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Synthesis and conformational and configurational studies of diastereoisomeric *O*-protected 4-(arylsulfonimidoyl)butane-1,2,3-triols

Joey S. W. Kwong,[a] Mary F. Mahon,[b] Matthew D. Lloyd[a] and Michael D. Threadgill[a,*]

[a]*Department of Pharmacy and Pharmacology, University of Bath, Claverton Down, Bath BA2 7AY, UK*
[b]*X-ray Crystallographic Unit, Department of Chemistry, University of Bath, Claverton Down, Bath BA2 7AY, UK*

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Abstract—Chiral sulfoximines have applications as transition-state mimicking enzyme inhibitors, as peptide isosteres and as chiral auxiliaries in synthesis. To access the required *O*-protected 4-(arylsulfonimidoyl)butane-1,2,3-triols, 4*S*,5*S*-di(hydroxymethyl)-2,2-dimethyl-1,3-dioxolane (prepared from diethyl *R*,*R*-tartrate) was converted into its monobenzyl ether. Mitsunobu-like coupling with thiophenols gave 4*S*,5*R*-4-(benzyloxymethyl)-2,2-dimethyl-5-(arylthiomethyl)-1,3-dioxolanes. Sulfoxidation and S-imination (trifluoroacetamide, iodosobenzene diacetate, rhodium acetate) proceeded without stereoselectivity, giving inseparable diastereomeric mixtures of 4*S*,5*R*,*S*(±)-4-(benzyloxymethyl)-2,2-dimethyl-5-(*N*-(trifluoroacetyl)arylsulfonimidoylmethyl)-1,3-dioxolanes. Removal of the trifluoroacetyl protection allowed chromatographic separation of the diastereomeric 4*S*,5*R*,*S*(±)-4-(benzyloxymethyl)-2,2-dimethyl-5-(arylsulfonimidoylmethyl)-1,3-dioxolanes. The configurations at sulfur were determined by X-ray crystallography and some analysis of the solution and solid-state conformations was carried out. The resulting *O*-protected 4-(arylsulfonimidoyl)butane-1,2,3-triols are of use in developing enzyme inhibitors.
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1. Introduction

Sulfoximines have attracted chemical and biological attentions since the discovery of α*S*,*S*(*S*)-methionine sulfoximine **1** (Fig. 1) as the toxic agent in agenised flour in the 1950s.[1] This compound inhibits glutamine synthetase,[2] the enzyme responsible for the formation of Gln from Glu and ammonia, and γ-glutamylcysteine synthetase,[3] which catalyses the first step in the biosynthesis of glutathione. Later studies showed that the homologue α*S*,*S*(*S*)-buthionine sulfoximine **2** is a more potent and selective inhibitor of γ-glutamylcysteine synthetase.[4,5] In **1** and **2**, the tetrahedral sulfoximine unit is acting as a mimic of the transition-state or intermediate of the enzyme-catalysed process.[2–4] Sulfoximines are configurationally stable. More recently, sulfoximines have been used in asymmetric synthesis as chiral ligands or chiral auxiliaries,[6–8] as peptidomimetics (e.g., **3**, Fig. 1)[9,10] and as transition-state mimics in the design of other enzyme inhibitors.[11] As part of our programme of design and synthesis of selective enzyme inhibitors,[12–14] we required the individual diastereoisomers of *O*-protected 2*S*,3*R*-4-(arylsulfonimidoyl)butane-1,2,3-triols with different configurations at sulfur.

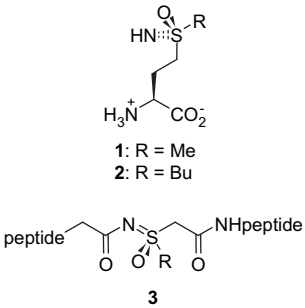

Figure 1. Structures of α*S*,*S*(*S*)-methionine sulfoximine **1**, α*S*,*S*(*S*)-buthionine sulfoximine **2** and a peptidomimetic **3** containing a sulfoximine.

