Stereospecific Synthesis of 1,2-Dioxolanes by Alkoxy Radical *β*-Fragmentation of Steroidal Cyclic Peroxyhemiacetals

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A new one-pot synthesis of 3,5-substituted 1,2-dioxolanes from six-membered cyclic peroxyhemiacetal derivatives of hexahydrobenzo[*c*][1,2]dioxin-8a-ol is described. A number of steroidal peroxyhemiacetals, (2*S*,2′*S*,3*R*)-(**11**), (2*S*,2′*R*,3*R*/*S*)-(**13**), (2*R*,2′*R*,3*R*/*S*)-2-(2′-hydroperoxypropyl-3′-phenylsulfonyl)-5α-cholestan-3-one 2′,3-peroxyhemiacetal (**17**), and (2*S*,5*R*)-2-hydroperoxy-3-phenylsulfonyl-4-nor-3,4-secocholestan-5-one 2,5-peroxyhemiacetal (**24**), have been prepared in order to test the scope and diastereoselectivity of the present methodology. These substrates were irradiated with visible light in the presence of (diacetoxyiodo)benzene and iodine to generate the corresponding alkoxy radical, which undergoes regioselective *β*-fission yielding a carbon radical, that further reacts in a stereoselective manner with an iodine atom to give a 10-membered peroxylactone. This iodide intermediate is intramolecularly substituted by the peroxide anion generated by intermolecular nucleophilic attack of a hydroxide or methoxide anion to the acyl carbon with concomitant carbon−oxygen bond cleavage. This operationally simple reaction permitted us to synthesize methyl (2*S*,2′*S*)-(**33**), (2*S*,2′*R*)-(**34**), (2*R*,2′*R*)-1-[5′-[(phenylsulfonyl)methyl]-[1′,2′]dioxolan-3′-yl]-2-nor-2,3-secocholestan-3-oate (**36**), and methyl (1′*R*,1‴*R*,3′a*S*,3″*R*,4′*S*,5′*S*,5″*S*,7′a*R*)-3-[5′-[5″-(phenylsulfonyl)methyl]-3″-methyl[1″,2″]dioxolan-3″-yl]-1′-(1‴,5‴-dimethylhexyl)-7′a-methyloctahydroinden-4′-yl]propanoate (**37**) in good yields.

1,2-Dioxolanes are found in biologically important compounds such as antifungal marine natural products,[1] prostaglandins, and oxidized lipids.[2] However, despite the significance of these compounds, only a small number of synthetic procedures have been reported to date. These methods basically rely upon cyclization of functionalized hydroperoxides,[3] dioxygenation of cyclopropane rings,[4] and 1,3-dipolar addition of carbonyl oxides[5] or hydroperoxycarbenium ions[6] to alkenes.

The synthesis of 1,3-diols in a stereocontrolled manner is of considerable interest because these subunits are present in naturally occurring substances, such as polyene macrolides,[7] with an important degree of structural complexity and significant physiological activity. 1,2-Dioxolanes are adequate precursors of 1,3-diols through reductive cleavage of the peroxide bond,[8] although *β*-keto alcohols can also be obtained.[9] These last compounds can be reduced in a diastereoselective manner to give *syn*-[10] or *anti*-diols.[11]

Earlier reports from this laboratory have described the synthesis of medium-sized lactones III via *β*-fragmenta-

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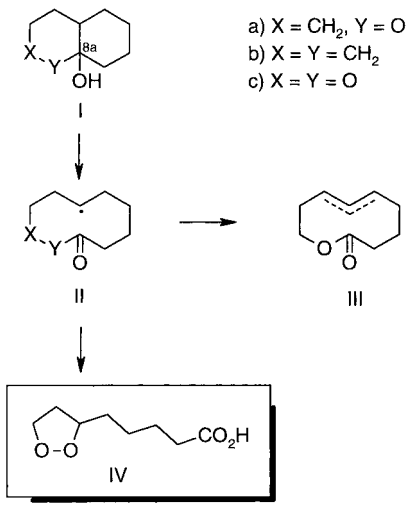
Scheme 1



tion of alkoxy radicals generated by irradiation of hemiacetals of the type of octahydrochromen-8a-ol (Ia) in the presence of a hypervalent organoiodine reagent[12] (Scheme 1). When the reaction is carried out under an oxygen atmosphere, the intermediate carbon radical IIb can be peroxidated and the resulting peroxy radical can be trapped by a conveniently positioned carbon−carbon or carbon−oxygen double bond to give 1,2-dioxolanes[13] or β-peroxylactones,[14] respectively. In a continuation of our studies, we envisioned a conceptually simple methodology for the construction of medium-sized peroxylactones, which, to the best of our knowledge, are hitherto unknown. This task could be accomplished by β-fragmentation of peroxyhemiacetal derivatives of hexahydrobenzo[*c*][1,2]dioxin-8a-ol (Ic) (Scheme 1), the sequence being analogous to that for the synthesis of medium-sized lactones III. In most cases, however, medium-sized peroxylactones could not be isolated and the radical intermediate IIc evolved to 1,2-dioxolane IV, presumably by intramolecular cyclization of the peroxide function promoted by nucleophilic hydroxide or methoxide ion attack (vide infra).

In this paper, we report on the preparation of steroidal (phenylsulfonyl)hydroperoxides **11**, **13**, **17**, and **24** as starting materials in order to explore the scope and regio- and stereoselectivity of this new approach to the synthesis of 1,2-dioxolanes. The synthesis of hydroperoxides is a well-documented process,[15] with a number of simple ways to prepare hydroperoxides from olefins being described in the literature.[16] The hydroperoxide function initially formed can be intramolecularly trapped by a carbonyl group in the appropriate position to give the corresponding cyclic peroxide derivatives of hexahydrobenzo[*c*][1,2]dioxin-8a-ol.[17] In fact, these peroxyhemiacetals on treatment with (diacetoxyiodo)benzene (DIB) and iodine under irradiation with visible light provided a new and efficient synthesis of 1,2-dioxolanes.[18]

Results and Discussion

Synthesis of Peroxyhemiacetals. Substrates **11**, **13**, **17**, and **24** to be used in this study were prepared from γ,δ-unsaturated ketones **2**, **3**, and **7** following the procedure of Yoshida and Isoe[17e] (vide infra). 2-Allyl-5α-cholestan-3-one isomers **2** and **3** were obtained from 2β-allyl-5α-cholestan-3α-ol (**1**), which in turn was prepared by treatment of 2α,3α-epoxy-5α-cholestane[19] with allylmagnesium bromide, essentially following a previously reported procedure.[20] Compound **1** was oxidized by pyridinium chlorochromate[21] to give **2**. Treatment of compound **2** with 0.5% methanolic NaOH afforded the thermodynamic γ,δ-enone **3** in 85% yield from the 2α,3α-epoxide (Scheme 2).

5-Oxo-4-nor-3,4-secocholest-2-ene (**7**) was prepared from 5,5-(ethylenedioxy)-4-nor-3,4-secocholestan-3-ol (**4**)[22] by treatment with *o*-nitrophenyl selenocyanate,[23] in the presence of tri-*n*-butylphosphine,[24] to give the nitrophenylseleno derivative **5** as a yellow noncrystalline solid, in 85% yield. The phenylseleno group of **5** underwent oxidative syn elimination by selenoxide rearrangement, with hydrogen peroxide,[25] yielding enone **6**. Finally, acid cleavage of the protective ethylenedioxy carbonyl group with *p*-toluenesulfonic acid in acetone afforded compound **7**, in 55% overall yield from **4** (Scheme 2).

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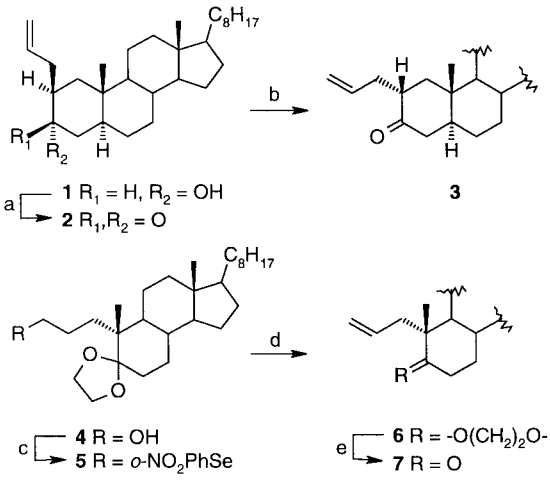
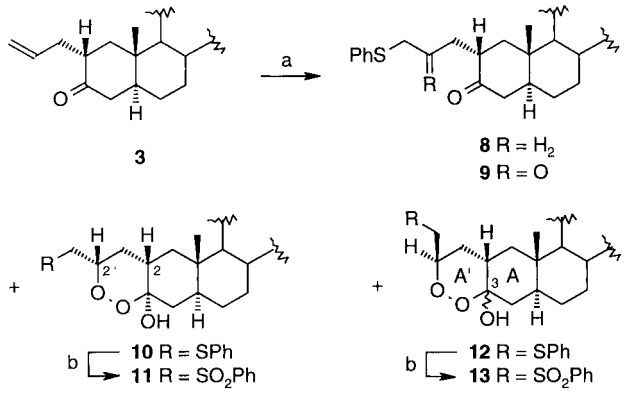
Scheme 2[a]



[a] Key: (a) PCC, CH_2Cl_2, rt, 20 h, 79%; (b) NaOH (0.5%), MeOH, rt, 1 h, 95%; (c) *o*-NO_2PhSeCN, *n*-Bu_3P, THF, 5 h, 85%; (d) H_2O_2 (30%), THF, rt, overnight, 82%; (e) *p*-TsOH·H_2O, acetone, rt, 20 h, 78%.

Scheme 3[a]

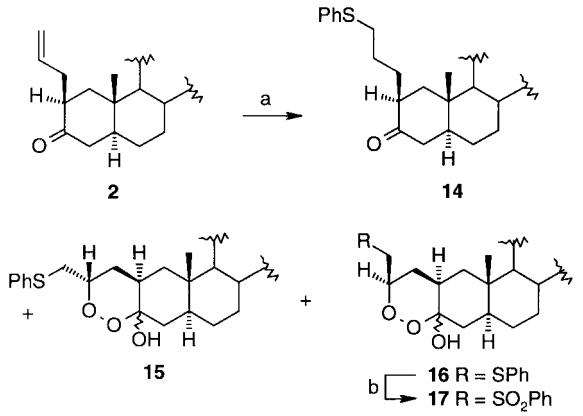


[a] Key: (a) PhSH, O_2, AcOH, rt, 45 h; (b) *m*-CPBA, CH_2Cl_2, rt, 45 min, 88−96%.

