reagent to give the ketal ketone **49**, which on treatment with sodium hydride in tetrahydrofuran afforded the trans-AB compound **50** as a single product. Evidence for the latter cis–trans isomerization is provided by the ^1H NMR spectral data, namely, an upfield shift (0.87 to 0.77 ppm) of the 19-methyl group resonance in going from **49** to **50**. Reduction of **50** with sodium borohydride in methanol followed by acid treatment of the resultant **51** gave the keto alcohol **52**, which was converted into the olefinic alcohol **54**, through the tosylhydrazone **53**, by successive treatment with *p*-toluenesulfonylhydrazide and *n*-butyllithium. Jones oxidation of **54** afforded the olefinic ketone **48** as a single product identical with that already derived from **47**. Finally, equilibration of **48** was effected by treatment with sodium hydride in boiling tetrahydrofuran to give a 1:1 mixture of **48** and **1**, the latter being identical with that already obtained from **47**. Equilibration of **1** was also carried out under the same conditions as those for **48** to afford a 1:1 mixture of **48** and **1**. Thus, by an alternative synthesis, we have unambiguously confirmed the structure of the product 17-methoxy-6-oxo-*D*-homo-18-nor-5β-androsta-2,13,15,17-tetraene, obtained as described before.

Experimental Section

General Methods. All melting points are uncorrected. Infrared (IR) spectra were recorded on a Hitachi EPI-3 spectrophotometer. Nuclear magnetic resonance (NMR) spectra were measured on a JEOL JNM-PMX-60 spectrometer. Chemical shifts are reported as δ values relative to internal tetramethylsilane (Me_4Si). Mass spectra were taken on a Hitachi RMU-7 spectrometer.

1-Ethenyl-2-(ethoxycarbonyl)-1-methylcyclohexan-5-one (9). To a stirred suspension of vinylmagnesium bromide prepared from 20 g (0.19 mol) of vinyl bromide, 5 g (0.2 mol) of magnesium, and 19 g (0.1 mol) of cuprous iodide in 200 mL of anhydrous tetrahydrofuran at −78 °C under an atmosphere of nitrogen was added a solution of 12 g (0.066 mol) of Hagemann's ester (**8**) in 50 mL of anhydrous tetrahydrofuran, and the reaction mixture stirred for 30 min at −78 °C. Water (10 mL) was added and the resulting mixture extracted three times with 200 mL of ether. The combined extract was washed with saturated ammonium chloride solution and dried over anhydrous sodium sulfate. Removal of the solvent afforded a crude product which was distilled under reduced pressure to give 9 g (65%) of **9** as a colorless oil: bp 90–95 °C (1 mmHg); IR ($CHCl_3$) 1725 cm^{-1}; NMR (CCl_4) δ 1.1 (3 H, s, CH_3), 1.25 (3 H, t, J = 7 Hz, CH_2CH_3), 4.15 (2 H, q, J = 7 Hz, CH_2CH_3), 4.7–6.1 (3 H, m, $CH{=}CH_2$); mass spectrum, m/e 210 (M^+). Anal. Calcd for $C_{12}H_{18}O_3{\cdot}0.5H_2O$: C, 65.73; H, 8.73. Found: C, 65.60; H, 8.42.

1-Ethenyl-2-(ethoxycarbonyl)-5,5-(ethylenedioxy)-1-methylcyclohexane (10). To a solution of 64 g (0.3 mol) of **9** in 400 mL of benzene was added a catalytic amount of *p*-toluenesulfonic acid and 20 g (0.32 mol) of ethylene glycol. The reaction mixture was refluxed in a flask fitted with a Dean–Stark trap. After 1 h, 0.9 equiv of water was collected, and the reaction mixture was cooled. The benzene solution was washed with saturated sodium bicarbonate solution and saturated sodium chloride solution and dried over anhydrous sodium sulfate. Removal of the solvent afforded a crude product which was distilled under reduced pressure to give 70.48 g (93%) of **10** as a colorless oil: bp 145–147 °C (10 mmHg); IR ($CHCl_3$) 1725 cm^{-1}; NMR (CCl_4) δ 1.15 (3 H, s, CH_3), 1.20 (3 H, t, J = 7 Hz, CH_2CH_3), 3.86 (4 H, s, OCH_2CH_2O), 4.05 (2 H, q, J = 7 Hz, CH_2CH_3), 4.7–6.2 (3 H, m, $CH{=}CH_2$); mass spectrum, m/e 254 (M^+). Anal. Calcd for $C_{14}H_{22}O_4$: C, 66.11; H, 8.72. Found: C, 66.27; H, 9.06.

1-Ethenyl-5-hydroxy-2-(hydroxymethyl)-1-methylcyclohexane (11). To a stirred suspension of 2 g (52.7 mmol) of lithium aluminum hydride in 150 mL of anhydrous tetrahydrofuran at 0 °C was added a solution of 7 g (33.33 mmol) of **9** in anhydrous tetrahydrofuran. After the mixture was stirred for 6 h at room temperature and 50 mL of water added, the inorganic material was removed by filtration. The residue resulting from evaporation of the filtrate was extracted with 200 mL of chloroform. The extract was dried over anhydrous sodium sulfate and evaporated to give a pale yellow oil which was distilled under reduced pressure to afford 3.8 g (67%) of **11** as a colorless oil: bp 128–130 °C (1 mmHg); IR ($CHCl_3$) 3500 cm^{-1}; NMR ($CDCl_3$) δ 1.1 (3 H, s, CH_3), 2.85 (2 H, br s, 2 OH, exchangeable with D_2O), 3.2–4.1 (3 H, m, CH_2OH and CHOH), 4.8–6.1 (3 H, m, $CH{=}CH_2$); mass spectrum, m/e 170 (M^+). Anal. Calcd for $C_{10}H_{18}O_2{\cdot}0.4H_2O$: C, 67.68; H, 10.68. Found: C, 67.60; H, 10.60.

1-Ethenyl-5,5-(ethylenedioxy)-2-(hydroxymethyl)-1-methylcyclohexane (16). Compound **16** was obtained from **10** by the procedure described above in 80% yield as a colorless oil: bp 132–133 °C (1 mmHg); IR ($CHCl_3$) 3500 cm^{-1}; NMR ($CDCl_3$) δ 1.03 (3 H, s, CH_3), 3.9 (4 H, s, OCH_2CH_2O), 4.8–6.15 (3 H, m, $CH{=}CH_2$); mass spectrum, m/e 212 (M^+). Anal. Calcd for $C_{12}H_{20}O_3{\cdot}0.1H_2O$: C, 67.35; H, 9.47. Found: C, 67.89; H, 9.50.