2. Synthesis

The synthetic approach to the target *O*-protected sulfoximine triols is shown in Scheme 1. We proposed that the four-carbon unit bearing the two carbon chiral centres could be introduced from a precursor available from the chiral pool. The sulfoximine chiral centre could be created by diastereoselective sulfoxidation of the intermediate aryl sulfide, followed by imination or, less efficiently, by generation of a mixture of diastereoisomeric sulfides and selective imination of one diastereoisomer.

Diethyl *R*,*R*-tartrate **4** contains the required secondary alcohols in the configurations corresponding to those in the synthetic targets **12** and **13**. These were protected as

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* Corresponding author. Tel.: +44 1225 386840; fax: +44 1225 386114; e-mail: m.d.threadgill@bath.ac.uk

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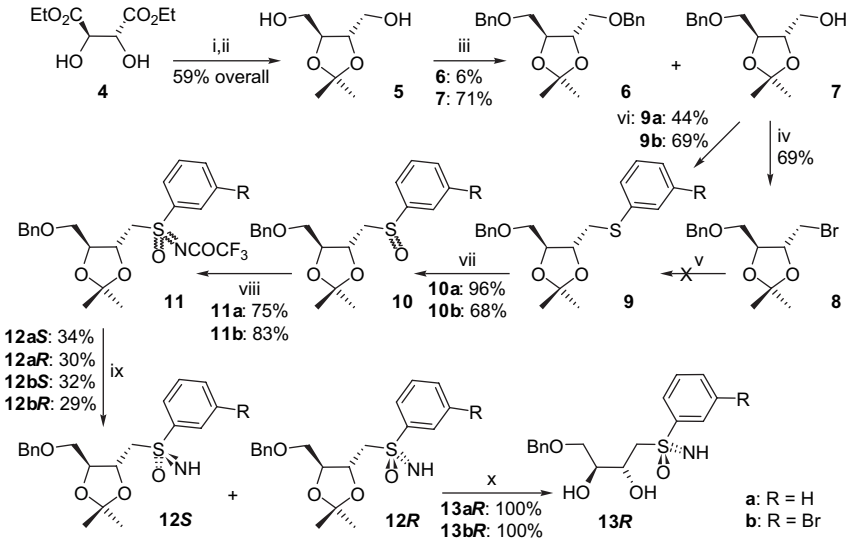

Scheme 1. Synthesis of the diastereoisomers of sulfoximines **13**. Reagents and conditions: (i) $(MeO)_2CMe_2$, TsOH, CH_2Cl_2, Δ; (ii) $LiAlH_4$, THF, Δ; (iii) NaH, BnBr, DMF, 0 °C; (iv) Ph_3P, CBr_4, THF; (v) PhSH, various bases, various conditions; (vi) PhSH/3-BrC_6H_4SH, Bu_3P, 1,1′-(azodicarbonyl)dipiperidine, THF,))); (vii) 3-$ClPhCO_3H$, CH_2Cl_2, −78 °C; (viii) CF_3CONH_2, MgO, $Rh_2(OAc)_4$, $PhI(OAc)_2$, CH_2Cl_2; (ix) NH_3, H_2O, MeOH; (x) HCl, H_2O, MeOH.

the acetonide by ketal exchange with 2,2-dimethoxypropane; the esters (mixed methyl and ethyl esters) were then reduced with lithium aluminium hydride to give the C_2-symmetric *S*,*S*-diol **5**. Desymmetrisation by monobenzylation with sodium hydride and benzyl bromide in DMF afforded **7** in 71% yield, which could be readily separated from the small quantity of dibenzyl ether **6** produced. The next step involved displacement of the primary OH with (substituted)-thiophenols, for which it would be necessary to convert it into a good leaving group. Treatment of **7** with tetrabromomethane and triphenylphosphine efficiently converted it into the bromo compound **8**. Interestingly, this primary alkyl halide could not be displaced with phenylthiolate anions under a variety of forcing conditions; study of the required angle of approach of the nucleophile to the electrophilic CH_2 in **8** in an S_N2 process indicated that steric crowding between the dioxolane and the incoming aromatic ring may preclude reaction. In contrast, displacement of the primary OH with the arylthio nucleophiles was achieved directly from **6** under Mitsunobu conditions (arylthiol, tributylphosphine, 1,1′-(azodicarbonyl)dipiperidine) to give the sulfides **9a** and **9b** in good yields.