Reaction of γ,δ-Unsaturated Ketones 2, 3, and 7 with Molecular Oxygen and Benzenethiol. The following general procedure[17e] was used to prepare the peroxyhemiacetals **11**, **13**, **17**, and **24**. Enone **3**, in acetic acid, was treated with benzenethiol (ca. 4 equiv), while a stream of oxygen was bubbled through the solution at room temperature to give (2′*S*)- and (2′*R*)-peroxyhemiacetals **10** and **12**, in 28 and 25% yield, respectively, the latter as an inseparable mixture (9:1) of cis- and trans-fused AA′ rings. Moreover, the sulfide **8** from benzenethiol reduction of the C-2′ radical intermediate, and the diketone **9**, formed by the acid-catalyzed rearrangement of the C-2′ hydroperoxide, were also obtained as minor products (Scheme 3). Sulfides **10** and **12** were oxidized with *m*-CPBA to the corresponding sulfones **11** and **13** in excellent yields.

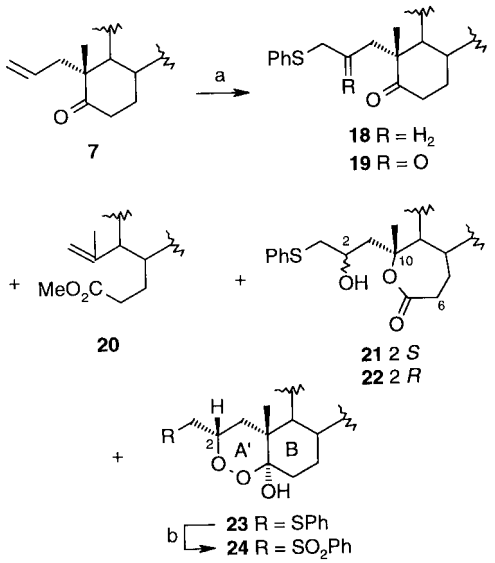
The reaction of enone **2** with the benzenethiol/O_2 system proceeded to give, apart from sulfide **14**, the expected peroxyhemiacetals **15** and **16**, albeit in low yield (Scheme 4). The reaction was more complex than that previously reported because in the acidic reaction conditions the enone **2** partially isomerized to enone **3**, and hence, peroxyhemiacetals **10** and **12** were also obtained in 8 and 4% yield, respectively. Sulfone **17** was obtained by oxidation of sulfide **16**, but all attempts to oxidize

Scheme 4[a]



[a] Key: (a) PhSH, O_2, AcOH, rt, 48 h; (b) *m*-CPBA, CH_2Cl_2, rt, 1 h, 92%.

Scheme 5[a]



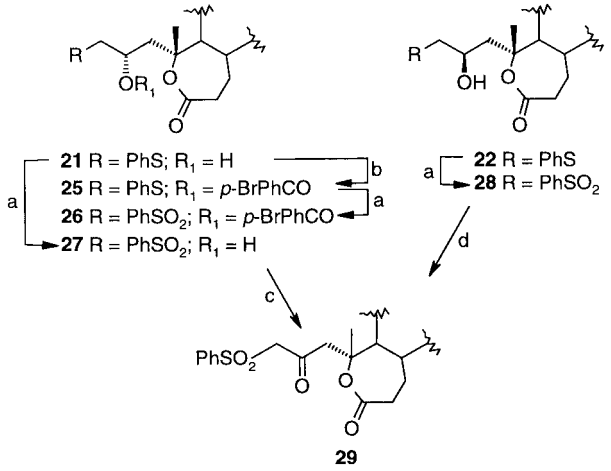
[a] Key: (a) PhSH, O_2, AcOH, rt, 36 h; (b) *m*-CPBA, CH_2Cl_2, rt, 30 min, 95%.

sulfide **15** proved to be unsuccessful, giving rise to a complex mixture of products that was not studied.

When the peroxidation reaction was conducted with the enone **7**, a complex mixture was formed from which the peroxyhemiacetal **23** was isolated in 26% yield. Apart from the previously observed side products **18** and **19**, three new compounds were also obtained: the olefin **20**, which was characterized as its methyl ester, and the seven-membered isomeric lactones **21** and **22** (Scheme 5). The structure of the olefin **20** has been investigated by spectroscopic methods and seems to proceed from the peroxyhemiacetal via a radical mechanism initiated by rupture of the peroxide bond. The lactones **21** and **22** differ only in the stereochemistry at C-2 because the corresponding sulfones **27** and **28** can be oxidized to the same ketone **29** (Scheme 6). The structure and stereochemistry of these lactones were confirmed by X-ray crystallographic analysis[26] of a crystalline *p*-bromoben-

(26) The author has deposited the atomic coordinates for this structure with the Cambridge Crystallographic Data Centre. The coordinates can be obtained, upon request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge, CB2 1EZ, UK.

Scheme 6[a]



[a] Key: (a) *m*-CPBA, CH_2Cl_2, rt, 30−50 min, 89−97%; (b) *p*-bromobenzoyl chloride, Py, rt, 24 h, 64%; (c) PCC, CH_2Cl_2, rt, 26 h, 29%; (d) TPAP, NMO, CH_2Cl_2, rt, 10 min, 38%.

zoate ester derivative **26**. The formation of lactones **21** and **22** can be explained by assuming that peroxyhemiacetal **23** and its unisolated epimer at C-2 undergo an intramolecular Baeyer−Villiger rearrangement.[27] Although there is some evidence for a stereoelectronic control in the regioselectivity of the Baeyer−Villiger reaction,[28] and accordingly, the migrating group in this case should be the secondary center at C-6, only products coming from the migration of the quaternary center (C-10) have been detected.[29]

In all cases, the γ-hydroperoxy carbonyl sulfides **10**, **12**, **15**, **16**, and **23** and sulfones **11**, **13**, **17**, and **24** obtained were in a ring-chain tautomeric equilibrium displaced far to the side of the cyclic peroxyhemiacetal grouping as evidenced by their spectroscopic data.[30] In fact, their IR spectra exhibited an absorption for a tertiary hydroxyl group in the 3578−3595 cm^{-1} region, and their ^{13}C NMR spectra do not present the resonance of a free carbonyl group, but rather a signal corresponding to a hemiacetal carbon at 99−105 ppm (singlet, DEPT experiment).

While the ^1H and ^{13}C NMR spectra for compounds **10**, **11**, **23**, and **24** indicated trans-fused AA′ rings as the sole structure, compounds **12** and **13** showed major signals for a cis-fused structure accompanied by minor signals for a trans-fused one (ca. 9:1, and 4:1, respectively) (Figure 1). In compounds **15**−**17**, the proportions of the two isomers are more balanced (trans:cis, ca. 1.5:1, 2.3:1, and 2.6:1, respectively). These results are in accord with MMX force-field[31] calculations.

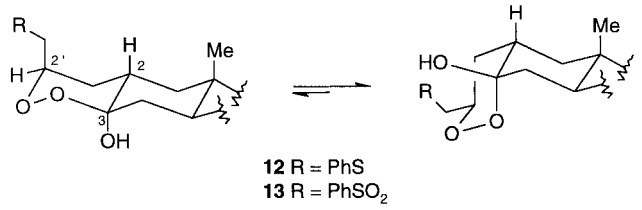
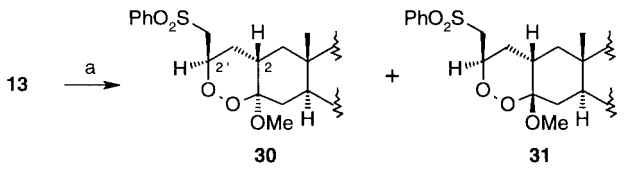


Figure 1. Peroxyhemiacetal tautomeric equilibrium.

Scheme 7[a]



[a] Key: (a) *p*-TsOH·H_2O, MeOH/CH_2Cl_2, rt, 24 h, 81% (ca. 1:1).

The sulfone **13** was studied as its conformationally locked methyl acetal derivatives **30** and **31** (Scheme 7). These compounds were obtained in 81% yield (ca. 1:1), by treatment of the sulfone **13** with MeOH in the presence of catalytic amounts of *p*-TsOH. The acetal **30** showed coupling constants at $J_{2'\alpha,1'\alpha} = 1.3$ Hz (eq−ax) and $J_{2'\alpha,1'\beta} = 4.5$ Hz (eq−eq), while acetal **31** showed $J_{2'\alpha,1'\beta} =$ 11.1 Hz (ax−ax) and $J_{2'\alpha,1'\alpha} = 1.8$ Hz (ax−eq) as corresponding for the trans- and cis-fused AA′ ring system, respectively.

Radical β-Fragmentation of Peroxyhemiacetals 11, 13, 17, and 24. At first, the sulfide **10** was subjected to our standard reaction conditions for generation of the alkoxy radical,[12] with 1.1−1.5 equiv of DIB and 1 equiv of I_2 at different temperatures (−20, 0, +20, or +40 °C) and reaction times (15−60 min) while the solution was irradiated with visible light, but unfortunately, all efforts to apply this β-fragmentation process failed and an inseparable mixture of unidentified products was obtained.