1-Ethenyl-5-hydroxy-1-methyl-2-[[(*p*-toluenesulfonyl)oxy]methyl]cyclohexane (12). To a solution of 3.6 g (2.18 mmol) of **11** in 50 mL of pyridine at 0 °C was added 4.84 g (25.39 mmol) of *p*-toluenesulfonyl chloride, and the mixture was stirred for 6 h at room temperature. The reaction mixture was added to 100 mL of water and extracted three times with 100 mL of dichloromethane. The combined extract was washed with water, 10% hydrochloric acid, and water and dried over anhydrous sodium sulfate. Removal of the solvent afforded a crude product which was chromatographed on 80 g of silica gel with benzene as eluent to give 5.65 g (82%) of **12** as a colorless oil: IR ($CHCl_3$) 3500 cm^{-1}; NMR (CCl_4) δ 1.0 (3 H, s, CH_3), 2.46 (3 H, s, $ArCH_3$), 3.4–4.2 (3 H, m, CHOH and CH_2OTs), 4.7–6.0 (3 H, m, $CH{=}CH_2$), 7.35 (2 H, d, J = 8.0 Hz, Ar H), 7.78 (2 H, d, J = 8.0 Hz, Ar H); mass spectrum, m/e 324 (M^+). Anal. Calcd for $C_{17}H_{24}SO_4{\cdot}0.2H_2O$: C, 62.27; H, 7.44. Found: C, 62.04; H, 7.69.

1-Ethenyl-5,5-(ethylenedioxy)-1-methyl-2-[[(*p*-toluenesulfonyl)oxy]methyl]cyclohexane (17). **17** was obtained from **16** by the procedure described above in 86% yield as colorless needles (from *n*-hexane): mp 78–79 °C; NMR (CCl_4) δ 1.01 (3 H, s, CH_3), 2.45 (3 H, s, $ArCH_3$), 4.8–6.0 (3 H, m, $CH{=}CH_2$), 7.33 (2 H, d, J = 8.0 Hz, Ar H), 7.76 (2 H, d, J = 8.0 Hz, Ar H); mass spectrum, m/e 366 (M^+). Anal. Calcd for $C_{19}H_{26}O_5S$: C, 62.27; H, 7.15. Found: C, 62.44; H, 7.61.

5-Acetoxy-1-ethenyl-1-methyl-2-[[(*p*-toluenesulfonyl)oxy]methyl]cyclohexane (13). To a solution of 3 g (9.26 mmol) of **12** in 30 mL of pyridine at room temperature under nitrogen was added 1.5 g (14.69 mmol) of acetic anhydride, and the mixture was stirred for 10 h at room temperature. The reaction mixture was added to 100 mL of water and extracted three times with 100 mL of ether. The combined ethereal extract was washed with water, 10% hydrochloric acid, and water and dried over anhydrous sodium sulfate. The crude product resulting from removal of the solvent was chromatographed on silica gel with benzene as eluent to give 2.8 g (83%) of **13** as a colorless oil: IR ($CHCl_3$) 1730 cm^{-1}; NMR (CCl_4) δ 1.0 (3 H, s, CH_3), 2.0 (3 H, s, $OCOCH_3$), 2.5 (3 H, s, $ArCH_3$), 3.7–4.2 (2 H, m, CH_2OTs), 4.7–6.0 (4 H, m, $CH{=}CH_2$ and CHOAc), 7.35 (2 H, d, J = 8 Hz, Ar H), 7.75 (2 H, d, J = 8 Hz, Ar H); mass spectrum, m/e 366 (M^+). Anal. Calcd for $C_{19}H_{26}SO_5$: C, 62.27; H, 7.15. Found: C, 62.02; H, 7.34.

5-Acetoxy-1-ethenyl-2-(iodomethyl)-1-methylcyclohexane (14). A mixture of 2 g (5.47 mmol) of **13**, 1.5 g (10 mmol) of sodium iodide, and 50 mL of acetone was refluxed for 10 h. After evaporation of the solvent, the residue was treated with 50 mL of water and extracted three times with 100 mL of ether. The extract was washed with water, saturated sodium thiosulfate solution, and saturated sodium chloride solution and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded a crude product which was chromatographed on 30 g of silica gel with hexane–benzene (2:1) as eluent to give 1.5 g (85%) of **14** as a colorless oil: IR ($CHCl_3$) 1730 cm^{-1}; NMR (CCl_4) δ 1.00 (3 H, s, CH_3), 1.91 (3 H, s, $OCOCH_3$), 2.55–3.5 (2 H, m, CH_2I), 4.7–6.0 (4 H, m, $CH{=}CH_2$ and CHOAc); mass spectrum, m/e 322 (M^+).

1-Ethenyl-5,5-(ethylenedioxy)-2-(iodomethyl)-1-methylcyclohexane (18). **18** was obtained from **17** by the procedure described above in 86% yield as colorless prisms: mp 46–47 °C;

NMR (CCl_4) δ 1.0 (3 H, s, CH_3), 3.35 (2 H, d, J = 9 Hz, CH_2I), 3.87 (4 H, s, OCH_2CH_2O), 4.6–6.03 (3 H, m, $CH=CH_2$); mass spectrum, m/e 322 (M^+). Anal. Calcd for $C_{12}H_{19}O_2I$: C, 44.75; H, 5.95. Found: C, 44.69; H, 5.98.

5-Acetoxy-1-ethenyl-1-methyl-2-(nitromethyl)cyclohexane (15). A stirred solution of 1 g (3.11 mmol) of **14** and 0.5 g (7.25 mmol) of sodium nitrite in 10 mL of dimethylformamide was heated at 80 °C for 15 h under an atmosphere of nitrogen. The reaction mixture was added to 50 mL of water and extracted three times with 50 mL of ether. The extract was washed with water and saturated sodium chloride solution and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded a crude product which was chromatographed on 20 g of silica gel with hexane–benzene (1:1) as eluent to give 213 mg (29%) of **15** as a pale yellow oil: IR ($CHCl_3$) 1725, 1550, 1380 cm^{-1}; NMR (CCl_4) δ 1.08 (3 H, s, CH_3), 2.0 (3 H, s, $OCOCH_3$), 3.85–4.6 (2 H, m, CH_2NO_2), 4.85–6.1 (4 H, m, $CH=CH_2$ and CHOAc); mass spectrum, m/e 241 (M^+). Anal. Calcd for $C_{12}H_{19}NO_4$: C, 59.73; H, 7.94; N, 5.81. Found: C, 60.20; H, 8.22; N, 5.62.

1-Ethenyl-5,5-(ethylenedioxy)-1-methyl-2-(nitromethyl)-cyclohexane (19). **19** was obtained from **18** by the procedure described above in 41% yield as a pale yellow oil: IR ($CHCl_3$) 1560, 1380 cm^{-1}; NMR (CCl_4) δ 1.03 (3 H, s, CH_3), 3.9 (4 H, s, OCH_2CH_2O), 3.7–4.55 (2 H, m, CH_2NO_2), 4.86–6.1 (3 H, m, $CH=CH_2$); mass spectrum, calcd for $C_{12}H_{19}NO_4$ m/e 241.1353, found m/e 241.1357.