At this point, it had been anticipated that the chirality of the sulfides **9** could be exploited to drive the sulfoxidation in a diastereoselective manner. However, no conditions could be found to achieve this diastereoselection, so **9a** was treated with 3-chloroperoxybenzoic acid to give a high yield of the sulfoxides **10a** as an inseparable 1:1 mixture of diastereoisomers. Similar reaction of the bromophenylsulfide **9b** gave the corresponding sulfoxides **10b**, also as an inseparable equimolar mixture. A variety of reagents and conditions have been used to generate sulfoximines from sulfoxides, including sodium azide/hot concd sulfuric acid[15] and *O*-(2,4,6-trimethylbenzenesulfonyl)hydroxylamine[16] but many are incompatible with the protecting groups used here. Okamura and Bolm have developed a very mild sulfoximination in which $PhI{=}NCOCF_3$ is generated in situ from iodosobenzene diacetate and trifluoroacetamide and Rh-catalysed transimination converts sulfoxides into *N*-trifluoroacetyl sulfoximines.[17] Application of this method to the mixture of diastereoisomeric Ph-unsubstituted sulfoxides **10a** gave a mixture of diastereoisomers of the *N*-trifluoroacetyl sulfoximines **11a**; the ratio of the diastereoisomers shifted from 1:1 in **10a** to 3:2 in **11a**, indicating that one diastereoisomer had reacted slightly more efficiently, but the isomers again could not be separated. In parallel, the bromophenylsulfoxides **10b** were converted into the inseparable *N*-trifluoroacetyl sulfoximines **11b** with no change in the 1:1 ratio of diastereoisomers.

The trifluoroacetyl groups were rapidly cleaved from **11a** and **11b** with ammonia, giving the free sulfoximines **12a** and **12b**, respectively. Now, the individual diastereoisomers contained H-bond donors and thus the diastereoisomers could be separated chromatographically, giving good yields of stereochemically pure **12a*R***, **12a*S***, **12b*R*** and **12b*S***. The acetal protection was removed by acid-catalysed hydrolysis from **12a*R*** and **12b*R*** to give the homochiral diols **13a*R*** and **13b*R***, respectively, to demonstrate that the secondary alcohols could be revealed without loss of stereochemical integrity. However, simple examination of the 1-D ^1H and ^{13}C NMR spectra did not allow assignment of the configurations at sulfur of the dioxolanylmethyl sulfoximines **12** or of the diols **13**.

3. X-ray crystallography and solution conformation studies

For each pair of diastereoisomeric sulfoximines **12a** and **12b**, one diastereoisomer was an oil but the other formed crystals (from ethanol/hexane) of quality suitable for X-ray crystallographic structure determination. The crystal structures (Fig. 2) confirmed that both crystalline diastereoisomers were of *S* configuration at sulfur, i.e., that they were **12a*S*** and **12b*S***.