Gratifyingly, when the reaction was performed with the sulfone **11**, at ca. 25 °C for 15 min, the dioxolane **32** was obtained in 55% yield (Scheme 8). Purification of the crude residue containing the acid **32** was better accomplished by methylation with ethereal diazomethane and chromatography of the resulting methyl ester **33** (64% overall yield). Dioxolane **32** presents in its IR spectrum stretches at 3500−2500 and 1728 cm^{-1} typical of a carboxylic acid function, but its structure and stereochemistry were better studied on the methyl ester derivative **33**. Accurate mass and elemental analysis measurements are in good agreement with the empirical formula $C_{37}H_{58}O_6S$ calculated for this derivative. The NMR spectra were carefully studied using DEPT, HMBC, and HMQC experiments to assign carbons and protons. The observed coupling constants of the signals at δ 4.32 (dddd) and 4.70 (dddd) corresponding to the protons at C-2β and C-2′β, respectively, do not provide conclusive evidence to determine the syn or anti stereochemistry of the disubstituted dioxolane ring. However, a syn relative stereochemistry could be assigned from ROESY experiments that established a correlation between the C-2 and C-2′ protons. The structure and relative stereochemistry of the dioxolane ring of compound **33** have been confirmed by X-ray crystallographic analysis.[26] The five-membered ring displays an envelope conformation in which the C-2′

(27) Krow, G. R. In *Organic Reactions*; Paquette, L. A., Ed.; John Wiley & Sons: New York, 1993; Vol. 43, pp 251−798.

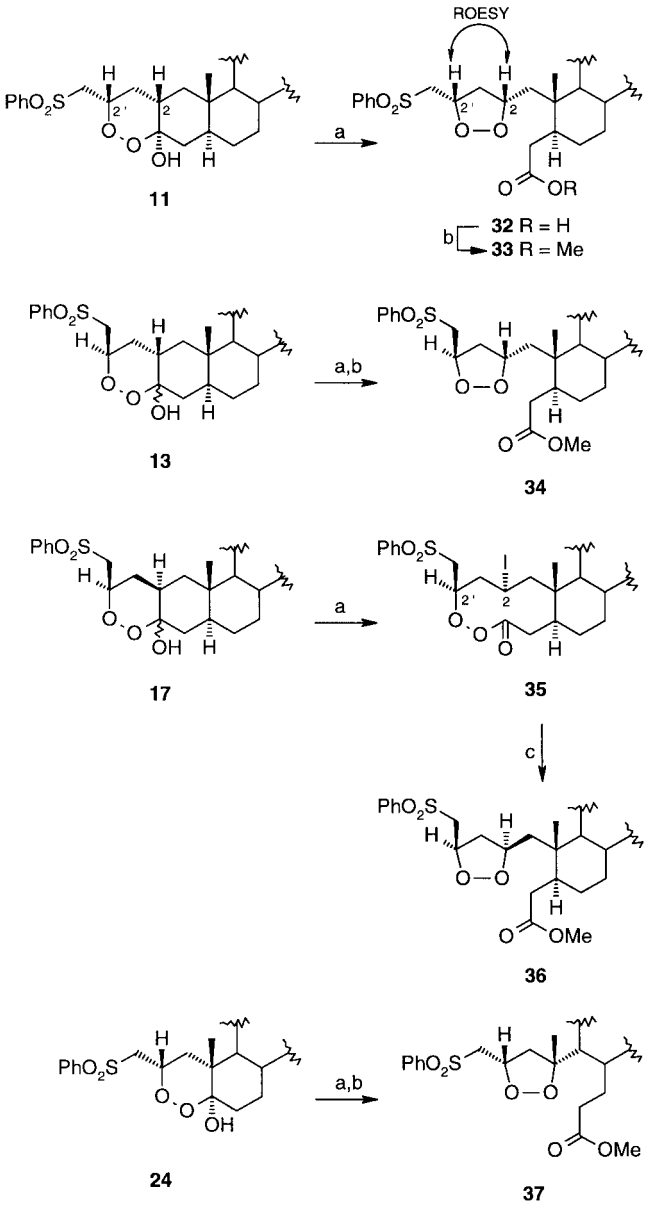
(28) (a) Chandrasekhar, S.; Roy, C. D. *Tetrahedron Lett.* **1987**, *28*, 6371−6372. (b) Deslongchamps, P. *Stereoelectronic Effects in Organic Chemistry*; Pergamon Press: Oxford, 1983.

(29) The steroidal numeration system is used throughout this section, although a more correct IUPAC systematic nomenclature has been used in the Experimental Section and Supporting Information for steroids with more than one ring opened.

(30) For related ring-chain tautomeric equilibrium of hydroxy ketones, see: (a) Escale, R.; Verducci, J. *Bull. Soc. Chim. Fr.* **1974**, 1203−1206. (b) Whiting, J. E.; Edward, J. T. *Can. J. Chem.* **1971**, *49*, 3799−3806. (c) Cottier, L.; Descotes, G. *Bull. Soc. Chim. Fr.* **1971**, 4557−4562. (d) Jones, P. R. *Chem. Rev.* **1963**, *63*, 461−487.

(31) MMX force field as implemented in PCMODEL (v. 4.0), Serena Software, Bloomington, IN 47402−3076.

Scheme 8: Synthesis of 1,2-Dioxolanes[a]



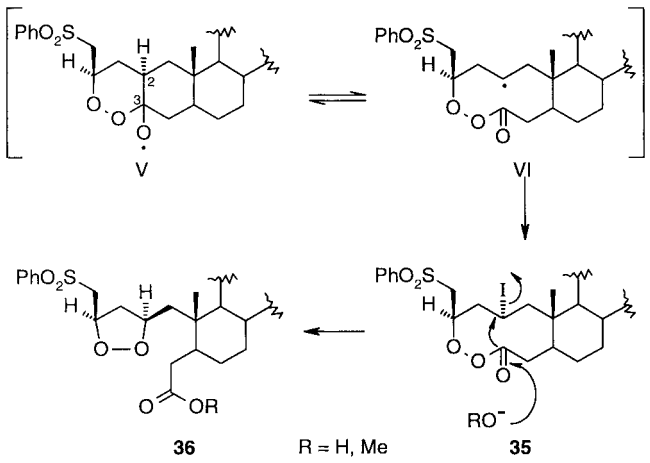
[a] Key: (a) DIB, I_2, CH_2Cl_2, *hν*, 20−30 °C, 15−30 min; (b) CH_2N_2, Et_2O, 0 °C, 5 min; (c) NaOMe, MeOH, rt, 3.5 h, 79%.

is below the plane formed by the peroxide group and the two other carbons.

An analogous procedure was used with sulfones **13**, **17**, and **24**, and the fragmentation proceeded smoothly under mild conditions, with a temperature below 30 °C and reaction times no longer than 30 min. When the fragmentation reaction was performed with the sulfone **13**, dioxolane **34** was obtained in 66% yield and showed spectroscopic data analogous to those of compound **33**. The principal difference came from the coupling constants for C-1′α and C-1′*β* protons at *δ* 2.43 and 2.70, respectively. On the other hand, no NOE correlation was observed between protons at C-2 and C-2′ in the 2D ROESY spectrum, and hence, **34** must have anti substituents at C-2 and C-2′ with the *S* and *R* configuration, respectively.

In the case of peroxyhemiacetal **17**, the unstable intermediate 10-membered cyclic peroxylactone **35** was obtained. This could be isolated by chromatotron chromatography on deactivated silica gel, and although it decomposed quickly its structure was fully characterized by its IR and ^1H and ^{13}C NMR spectroscopic data. In fact, peroxylactone **35** presents in its IR spectrum a carbon−oxygen stretch at 1770 cm^{-1} of the peroxylactone group. The ^1H NMR spectrum shows complex signals at *δ* 4.25 and 4.75 corresponding to the protons at C-2 and C-2′, respectively, while in its ^{13}C NMR the signals corresponding to these carbons appear at *δ* 19.6 and 84.3, respectively, assigned by DEPT, HMBC, and HMQC experiments. When the crude reaction mixture was treated with sodium methoxide, dioxolane **36** was obtained as the sole product (79% yield).

Scheme 9



However, when the fragmentation reaction was performed with peroxyhemiacetal **24**, the corresponding dioxolane **37** was obtained only in moderate yield, presumably due to the reactivity of the C-radical intermediate.

A plausible mechanism for the formation of dioxolanes **33**, **34**, **36**, and **37** is shown in Scheme 9, exemplified by dioxolane **36**, and involves the in situ generation of the alkoxy radical V from the corresponding peroxyhemiacetal **17**. This alkoxy radical undergoes regioselective C_2-C_3 bond fragmentation to provide the carbon radical VI, which abstracts in a stereoselective manner an iodine atom from the reaction medium to give the 10-membered iodoperoxylactone **35**. The formation of 1,2-dioxolanes from this medium-sized peroxylactone intermediate suggests the nucleophilic attack of a hydroxide or methoxide anion on the acyl carbon and then the resulting peroxyanion produces intramolecular nucleophilic substitution of the iodide at C-2 to give **36**. A survey of the literature revealed that there exist examples involving a nucleophilic hydroxide ion attack to the acyl carbon of a peroxy ester. Indeed, the hydrolysis of a peroxy ester to give a carboxylic acid and a hydroperoxide occurs by this mechanism.[32] As can be observed, a retention of configuration by a double inversion has occurred at C-2. Of particular interest from the mechanistic point of view was the isolation of the peroxylactone **35** and its further transformation to the methyl ester **36** by treatment with methanolic sodium methoxide solution, since it strongly supports the proposed mechanism for the formation of dioxolanes. It is also noteworthy that despite the fact

(32) For nucleophilic reaction of peroxy esters see: Sawaki, Y. In *Organic Peroxides*; Ando, W., Ed.; John Wiley & Sons: New York, 1992; p 452.

that the β-fragmentation sequence occurs through a radical process, total stereospecificity was observed for the resulting dioxolanes and hence for the iodide intermediates. In conclusion, this methodology is a good procedure for the preparation of 1,2-dioxolanes in a stereospecific manner. However, the synthesis of the peroxyhemiacetal precursors should be improved, and attempts in this direction are in progress.

