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REACTIONS OF EPOXIDES—XXI*

BORON TRIFLUORIDE CATALYSED REARRANGEMENTS OF SOME 3α-SUBSTITUTED-5,6-OXIDOCHOLESTANES

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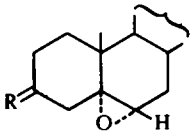
Abstract—3α-Hydroxy-5,6-epoxycholestanes gave 6-hydroxy-3α,10α-oxido-5β-methyl-19-nor compounds in addition to 6-ketones and backbone rearranged $\Delta^{13(17)}$-olefins on BF_3-catalysed rearrangement. Similar treatment of 3α-acetoxy-5β,6β-epoxycholestane gave 5α-acetoxy-cholestane-3α,6β-diol.

REPORTS of BF_3-catalysed rearrangements of 3α-substituted-5,6-epoxides have been limited to studies of 3α-acetoxy-5,6α-epoxy-5α-cholestane[1,2] (**1b**) and of 3,3-ethylenedioxy-5,6-epoxides with and without a 6-methyl-substituent.[3,4] In the latter cases the effects of the 3α-O atom of the ketal group on the rearrangement process are complicated by the presence of the second ketal O atom. Accordingly, we examined the rearrangements of 3α-hydroxy- and 3α-acetoxy- 5α,6α- and 5β,6β-epoxycholestanes.

While epoxidation of epicholesterol with monoperoxyphthalic acid gave the 3α-hydroxy-5α,6α-epoxide (**1a**) in good yield and traces of the corresponding 5β,6β-epoxide (**2a**), a better route to the β-epoxide was required. Reaction of 3β-hydroxy-5,6β-epoxy-5β-cholestane (**3a**) with toluene-*p*-sulphonyl chloride in pyridine gave, in addition to the 3β-tosyloxy-5,6-chlorohydrins (**4** and **5**), the tosyloxy-epoxide (**3b**). Treatment of the tosyloxy-epoxide (**3b**) with Li_2CO_3-DMF at reflux, followed by mild basic hydrolysis, gave a separable (chromatography) mixture of 5,6β-epoxy-5α-cholest-2-ene (**6**; 9%), cholest-4-en-6-one (**7**; 4%), 6β-hydroxy-cholesta-2,4-diene (**8**; 7%) and the required 3α-hydroxy-5,6β-epoxy-5β-cholestane (**2a**; 42%). The above structural assignments were confirmed by NMR spectra and comparison (where possible) with authentic samples. The $\Delta^{2,4}$-diene system for compound (**8**) was indicated by the UV spectrum (λ_{max} 265 mμ; ε6400). Oxidation of the dienol (**8**) with CrO_3-pyridine[5] gave a separable mixture of the known cholesta-2,4-dien-6-one (**9**) and cholesta-2,5-dien-4-one (**10**). The isomeric cholesta-2,5-dien-4-one (**10**) is considered to arise from the very labile[6] cholesta-2,4-dien-6-ol (**8**) system by allylic rearrangement followed by oxidation.

The mechanistic route to cholest-4-en-6-one (**7**) and cholesta-2,4-dien-6-ol (**8**) from the 3β-tosyloxy-5β,6β-epoxide (**3**) is of interest. By monitoring the product from the reaction of the tosylate (**3b**) at all stages by TLC it was demonstrated that while compounds (**7** and **8**) were absent from the reaction product prior to chromatography

* Part XX, B. N. Blackett, J. M. Coxon, M. P. Hartshorn, B. L. J. Jackson and C. N. Muir, *Tetrahedron* **25**, 459 (1969).



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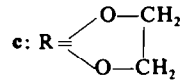
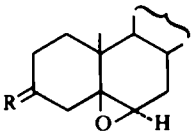
c: R = 



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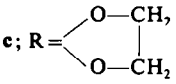
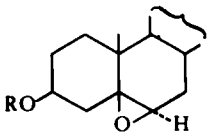
c; R = 



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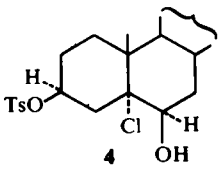

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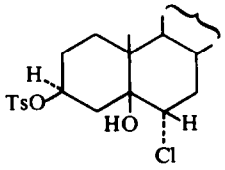

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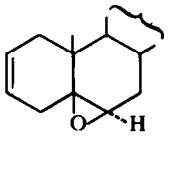

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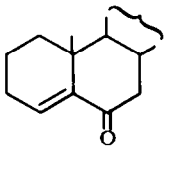

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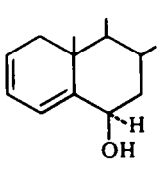

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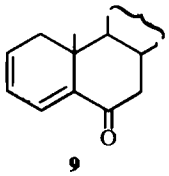

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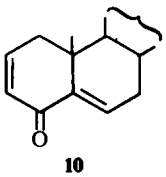

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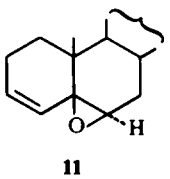

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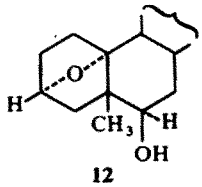
on deactivated alumina, a further compound disappeared on chromatography. The R_f value for the alumina-labile compound was of the correct order for a Δ^3-5β,6β-epoxide structure (**11**). We therefore suggest the intermediacy of compound (**11**) in the formation of cholest-4-en-6-one (**7**) and cholesta-2,4-dien-6-ol (**8**).