5-Acetoxy-1-ethenyl-1-methyl-2-(1-nitroethenyl)cyclohexane (22). To the solution resulting from addition of 0.7 mL of 37% formaldehyde to a mixture of 580 mg (7.95 mmol) of diethylamine and 0.5 mL of water at 0 °C was added a solution of 1.6 g (6.64 mmol) of **15** in 2 mL of methanol. After being stirred for 2 h at room temperature, the reaction mixture was treated with 10 mL of water and extracted three times with 50 mL of ether. The combined extract was washed with water and saturated sodium chloride solution and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded a crude product, **20**, which was used in the next reaction without further purification. A solution of the crude **20** in 20 mL of benzene was saturated with hydrogen chloride and refluxed for 10 h. The cooled reaction mixture was washed with water and dried over anhydrous sodium sulfate. The crude product resulting from evaporation of the solvent was chromatographed on 20 g of silica gel with hexane–benzene (1:1) as eluent to give 1.23 g (73%) of **22** as a pale yellow oil: IR ($CHCl_3$) 1725, 1520, 1380 cm^{-1}; NMR (CCl_4) δ 1.1 (3 H, s, CH_3), 2.0 (3 H, s, $OCOCH_3$), 3.0–3.46 (1 H, m, $CHC(NO_2)=CH_2$), 4.6–6.0 (5 H, m, CHOAc and olefinic protons), 6.4 (1 H, br s, $C(NO_2)=CHH$); mass spectrum, m/e 253 (M^+). Anal. Calcd for $C_{13}H_{19}NO_4$: C, 61.64; H, 7.56; N, 5.53. Found: C, 61.16; H, 7.81; N, 5.45.

1-Ethenyl-5,5-(ethylenedioxy)-1-methyl-2-(1-nitroethenyl)cyclohexane (23). **23** was obtained from **19** by the procedure described above in 81% yield as a pale yellow oil: IR ($CHCl_3$) 1530, 1380 cm^{-1}; NMR (CCl_4) δ 1.05 (3 H, s, CH_3), 3.0–3.5 (1 H, m, $CHC(NO_2=CH_2)$, 3.85 (4 H, s, OCH_2CH_2O), 4.57–5.9 (4 H, m, olefinic protons), 6.3 (1 H, br s, $C=CHH$); mass spectrum, m/e 253 (M^+). Anal. Calcd for $C_{13}H_{19}NO_4$: C, 61.64; H, 7.56; N, 5.53. Found: C, 61.37; H, 7.70; N, 5.24.

5-Acetoxy-2-[2-(1-cyano-4-methoxybenzocyclobutenyl)-1-nitroethyl]-1-ethenyl-1-methylcyclohexane (4). To a stirred suspension of sodium amide [prepared from 100 mg (4.35 mmol) of sodium] in 20 mL of liquid ammonia at −78 °C under an atmosphere of nitrogen was added 264.72 mg (1.66 mmol) of 1-cyano-4-methoxybenzocyclobutene in 5 mL of anhydrous tetrahydrofuran. After 5 min at −78 °C, a solution of 351 mg (1.39 mmol) of **22** in 5 mL of anhydrous tetrahydrofuran was added to the reaction mixture. After being stirred for 30 min, the reaction mixture was treated with excess solid ammonium chloride and the solvent evaporated. The residual reddish gum was diluted with 20 mL of water and extracted three times with 50 mL of ether. The combined extract was washed with water and saturated sodium chloride and dried over anhydrous sodium sulfate. Removal of the solvent afforded a crude product which was chromatographed on 5 g of silica gel with benzene as eluent to give 354.3 mg (62%) of **4** as a pale yellow oil: IR ($CHCl_3$) 2230, 1725, 1550, 1360 cm^{-1}; NMR (CCl_4) δ 1.2 (3 H, s, CH_3), 2.0 (3 H, s, $OCOCH_3$), 3.77 (3 H, s, OCH_3), 4.5–6.0 (5 H, m, $CHNO_2$, CHOAc, and $CH=CH_2$), 6.5–7.2 (3 H, m, Ar H); mass spectrum, m/e 412 (M^+). Anal. Calcd for $C_{23}H_{28}N_2O_5 \cdot 1.45H_2O$: C, 62.98; H, 7.10. Found: C, 62.44; H, 6.48.

2-[2-(1-Cyano-4-methoxybenzocyclobutenyl)-1-nitroethyl]-1-ethenyl-5,5-(ethylenedioxy)-1-methylcyclohexane (5). **5** was obtained from **23** by the procedure described for the synthesis of **4** in 72% yield as a pale yellow oil: IR ($CHCl_3$) 2230, 1550, 1370 cm^{-1}; NMR (CCl_4) δ 1.3 (3 H, s, CH_3), 3.76 (3 H, s, OCH_3), 3.88 (4 H, s, OCH_2 CH_2O), 4.6–6.1 (4 H, m, $CHNO_2$ and $CH=CH_2$), 6.68–7.3 (3 H, m, Ar H); mass spectrum, m/e 412 (M^+). Anal. Calcd for $C_{23}H_{28}N_2O_5$: C, 66.97; H, 6.84; N, 6.79. Found: C, 66.91; H, 6.97; N, 6.50.

2β-Acetoxy-8α-cyano-17-methoxy-6α-nitro-*D*-homo-18-nor-5α-androsta-13,15,17-triene (2). A solution of 300 mg (0.73 mmol) of **4** in 30 mL of *o*-dichlorobenzene was stirred under an atmosphere of nitrogen at 180 °C for 2 h. After evaporation of the solvent, the residue was chromatographed on 5 g of silica gel with benzene as eluent to give 282 mg (94%) of **2** as a colorless oil: IR ($CHCl_3$) 2220, 1725, 1550, 1360 cm^{-1}; NMR (CCl_4) δ 0.35 (3 H, s, CH_3), 1.77 (3 H, s, $OCOCH_3$), 3.8 (3 H, s, OCH_3), 4.5 (1 H, distorted t, J = 12 Hz, $CHNO_2$), 5.1 (1 H, br s, CHOAc), 6.7–7.5 (3 H, m, Ar H); mass spectrum, m/e 412 (M^+). Anal. Calcd for $C_{23}H_{28}N_2O_5 \cdot H_2O$; C, 64.17; H, 7.02; N, 6.51. Found: C, 64.54: H, 7.48; N, 6.23.

8α-Cyano-2,2-(ethylenedioxy)-17-methoxy-6α-nitro-*D*-homo-18-nor-5α-androsta-13,15,17-triene (3). **3** was obtained from **5** by the procedure described for the synthesis of **2** in 96% yield as colorless prisms (from methanol): mp 155–156 °C; IR ($CHCl_3$) 2230, 1560, 1370 cm^{-1}; NMR (CCl_4) δ 0.3 (3 H, s, CH_3), 3.8 (7 H, s, OCH_2CH_2O and OCH_3), 4.4 (1 H, distorted t, J = 12 Hz, $CHNO_2$), 6.5–7.3 (3 H, m, Ar H); mass spectrum, m/e 412 (M^+). Anal. Calcd for $C_{23}H_{28}N_2O_5 \cdot H_2O$: C, 64.17; H, 7.02; N, 6.51. Found: C, 64.38; H, 6.62; N, 6.24.