Experimental Section

General Methods. Melting points were determined with a hot-stage apparatus and are uncorrected. Optical rotation measurements were recorded at room temperature in $CHCl_3$. IR spectra were recorded in $CHCl_3$ solutions. ^1H NMR spectra were determined at 200, 400, or 500 MHz for $CDCl_3$ solutions in parts per million from residual $CHCl_3$ (7.26 ppm) as internal reference. Homonuclear coupling constants (J) were confirmed by COSY or single-frequency decoupling experiments. ^{13}C NMR spectra were recorded at 50.3 or 125.7 MHz and chemical shifts are reported in ppm from the central peak of $CDCl_3$ (δ = 77.0) as internal reference. Signal chemical shift and multiplicity assignments (CH_3, q; CH_2, t; CH, d; C, s) were made from DEPT, HETCOR, and HMBC spectra. Mass spectra were determined at 70 eV. Merck silica gel 60 PF_{254} and 60 (0.063−0.2 mm) were used for preparative thin-layer chromatography (TLC) and column chromatography, respectively. Circular layers of 1 mm of Merck silica gel 60 PF_{254} containing gypsum were used on a Chromatotron for centrifugally assisted chromatography. Commercial reagents and solvents were analytical grade or were purified by standard procedures prior to use.[33] All reactions involving air- or moisture-sensitive materials were carried out under a nitrogen atmosphere. The spray reagent for TLC was vanillin (1 g) in H_2SO_4−EtOH (4:1; 200 mL). (Diacetoxyiodo)benzene (DIB) 98% was purchased from Aldrich.

Details of the experimental procedures, physical properties, and spectroscopic data for compounds **1**−**7** are included in the Supporting Information.

Reaction of 2α-(2-Propenyl)-5α-cholestan-3-one (3) with Benzenethiol and Oxygen. A solution of olefin **3** (500 mg, 1.17 mmol) and benzenethiol (0.5 mL, 4.88 mmol) in acetic acid (12.5 mL) was treated with a stream of oxygen bubbled through the reaction mixture, at room temperature, for 45 h. The reaction was quenched with water and extracted with CH_2Cl_2. The organic layer was washed with 2% NaOH, 5% hydrochloric acid, and water, dried over Na_2SO_4, and concentrated under reduced pressure. Silica gel column chromatography of the residue (hexanes−EtOAc 95:5) gave 2α-[3-(phenylthio)propyl]-5α-cholestan-3-one (**8**) (69 mg, 11%), 2α-[2-oxo-3-(phenylthio)propyl]-5α-cholestan-3-one (**9**) (39 mg, 6%), (2*S*,2′*S*,3*R*)-2-[2′-hydroperoxy-3′-(phenylthio)propyl]-5α-cholestan-3-one 2′,3-peroxyhemiacetal (**10**) (187 mg, 28%), and (2*S*,2′*R*,3*R*/*S*)-2-[2′-hydroperoxy-3-(phenylthio)propyl]-5α-cholestan-3-one 2′,3-peroxyhemiacetal (**12**) (167 mg, 25%). Physical properties and spectroscopic data for side products **8** and **9** are provided in the Supporting Information. Peroxyhemiacetal **10**: mp 150−151 °C (from *n*-hexane); $[\alpha]_D = -111$ (c = 0.166); IR 3579, 1610 cm^{-1}; ^1H NMR (200 MHz) δ 0.64 (3H, s), 0.84 (3H, s), 0.85 (6H, d, J = 6.5 Hz), 0.88 (3H, d, J = 6.4 Hz), 2.85 (1H, dd, J = 13.8, 7.0 Hz), 3.07 (1H, dd, J = 13.8, 5.5 Hz), 4.37 (1H, dddd, J = 10.3, 7.0, 5.5, 2.1 Hz), 7.30 (5H, m); ^{13}C NMR (50.3 MHz) δ 12.0 (q), 12.8 (q), 18.7 (q), 21.3 (t), 22.6 (q), 22.8 (q), 23.8 (t), 24.2 (t), 28.0 (d), 28.15 (t), 28.22 (t), 30.7 (t), 31.9 (t), 35.3 (d), 35.8 (d), 36.2 (t), 36.3 (t), 36.5 (t), 37.0 (s), 37.1 (d), 39.5 (t), 40.0 (t), 41.2 (t), 42.6 (s), 43.3 (d), 54.0 (d), 56.2 (d), 56.4 (d), 81.0 (d), 101.3 (s), 126.5 (d), 129.1 (d × 2), 129.6 (d × 2), 135.6 (s); MS m/z (rel intensity) 550 ($M^+ - H_2O$, 10), 534 (50); HRMS calcd for $C_{36}H_{54}O_2S$ 550.3845, found 550.3844. Anal. Calcd for $C_{36}H_{56}O_3S$: C, 76.01; H, 9.92; S, 5.64. Found: C, 76.35; H, 10.23; S, 5.36. Peroxyhemiacetal **12** (inseparable mixture, cis-:trans-fused AA′ rings, 9:1): amorphous; IR 3578, 1698 cm^{-1}; ^1H NMR (200 MHz) cis-fused, δ 0.64 (3H, s), 0.82 (3H, s), 0.86 (6H, d, J = 6.7 Hz), 0.89 (3H, d, J = 7.2 Hz), 2.84 (1H, dd, J = 13.7, 6.5 Hz), 3.04 (1H, dd, J = 13.7, 5.9 Hz), 4.47 (1H, dddd, J = 10.6, 7.1, 5.9, 1.2 Hz), 7.30 (5H, m); ^{13}C NMR (50.3 MHz) cis-fused, δ 11.8 (q), 12.1 (q), 18.7 (q), 21.2 (t), 22.6 (q), 22.8 (q), 23.8 (t), 24.2 (t), 27.8 (t), 28.0 (d), 28.2 (t), 30.5 (t), 31.6 (t), 33.0 (d), 35.2 (d), 35.8 (d), 36.2 (t), 36.7 (t), 38.3 (t), 39.50 (t), 39.54 (s), 39.9 (t), 40.8 (t), 42.0 (d), 42.5 (s), 53.8 (d), 56.2 (d), 56.4 (d), 75.6 (d), 99.9 (s), 126.5 (d), 129.1 (d × 2), 129.7 (d × 2), 135.9 (s); MS m/z (rel intensity) 550 ($M^+ - H_2O$, 6), 535 (15); HRMS calcd for $C_{36}H_{54}O_2S$ 550.3845, found 550.3808. Anal. Calcd for $C_{36}H_{56}O_3S$: C, 76.01; H, 9.92; S, 5.64. Found: C, 75.85; H, 10.14; S, 5.82. The ^1H and ^{13}C NMR data of the minor isomer (trans-fused) could not be selected from the spectra of the mixture.

(2*S*,2′*S*,3*R*)-2-[2-Hydroperoxy-3-(phenylsulfonyl)propyl]-5α-cholestan-3-one 2′,3-Peroxyhemiacetal (11). To a solution of phenylsulfide **10** (114 mg, 0.2 mmol) in CH_2Cl_2 (6 mL) was added 85% *m*-CPBA (103 mg, 0.51 mmol), and the resulting solution was stirred at room temperature for 45 min. The reaction mixture was poured into water and extracted with CH_2Cl_2. The organic layer was washed with 1% NaOH, 5% hydrochloric acid, and water, dried (Na_2SO_4), and evaporated. Chromatotron chromatography of the residue (benzene−EtOAc 97:3) afforded sulfone **11** (117 mg, 96%): mp 168−169 °C (from acetone−*n*-hexane); $[\alpha]_D = +43$ (c = 0.142); IR 3595, 1325, 1151 cm^{-1}; ^1H NMR (400 MHz) δ 0.65 (3H, s), 0.84 (3H, s), 0.85 (6H, d, J = 5.6 Hz), 0.88 (3H, d, J = 8.0 Hz), 1.95 (1H, m), 3.14 (1H, dd, J = 14.8, 5.1 Hz), 3.32 (1H, dd, J = 14.8, 6.4 Hz), 4.72 (1H, dddd, J = 10.3, 6.4, 5.1, 1.5 Hz), 7.56 (2H, dd, J = 7.9, 7.9 Hz), 7.66 (1H, dd, J = 7.4, 7.4 Hz), 7.93 (2H, d, J = 7.3 Hz);^{13}C NMR (50.3 MHz) δ 12.1 (q), 12.8 (q), 18.7 (q), 21.3 (t), 22.6 (q), 22.8 (q), 23.8 (t), 24.1 (t), 28.0 (d), 28.1 (t), 28.2 (t), 31.3 (t), 31.9 (t), 35.3 (d), 35.8 (d), 36.1 (t), 36.6 (t), 37.0 (s), 37.1 (d), 39.5 (t), 39.9 (t), 40.9 (t), 42.6 (s), 43.3 (d), 53.9 (d), 56.2 (d), 56.3 (d), 59.1 (t), 77.0 (d), 101.4 (s), 128.1 (d × 2), 129.3 (d × 2), 134.0 (d), 139.5 (s); MS m/z (rel intensity) 582 ($M^+ - H_2O$, 6), 385 (100); HRMS calcd for $C_{36}H_{54}O_4S$ 582.3743, found 582.3734. Anal. Calcd for $C_{36}H_{56}O_5S$: C, 71.96; H, 9.39; S, 5.34. Found: C, 71.68; H, 9.55; S, 5.54.