3α-*Hydroxy*-5,6β-*epoxy*-5β-*cholestane* (**2a**). Reaction of epoxide (**2a**) with BF_3-etherate in benzene was shown by TLC to be rapid (**35** sec). Chromatography on alumina allowed the separation of the major products. The first compound eluted was identified as the 3α,10α-oxido-compound (**12**; 28%) on the following evidence. The NMR spectrum* of (**12**) exhibited the following signals: δ 4·34 ppm ($W_{h/2}$ = 12 c/s, 1H; C^3-H), 3·75 ppm ($W_{h/2}$ = 15 c/s, 1H; $C^6\underline{H}OH$), 1·075 ppm (5β-CH_3). Oxidation of the hydroxy-ether (**12**) with CrO_3-acetone gave the keto-ether (**13**): δ 4·33 ppm ($W_{h/2}$ 12 c/s, 1H; C^3-H), 1·30 ppm (5β-CH_3). An isomeric hydroxy-ether (**14**) is obtained (see below) from BF_3-catalysed rearrangement of the 3α-hydroxy-5α,6α-epoxide (**1a**). Oxidation of hydroxy-ether (**14**) gave the same keto-ether (**13**), thus confirming that hydroxy-ethers (**12** and **14**) contained a similar ether-structure but were epimeric at C-6. Since the NMR spectrum of hydroxy-ether (**12**) reveals only one proton geminal to an ether-O atom, the remaining point of attachment of the ether bridge must be 5α- or 10α-. The former possibility may be excluded on two bases. Firstly, the appearance of the C^3—H signal in the NMR spectrum of 3α,5-oxido-5α-cholestane (**15**) differed markedly from that of the C^3—H signals for hydroxy-ethers

* Determined at 60 Mc for 10–15% solns in $CDCl_3$ containing $CHCl_3$ and TMS as internal standards.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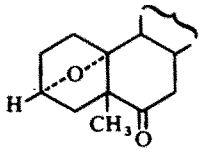
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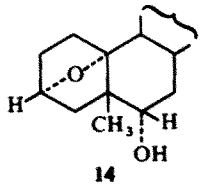
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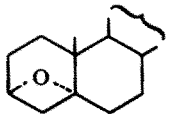
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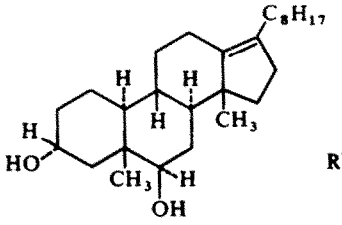
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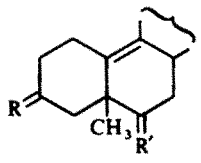

17a: R=αOH, H : R′=βOH, H
b: R=R′=O

(**12** and **14**). Secondly, the marked (0·225 and 0·19 ppm) downfield shift of the 10β- or 5β-CH_3 signal on oxidation of hydroxy-ethers (**12** and **14**) respectively is inconsistent[7] with the pattern expected for a 3α,5α-oxido-10β-CH_3- structure. However, marked downfield shifts (0·25 ppm) for the 5β-CH_3 signal have been noted[8] on oxidation of back-bone rearranged steroids containing both 6α- and 6β-hydroxy-5β-CH_3- structural features. Since the relative stereochemistry (Dreiding models) of the 6-hydroxyl and 5β-CH_3 functions for the hydroxy-ethers (**12** and **14**), and the 6-ketone and 5β-CH_3 functions for the keto-ether (**13**), closely resemble that for the corresponding back-bone rearranged compounds the limited NMR analogy would appear secure.

Elution with benzene and benzene-ether mixtures gave epoxide (**2a**; 7%) and 3α-hydroxy-5α-cholestan-6-one (19%) respectively, each being identified by comparison with an authentic sample.

Finally elution with ether–methanol gave the back-bone rearranged 3α,6β-diol (**16**; 36%), the structure of which followed[2,8,9] from a consideration of its UV and NMR spectra (see Experimental).

Extended treatment (30 min) of the epoxide (**2a**) with BF_3–etherate in benzene gave the following products: unidentified non-polar material (7%), 3α-hydroxy-5α-cholestan-6-one (19%), epoxide (**2a**; 4%), the 3α,6β-dihydroxy-Δ^9-compound (**17a**; 22%) and the rearranged 3α,6β-diol (**16**; 41%). The structure of the Δ^9-diol (**17a**) followed from a consideration of its UV and NMR spectra and its conversion on oxidation with CrO_3-acetone into the known Δ^9-3,6-diketone.[10]

Comparison of the relative yields of products from the short and long-term reactions above suggested that the 3α,10α-oxido-6β-alcohol (**12**) was converted on longer-term (30 min) treatment with BF_3-etherate in benzene into a mixture (ca. 4 : 1) of the Δ^9- (**17a**) and $\Delta^{13(17)}$- (**16**) 3α,6β-diols. This conclusion was confirmed by an independent reaction.