3β-Acetoxy-8α-cyano-17-methoxy-*D*-homo-18-nor-5α-androsta-13,15,17-triene (26). A solution of 18 mg (0.05 mmol) of **25** in 10 mL of *o*-dichlorobenzene was heated at 180 °C for 2 h under an atmosphere of nitrogen. Evaporation of the solvent afforded an oil which was chromatographed on 2 g of silica gel with benzene as eluent to give 17 mg (94%) of **26** as a colorless oil: IR ($CHCl_3$) 2240, 1730 cm^{-1}; NMR (CCl_4) δ 0.19 (3 H, s, CH_3), 1.93 (3 H, s, $OCOCH_3$), 3.8 (3 H, s, OCH_3), 4.3–4.9 (1 H, m, CHOAc), 6.5–7.4 (3 H, m, Ar H); mass spectrum, m/e 367 (M^+). Anal. Calcd for $C_{23}H_{29}NO_3 \cdot 0.4$ H_2O: C, 73.72; H, 8.10; N, 3.74. Found: C, 73.63; H, 8.05; N, 3.45.

8α-Cyano-17-methoxy-6α-nitro-2-oxo-*D*-homo-18-nor-5α-androsta-13,15,17-triene (29). A solution of 150 mg (0.36 mmol) of **3** in 20 mL of tetrahydrofuran and 1 mL of 10% hydrochloric acid was stirred for 2 h at room temperature. After evaporation of the solvent, the reaction mixture was diluted with 20 mL of water and extracted three times with 50 mL of dichloromethane. The combined extract was washed with water and dried over anhydrous sodium sulfate. Evaporation of the solvent gave a solid which was recrystallized from benzene–hexane (1:1) to afford 127.2 mg (96%) of **29** as colorless prisms: mp 185–186 °C; IR ($CHCl_3$) 2230, 1710, 1560, 1360 cm^{-1}; NMR ($CDCl_3$) δ 0.1 (3 H, s, CH_3), 3.76 (3 H, s, OCH_3), 4.5 (1 H, dt, J = 4, 12 Hz, $CHNO_2$), 6.55–7.2 (3 H, m, Ar H); mass spectrum, m/e 368 (M^+). Anal. Calcd for $C_{21}H_{24}N_2O_4$: C, 68.46; H, 6.57; N, 7.60. Found: C, 68.01; H, 6.70; N, 7.25.

8α-Cyano-2β-hydroxy-17-methoxy-6α-nitro-*D*-homo-18-nor-5α-androsta-13,15,17-triene (30). To a solution of 120 mg (0.33 mmol) of **29** in 20 mL of methanol was added 15 mg (0.4 mmol) of sodium borohydride at 0 °C. After the mixture was stirred for 30 min at 0 °C and the solvent evaporated, the residue was diluted with 20 mL of water and extracted three times with 50 mL of ethyl acetate. The combined extract was washed with water and dried over anhydrous sodium sulfate. Evaporation of the solvent gave a crude product which was chromatographed on 4 g of silica gel with benzene as eluent to afford 107.5 mg (88%) of **30** as a colorless syrup: IR ($CHCl_3$) 3500, 2230, 1560, 1370 cm^{-1}; NMR ($CDCl_3$) δ 0.5 (3 H, s, CH_3), 3.8 (3 H, s, OCH_3), 3.95–4.7 (2 H, m, CHOH and $CHNO_2$), 6.8–7.35 (3 H, m, Ar H); mass spectrum, m/e 370 (M^+); calcd for $C_{21}H_{26}N_2O_4$ m/e 370.1888, found m/e 370.1888.

Compound **30** was prepared alternatively as follows. A solution of 50 mg (0.12 mmol) of **2** in 2 mL of 0.1 N ethanolic sodium

hydroxide was stirred for 30 min at room temperature. The reaction mixture was diluted with 10 mL of water and extracted three times with 20 mL of ethyl acetate. The combined extract was washed with water and dried over anhydrous sodium sulfate. After evaporation of the solvent, the residue was chromatographed on 1 g of silica gel with benzene as eluent to give 38 mg (86%) of **30** as a colorless syrup which was identical with the sample obtained from the reduction of **29** with respect to the IR ($CHCl_3$) and NMR ($CDCl_3$) spectra.

8α-Cyano-17-methoxy-6α-nitro-*D*-homo-18-nor-5α-androsta-2,13,15,17-tetraene (31). To a solution of 320 mg (0.86 mmol) of **30** in 2 mL of pyridine and 10 mL of dichloromethane at 0 °C was added 240 mg (2 mmol) of thionyl chloride. The reaction mixture was stirred for 30 min at 0 °C and added to 20 mL of ice-cooled water. The aqueous layer was extracted twice with 50 mL of dichloromethane. The combined extract was washed with water, 10% hydrochloric acid, saturated sodium bicarbonate solution, and water and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded a crude product which was chromatographed on 2 g of silica gel with hexane–benzene (1:1) as eluent to give 228.5 mg (76%) of **31** as colorless needles which were recrystallized from methanol: mp 134–136 °C; IR ($CHCl_3$) 2230, 1560, 1380 cm^{-1}; NMR (CCl_4) δ 0.25 (3 H, s, CH_3), 3.75 (3 H, s, OCH_3), 4.42 (1 H, dt, J = 4, 12 Hz, $CHNO_2$), 5.3–5.9 (2 H, m, olefinic protons), 6.6–7.45 (3 H, m, Ar H); mass spectrum, m/e 352 (M^+). Anal. Calcd for $C_{21}H_{24}N_2O_3$: C, 68.41; H, 7.05; N, 7.60. Found: C, 68.47; H, 6.74; N, 7.20.

8α-Cyano-17-methoxy-6-oxo-*D*-homo-18-nor-5β-androsta-2,13,15,17-tetraene (32). To a solution of 1 g (13 mmol) of ammonium acetate in 4 mL of water and 1.6 mL of 20% aqueous titanium trichloride (2 mmol) was added 168 mg (0.48 mmol) of **31** in 5 mL of tetrahydrofuran, and the mixture was stirred under nitrogen for 12 h at room temperature. The reaction mixture was poured into 10 mL of water and extracted three times with 50 mL of ethyl acetate. The combined extract was washed with water and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded a crude product which was chromatographed on 2 g of silica gel with benzene–hexane (1:1) as eluent to give 87 mg (57%) of **32** as colorless needles which were recrystallized from methanol: mp 174–175 °C; IR ($CHCl_3$) 2225, 1720 cm^{-1}; NMR ($CDCl_3$) δ 0.75 (3 H, s, CH_3), 3.8 (3 H, s, OCH_3), 5.75 (2 H, br s, olefinic protons), 6.6–7.5 (3 H, m, Ar H); mass spectrum, m/e 321 (M^+). Anal. Calcd for $C_{21}H_{23}NO_2 \cdot 0.7H_2O$: C, 75.71; H, 7.36; N, 4.19. Found: C, 75.64; H, 7.11; N, 4.17.