(2*S*,2′*R*,3*R*/*S*)-2-[2-Hydroperoxy-3-(phenylsulfonyl)propyl]-5α-cholestan-3-one 2′,3-Peroxyhemiacetal (13). Sulfide **12** (93 mg, 0.164 mmol) in CH_2Cl_2 (7 mL) was treated with 85% *m*-CPBA (84 mg, 0.41 mmol) at room temperature for 50 min. Workup as above and chromatotron chromatography of the residue (benzene−EtOAc 97.5:2.5) gave the sulfone **13** (inseparable mixture, cis-/trans-fused AA′ rings, 4:1) (86.5 mg, 88%): mp 164−166 °C (from acetone−*n*-pentane); $[\alpha]_D = +77$ (c = 0.246); IR 3579, 1307, 1148 cm^{-1}; ^1H NMR (400 MHz) cis-fused, δ 0.65 (3H, s), 0.81 (3H, s), 0.87 (6H, d, J = 6.4 Hz), 0.92 (3H, d, J = 6.3 Hz), 3.12 (1H, dd, J = 14.8, 7.1 Hz), 3.29 (1H, dd, J = 14.8, 4.5 Hz), 4.92 (1H, dddd, J = 10.7, 7.1, 4.5, 1.5 Hz), 7.57 (2H, dd, J = 8.0, 8.0 Hz), 7.67 (1H, dd, J = 7.6, 7.6 Hz), 7.94 (2H, d, J = 7.6 Hz); trans-fused, 0.64 (3H, s), 0.81 (3H,s), 0.86 (6H, d, J = 8.0 Hz), 0.91 (3H, d, J = 6.3 Hz), 3.49 (1H, dd, J = 14.5, 5.8 Hz), 3.99 (1H, dd, J = 14.5, 6.1 Hz), 4.76 (1H, dddd, J = 6.1, 5.8, 4.8, 1.8 Hz), 7.57 (2H, dd, J = 8.0, 8.0 Hz), 7.67 (1H, dd, J = 7.6, 7.6 Hz), 7.94 (2H, d, J = 7.6 Hz); ^{13}C NMR (50.3 MHz) cis-fused, δ 11.7 (q), 12.0 (q), 18.7 (q), 21.2 (t), 22.5 (q), 22.8 (q), 23.8 (t), 24.2 (t), 27.7 (t), 28.0 (d), 28.2 (t), 30.9 (t), 31.6 (t), 32.6 (d), 35.2 (d), 35.8 (d), 36.1 (t), 36.1 (s), 38.5 (t), 39.5 (t), 39.9 (t), 40.5 (t), 42.0 (d), 42.5 (s), 53.7 (d), 56.2 (d), 56.3 (d), 59.4 (t) 71.4 (d), 99.8 (s), 128.1 (d × 2), 129.2 (d × 2), 134.0 (d), 139.8 (s); trans-fused, 12.0 (q), 12.9 (q), 18.7 (q), 21.2 (t), 22.5 (q), 22.8 (q), 23.8 (t), 24.1 (t), 28.0 (d), 28.1 (t), 28.4 (t), 31.7 (t), 31.8 (t), 32.6 (d), 35.3 (d), 35.7 (d), 36.8 (t), 37.1 (s), 38.5 (t), 39.5 (t), 39.8 (t), 40.6 (t), 42.6 (s), 43.3 (d), 53.9 (d), 56.2 (d), 56.3 (d), 57.4 (t), 75.0 (d), 101.8 (s), 128.0 (d × 2), 129.2 (d × 2), 133.9 (d), 139.6 (s); MS m/z (rel intensity) 600 (M^+, <1), 582 (15), 141 (100); HRMS calcd for $C_{36}H_{54}O_4S$ 582.3743, found 582.3748. Anal. Calcd for $C_{36}H_{56}O_5S$: C, 71.96; H, 9.39; S, 5.34. Found: C, 71.77; H, 9.16; S, 5.49.

(33) Perrin, D. D.; Armarego, W. L. F. *Purification of Laboratory Chemicals*, 3rd ed.; Pergamon Press: New York, 1988.

Reaction of 2β-(2-Propenyl)-5α-cholestan-3-one (2) with Benzenethiol and Oxygen. A solution of alkene **2** (350 mg, 0.82 mmol) in acetic acid (15 mL) was treated with PhSH (0.4 mL, 3.9 mmol) and oxygen for 48 h as described previously. Workup and chromatotron chromatography of the residue (hexanes−EtOAc 49:1−7:3) afforded (2*R*,2′*S*,3*R*/*S*)-2-[2′-hydroperoxy-3′-(phenylthio)propyl]-5α-cholestan-3-one 2′,3-peroxyhemiacetal (**15**) (28 mg, 6%), 2β-[3-(phenylthio)propyl]-5α-cholestan-3-one (**14**) (9 mg, 2%), peroxyhemiacetal **10** (37 mg, 8%), (2*R*,2′*R*,3*R*/*S*)-2-[2′-hydroperoxy-3-(phenylthio)propyl]-5α-cholestan-3-one 2′,3-peroxyhemiacetal (**16**) (80 mg, 17%), and peroxyhemiacetal **12** (19 mg, 4%). Physical properties and spectrocopic data for the side product **14** are provided in the Supporting Information. Peroxyhemiacetal **15** (inseparable mixture, trans-/cis-fused AA′ rings, 1.5:1): amorphous; IR 3620, 1584 cm^{-1}; ^1H NMR (200 MHz) trans-fused, δ 0.64 (3H, s), 0.74 (3H, s), 0.87 (6H, d, *J* = 6.7 Hz), 0.92 (3H, d, *J* = 6.4 Hz), 3.12 (1H, dd, *J* = 13.2, 7.2 Hz), 3.36 (1H, dd, *J* = 13.2, 5.0 Hz), 4.62 (1H, m), 7.35 (5H, m); cis-fused, 0.63 (3H, s), 0.69 (3H, s), 0.87 (6H, d, *J* = 6.7 Hz), 0.91 (3H, d, *J* = 6.4 Hz), 3.37 (1H, dd, *J* = 13.2, 6.6 Hz), 3.63 (1H, dd, *J* = 13.2, 7.0 Hz), 4.44 (1H, m), 7.35 (5H, m); ^{13}C NMR (50.3 MHz) trans-fused, δ 10.9 (q), 12.0 (q), 18.6 (q), 21.0 (t), 22.5 (q), 22.8 (q), 23.8 (t), 24.2 (t), 27.9 (t), 28.0 (d), 28.2 (t), 31.6 (t), 35.2 (d), 35.8 (d), 36.1 (t), 36.2 (s), 37.5 (t), 39.3 (t), 39.5 (t × 2), 39.9 (t), 41.2 (d), 41.5 (d), 42.4 (s), 44.7 (t), 53.4 (d), 56.2 (d), 56.4 (d), 76.2 (d), 98.0 (s), 126.1 (d), 128.0 (d), 128.6 (d), 128.9 (d), 129.3 (d), 132.4 (s); cis-fused, 11.0 (q), 12.0 (q), 18.6 (q), 21.0 (t), 22.5 (q), 22.8 (q), 23.8 (t), 24.2 (t), 27.9 (t), 28.0 (d), 28.2 (t), 31.6 (t), 35.2 (d), 35.5 (s), 35.8 (d), 36.1 (t), 39.0 (t), 39.4 (t × 2), 39.6 (t), 40.0 (t), 41.3 (d), 42.0 (t), 42.3 (d), 42.4 (s), 53.4 (d), 56.2 (d), 56.4 (d), 78.5 (d), 97.9 (s), 126.0 (d), 128.5 (d × 2), 128.9 (d), 129.1 (d), 132.8 (s); MS *m*/*z* (rel intensity) 435 ($M^+ - H_2O - CH_3$, 5), 109 (100). Anal. Calcd for $C_{36}H_{56}O_3S$: C, 76.01; H, 9.92; S, 5.64. Found: C, 76.22; H, 9.74; S, 5.87. Peroxyhemiacetal **16** (inseparable mixture, trans-/cis-fused AA′, 2.3:1): amorphous; IR 3579, 1468 cm^{-1}; ^1H NMR (200 MHz) trans-fused, δ 0.66 (3H, s), 0.88 (6H, d, *J* = 6.7 Hz), 0.91 (3H, d, *J* = 6.6 Hz), 3.03 (1H, dd, *J* = 13.5, 7.1 Hz), 3.29 (1H, dd, *J* = 13.5, 6.1 Hz), 4.12 (1H, m), 7.30 (5H, m); cis-fused, 0.66 (3H, s), 0.72 (3H, s), 0.88 (6H, d, *J* = 6.7 Hz), 0.91 (3H, d, *J* = 6.6 Hz), 2.89 (1H, dd, *J* = 13.5, 8.1 Hz), 3.07 (1H, dd, *J* = 13.3, 5.2 Hz), 4.49 (1H, m), 7.30 (5H, m); ^{13}C NMR (50.3 MHz) trans-fused, δ 12.1 (q), 14.96 (q), 18.6 (q), 21.1 (t), 22.5 (q), 22.8 (q), 23.8 (t), 24.1 (t), 28.0 (d), 28.2 (t), 31.7 (t), 33.5 (d), 33.9 (t), 35.0 (d), 35.8 (d), 35.9 (s), 36.1 (t), 37.7 (d), 37.8 (t), 39.5 (t × 2), 40.0 (t), 40.2 (t), 42.0 (d), 42.6 (s), 55.2 (d), 56.2 (d × 2), 80.6 (d), 104.8 (s), 128.3 (d), 129.0 (d × 2), 129.5 (d × 2), 135.7 (s); cis-fused, 12.1 (q), 15.0 (q), 18.6 (q), 21.1 (t), 22.5 (q), 22.8 (q), 23.8 (t), 24.1 (t), 27.97 (d), 28.03 (t), 31.2 (t), 34.1 (t), 34.4 (t), 35.1 (d), 35.75 (d), 35.82 (s), 36.1 (t), 37.7 (d), 37.8 (t), 39.5 (t × 2), 39.8 (t), 40.2 (t), 41.7 (d), 42.6 (s), 55.2 (d), 56.2 (d × 2), 77.6 (d), 104.2 (s), 128.5 (d), 128.2 (d × 2), 129.0 (d × 2), 135.4 (s); MS *m*/*z* (rel intensity) 535 ($M^+ - H_2O - CH_3$, 5), 109 (100). Anal. Calcd for $C_{36}H_{56}O_3S$: C, 76.01; H, 9.92; S, 5.64. Found: C, 76.24; H, 9.79; S, 5.53.