3α-*Acetoxy*-5,6β-*epoxy*-5β-*cholestane* (**2b**). Treatment of the 3α-acetoxy-epoxide (**2b**) with BF_3-etherate in methylene chloride rapidly (30 sec) gave a single product

(TLC). The composition of the reaction mixture was not further changed by prolonged (12 hr) reaction. The product isolated from a short-term (30 sec) reaction was identified as the 5α-acetoxy-3α,6β-diol (**18a**) on the basis of IR and NMR spectra, and of the conversion of the acetoxy-diol (**18a**) into the known[11] 5α-acetoxy-3,6-diketone (**18b**) on oxidation with CrO_3–acetone. The acetoxy-diol (**18a**) is considered to arise (Fig. 1) from the acetoxy-epoxide (**2b**) *via* the 3α,5α-acetonium ion (**19**), which on treatment with aqueous $NaHCO_3$ gives the 3α-hydroxy-5α-acetate structure.[12]

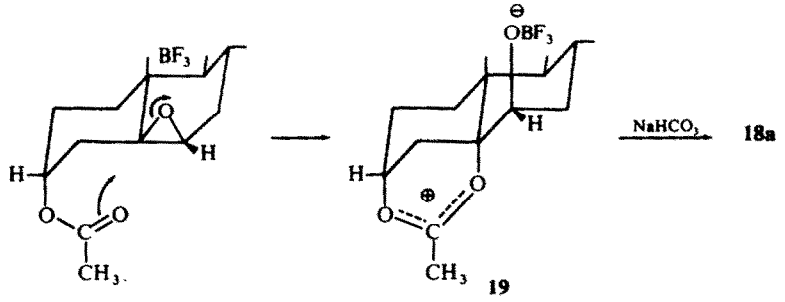
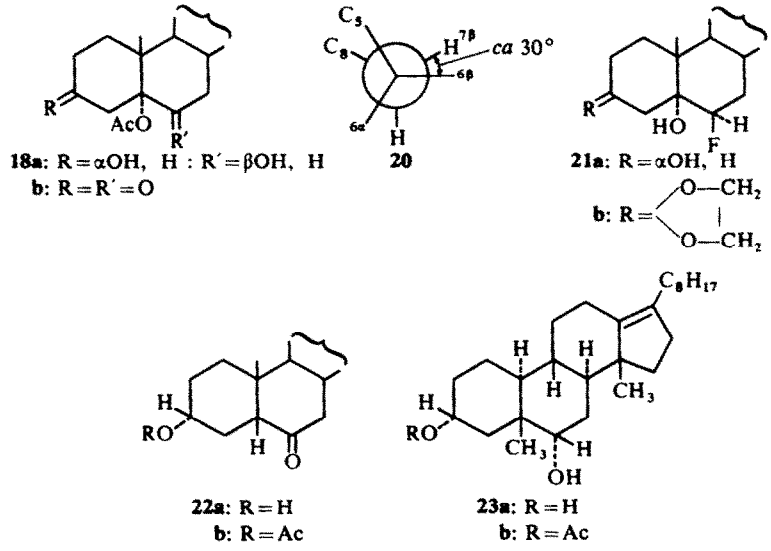


FIG. 1

3α-Hydroxy-5,6α-epoxy-5α-cholestane (**1a**). Reaction of epoxide (**1a**) with BF_3-etherate in benzene was shown (TLC) to be rapid (25 sec). Chromatography on alumina allowed the separation of the major products. The first compound eluted was identified as the 3α,10α-oxido-6α-hydroxy compound (**14**; 13%) on the following



evidence. Oxidation of the hydroxy–ether (**14**) gave the keto–ether (**13**), also obtained from the epimeric alcohol (**12**). The NMR spectrum of **14** exhibited the following signals: δ 4·37 ppm ($W_{h/2}$=12 c/s, 1H; C^3—H), 3·55 ppm ($W_{h/2}$=9 c/s, 1H;

$C^6\underline{H}OH$), 1·11 ppm (5β-CH_3). For the 6-hydroxy-3α,10α-ethers (**12** and **14**) rings A and B are constrained in the flexible boat form. The deshielded position (Δ 0·2 ppm) of the C^6—$\underline{H}$ in the 6β-hydroxy-ether (**12**) relative to the corresponding signal for the 6α-hydroxy-ether (**14**) may be rationalized in terms of the deshielding effect of the ether–oxygen on the immediately adjacent 6α-H in **12**. In order to minimize non-bonded interactions associated with a pure boat conformation, and to relieve interactions between the C^1- and C^{11}-methylene groups, it is suggested that the 3α,10α-ethers (**12** and **14**) exist in a conformation defined by the Newman projection (**20**) for the C^6–C^7 bond. Evidence for this conformation is available in half-band widths of the $C^6\underline{H}OH$ signals for the hydroxy-ethers (**12** and **14**); $W_{h/2}$ is significantly larger for the 6β-hydroxy-(6α-H)-ether (**12**).