17-Methoxy-6-oxo-*D*-homo-18-nor-5β-androsta-2,13,15,17-tetraene (1). To a solution of 12 mg (0.5 mmol) of sodium in 20 mL of liquid ammonia at −78 °C was added a solution of 64 mg (0.2 mmol) of **32** in 10 mL of anhydrous tetrahydrofuran containing 3 drops of absolute ethanol. After the reaction mixture had been stirred for 30 min at −78 °C, 5 mL of ethanol was added, and the solvent was evaporated. The residue was diluted with 50 mL of water and extracted three times with ethyl acetate. The combined extract was washed with water and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded a crude product which was used in the following reaction without further purification. To a solution of the above crude product in 5 mL of acetone at 0 °C was added 0.3 mL of Jones reagent. After being stirred for 10 min at 0 °C, the reaction mixture was diluted with 10 mL of water and extracted three times with 50 mL of ethyl acetate. The combined extract was washed with water and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded a crude product which was chromatographed on 1 g of silica gel with hexane–benzene (1:1) as eluent to give 40.6 mg (69%) of **1** as colorless prisms (from methanol): mp 167–168 °C; IR ($CHCl_3$) 1705 cm^{-1}; NMR (CCl_4) δ 1.23 (3 H, s, CH_3), 3.73 (3 H, s, OCH_3), 5.6 (2 H, br s, olefinic protons), 6.4–7.0 (3 H, m, Ar H); mass spectrum, calcd for $C_{20}H_{24}O_2$ m/e 296.1792, found m/e 296.1794.

Birch Reduction of 33. A solution of 1 g (2.96 mmol) of **33** in 90 mL of dry ether was added cautiously to 200 mL of liquid ammonia. To this solution at −78 °C was added 1 g (25.6 mmol) of potassium. After the mixture was stirred for 30 min at −78 °C, 10 mL of absolute ethanol was added dropwise, and the solvent was then evaporated. The residue was diluted with 30 mL of water and the mixture extracted three times with 30 mL of ethyl acetate. This organic extract was washed with aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded a yellow oil which was chromatographed on 40 g of silica gel with hexane–benzene (3:7) as eluent to give 200 mg (22%) of **36** as a colorless oil: NMR (CCl_4) δ 1.07 (3 H, s, CH_3), 3.9 (4 H, s, OCH_2CH_2O), 5.34 (1 H, br s, olefinic proton), 6.95–7.4 (3 H, m, Ar H); mass spectrum, m/e 310 (M^+). Anal. Calcd for $C_{21}H_{26}O_2$: C, 81.25; H, 8.44. Found: C, 81.08; H, 8.41.

Further elution with hexane–benzene (3:7) gave 200 mg (20%) of **34** as colorless prisms (from methanol): mp 116.5–117 °C; NMR (CCl_4) δ 1.04 (3 H, s, CH_3), 3.75 (3 H, s, CH_3), 3.89 (4 H, s, OCH_2CH_2O), 5.45 (1 H, br s, olefinic proton), 6.5–7.3 (3 H, m, Ar H); mass spectrum, m/e 340 (M^+). Anal. Calcd for $C_{22}H_{28}O_3$: C, 77.61; H, 8.29. Found: C, 77.32; H, 8.28.

Birch reduction of **33** was also carried out in a similar manner by using lithium and sodium, and the results are given in Table I. The most efficient method for the preparation of **34** is as follows.

A solution of 11.5 g (34 mmol) of **33** in 300 mL of anhydrous tetrahydrofuran was added cautiously to 700 mL of liquid ammonia. To this solution at −78 °C was added 1.7 g (74 mmol) of sodium and 2 mL of absolute ethanol. After the mixture was stirred for 30 min at −78 °C, 70 mL of absolute ethanol was added dropwise, and the solvent was then evaporated. The reddish residue was diluted with 300 mL of water and the mixture extracted three times with 200 mL of benzene. This organic extract was washed with aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Removal of the solvent afforded an oily product which was crystallized from methanol to give 6.85 (59%) of **34** as colorless prisms. Concentration of the mother liquid afforded an oil which was chromatographed on 100 g of silica gel with hexane–dichloromethane (3:2) as eluent to give 4.0 g (35%) of **35** as a colorless oil: NMR (CCl_4) δ 1.26 (3 H, s, CH_3), 3.77 (3 H, s, OCH_3), 3.92 (4 H, s, OCH_2CH_2O), 5.4 (1 H, br s, olefinic proton), 6.5–7.3 (3 H, m, Ar H); mass spectrum, m/e 340 (M^+). Anal. Calcd for $C_{22}H_{28}O_3$: C, 77.61; H, 8.29. Found: C, 77.31; H, 7.99.

17-Methoxy-3-oxo-*D*-homo-18-norandrosta-4,13,15,17-tetraene (37). To a solution of 120 mg (0.35 mmol) of **34** in 5 mL of tetrahydrofuran at room temperature was added 0.5 mL of 2 N hydrochloric acid, and the mixture was stirred for 3 h. The reaction mixture was diluted with 5 mL of water and the resulting solution extracted three times with 20 mL of ethyl acetate. This extract was washed with aqueous sodium bicarbonate solution and aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Removal of the solvent afforded a yellow oil which was chromatographed on 3 g of silica gel with benzene as eluent to give 90 mg (86%) of **37** as colorless prisms (from hexane): mp 139–140 °C; IR ($CHCl_3$) 1660 cm^{-1}; NMR (CCl_4) δ 1.22 (3 H, s, CH_3), 3.76 (3 H, s, OCH_3), 5.76 (1 H, br s, olefinic proton), 6.5–7.4 (3 H, m, Ar H); mass spectrum, m/e 296 (M^+). Anal. Calcd for $C_{20}H_{24}O_2 \cdot 0.1H_2O$: C, 80.55; H, 8.18. Found: C, 80.19; H, 8.04.

17-Methoxy-3-oxo-*D*-homo-18-nor-5α,8α-androsta-4,13,15,17-tetraene (38). **38** was obtained from **35** by the procedure described above in 94% yield as a yellow oil: IR ($CHCl_3$) 1660 cm^{-1}; NMR (CCl_4) δ 0.87 (3 H, s, Ar H), 3.7 (3 H, s, OCH_3), 5.62 (1 H, br s, olefinic proton), 6.3–7.1 (3 H, m, Ar H); mass spectrum, m/e 296 (M^+). Anal. Calcd for $C_{20}H_{24}O_2 \cdot 0.1H_2O$: C, 80.55; H, 8.18. Found: C, 80.23; H, 8.31.