(2*R*,2′*R*,3*R*/*S*)-2-[2′-Hydroperoxy-3′-(phenylsulfonyl)propyl]-5α-cholestan-3-one 2′,3-Peroxyhemiacetal (17). A solution of **16** (33 mg, 0.058 mmol) in CH_2Cl_2 (3 mL) was treated with 55% *m*-CPBA (33 mg, 0.11 mmol) for 1 h as described previously. Chromatotron chromatography of the residue (hexanes−EtOAc 4:1) afforded sulfone **17** (32 mg, 92%) (inseparable mixture, trans-/cis-fused AA′, 2.6:1): mp 140−144 °C (from acetone−*n*-hexane); $[\alpha]_D = -36$ (*c* = 0.22); IR 3579, 1308, 1152 cm^{-1}; ^1H NMR (500 MHz) trans-fused, δ 0.65 (3H, s), 0.82 (3H, s), 0.86 (3H, d, *J* = 6.6 Hz), 0.87 (3H, d, *J* = 6.6 Hz), 0.90 (3H, d, *J* = 6.5 Hz), 3.31 (1H, dd, *J* = 14.4, 5.2 Hz), 3.66 (1H, dd, *J* = 14.5, 6.6 Hz), 4.58 (1H, dddd, *J* = 9.3, 6.8, 6.6, 5.2 Hz), 7.58 (2H, d, *J* = 7.5, 6.7 Hz), 7.66 (1H, dd, *J* = 7.6, 7.6 Hz), 7.92 (2H, *J* = 7.3 Hz); cis-fused, 0.66 (3H, s), 0.82 (3H, s), 0.86 (3H, d, *J* = 6.6 Hz), 0.87 (3H, d, *J* = 6.6 Hz), 0.91 (3H, d, *J* = 6.5 Hz), 3.29 (1H, dd, *J* = 14.3, 8.9 Hz), 3.40 (1H, dd, *J* = 14.6, 4.8 Hz), 4.75 (1H, dddd, *J* = 11.7, 8.9, 4.8, 4.6 Hz), 7.58 (2H, dd, *J* = 7.5, 7.5 Hz), 7.66 (1H, dd, *J* = 7.6, 7.6 Hz), 7.92 (2H, d, *J* = 7.3 Hz); ^{13}C NMR (50.3 MHz) trans-fused, δ 12.1 (q), 14.8 (q), 18.6 (q), 21.1 (t), 22.5 (q), 22.8 (q), 23.8 (t), 24.1 (t), 28.0 (t), 28.0 (d), 28.2 (t), 31.6 (d), 33.3 (d), 34.0 (t), 35.0 (d), 35.7 (d), 35.9 (s), 36.1 (t), 37.0 (d), 39.5 (t), 39.8 (t), 39.9 (t), 41.89 (d), 42.6 (s), 55.2 (d), 56.2 (d × 2), 60.4 (t), 75.3 (d), 105.0 (s), 128.0 (d × 2), 129.3 (d × 2), 133.8 (d), 139.8 (s); cis-fused, 12.1 (q), 15.3 (q), 18.6 (q), 21.2 (t), 22.5 (q), 22.8 (q), 23.8 (t), 24.1 (t), 28.0 (d), 28.0 (t), 28.2 (t), 32.0 (t), 33.3 (t), 34.4 (t), 35.1 (d), 35.7 (d), 35.9 (s), 36.1 (t), 37.0 (d), 39.5 (t), 39.8 (t), 39.9 (t), 41.9 (d), 42.5 (s), 56.2 (d × 2), 55.2 (d), 60.0 (t), 73.6 (t), 104.2 (s), 128.1 (d × 2), 129.4 (d × 2), 134.0 (d), 139.3 (s); MS *m*/*z* (rel intensity) 566 ($M^+ - H_2O_2$, 12), 398 (66). Anal. Calcd for $C_{36}H_{56}O_5S$: C, 71.96; H, 9.39;, 5.34. Found: C, 71.88; H, 9.48; S, 5.16.

Reaction of 4-Nor-3,4-secocholest-2-en-5-one (7) with Benzenethiol and Oxygen. To a solution of the olefin **7** (117 mg, 0.31 mmol) in AcOH (5.4 mL) was added benzenethiol (PhSH) (0.152 mL, 1.29 mmol), and then a stream of oxygen was bubbled through the resulting mixture at room temperature for 36 h. The reaction mixture was poured into water and extracted with CH_2Cl_2. The organic layer was washed with 1% NaOH, 5% hydrochloric acid (5 mL), and water, dried (Na_2SO_4), and evaporated. Chromatotron chromatography of the residue (hexanes−EtOAc 100:0 to 1:1) gave 3-(phenylthio)-4-nor-3,4-secocholestan-5-one (**18**) (11 mg, 7%), 3-(phenylthio)-4-nor-3,4-secocholestane-2,5-dione (**19**) (30 mg, 19%), (2*S*,5*R*)-hydroperoxy-3-(phenylthio)-4-nor-3,4-secocholestan-5-one 2,5-peroxyhemiacetal (**23**) (42 mg, 26%), and a mixture that after methylation was resolved by chromatotron chromatography (hexanes−EtOAc 4:1) in the olefin **20** (11 mg, 9%), (3*R*,3a*R*,-5a*S*,6*R*,10a*S*,10b*S*,2′*S*,1″*R*)-(**21**) (13 mg, 8%), and (3*R*,3a*R*,-5a*S*,6*R*,10a*S*,10b*S*,2′*R*,1″*R*)-3-(1″,5″-dimethylhexyl)-6-[2′-hydroxy-3′-(phenylthio)propyl]-3a,6-dimethyl-dodecahydro-7-oxacyclohepta[*e*]inden-8-one (**22**) (5 mg, 3%). Physical properties and spectroscopic data for side products **18**−**22** are included in the Supporting Information. Peroxyhemiacetal **23**: amorphous; IR 3576, 1583 cm^{-1}; ^1H NMR (200 MHz) δ 0.65 (3H, s), 0.87 (6H, d, *J* = 6.5 Hz), 0.90 (3H, d, *J* = 8.3 Hz), 1.00 (3H, s), 2.77 (1H, dd, *J* = 13.5, 7.1 Hz), 3.05 (1H, dd, *J* = 13.5, 5.4 Hz), 4.48 (1H, dddd, *J* = 11.4, 7.1, 5.4, 1.3 Hz), 7.36 (5H, m); ^{13}C NMR (50.3 MHz) δ 11.9 (q), 18.0 (q), 18.6 (q), 21.4 (t), 22.5 (q), 22.8 (q), 23.8 (t), 24.1 (t), 27.1 (t), 28.0 (d), 28.2 (t), 31.5 (t), 34.0 (t), 34.6 (d), 35.7 (d), 36.1 (t), 36.6 (t), 38.9 (s), 39.5 (t), 39.7 (t), 42.3 (s), 43.1 (d), 55.9 (d), 56.1 (d), 75.9 (d), 102.4 (s), 126.7 (d), 129.0 (d × 2), 130.2 (d × 2), 135.4 (s); MS *m*/*z* (rel intensity) 496 ($M^+ - H_2O$, <1), 123 (100). Anal. Calcd for $C_{32}H_{50}O_3S$: C, 74.66; H, 9.79; S, 6.23. Found: C, 74.75; H, 9.65; S, 6.05.

(2*S*,5*R*)-[2-Hydroperoxy-3-(phenylsulfonyl)]-4-nor-3,4-secocholestan-5-one 2,5-Peroxyhemiacetal (24). A solution of sulfide **23** (31 mg, 0.06 mmol) in CH_2Cl_2 (2 mL) was treated with 55% *m*-CPBA (50 mg, 0.16 mmol) at room temperature for 1 h. Workup as previously described and chromatotron chromatography (hexanes−EtOAc 7:3) afforded the sulfone **24** (31 mg, 94%): amorphous; IR 3577, 1308, 1154 cm^{-1}; ^1H NMR (500 MHz) δ 0.66 (3H, s), 0.87 (3H, d, *J* = 6.4 Hz), 0.88 (3H, d, *J* = 6.4 Hz), 0.93 (3H, d, *J* = 6.4 Hz), 0.98 (3H, s), 3.11 (1H, dd, *J* = 14.8, 5.6 Hz), 3.26 (1H, dd, *J* = 14.8, 6.0 Hz), 4.85 (1H, dddd, *J* = 11.6, 6.0, 5.7, 1.9 Hz), (3H, s), 7.57 (2H, dd, *J* = 8.0, 8.0 Hz), 7.66 (1H, dd, *J* = 7.2, 7.2 Hz), 7.92 (2H, d, *J* = 7.2 Hz); ^{13}C NMR (50.3 MHz) δ 11.9 (q), 17.9 (q), 18.6 (q), 21.4 (t), 22.5 (q), 22.8 (q), 23.8 (t), 24.1 (t), 27.0 (t), 28.0 (d), 28.2 (t), 31.8 (t), 34.57 (t), 34.58 (d), 35.7 (d), 36.1 (t), 38.7 (s), 39.5 (t), 39.7 (t), 42.3 (s), 43.0 (d), 55.8 (d), 56.1 (d), 59.1 (t), 71.8 (d), 102.5 (s), 128.0 (d × 2), 129.3 (d × 2), 134.0 (d), 139.6 (s); MS *m*/*z* (rel intensity) 546 (M^+, <1), 528 (4), 77 (100). Anal. Calcd for $C_{32}H_{50}O_5S$: C, 70.29; H, 9.22; S, 5.86. Found: C, 70.47; H, 9.37; S, 5.53.

Details of the experimental procedures, physical properties, and spectroscopic data for compounds **25**−**29** are included in the Supporting Information.

Reaction of Peroxyhemiacetal 13 with Methanol−*p*-Toluenesulfonic Acid. To a solution of sulfone **13** (50 mg, 0.084 mmol) in MeOH−CH_2Cl_2 (5:2, 14 mL) was added *p*-TsOH·H_2O (5 mg, 0.026 mmol), and the resulting mixture stirred at room temperature for 24 h. The solvent was