The conformations of **12a*S*** in solution in chloroform and in the crystal were compared with each other and with the

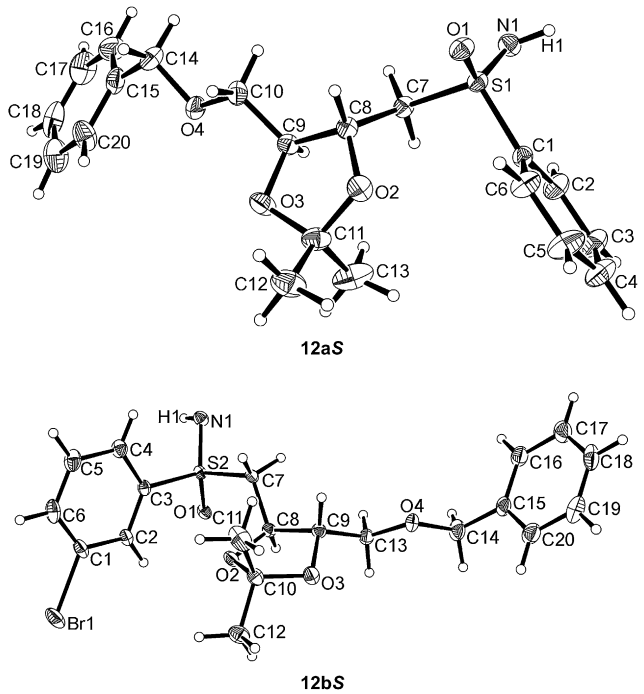

Figure 2. X-ray crystal structures of **12a*S*** and **12b*S*** with crystallographic numbering.

solution conformation of the diastereoisomer **12a*R***. Similar comparisons were made for the Ar-bromo analogues **12b*S*** and **12b*R***. Since it may be postulated that the N–H of the sulfoximine may form an intramolecular H-bond with the adjacent dioxolane oxygen, forming five/six-membered fused ring structures, MM2 energy-minimised structures were calculated for **12a*R*** and **12a*S*** with and without the constraints of these intramolecular H-bonds (Fig. 3). The predicted conformations of the two diastereoisomers without the intramolecular H-bonds are very similar to each other. In contrast, the predicted intramolecularly H-bonded conformation of **12a*R*** is very crowded, with the six- and five-membered rings almost orthogonal, whereas that of **12a*S*** is more open. In the predicted intramolecularly H-bonded conformation of **12a*R***, the dihedral angle between 4-H and 5-H of the dioxolane is ca. 90°; the observed ^3J=8.2 Hz coupling is inconsistent with such an angle. Thus **12a*R*** is likely to adopt a conformation without an intramolecular H-bond in solution in chloroform, where this dihedral angle is ca. 165°. The predicted conformation of the diastereoisomer **12a*S*** in the intramolecularly H-bonded structure has the five-membered dioxolane ring in a half-chair and the six-membered ring in a twist-boat; this gives the dihedral angle between 4-H and 5-H as ca. 140°, whereas the corresponding angle in the non-H-bonded conformer is ca. 165°. The observed coupling ^3J=7.9 Hz between these protons is consistent with both conformers. The NOESY spectrum of **12a*S*** also did not distinguish between the possible conformers in chloroform but allowed assignment of the signals from the geminal dimethyl unit. There were cross-peaks between the 4-H signal and the upfield methyl signal at δ 1.21 and between the 5-H signal and the downfield methyl peak at δ 1.29, showing that the former singlet is due to the methyl *cis* to the 4-CH_2OBn and the latter is due to the methyl *trans* to this substituent. The NMR spectra of the Ar-bromo analogues **12b*R*** and **12b*S*** were very similar, showing that the remote bromine had little effect on the