3β-Hydroxy-*D*-homo-18-nor-5α-androst-13(17a)-en-17-one (39). To 50 mL of liquid ammonia was added 80 mg (0.27 mmol) of **37** in 20 mL of anhydrous tetrahydrofuran. To the stirred solution at −78 °C was added 100 mg (14.3 mmol) of lithium. After 10 min, 4 mL of ethanol was added and the mixture stirred for 10 min. The reaction mixture was treated with solid ammonium chloride and the solvent evaporated. The residue was extracted with ethyl acetate. The combined extract was washed with aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded an oil. This crude product was used for the next reaction without further purification. A solution of the crude product in 10 mL of methanol containing 1 mL of 10% hydrochloric acid was heated at 50 °C for 30 min. After cooling, the solution was diluted with 10 mL of water and the mixture extracted three times with 20 mL of ethyl acetate. This extract was washed with aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded a yellow oil which was purified by chromatography of 3 g of silica gel with benzene–ethyl acetate

(9:1) as eluent to give 60 mg (77%) of **39** as colorless prisms (from methanol): mp 183–184 °C (lit.[2] 183–185 °C); identical (IR, NMR) with an authentic sample.

3β-Hydroxy-*D*-homo-18-nor-5α,8α,14β-androst-13(17a)-en-17-one (40). **40** was obtained from **37** by the procedure described above in 67% yield as colorless prisms (from acetone): mp 200–202 °C (lit.[2] 202–204 °C); identical (IR, NMR) with an authentic sample.

3,3-(Ethylenedioxy)-6β-hydroxy-17-methoxy-*D*-homo-18-nor-5β-androsta-13,15,17-triene (41). To a solution of 3.5 g (10.3 mmol) of **34** in 15 mL of anhydrous tetrahydrofuran at 0 °C under an atmosphere of nitrogen was added dropwise 45 mL (4.5 mmol) of a 1.0 M tetrahydrofuran solution of borane. The reaction mixture was stirred for 8 h at room temperature, cooled to 0 °C, and then treated with 0.5 mL of water, followed by 10 mL of 3 N sodium hydroxide and 10 mL of 30% hydrogen peroxide. After the mixture was stirred for an additional 8 h at room temperature, aqueous ammonium chloride solution was added. Evaporation of the solvent gave a reddish gum which was extracted three times with 50 mL of ethyl acetate. The combined extract was washed with aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded an oily product which was chromatographed on 80 g of silica gel with dichloromethane–ethyl acetate (4:1) as eluent to give 3.3 g (90%) of **41** as colorless prisms (from methanol): mp 188–189 °C; IR ($CHCl_3$) 3610 cm^{-1}; NMR (CCl_4) δ 1.13 (3 H, s, CH_3), 3.76 (3 H, s, OCH_3), 3.88 (4 H, s, OCH_2CH_2O), 6.5–7.4 (3 H, m, Ar H); mass spectrum, *m/e* 358 (M^+). Anal. Calcd for $C_{22}H_{30}O_4 \cdot 0.1H_2O$: C, 73.34; H, 8.45. Found: C, 73.09; H, 8.56.

6β-Acetoxy-3,3-(ethylenedioxy)-17-methoxy-*D*-homo-18-nor-5β-androsta-13,15,17-triene (42). To a solution of 135 mg (0.38 mmol) of **41** in 5 mL of pyridine was added 0.2 mL of acetic anhydride and a catalytic amount of 4-(dimethylamino)pyridine. The reaction mixture was stirred at room temperature for 8 h. After 5 mL of water was added, the resulting mixture was extracted three times with ethyl acetate. This extract was washed with aqueous potassium hydrogen sulfate solution and aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Removal of the solvent afforded a yellow oil which was chromatographed on 5 g of silica gel with benzene–ethyl acetate (9:1) as eluent to give 148 mg (98%) of **42** as a colorless oil: IR ($CHCl_3$) 1728 cm^{-1}; NMR (CCl_4) δ 1.08 (3 H, s, CH_3), 2.03 (3 H, s, $OCOCH_3$), 3.76 (3 H, s, OCH_3), 3.9 (4 H, s, OCH_2CH_2O), 4.87 (1 H, br s, $CHOCOCH_3$), 6.5–7.4 (3 H, m, Ar H); mass spectrum, calcd for $C_{24}H_{32}O_5$ *m/e* 400.2271, found *m/e* 400.2273.

6β-Acetoxy-17-methoxy-3-oxo-*D*-homo-18-nor-5β-androsta-13,15,17-triene (43). To a solution of 145 mg (0.36 mmol) of **42** in 5 mL of tetrahydrofuran at room temperature was added dropwise 0.5 mL of 5% hydrochloric acid. The reaction mixture was stirred for 6 h at room temperature and diluted with 5 mL of water. The resulting mixture was extracted three times with 20 mL of ethyl acetate. This extract was washed with aqueous sodium bicarbonate solution and aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded a yellow oil which was chromatographed on 5 g of silica gel with benzene–ethyl acetate (9:1) as eluent to give 125 mg (97%) of **43** as a colorless oil: IR ($CHCl_3$) 1722 cm^{-1}; NMR (CCl_4) δ 1.16 (3 H, s, CH_3), 2.06 (3 H, s, $OCOCH_3$), 3.78 (3 H, s, OCH_3), 4.86 (1 H, br s, $CHOCOCH_3$), 6.5–7.4 (3 H, m, Ar H); mass spectrum, calcd for $C_{22}H_{28}O_4$ *m/e* 356.1963, found *m/e* 356.1960.

6β-Acetoxy-3α-hydroxy-17-methoxy-*D*-homo-18-nor-5β-androsta-13,15,17-triene (44). To a stirred solution of 130 mg (0.37 mmol) of **43** in 5 mL of methanol at room temperature was added portionwise 30 mg (0.53 mmol) of sodium borohydride. After being stirred for 30 min and diluted with 5 mL of water, the resulting mixture was extracted three times with 20 mL of ethyl acetate. This extract was washed with aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded a residue which was chromatographed on 5 g of silica gel with benzene–ethyl acetate (4:1) as eluent to give 125 mg (96%) of **44** as a colorless oil: IR ($CHCl_3$) 3603 cm^{-1}; NMR (CCl_4) δ 1.02 (3 H, s, CH_3), 2.03 (3 H, s, $OCOCH_3$), 3.75 (3 H, s, OCH_3), 4.9 (1 H, br s, $CHOCOCH_3$), 6.5–7.4 (3 H, m, Ar H); mass spectrum, calcd for $C_{22}H_{30}O_4$ *m/e* 358.2132, found *m/e* 358.2131.