The second compound eluted was the fluorohydrin (**21**; 47%), the structure of which was confirmed by its NMR spectrum. In particular, the character of the signals due to the 19-CH_3 (δ 1·04 ppm; $J=5$ c/s) and C^6—H (δ 4·30 ppm; $J=50$ c/s) point to a 6β-F function.

Elution with benzene–ether gave a gum, the major component (ca. 70%) of which was shown (TLC and NMR) to be 3α-hydroxy-5β-cholestan-6-one (**22a**; estimated 14% yield). Acetylation of the mixture gave a product, the major component of which was identical with an authentic sample (**22b**).

Further elution with benzene–ether mixtures again gave a mixture (ca. 7:2:1 by TLC) of three components. Comparison of TLC and NMR data for an authentic sample of the 3α,6α-dihydroxy-$\Delta^{13(17)}$-compound (**23a**) with the data for the above mixture allowed the identification as (**23a**) of the major component (estimated 10% yield).

Reaction of the 6α-hydroxy-ether (**14**) with BF_3-etherate in benzene for 3 hr gave a complex mixture (TLC), in which the 3α,6α-dihydroxy-$\Delta^{13(17)}$-compound (**23a**) appeared to be a major product.

DISCUSSION

As in backbone rearrangements the mechanistic path to the 6-hydroxy-3α-10α-ethers (**12** and **14**) involves C^5—O bond cleavage to give a C-5 carbonium ion, followed by migration of the 19-Me group to the 5β-position. For the 3α-hydroxy compounds (**1a** and **2a**) capture of the C-10 carbonium ion by the conveniently placed 3α-OH group competes with the 9α-10α-hydride shift, the next step in the backbone rearrangement.

The isolation from the BF_3-catalysed rearrangement of the 3α-hydroxy-5β,6β-epoxide (**2a**) of products (total 63%) with a 5β-methyl-19-nor-structure (i.e. **12** and **16**) provides further evidence in support of the suggestion[13] that BF_3-catalysed rearrangements of epoxides may involve tertiary carbonium ions as discrete intermediates. Similar BF_3-catalysed epoxide rearrangements involving migration of a functional group *cis* to the departing epoxide oxygen atom have been noted earlier.[8,14]

A notable feature of the rearrangements of the 5,6-epoxides (**1a, 1b, 2a**) is the relatively low yield (14–19%) of 6-ketones. While only fluorohydrin (**21b**; ca. 50%) was isolated[3] from the rearrangement of the 3-ketal-5α,6α-epoxide (**1c**), 6-ketones (56%) and a $\Delta^{13(17)}$ backbone rearranged compound (10%) were major products[4] from rearrangement of the 3-ketal-5β,6β-epoxide (**2c**). It is now clear that this anomaly is

more apparent than real. The rearrangement of the 3-ketal-5α,6α-epoxide (**1c**) was carried out in benzene–ether solvent (1 : 1) while the rearrangements in this present work used benzene solutions. Evidence is now available[15] which points to a distinct change in reaction products on admixture of only very small quantities (ca. 1-3%) of ether to the benzene solvent for BF_3-catalysed rearrangements of epoxides.

The inversion on the relative yields of 6-ketone and 5β-methyl-19-nor products from the 3-ethylenedioxy-ketal-(56 : 10) and 3α-hydroxy-(19 : 63) 5β,6β-epoxides may be rationalized in terms of the interaction in the transition state between the migrating 19-Me group and the 3β-O atom of the 3-ketal function. This effect would depress the relative yield of 5β-methyl-19-nor products from the 3-ketal-epoxide (**2c**).

EXPERIMENTAL

Rotations were measured for $CHCl_3$ solns at room temp. IR spectra were recorded on a Perkin–Elmer 337 spectrometer. UV spectra were recorded for cyclohexane solns. Alumina used for chromatography was P. Spence, Grade H, deactivated by the addition of 5% of 10% AcOH. Silica gel used for chromatography was Crosfield Sorbsil Grade 60–120. Light petroleum refers to the fraction of b.p. 50–70°. ORD curves (in MeOH) were kindly determined by Professor W. Klyne. NMR spectra were determined at 60 Mc in $CDCl_3$ with $CHCl_3$ and TMS as internal standards.

3β-*Tosyloxy*-5,6β-*epoxy*-5β-*cholestane* (**3b**)

The epoxide **3a** (25 g) in pyridine (50 ml) was added to toluene-*p*-sulphonyl chloride (22·5 g) in pyridine (50 ml) and the resulting soln kept at 20° for 16 hr. The steroidal material (34·65 g), isolated *via* ether, was adsorbed on silica (1 kg). Elution with light petroleum–benzene (1 : 4) and crystallization from pentane–ether gave the *epoxy-tosylate* (**3b**) as plates (15·5 g), m.p. 99·5–100·5°, $[\alpha]_D$ + 11° (*c* 0·82) ν_{max} (Nujol) 1350, 1185 and 1170 cm^{-1}. (Found: C, 73·3; H, 9·3; S, 5·95. $C_{34}H_{52}SO_4$ requires: C, 73·7; H, 9·4; S, 5·8%); NMR δ 7·88, 7·74, 7·41, 7·28 ppm (aromatic H); 4·58 ppm ($W_{h/2}$ 18 c/s; C^3-H); 2·98, 2·93 ppm (C^6-H); 2·45 ppm ($C\underline{H}_3$—C_6H_4—); 0·96 ppm ($C^{19}H_3$); 0·63 ppm ($C^{18}H_3$); 0·92, 0·82 ppm (side-chain CH_3).