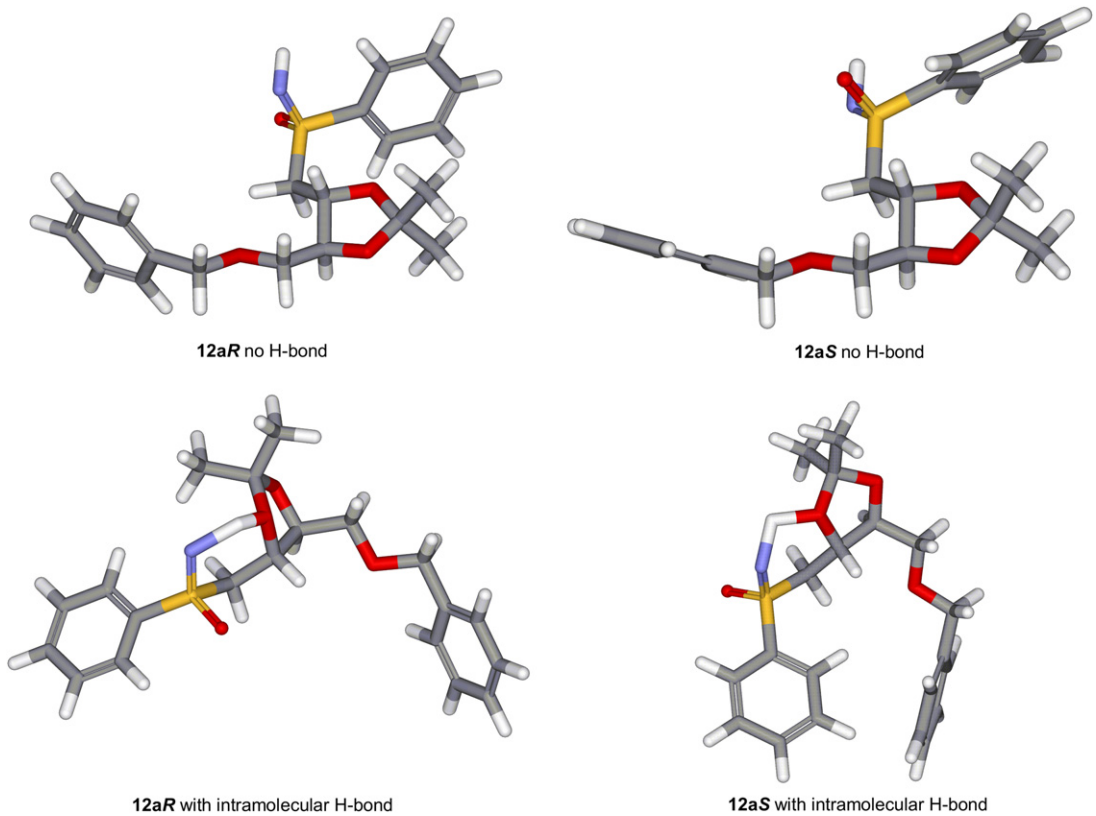

Figure 3. MM2 energy-minimised model structures of **12a*R*** and **12a*S*** without and with constraining intramolecular H-bond from sulfoximine N–H to O-1 of the dioxolane ring. Red, O; white, H; grey, C; blue, N; yellow, S.

conformations of the diastereoisomers in solution. Overlap of some signals and poor resolution of some multiplets in the ^{1}H NMR spectra of the deprotected derivatives **13a*R*** and **13b*R*** precluded any detailed analysis of their conformations in solution.

The crystal structures of **12a*S*** and **12b*S*** (Fig. 2) are remarkably similar and show extended conformations, with intermolecular H-bonding. In the structure of **12a*S***, the dihedral angle between the 4-*C*H$_2$OBn and the 5-*C*H$_2$SO(NH)Ph groups is 104°, corresponding to a half-chair conformation for the five-membered ring. The former bulky substituent almost eclipses the 5-H and that the latter large group is close to eclipsing the 4-H. The methyl cis to the 5-*C*H$_2$SO(NH)Ph group is in the *pseudo*-axial position. The crowded 5-C–CH$_2$S bond is in a staggered conformation, with the sulfoximine antiperiplanar to 4-C and *gauche* to the ring-oxygen. Interestingly, the bond from the CH$_2$ to the sulfoximine is also staggered but with the apparently bulky groups (Ph and dioxolane) almost *gauche* to each other (dihedral angle 81°). The structure of **12b*S*** shows a slightly smaller dihedral angle between the 4-*C*H$_2$OBn and the 5-*C*H$_2$SO(NH)Ph groups (97°) and the half-chair conformation of the dioxolane ring is distorted. The eclipsing of the 4-H and 5-H by their vicinal substituents is correspondingly diminished. The methyl *cis* to the 5-CH$_2$SO(NH)Ph group is again in the *pseudo*-axial position. The conformational arrangements of the two major side-chains are very similar to those in **12a*S***. As expected, the sulfoximine-sulfur atoms were approximately tetrahedral. The O═S═N bond angles in **12a*S*** and **12b*S*** were both 122°. Both compounds had S═N bond lengths of 1.52 Å and S═O bond lengths of 1.46 Å.