6β-Acetoxy-17-methoxy-3α-[(*p*-toluenesulfonyl)oxy]-*D*-homo-18-nor-5β-androsta-13,15,17-triene (45). To a solution of 120 mg (0.34 mmol) of **44** in 5 mL of pyridine at room temperature was added 80 mg (0.42 mmol) of *p*-toluenesulfonyl chloride and a catalytic amount of 4-(dimethylamino)pyridine. The reaction mixture was stirred for 6 h at room temperature. After 5 mL of water was added, the resulting mixture was extracted three times with 20 mL of ethyl acetate. This extract was washed with aqueous potassium hydrogen sulfate solution and aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Removal of the solvent afforded a yellow oil which was chromatographed on 5 g of silica gel with benzene–ethyl acetate (19:1) as eluent to give 155 mg (90%) of **45** as colorless prisms: mp 66–68 °C; IR ($CHCl_3$) 1720 cm^{-1}; NMR (CCl_4) δ 1.02 (3 H, s, CH_3), 2.0 (3 H, s, $OCOCH_3$), 2.47 (3 H, s, CH_3Ar), 3.75 (3 H, s, OCH_3), 4.2–4.8 (1 H, m, CHOTs), 4.83 (1 H, br s, $CHOCOCH_3$), 6.5–7.3 (3 H, m, Ar H), 7.4 (2 H, d, J = 8 Hz, Ar H), 7.85 (2 H, d, J = 8 Hz, Ar H); mass spectrum, *m/e* 512 (M^+). Anal. Calcd for $C_{29}H_{36}O_6S \cdot 0.2H_2O$: C, 67.47; H, 7.11. Found: C, 67.07; H, 6.59.

6β-Hydroxy-17-methoxy-3α-[(*p*-toluenesulfonyl)oxy]-*D*-homo-18-nor-5β-androsta-13,15,17-triene (46). To a solution of 60 mg (0.12 mmol) of **45** in 10 mL of methanol at room temperature was added portionwise 30 mg (0.22 mmol) of potassium carbonate. The reaction mixture was stirred for 8 h and diluted with 5 mL of water, and the resulting mixture was extracted three times with 30 mL of ethyl acetate. This extract was washed with aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded a yellow oil which was purified by chromatography on 5 g of silica gel with benzene–ethyl acetate (9:1) as eluent to give 54 mg (98%) of **46** as a colorless oil: IR ($CHCl_3$) 3625 cm^{-1}; NMR (CCl_4) δ 1.10 (3 H, s, CH_3), 2.47 (3 H, s, CH_3Ar), 3.75 (3 H, s, OCH_3), 4.2–4.8 (1 H, m, CHOTs), 6.5–7.3 (3 H, m, Ar H), 7.4 (2 H, d, J = 8 Hz, Ar H), 7.86 (2 H, d, J = 8 Hz, Ar H); mass spectrum, *m/e* 470 (M^+). Anal. Calcd for $C_{27}H_{34}O_5S$: C, 68.90; H, 7.28. Found: C, 68.78; H, 7.48.

17-Methoxy-6-oxo-3α-[(*p*-toluenesulfonyl)oxy]-*D*-homo-18-nor-18-5β-androsta-13,15,17-triene (47). To a solution of 25 mg (0.05 mmol) of **46** in 1 mL of acetone at 0 °C was added 0.05 mL of Jones reagent, and the mixture was stirred for 5 min. After dilution with 5 mL of water, the resulting mixture was extracted with ethyl acetate. This extract was washed with aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded an oil which was chromatographed on 3 g of silica gel with benzene as eluent to give 22 mg (89%) of **47** as a colorless oil: IR ($CHCl_3$) 1710 cm^{-1}; NMR (CCl_4) δ 0.83 (3 H, s, CH_3), 2.47 (3 H, s, CH_3Ar), 3.77 (3 H, s, OCH_3), 4.2–4.8 (1 H, m, CHOTs), 6.5–7.2 (3 H, m, Ar H), 7.4 (2 H, d, J = 8 Hz, Ar H), 7.83 (2 H, d, J = 8 Hz, Ar H); mass spectrum, calcd for $C_{27}H_{32}O_5S$ *m/e* 468.1968, found *m/e* 468.1968.

Elimination of Tosylate 47. A mixture of 10 mg (0.096 mmol) of lithium bromide, 10 mg (0.15 mmol) of lithium carbonate, and 20 mg (0.043 mmol) of **47** in 3 mL of dimethylformamide was heated at 150 °C for 6 h. After dilution with 5 mL of water, the resulting mixture was extracted three times with 10 mL of ethyl acetate. This extract was washed with aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded a yellow oil which was chromatographed on 2 g of silica gel with hexane–benzene (1:1) as eluent to give 5 mg (39%) of a 1:1 mixture of **48** and **1**. For **48**: colorless prisms (from methanol); mp 142–143 °C; IR ($CHCl_3$) 1705 cm^{-1}; NMR (CCl_4) δ 0.73 (3 H, s, CH_3), 3.7 (3 H, s, OCH_3), 5.6 (2 H, br s, olefinic protons), 6.4–7.2 (3 H, m, Ar H); mass spectrum, *m/e* 296 (M^+). The physical data of **1** were identical with those of the sample obtained by the thermolysis of the benzocyclobutene.

3,3-(Ethylenedioxy)-17-methoxy-6-oxo-*D*-homo-18-nor-5β-androsta-13,15,17-triene (49). To a stirred solution of 2.1 g (5.86 mmol) of **41** in 40 mL of acetone and 40 mL of tetrahydrofuran at 0 °C was added dropwise 4 mL of Jones reagent, and the mixture was stirred for 20 min at 0 °C. The reaction mixture was diluted with 50 mL of water and extracted three times with 50 mL of ethyl acetate. This extract was washed with aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Removal of the solvent afforded a yellow oil which was chromatographed on 40 g of silica gel with benzene–ethyl

acetate (9:1) as eluent to give 1.9 g (91%) of **49** as a colorless oil: IR ($CHCl_3$) 1700 cm^{-1}; NMR (CCl_4) δ 0.87 (3 H, s, CH_3), 3.76 (3 H, s, OCH_3), 3.9 (4 H, s, OCH_2CH_2O), 6.5–7.3 (3 H, m, Ar H); mass spectrum, m/e 356 (M^+). Anal. Calcd for $C_{22}H_{28}O_4$: C, 74.13; H, 7.92. Found: C, 74.17; H, 7.70.

3,3-(Ethylenedioxy)-17-methoxy-6-oxo-*D*-homo-18-nor-5α-androsta-13,15,17-triene (50). A mixture of 3.0 g (8.43 mmol) of **49** and 2.0 g (41.7 mmol) of sodium hydride (50% in oil) in 500 mL of anhydrous tetrahydrofuran was refluxed for 2 h under an atmosphere of nitrogen. After the mixture cooled, 10 mL of aqueous ammonium chloride was carefully added and the solvent evaporated. The yellow residue was extracted three times with 50 mL of ethyl acetate. The combined extract was washed with aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded a yellow oil which was purified by chromatography on 60 g of silica gel with dichloromethane–ethyl acetate (9:1) as eluent to give 2.65 g (88%) of **50** as colorless prisms (from methanol): mp 137–138 °C; IR ($CHCl_3$) 1700 cm^{-1}; NMR (CCl_4) δ 0.78 (3 H, s, CH_3), 3.73 (3 H, s, OCH_3), 3.88 (4 H, s, OCH_2CH_2O), 6.5–7.3 (3 H, m, Ar H); mass spectrum, m/e 356 (M^+). Anal. Calcd for $C_{22}H_{28}O_4 \cdot 0.2H_2O$: C, 73.39; H, 7.95. Found: C, 73.26; H, 8.01.