Elution with benzene gave a solid (19·0 g) which was partially separated by further careful chromatography into its two components, chlorohydrins (**4** and **5**), present in relative yield ca. 3 : 1. The pure compounds were characterized: *chlorohydrin* (**4**), m.p. 157–162 (dec), ν_{max} (CS_2) 3625, 1370, 1191, 1179 cm^{-1}. (Found: C, 68·6; H, 8·7; S, 5·0. $C_{34}H_{53}SO_4Cl$ requires: C, 68·8; H, 9·0; S, 5·4%); NMR δ 7·91, 7·77, 7·43, 7·28 ppm (aromatic H); 5·12 ppm ($W_{h/2}$ 25 c/s; C^3—H); 3·88 ppm ($W_{h/2}$ 5 c/s; C^6—H); 2·46 ppm ($C\underline{H}_3$—C_6H_4—); 1·25 ppm ($C^{19}H_3$); 0·66 ppm ($C^{18}H_3$); 0·91, 0·81 ppm (side chain CH_3).

Chlorohydrin (**5**), m.p. 140·5–143° (dec), ν_{max} (CS_2) 3610, 1190, 1179 cm^{-1}, (Found: C, 69·1; H, 9·0; S, 5·6. $C_{34}H_{53}SO_4Cl$ requires C, 68·8; H, 9·0; S, 5·4%); NMR δ 7·91, 7·77, 7·43, 7·28 ppm (aromatic H); 5·02 ppm ($W_{h/2}$ 8 c/s; C^3—H; 4·27 ppm ($W_{h/2}$ 20 c/s; C^6—H); 2·45 ppm ($C\underline{H}_3$—C_6H_4—); 0·96 ppm ($C^{19}H_3$); 0·63 ppm ($C^{18}H_3$); 0·91 and 0·81 ppm (side chain CH_3).

3α-*Hydroxy*-5,6β-*epoxy*-5β-*cholestane* (**2a**)

The epoxy-tosylate (**3b**; 23·5 g) was heated under reflux for 2 hr with Li_2CO_3 (27·5 g) in DMF (280 ml). Isolation by means of ether gave a gum (16·52 g) which was treated with KOH (8 g) in MeOH (400 ml) at 20° for 24 hr. The solid material (12·8 g), isolated *via* ether was adsorbed onto alumina (750 g). Elution with light petroleum gave a gum (131 mg) which was not investigated.

Elution with light petroleum–benzene (40 : 1) gave 5,6β-*epoxy*-5β-*cholest*-2-*ene* (**6**; 1·43 g) as needles (Et_2O), m.p. 74–75°, $[\alpha]_D$ + 30° (*c* 1·07), NMR 5·83, 5·77, 5·73 ppm (C^2—H, C^3—H); 3·01, 2·98 ppm (C^6—H); 0·985 ppm ($C^{19}H_3$); 0·65 ppm ($C^{18}H_3$) 0·92, 0·82 ppm (side chain CH_3); (Found: C, 84·4; H, 11·5. $C_{27}H_{44}O$ requires; C, 84·5; H, 11·45%).

Elution with light petroleum–benzene (4 : 1) gave **7** (700 mg) as needles (from pentane), m.p. and m.m.p. 106–107°, $[\alpha]_D$ + 27° (*c* 1·07), ν_{max} (KBr) 1693 cm^{-1}; NMR δ 6·45, 6·39, 6·32 ppm (C^4—H); 0·98 ppm ($C^{19}H_3$); 0·71 ppm ($C^{18}H_3$); 0·92 and 0·82 ppm (side chain CH_3).

Elution with light petroleum–benzene (3 : 2) gave 6β-*hydroxy*-*cholesta*-2,4-*diene* (**8**; 1·03 g) as fine needles (from Et_2O), m.p. 94–95°, $[\alpha]_D^{CCl_4}$ + 175° (*c* 1·05), ν_{max} (CS_2) 3625, 3047 cm^{-1}, λ_{max} 265 mμ (ε

6400), (Found: C, 84·6; H, 11·55. $C_{27}H_{44}$ requires: C, 84·5; H, 11·45%); NMR δ 5·80 ppm (C^2—H, C^3—H, C^4—H); 4·34, 4·30, 4·25 ppm (C^6—H); 1·11 ppm ($C^{19}H_3$); 0·72 ppm ($C^{18}H_3$); 0·92, 0·82 ppm (side chain CH_3), ORD (MeOH) a_{238}^{286} +741.

Elution with light petroleum–benzene (2:3) gave **2a** (7·1 g) as prisms (CH_2Cl_2), m.p. 160–161°, $[\alpha]_D$ +1° (*c* 0·55), NMR δ 4·18 ppm ($W_{h/2}$ 8 c/s; C^3—H); 3·09, 3·05 ppm (C^6—H); 0·98 ppm ($C^{19}H_3$); 0·65 ppm ($C^{18}H_3$); 0·92, 0·82 ppm (side chain CH_3). (Lit. values[16]: m.p. 165–167°).