4. Conclusions

In this paper, we have reported the synthesis of two series of diastereoisomeric *O*-protected 4-(arylsulfonimidoyl)butane-1,2,3-triols, deriving the configuration of the two secondary alcohols from diethyl *R*,*R*-tartrate. A Mitsunobu reaction introduced the arylthio substituents. Peroxyacid sulfoxidation proceeded without diastereocontrol and Rh-catalysed oxidative imination gave the corresponding *N*-trifluoroacetyl sulfoximines as inseparable mixtures of diastereoisomers at sulfur. Removal of the TFA protection afforded the free NH sulfoximines, which were readily separated chromatographically. The configurations of the crystalline *S*(*S*) dioxolanes **12a*S*** and **12b*S*** were established by X-ray crystallography, for both the S-Ph and S-(3-BrAr) series. However, both corresponding *S*–*R* stereoisomers **12a*R*** and **12b*S*** were oils. Removal of the acetonide protection exposed the secondary alcohols in **13a*R*** and **13b*R***. The homochiral *O*-protected 4-(arylsulfonimidoyl)butane-1,2,3-triols are of potential use in developing enzyme inhibitors.

5. Experimental

5.1. General

IR spectra were obtained on a Perkin–Elmer 782 spectrometer as KBr discs or as liquid films. NMR spectra were recorded either on a Jeol EX270, Varian Mercury 400 or Varian United Inova 600 spectrometers of samples in CDCl$_3$, unless otherwise stated. Mass spectra were obtained by electrospray (ES), electron impact (EI) or fast atom bombardment (FAB) ionisation. Melting points were measured with a Thermo Galen Kofler block (uncorrected). Optical rotations were measured in a 1.0 dm cell on an Optical Activity Ltd. polarimeter and concentrations are expressed in g/100 mL. The chromatographic stationary phase was silica gel. THF refers to tetrahydrofuran and DMF refers to dimethylformamide. THF was dried with Na. Solutions in organic solvents were dried with MgSO$_4$. Solvents were evaporated under reduced pressure. Experiments were conducted at ambient temperature, unless otherwise stated.

5.2. 4*S*,5*S*-Di(hydroxymethyl)-2,2-dimethyl-1,3-dioxolane (5)

Diethyl (*R*,*R*)-2,3-dihydroxybutanedioate **4** (15.0 g, 70 mmol), 2,2-dimethoxypropane (32 g, 320 mmol) and TsOH·H$_2$O (198 mg, 1.0 mmol) in CH$_2$Cl$_2$ (200 mL) were boiled under reflux in a Soxhlet apparatus for 7 days through activated 4 Å molecular sieves (33 g). Dry Na$_2$CO$_3$ (83 mg, 1.0 mmol) was added. Filtration, drying, evaporation and chromatography (EtOAc/hexane, 2:3) afforded a mixture of diethyl, monoethyl-monomethyl and dimethyl esters of (4*R*,5*R*)-2,2-dimethyl-1,3-dioxolane-4,5-dicarboxylic acid (12 g, ca. 67%) as a pale buff oil. LiAlH$_4$ (2.0 M in THF, 51.5 mL, 103 mmol) was added during 1.5 h to this material in dry THF (80 mL) and the mixture was boiled under reflux for 5 h, then cooled to 0 °C. Water (10 mL), aq NaOH (4 M, 10 mL) and water (30 mL) were added cautiously in turn. The suspension was filtered and the solids were extracted with boiling 1,4-dioxane (3×100 mL). The solvents were evaporated from the combined extracts to give **5** (6.7 g, 85%) as a pale yellow oil with spectroscopic data identical to those reported in the literature.[14,18]