3,3-(Ethylenedioxy)-6β-hydroxy-17-methoxy-*D*-homo-18-nor-5α-androsta-13,15,17-triene (51). To a stirred solution of 540 mg (1.4 mmol) of **50** in 50 mL of dichloromethane and 10 mL of methanol at 0 °C was added portionwise 50 mg (1.3 mmol) of sodium borohydride, and the mixture was stirred for 1.5 h at 0 °C. After 2 mL of aqueous ammonium chloride solution was added, the resulting mixture was concentrated under reduced pressure. The residue was extracted three times with 30 mL of ethyl acetate. The combined extract was washed with aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Removal of the solvent afforded a yellow oil which was chromatographed on 10 g of silica gel with dichloromethane–ethyl acetate (4:1) as eluent to give 505 mg (93%) of **51** as a colorless oil: IR ($CHCl_3$) 3640 cm^{-1}; NMR (CCl_4) δ 1.0 (3 H, s, CH_3), 3.65 (3 H, s, OCH_3), 3.8 (4 H, s, OCH_2CH_2O), 6.3–7.2 (3 H, m, Ar H); mass spectrum, m/e 358 (M^+). Anal. Calcd for $C_{22}H_{30}O_4$: C, 73.71; H, 8.44. Found: C, 73.47; H, 7.89.

6β-Hydroxy-17-methoxy-3-oxo-*D*-homo-18-nor-5α-androsta-13,15,17-triene (52). A solution of 490 mg (1.37 mmol) of **51** and a catalytic amount of *p*-toluenesulfonic acid in 40 mL of acetone was refluxed for 3 h. The reaction mixture was cooled to 0 °C and neutralized with aqueous sodium bicarbonate solution, and the solution was evaporated under reduced pressure. The residue was diluted with 5 mL of water and extracted three times with 30 mL of ethyl acetate. The combined extract was washed with aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Evaporation of the solvent gave a yellow oil which was crystallized from methanol to afford 370 mg (86%) of **52** as colorless prisms: mp 204–205 °C; IR ($CHCl_3$) 3610, 1700 cm^{-1}; NMR ($CDCl_3$) δ 1.23 (3 H, s, CH_3), 3.77 (3 H, s, OCH_3), 3.93 (1 H, br s, CHOH), 6.5–7.3 (3 H, m, Ar H); mass spectrum, m/e 314 (M^+). Anal. Calcd for $C_{20}H_{26}O_3$: C, 76.40; H, 8.34. Found: C, 76.52; H, 8.01.

***p*-Toluenesulfonylhydrazone (53) of 52.** A mixture of 350 mg (1.12 mmol) of **52** and 225 mg (1.21 mmol) of *p*-toluenesulfonylhydrazine in 30 mL of methanol containing 1 drop of concentrated sulfuric acid was refluxed for 1 h with stirring. The reaction mixture was cooled to 0 °C and neutralized with aqueous sodium bicarbonate solution. The solvent was removed by evaporation to give a pale yellow solid which was recrystallized from methanol to afford 516 mg (96%) of **53** as colorless prisms: dec 189–190 °C; IR ($CHCl_3$) 3625 cm^{-1}; NMR ($CDCl_3$) δ 1.3 (3 H, s, CH_3), 2.39 (3 H, s, CH_3Ar), 3.71 (3 H, s, OCH_3), 3.87 (1 H, br s, CHOH), 6.4–7.2 (3 H, m, Ar H), 7.25 (2 H, d, J = 8 Hz, Ar H), 7.82 (2 H, d, J = 8 Hz, Ar H); mass spectrum, m/e 328 (M^+ − 154). Anal. Calcd for $C_{27}H_{34}N_2O_4S$: C, 67.19; H, 7.10; N, 5.80. Found: C, 66.81; H, 7.15; N, 5.53.

6β-Hydroxy-17-methoxy-*D*-homo-18-nor-5α-androsta-2,13,15,17-tetraene (54). To a stirred solution of 100 mg (0.2 mmol) of **53** in 4 mL of anhydrous tetrahydrofuran at 0 °C was added 1 mL (1.56 mmol) of 1.56 M *n*-butyllithium. The reaction mixture was stirred for 5 h at room temperature, cooled to 0 °C, and neutralized with aqueous ammonium chloride solution. The resulting mixture was extracted three times with 20 mL of ethyl acetate. This extract was washed with aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Removal of the solvent afforded a pale brown oil which was chromatographed on 3 g of silica gel with benzene–ethyl acetate (19:1) as eluent to give 32 mg (52%) of **54** as colorless prisms (from hexane–benzene): mp 139–140 °C; IR ($CHCl_3$) 3620 cm^{-1}; NMR (CCl_4) δ 0.97 (3 H, s, CH_3), 3.7 (3 H, s, OCH_3), 5.6 (2 H, br s, olefinic protons), 6.3–7.2 (3 H, m, Ar H); mass spectrum, m/e 298 (M^+); calcd for $C_{20}H_{26}O_2$ m/e 298.1952, found m/e 298.1954.

17-Methoxy-6-oxo-*D*-homo-18-nor-5α-androsta-2,13,15,17-tetraene (48). To a solution of 31 mg (0.1 mmol) of **54** in 2 mL of acetone at 0 °C was added 0.1 mL of Jones reagent. After being stirred for 5 min at 0 °C, the reaction mixture was diluted with water and the solution extracted three times with 10 mL of ethyl acetate. The combined extract was washed with aqueous sodium chloride and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded a yellow oil which was purified by chromatography on 2 g of silica gel with benzene as eluent to give 26 mg (84%) of **48** as colorless prisms (from methanol): mp 142–143 °C; IR ($CHCl_3$) 1705 cm^{-1}; NMR (CCl_4) δ 0.73 (3 H, s, CH_3), 3.7 (3 H, s, OCH_3), 5.6 (2 H, br s, olefinic protons), 6.4–7.2 (3 H, m, Ar H); mass spectrum, m/e 296 (M^+). Anal. Calcd for $C_{20}H_{24}O_2 \cdot 0.1H_2O$: C, 80.55; H, 8.18. Found: C, 80.29; H, 8.01. This compound was identical (IR, NMR) with the sample obtained from the alternative synthetic method.

Equilibration of 48. A mixture of 18 mg (0.06 mmol) of **48** and 10 mg (0.21 mmol) of 50% sodium hydride in 20 mL of tetrahydrofuran was refluxed for 4 h under a current of nitrogen. After the mixture cooled, aqueous ammonium chloride solution was added, and the mixture was condensed under reduced pressure. The residue was extracted three times with 10 mL of ethyl acetate. This organic extract was washed with aqueous sodium chloride solution and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded an oil which was chromatographed on 6 g of silica gel with hexane–benzene (1:1) as eluent to give 17 mg (94%) of a mixture of **48** and **1** (ratio 1:1).

Equilibration of 1. Equilibration of **1** was carried out under the same conditions as described above to give a mixture of **48** and **1** (ratio 1:1).

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