Elution with benzene–ether (9:1) gave a mixture of polar compounds (1·2 g) Which was not investigated.

Oxidation of cholesta-2,4-dien-6β-ol (**8**)

Chromium trioxide–pyridine complex (300 mg in 3 ml) was added to the steroid (346 mg) in pyridine (1 ml) and the mixture kept at 20° for 2 hr. The steroidal material (180 mg), isolated by means of CH_2Cl_2, was adsorbed onto alumina (20 g).

Elution with light petroleum–benzene (9:1) gave **9** (99 mg) as needles (EtOH), m.p. 127–128°, $[\alpha]_D$ +21° (*c* 0·93), ν_{max} (KBr) 1670 cm^{-1}, λ_{max} 305·5 mμ (ε 8100), NMR δ 6·91, 6·86, 6·85, 6·80 ppm (C^4—H); 6·125, 6·10, 6·07, 6·05 ppm (C^2—H, C^3—H); 1·02 ppm ($C^{19}H_3$); 0·71 ppm ($C^{18}H_3$); 0·925, 0·825 ppm (side chain CH_3), ORD (MeOH) a_{277}^{324} +306. (Lit. value[6]: m.p. 129–130°).

Elution with benzene gave **10** (60 mg) as a gum (ca. 80% pure by TLC), λ_{max} 234 mμ (ε 8100), 264 mμ (ε 4380), ν_{max} (film) 1666 cm^{-1}, NMR δ 6·89, 6·84, 6·81, 6·76 ppm (C^2—H, C^6—H); 6·24, 6·20, 6·19, 6·17, 6·07, 6·05, 6·03, 6·01 ppm (C^3—H); 1·10 ppm ($C^{19}H_3$); 0·71 ppm ($C^{18}H_3$); 0·92, 0·82 ppm (side chain CH_3).

BF_3-*Catalysed rearrangement of* 3α-*hydroxy*-5,6β-*epoxy*-5β-*cholestane* (**2a**)

(a) The epoxide (200 mg) in benzene (2 ml) was treated with BF_3—Et_2O (0·2 ml) for 35 sec. The product, isolated *via* ether was adsorbed on alumina (20 g). Elution with light petroleum–benzene (1:1) gave non-polar material (6 mg) which was not investigated.

Elution with benzene gave 6β-*hydroxy*-3α,10α-*oxido*-5β-*methyl*-19-*norcholestane* (**12**; 55 mg) as needles ($CHCl_3$), m.p. 168–169°, ν_{max} (KBr) 3460, 917 cm^{-1}, (Found: C, 80·35; H, 11·6. $C_{27}H_{46}O_2$ requires: C, 80·4; H, 11·5%); NMR δ 4·34 ppm ($W_{h/2}$ 12 c/s; C^3—H); 3·89, 3·75, 3·62 ppm (C^6—H); 1·075 ppm ($C^{19}H_3$); 0·66 ppm ($C^{18}H_3$); 0·92, 0·82 ppm (side chain CH_3).

Further elution with benzene gave starting material (15 mg) m.p. 159–161°. Elution with benzene–ether (3:2) gave 3α-hydroxy-5α-cholestan-6-one (38 mg) as needles (MeOH), m.p. 157–159°, $[\alpha]_D$ +3° (*c* 1·05), ν_{max} (KBr) 3466, 1713 cm^{-1}, NMR δ 4·13 ppm ($W_{h/2}$ 6 c/s; C^3—H); 0·73 ppm ($C^{19}H_3$); 0·67 ppm ($C^{18}H_3$); 0·92, 0·825 ppm (side chain CH_3). Lit. Values,[1] m.p. 160–161°, $[\alpha]_D$ +2·6°.

Elution with Et_2O-MeOH (50:1) gave the 3α,6β-*dihydroxy*-$\Delta^{1(3)(17)}$-*olefin* (**16**; 72 mg) as plates (Et_2O), m.p. 134–135°, $[\alpha]_D$ +24° (*c* 0·5), ν_{max} (KBr) 3340 cm^{-1}, $\varepsilon_{195\ nm}$ 11800, ε_{200} 10300, ε_{205} 9000, ε_{210} 7400, (Found: C, 78·6; H, 11·3. $C_{27}H_{46}O_2$ $\frac{1}{2}H_2O$ requires C, 78·6; H, 11·52%); NMR δ 3·85 ppm ($W_{h/2}$ 20 c/s; C^3—H); 3·33 ppm ($W_{h/2}$ 14 c/s; C^6—H); 1·01, 0·91 ppm (decoupled −88 c/s; $C^{21}H_3$); 0·905 ppm (5β-CH_3); 0·85 ppm (14β-CH_3); 0·905, 0·795 ppm ($C^{26}H_3$, $C^{27}H_3$).

(b) The epoxide (1 g) in benzene (10 ml) was treated with BF_3·Et_2O (1 ml) and the mixture kept at 20° for 30 min. The product, isolated by means of ether, was adsorbed onto alumina (80 g).