evaporated under reduced pressure and the residue dissolved in CH_2Cl_2 (5 mL) and then treated with Dowex 1-X_8 (20 mg) at room temperature for 30 min. The solid phase was removed by filtration, the solvent evaporated off, and the residue purified by chromatotron chromatography (benzene−EtOAc 99.4:0.6), giving (2*S*,2′*R*)-3α-methoxy- (**30**) (19 mg, 37%) and (2*S*,2′*R*)-3*β*-methoxy-2-[2′-hydroperoxy-3′-(phenylsulfonyl)propyl]-5α-cholestan-3-one 2′,3-peroxyhemiacetal (**31**) (23 mg, 44%). Compound **30**: mp 174−176 °C (from $CHCl_3$−MeOH); $[\alpha]_D = -155$ (*c* = 0.12); IR 1307, 1151 cm^{-1}; ^1H NMR (200 MHz) *δ* 0.6 (3H, s), 0.84 (3H, s), 0.86 (6H, d, *J* = 6.8 Hz), 0.89 (3H, d, *J* = 6.3 Hz), 2.22 (1H, ddd, *J* = 13.0, 12.9, 5.4 Hz), 3.19 (3H, s), 3.49 (1H, dd, *J* = 14.5, 5.5 Hz), 3.95 (1H, dd, *J* = 14.5, 6.1 Hz), 4.69 (1H, dddd, *J* = 5.9, 5.4, 4.5, 1.3 Hz), 7.50 (2H, m), 7.95 (2H, m); ^{13}C NMR (50.3 MHz) *δ* 12.1 (q), 15.2 (q), 18.6 (q), 21.3 (t), 22.6 (q), 22.8 (q), 23.8 (t), 24.1 (t), 27.9 (t), 28.0 (d), 28.2 (t × 2), 30.6 (t), 32.0 (t), 32.2 (d), 35.3 (d), 35.8 (d), 36.2 (t), 37.0 (s), 39.5 (t), 39.9 (t), 40.4 (d), 42.6 (s), 42.9 (d), 47.8 (q), 54.0 (d), 56.2 (d), 56.3 (t), 57.9 (t), 74.7 (d), 103.5 (s), 128.1 (d × 2), 129.3 (d × 2), 133.8 (d), 139.6 (s); MS *m*/*z* (rel intensity) 614 (M^+, 1), 389 (100); HRMS calcd for $C_{37}H_{58}O_5S$ 614.4005, found 614.4000. Anal. Calcd for $C_{37}H_{58}O_5S$: C, 72.27; H, 9.51; S, 5.21. Found: C, 72.09; H, 9.75; S, 5.14. Compound **31**: mp 148−149 °C (from MeOH); $[\alpha]_D = +112$ (*c* = 0.14); IR 1308, 1147 cm^{-1}; ^1H NMR (200 MHz) *δ* 0.64 (3H, s), 0.78 (3H, s), 0.86 (6H, d, *J* = 6.3 Hz), 0.92 (3H, d, *J* = 6.4 Hz), 2.13 (1H, ddd, *J* = 13.2, 13.1, 5.2 Hz), 3.07 (1H, dd, *J* = 14.7, 4.8 Hz), 3.17 (3H, s), 3.26 (1H, dd, *J* = 14.7, 6.7 Hz), 4.89 (1H, dddd, *J* = 11.1, 6.4, 4.8, 1.8 Hz), 7.61 (3H, m), 7.95 (2H, m); ^{13}C NMR (50.3 MHz) *δ* 11.7 (q), 12.1 (q), 18.7 (q), 21.1 (t), 22.6 (q), 22.8 (q), 23.8 (t), 24.2 (t), 28.0 (d), 28.1 (t), 28.2 (t), 31.0 (t), 31.7 (t), 32.3 (d), 34.1 (t), 35.2 (d), 35.8 (t), 35.9 (s), 36.2 (t), 39.5 (t), 39.8 (t), 40.4 (t), 41.9 (d), 42.5 (s), 48.1 (s), 53.7 (d), 56.2 (d), 56.3 (d), 59.6 (t), 70.8 (d), 101.6 (s), 128.1 (d × 2), 129.2 (d × 2), 133.8 (d), 139.9 (s); MS *m*/*z* (rel intensity) 614 (M^+, <1), 389 (100); HRMS calcd for $C_{37}H_{58}O_5S$ 614.4005, found 614.3996. Anal. Calcd for $C_{37}H_{58}O_5S$: C, 72.27; H, 9.51; S, 5.21. Found: C, 72.19; H, 9.54; S, 5.26.

Reaction of Peroxyhemiacetal 11 with (Diacetoxyiodo)benzene−Iodine. A solution of peroxyhemiacetal **11** (20 mg, 0.033 mmol) in CH_2Cl_2 (10 mL) containing (diacetoxyiodo)benzene (DIB) (43 mg, 0.12 mmol) and iodine (16.2 mg, 0.06 mmol) was irradiated with two 80 W tungsten-filament lamps at 24−28 °C for 15 min. The reaction mixture was then poured into water and extracted with CH_2Cl_2. The organic layer was washed with aqueous saturated sodium thiosulfate, dried, and concentrated in vacuo. Chromatotron chromatography of the residue (hexanes−EtOAc 1:1) yielded compound **32** (23 mg, 55%): amorphous; IR 3500−2500, 1728, 1321, 1151 cm^{-1}; ^1H NMR (200 MHz) *δ* 0.62 (3H, s), 0.72 (3H, s), 0.86 (6H, d, *J* = 6.6 Hz), 0.89 (3H, d, *J* = 5.9 Hz), 2.09 (1H, d, *J* = 12.2 Hz), 2.38 (1H, d, *J* = 12.7 Hz), 3.04 (1H, ddd, *J* = 12.4, 7.5, 7.5 Hz), 3.27 (1H, dd, *J* = 14.3, 6.2 Hz), 3.58 (1H, dd, *J* = 14.2, 6.3 Hz), 4.32 (1H, m), 4.70 (1H, m), 7.61 (3H, m), 7.92 (2H, m); ^{13}C NMR (50.3 MHz) *δ* 12.0 (q), 15.8 (q), 18.6 (q), 21.8 (t), 22.6 (q), 22.8 (q), 23.8 (t), 24.1 (t), 28.0 (d), 28.2 (t), 31.2 (t), 35.5 (d), 35.7 (d), 35.9 (t), 36.1 (t), 38.3 (s), 39.0 (t), 39.5 (t × 2), 39.7 (t), 39.9 (d), 42.2 (s), 47.7 (t), 48.5 (d), 56.1 (d), 56.3 (d), 60.6 (t), 74.5 (d), 77.7 (d), 128.1 (d × 2), 129.4 (d × 2), 134.0 (d), 139.6 (s), 179.0 (s); MS *m*/*z* (rel intensity) 388 ($M^+ - C_{10}H_{12}O_4S$, 4), 77 (100); HRMS calcd for $C_{26}H_{44}O_2$ 388.3342, found 388.3350. Anal. Calcd for $C_{36}H_{56}O_6S$: C, 70.09; H, 9.15; S, 5.20. Found: C, 70.24; H, 9.22; S, 4.98. Compound **32** (18 mg, 0.028 mmol) in ether (1 mL) was treated with ethereal CH_2N_2 at 0 °C for 5 min, and then the solvent was evaporated and the residue purified by chromatotron chromatography (hexanes−EtOAc 4:1) yielding methyl ester **33** (18 mg, 98%): mp 135−136 °C (from acetone−*n*-hexane); $[\alpha]_D = +67$ (*c* = 0.164); IR 1739, 1322, 1155 cm^{-1}; ^1H NMR (500 MHz) *δ* 0.62 (3H, s), 0.72 (3H, s), 0.87 (3H, d, *J* = 6.6 Hz), 0.88 (3H, d, *J* = 6.6 Hz), 0.90 (3H, d, *J* = 6.5 Hz), 1.92 (1H, dd, *J* = 14.4, 1.1 Hz), 2.07 (1H, ddd, *J* = 12.9, 8.2, 4.9 Hz), 2.32 (1H, dd, *J* = 14.4, 2.3 Hz), 3.04 (1H, ddd, *J* = 12.4, 7.5, 7.5 Hz), 3.26 (1H, dd, *J* = 14.3, 6.2 Hz), 3.59 (1H, dd, *J* = 14.3, 6.2 Hz), 3.67 (3H, s), 4.32 (1H, dddd, *J* = 7.5, 7.5, 7.5, 3.5 Hz), 4.70 (1H, dddd, *J* = 11.2, 6.1, 6.1, 6.1 Hz), 7.59 (2H, dd, *J* = 7.9, 7.9 Hz), 7.68 (1H, dd, *J* = 7.5, 7.5 Hz), 7.92 (2H, d, *J* = 7.5 Hz); ^{13}C NMR (50.3 MHz) *δ* 12.0 (q), 15.8 (q), 18.7 (q), 21.8 (t), 22.6 (q), 22.8 (q), 23.8 (t), 24.2 (t), 28.0 (d), 28.2 (t), 31.3 (t), 35.6 (d), 35.8 (d), 36.0 (t), 36.2 (t), 38.4 (s), 39.1 (t), 39.5 (t × 2), 39.8 (t), 40.1 (d), 42.3 (s), 47.8 (t), 48.6 (d), 51.6 (q), 56.2 (d), 56.4 (d), 60.9 (t), 74.5 (d), 77.6 (d), 128.1 (d × 2), 129.3 (d × 2), 133.9 (d), 139.7 (s), 174.1 (s); MS *m*/*z* (rel intensity) 630 (M^+, 56), 612 (6), 388 (100); HRMS calcd for $C_{37}H_{58}O_6S$ 630.3954, found 630.3958. Anal. Calcd for $C_{37}H_{58}O_6S$: C, 70.44; H, 9.27; S, 5.08. Found: C, 70.54; H, 9.43; S, 4.91. Conducting the reaction as before and then treating the crude residue containing the acid **32** with ethereal CH_2N_2 at 0 °C for 5 min followed by purification gave methyl ester **33** in 64% yield.

Reaction of Peroxyhemiacetal 13 with (Diacetoxyiodo)benzene−Iodine. A solution of **13** (25 mg, 0.042 mmol) in CH_2Cl_2 (4.5 mL) treated with DIB (37 mg, 0.084 mmol) and I_2 (11 mg, 0.042 mmol) was irradiated at 26−28 °C, for 15 min, as described previously. After workup, the residue was dissolved in ether (2 mL) and treated at 0 °C with ethereal CH_2N_2. After 5 min, the solution was evaporated and the residue purified by chromatotron chromatography (hexanes−EtOAc 4:1), giving dioxolane **34** (18 mg, 66%): mp 128−130 °C (from EtOAc−*n*-pentane); $[\alpha]_D = +9$ (*c* = 0.10); IR 1729, 1309, 1150 cm^{-1}; ^1H NMR (400 MHz) *δ* 0.63 (3H, s), 0.72 (3H, s), 0.87 (3H, d, *J* = 6.6 Hz), 0.88 (3H, d, *J* = 6.6 Hz), 0.90 (3H, d, *J* = 6.5 Hz), 1.95 (1H, d, *J* = 14.4 Hz), 2.31 (1H, dd, *J* = 14.4, 2.1 Hz), 2.43 (1H, ddd, *J* = 13.5, 7.9, 6.2 Hz), 2.70 (1H, ddd, *J* = 11.9, 7.3, 4.0 Hz), 3.28 (1H, dd, *J* = 14.2, 6.7 Hz), 3.50 (2H, dd, *J* = 14.2, 5.6 Hz), 3.68 (3H, s), 4.43 (1H, dddd, *J* = 9.3, 9.3, 3.2, 0 Hz), 4.70 (1H, dddd, *J* = 12.3, 12.3, 6.3, 6.3 Hz), 7.59 (2H, dd, *J* = 7.6, 7.6, 1.4 Hz), 7.67 (1H, dd, *J* = 7.3, 7.3 Hz), 7.93 (2H, d, *J* = 8.1 Hz); ^{13}C NMR (50.3 MHz) *δ* 12.0 (q), 15.8 (q), 18.6 (q), 21.7 (t), 22.6 (q), 22.9 (q), 23.8 (t), 24.1 (t), 28.0 (d), 28.2 (t × 2), 31.3 (t), 35.4 (d), 35.7 (d), 36.0 (t), 36.1 (t), 38.5 (s), 39.5 (t), 39.7 (t), 40.0 (d), 40.1 (t), 42.3 (s), 47.4 (t), 48.6 (d), 51.7 (q), 56.1 (d), 56.4 (d), 59.5 (t), 74.0 (d), 76.9 (d), 128.1 (d × 2), 129.4 (d × 2), 134.0 (d), 139.4 (s), 174.3 (s); MS *m*/*z* (rel intensity) 631 ($M^+ + 1$, 17), 389 (100); HRMS calcd for $C_{37}H_{58}O_6S$ 630.3954, found 630.3955. Anal. Calcd for $C_{37}H_{58}O_6S$: C, 70.44; H, 9.27; S, 5.08. Found: C, 70.47; H, 9.31; S, 4.83.

Reaction of Peroxyhemiacetal 17 with (Diacetoxyiodo)benzene−Iodine. A solution of **17** (20 mg, 0.033 mmol) in CH_2Cl_2 (3 mL) was treated with DIB (20 mg, 0.067 mmol) and I_2 (13 mg, 0.051 mmol). The mixture was irradiated as previously at 22−25 °C for 25 min. After usual workup and chromatotron chromatography (hexanes−EtOAc 4:1), peroxylactone **35** (8.5 mg, 35%) was obtained: amorphous; IR 1770, 1309, 1153 cm^{-1}; ^1H NMR (500 MHz) *δ* 0.66 (3H, s), 0.70 (3H, s), 0.87 (3H, d, *J* = 6.6 Hz), 0.88 (3H, d, *J* = 6.6 Hz), 0.93 (3H, d, *J* = 6.5 Hz), 1.67 (1H, dd, *J* = 13.1, 3.3 Hz), 2.35 (1H, dd, *J* = 17.4, 5.0 Hz), 2.50 (1H, ddd, *J* = 15.6, 11.1, 11.0 Hz), 2.82 (1H, d, *J* = 12.0 Hz) 2.99 (1H, dd, *J* = 15.8, 1.4 Hz), 3.24 (1H, dd, *J* = 14.2, 8.5 Hz), 3.60 (1H, dd, *J* = 14.2, 2.2 Hz), 4.25 (1H, m), 4.75 (1H, dddd, *J* = 8.1, 8.1, 8.1, 0 Hz), 7.59 (2H, dd, *J* = 7.9, 7.9 Hz), 7.68 (1H, dd, *J* = 7.5, 7.5 Hz), 7.92 (2H, d, *J* = 8.1 Hz); ^{13}C NMR (50.3 MHz) *δ* 12.5 (q), 15.3 (q), 18.6 (q), 19.6 (d), 22.6 (q), 22.8 (q), 23.4 (t), 23.8 (t), 24.1 (t), 28.0 (d), 28.3 (t), 29.6 (t), 30.6 (t), 35.7 (d), 35.8 (d), 36.1 (t × 2), 38.4 (d), 39.4 (t), 39.5 (t × 2), 41.9 (s), 42.4 (s), 46.2 (d), 48.9 (t), 56.1 (d), 56.6 (d), 58.3 (t), 84.3 (d), 127.9 (d × 2), 129.6 (d × 2), 134.3 (d), 139.5 (s), 175.2 (s). Anal. Calcd for $C_{36}H_{55}IO_5S$: C, 59.49; H, 7.63; S, 4.41. Found: C, 59.22; H, 7.78; S, 4.75.

Reaction of the Peroxylactone 35 with Sodium Methoxide. A solution of peroxylactone **35** (5.2 mg, 0.007 mmol) in MeOH (0.5 mL) was treated with NaOMe (0.5 mg, 0.009 mmol) at room temperature for 3.5 h and then poured into 5% aqueous HCl and extracted with CH_2Cl_2. The organic layer was dried and evaporated in the usual way, and the residue dissolved in ether (0.5 mL) was treated with excess of ethereal CH_2N_2. After 30 min, the solution was evaporated and the residue purified by chromatotron chromatography (benzene−EtOAc 97:3), giving the methyl ester **36** (3.4 mg, 79%): amorphous; IR 1728, 1308, 1150 cm^{-1}; ^1H NMR (500 MHz) *δ*

0.64 (3H, s), 0.73 (3H, s), 0.86 (3H, d, J = 6.6 Hz), 0.87 (3H, d, J = 6.6 Hz), 0.92 (3H, d, J = 6.6 Hz), 1.74 (1H, dd, J = 15.6, 3.3 Hz), 1.86 (1H, dd, J = 11.2, 1.7 Hz), 1.94 (1H, m), 2.09 (1H, ddd, J = 12.5, 8.2, 5.3 Hz), 2.42 (1H, d, J = 11.8 Hz), 3.00 (1H, ddd, J = 12.3, 7.1, 7.1 Hz), 3.28 (1H, dd, J = 14.2, 6.6 Hz), 3.56 (1H, dd, J = 14.3, 5.6 Hz), 3.59 (3H, s), 4.28 (1H, dddd, J = 7.7, 7.7, 7.7, 2.8 Hz), 4.70 (1H, dddd, J = 6.2, 6.2, 6.2, 5.9 Hz), 7.59 (2H, dd, J = 8.4, 8.4 Hz), 7.68 (1H, dd, J = 7.7, 7.7 Hz), 7.92 (2H, d, J = 7.9 Hz); ^{13}C NMR (125.7 MHz) δ 12.0 (q), 16.0 (q), 18.7 (q), 21.8 (t), 22.6 (q), 22.8 (q), 23.8 (t), 24.2 (t), 27.8 (t), 27.9 (d), 28.1 (t), 31.3 (t), 35.3 (d), 35.78 (d), 35.82 (d), 36.2 (t), 38.3 (t), 39.0 (s), 39.5 (t), 39.9 (t), 40.2 (t), 42.3 (s), 47.7 (t), 48.1 (d), 51.6 (q), 56.3 (d), 56.6 (d), 60.6 (t), 74.4 (d), 77.7 (d), 128.1 (d × 2), 129.4 (d × 2), 134.0 (d), 139.5 (s), 174.1 (s); MS *m*/*z* (rel intensity) 558 (M^+, 15), 77 (100). Anal. Calcd for $C_{37}H_{58}O_6S$: C, 70.44; H, 9.27; S, 5.08. Found: C, 70.56; H, 9.17; S, 5.28.

Reaction of Peroxyhemiacetal 24 with (Diacetoxyiodo)benzene−Iodine. A solution of **24** (20 mg, 0.037 mmol) in CH_2Cl_2 (2 mL) was treated with DIB (17 mg, 0.053 mmol) and I_2 (7 mg, 0.028 mmol) and irradiated as described above for 30 min at 24−25 °C. Workup and methylation afforded a residue that was purified by chromatotron chromatography (hexanes−EtOAc 7:3), giving methyl (1′*R*,1‴*R*,3′a*S*,3″*R*,4′*S*,-5′*S*,5″*S*,7′a*R*)-3-[5′-[5″-[(phenylsulfonyl)methyl]-3″-methyl-[1″,2″]dioxolan-3″-yl]-1′-(1‴,5‴-dimethylhexyl)-7′a-methyloctahydroinden-4′-yl]propanoate (**37**) (5 mg, 24%): amorphous; IR 1729, 1309, 1152 cm^{-1}; ^{1}H NMR (500 MHz) δ 0.68 (3H, s), 0.87 (3H, d, J = 6.5 Hz), 0.88 (3H, d, J = 6.6 Hz), 0.91 (3H, d, J = 6.5 Hz), 1.27 (3H, s), 2.11 (1H, ddd, J = 16.4, 12.3, 4.5 Hz), 2.25 (1H, dd, J = 12.7, 4.5 Hz), 2.42 (1H, ddd, J = 15.7, 11.4, 4.2 Hz), 2.84 (1H, dd, J = 12.8, 8.3 Hz), 3.30 (1H, dd, J = 14.3, 7.3 Hz), 3.57 (1H, dd, J = 14.2, 5.3 Hz), 3.64 (3H, s), 4.62 (1H, dddd, J = 8.5, 7.2, 5.8, 4.5 Hz), 7.59 (2H, dd, J = 7.8, 7.7 Hz), 7.68 (1H, dd, J = 7.2, 7.1 Hz), 7.94 (2H, d, J = 8.4 Hz); ^{13}C NMR (50.3 MHz) δ 12.0 (q), 18.6 (q), 19.3 (q), 22.6 (q), 22.8 (q), 23.8 (t), 24.1 (t), 25.3 (t), 26.3 (t), 27.8 (t), 27.9 (t), 28.0 (d), 35.75 (d), 35.79 (d), 36.0 (t), 39.5 (t), 39.8 (t), 42.5 (s), 46.1 (d), 51.4 (q), 51.9 (t), 52.3 (d), 56.3 (d), 59.6 (t), 74.3 (d), 89.8 (s), 128.0 (d × 2), 129.4 (d × 2), 134.0 (d), 139.4 (s), 175.1 (s); MS *m*/*z* (rel intensity) 576 (M^+, 1), 77 (100). Anal. Calcd for $C_{33}H_{52}O_6S$: C, 68.71; H, 9.09; S, 5.56. Found: C, 68.87; H, 9.26; S; 5.24.

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Supporting Information Available: Experimental procedures, physical properties, and spectroscopic data for compounds **1**−**7** and **25**−**29**; characterization of compounds **8**, **9**, **14**, **18**−**22**; X-ray data for compounds **25** and **33**, including tables of atomic coordinates, bond lengths, and bond angles (23 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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