Elution with light petroleum–benzene (1:1) gave non-polar mixtures (76 mg); benzene-ether (7:3) gave 3α-hydroxy-5α-cholestan-6-one (193 mg), followed by starting material (36 mg).

Elution with benzene-ether (1:3) gave the 3α,6β-*dihydroxy*-Δ^9-*olefin* (**17a**; 219 mg) as a gum (pure by TLC), $[\alpha]_D$ +73° (*c* 1·09), ν_{max} (CS_2) 3624 cm^{-1}, $\varepsilon_{205\ nm}^{EtOH}$ 8150, ε_{207} 7530, ε_{210} 6200, ε_{215} 3760, (Found: C, 80·5; H, 11·8. $C_{27}H_{46}O_2$ requires C, 80·4; H, 11·5%); NMR δ 3·95 ppm ($W_{h/2}$ = 15 c/s) 3·575 ppm ($W_{h/2}$ = 16 c/s) (C^3—H, C^6—H); 1·035 ppm (5β-CH_3); 0·81 ppm ($C^{18}H_3$); 0·92, 0·82 ppm (side chain CH_3).

Elution with Et_2O-MeOH (19:1) gave the $\Delta^{1(3)(17)}$-compound (**16**; 415 mg), m.p. and m.m.p. 133–135°.

3α,10α-*Oxido*-5β-*methyl*-19-*norcholestan*-6-*one* (**13**)

Oxidation of **12** (20 mg) with chromic acid–acetone gave (**13**; 12 mg) as plates (Et_2O), m.p. 94–95°, $[\alpha]_D$ −10° (*c* 0·99), ν_{max} (KBr) 1716 cm^{-1}, (Found: C, 80·7; H, 11·2. $C_{27}H_{44}O_2$ requires: C, 81·0; H, 11·0%); NMR δ 4·33 ppm ($W_{h/2}$ = 12 c/s; C^3—H); 1·30 ppm (5β-CH_3); 0·73 ppm ($C^{18}H_3$); 0·92, 0·82 ppm (side chain CH_3). The material was identical with that obtained below by oxidation of **14**.

3α,5-Oxido-5α-cholestane (**15**)

The ether, prepared as in the lit,[17] needles (acetone), m.p. 82–83°, $[\alpha]_D$ +54° (*c* 0·95) (Lit. values:[17] m.p. 82–86°, $[\alpha]_D$ +59°), ν_{max} (KBr) 890 cm^{-1} gave NMR δ 4·51, 4·39 ppm (C^3—H); 0·89 ppm ($C^{19}H_3$); 0·67 ppm ($C^{18}H_3$); 0·91, 0·82 ppm (side chain CH_3).

Δ^9-3,6-Diketone (**17b**)

Oxidation of **17a** (82 mg) with chromic acid–acetone gave the Δ^9-3,6-diketone(**17b**; 60 mg) as needles (Et_2O–MeOH), m.p. and m.m.p. 102–103°, $[\alpha]_D$ +44° (*c* 1·01), NMR δ 1·22 ppm (5β-CH_3); 0·81 ppm ($C^{18}H_3$); 0·925, 0·825 ppm (side chain CH_3). (Lit. values:[10] m.p. 105–106°, $[\alpha]_D$ +46°.)

3α-Acetoxy-5,6β-epoxy-5β-cholestane (**2b**)

The hydroxy-epoxide (**2a**; 2·5 g) in pyridine (25 ml) was treated with Ac_2O (2·5 ml) and the soln kept at 20° for 36 hr. The crude product (2·63 g), isolated *via* ether, was adsorbed onto alumina (120 g).

Elution with light petroleum gave the *acetoxy-epoxide* (**2b**; 2·33 g) as needles (pentane), m.p. 61·5–62°, $[\alpha]_D$ +6° (*c* 1·17), ν_{max} (KBr) 1740, 1245 cm^{-1}, (Found: C, 78·2; H, 11·0. $C_{29}H_{48}O_3$ requires: C, 78·4; H, 10·8%); NMR δ5·13 ppm ($W_{h/2}$=8 c/s; C^3—H); 3·01, 2·975 ppm (C^6—H); 1·00 ppm ($C^{19}H_3$); 0·66 ppm ($C^{18}H_3$); 0·92 and 0·82 ppm (side chain CH_3).

BF_3-*Catalysed rearrangement of* 3α-*acetoxy*-5,6β-*epoxy*-5β-*cholestane* (**2b**)

The epoxide (480 mg) in CH_2Cl_2 (5 ml) was treated with $BF_3 \cdot Et_2O$ (0·5 ml) and kept at 20° for 1 min. The crude product (492 mg), isolated *via* CH_2Cl_2, was crystallized from CH_2Cl_2 to give the 5α-*acetoxy*-3α,6β-*diol* (**18a**; 420 mg) as plates, m.p. 181–182°, $[\alpha]_D$ +6° (*c* 1·01), ν_{max} (KBr) 3414, 1734 cm^{-1}, (Found: C, 75·15; H, 11·0. $C_{29}H_{50}O_4$ requires: C, 75·4; H, 10·8%) NMR δ 4·65 ppm ($W_{h/2}$=5·5 c/s; C^6—H); 4·18 ppm ($W_{h/2}$=8·5 c/s; C^3—H); 2·00 ppm ($C\underline{H}_3$—CO_2—); 1·15 ppm ($C^{19}H_3$); 0·69 ppm ($C^{18}H_3$); 0·92, 0·82 ppm (side chain CH_3).

5α-Acetoxy-cholesta-3,6-*dione* (**18b**)

Oxidation of the acetoxy-diol (**18a**; 100 mg) with chromic acid–acetone gave the diketone (**18b**; 82 mg) as prisms (MeOH), m.p. 160–162°, $[\alpha]_D$ +3° (*c* 0·96); (Lit. values:[11] m.p. 165–166°, $[\alpha]_D$ +3·7°); NMR δ 2·02 ppm ($C\underline{H}_3$—CO_2—); 1·04 ppm ($C^{19}H_3$); 0·68 ppm ($C^{18}H_3$); 0·92, 0·82 ppm (side chain CH_3).

BF_3-*Catalysed rearrangement of* 3α-*hydroxy*-5,6α-*epoxy*-5α-*cholestane* (**1a**)

The epoxide (1 g) in benzene (10 ml) was treated with $BF_3 \cdot Et_2O$ (1 ml) and the soln kept at 20° for 25 sec. The product, isolated *via* Et_2O, was adsorbed onto alumina (70 g).

Elution with light petroleum–benzene (3 : 2) gave the 6α-*hydroxy*-3α,10α-*oxido-compound* (**14**; 132 mg) as needles (pentane), m.p. 106–108°, $[\alpha]_D$ +6° (*c* 1·11), ν_{max} (KBr) 3453, 913 cm^{-1}, (Found: C, 80·6; H, 11·35. $C_{27}H_{46}O_2$ requires: C, 80·4; H, 11·5%); NMR δ 4·375 ppm ($W_{h/2}$=12 c/s; C^3—H); 3·55 ppm ($W_{h/2}$ = 9 c/s; C^6—H); 3·30 ppm (OH; removed by D_2O); 1·11 ppm (5β-CH_3); 0·67 ppm ($C^{18}H_3$); 0·92, 0·82 (side chain CH_3).

Elution with light petroleum–benzene (2 : 3) gave the *fluorohydrin* (**21a**; 474 mg) as needles ($CHCl_3$), m.p. 185–186°, $[\alpha]_D$ +7° (*c* 1·03), ν_{max} (KBr) 3290 cm^{-1} (Found: C, 76·8; H, 11·2; F, 4·5. $C_{27}H_{47}O_2F$ requires: C, 76·8; H, 11·1; F, 4·5%); NMR δ 4·33 ($W_{h/2}$=8 c/s; C^3—H); 4·30 ppm (J=50 c/s; C^6—H); 3·14 ppm (OH; removed by D_2O); 1·04 ppm (J=5·5 c/s; $C^{19}H_3$); 0·67 ppm ($C^{18}H_3$); 0·92, 0·82 ppm (side chain CH_3).

Elution with benzene–ether (1 : 1) gave **22a** 271 mg) as a gum (70% pure by TLC). ν_{max} (film) 3462, 1700 cm^{-1}, NMR (CCl_4)δ 3·48 ppm ($W_{h/2}$ = 21 c/s; C^3—H); 0·85 ppm ($C^{19}H_3$); 0·67 ppm ($C^{18}H_3$); 0·92, 0·82 ppm (side chain CH_3). Acetylation of the gum (Ac_2O–pyridine, 2 hr at 80°) gave **22b** identified by comparison (TLC, NMR) with an authentic sample.

Further elution with benzene–ether (1 : 1) gave a mixture (152 mg) of three compounds (TLC ratio: 7 : 2 : 1). The major component was identified as **23a** by comparison (TLC, NMR) with an authentic sample, prepared by hydrolysis of **23b**.[2] The pure 3α,6α-*diol* (**23a**) gave needles (MeOH), m.p. 146–148°, $[\alpha]_D$ +50° (*c* 1·16), ν_{max} (KBr) 3360 cm^{-1}, (Found: C, 80·3; H, 11·8. $C_{27}H_{46}O_2$ requires: C, 80·4; 11·5%); NMR δ 3·65 ppm ($W_{h/2}$=16 c/s, C^3—H); 3·42 ppm ($W_{h/2}$=6 c/s; C^6—H); 1·85 ppm (OH; removed by D_2O); 0·90 ppm (5β—CH_3, 14β—CH_3); 1·00, 0·90 ($C^{21}H_3$; decoupled −88 c/s); 0·90, 0·80 ppm (side chain CH_3).

Oxidation of 6α-*hydroxy*-3α,10α-*oxido*-5β-*methyl*-19-*norcholestane* (**14**)

Oxidation of the hydroxy–ether (**14**; 100 mg) with chromic acid–acetone gave the 6-ketone (**13**; 75 mg) as plates (Et_2O), m.p. and m.m.p. 94–95°, $[\alpha]_D$ −9° (*c* 1·01).

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