5.3. 4*S*,5*S*-Di(benzyloxymethyl)-2,2-dimethyl-1,3-dioxolane (6) and 4*S*,5*S*-4-benzyloxymethyl-5-hydroxymethyl-2,2-dimethyl-1,3-dioxolane (7)

NaH (60% in mineral oil, 1.9 g, 46 mmol, pre-washed with dry pentane) was stirred in dry DMF (20 mL) at 0 °C under N$_2$ for 30 min. Compound **5** (6.7 g, 42 mmol) in dry DMF (20 mL) was then added dropwise and the mixture was stirred for 30 min before benzyl bromide (7.35 g, 43 mmol) was added. The mixture was stirred for 1.5 h and was poured into ice-water (250 mL) and extracted thrice with Et$_2$O. The combined extracts were washed with water and brine. Drying, evaporation and chromatography (hexane/Et$_2$O, 1:1] gave **6** (500 mg, 6%) as a pale yellow oil with spectroscopic data identical to those reported in the literature.[14] Further elution gave **7** (3.6 g, 71%) as a pale yellow oil with spectroscopic data identical to those reported in the literature.[14]

5.4. 4*S*,5*R*-4-(Benzyloxymethyl)-5-(bromomethyl)-2,2-dimethyl-1,3-dioxolane (8)

Ph$_3$P (353 mg, 1.3 mmol) in dry THF (1.0 mL) was added dropwise to **7** (280 mg, 1.1 mmol) and CBr$_4$ (409 mg, 1.2 mmol) in dry THF (2.0 mL) at 0 °C under N$_2$ and the

mixture was stirred for 3 h. Evaporation and chromatography (hexane/Et_2O, 1:1) gave **8** (240 mg, 69%) as a colourless oil: ^{1}H NMR δ 1.43 (3H, s, Me), 1.45 (3H, s, Me), 3.46–3.54 (2H, m, $BrCH_2$), 3.62–3.69 (2H, m, $BnOCH_2$), 4.04–4.12 (2H, m, 4,5-H_2), 4.59 (2H, s, $PhCH_2$), 7.30–7.38 (5H, m, Ph-H_5); ^{13}C NMR δ 27.1 (Me), 27.2 (Me), 32.6 ($BrCH_2$), 70.4 (BnO*C*H_2), 73.6 (Ph*C*H_2), 77.2 (5-C), 78.8 (4-C), 110.0 (*C*Me_2), 127.7 (Ph 3,5-C_2), 127.8 (Ph 2,6-C_2), 128.4 (Ph 4-C), 137.7 (Ph 1-C); MS (FAB) *m/z* 317.0563 (M+H) ($C_{14}H_{20}O_3{}^{81}Br$ requires 317.0575), 316.0503 (M) ($C_{14}H_{19}O_3{}^{81}Br$ requires 316.0497), 235 (M−Br), 220 (M−CH_2Br); $[\alpha]_D^{20}$ +3.6 (*c* 1.7, $CHCl_3$).

5.5. 4*S*,5*R*-4-(Benzyloxymethyl)-2,2-dimethyl-5-(phenylthiomethyl)-1,3-dioxolane (9a)

PhSH (327 mg, 3.0 mmol) was added to Bu_3P (601 mg, 3.0 mmol) and 1,1′-(azodicarbonyl)dipiperidine (749 mg, 2.97 mmol) in dry THF (7.0 mL) under Ar at 0 °C and the mixture was sonicated for 30 min. During this sonication, **7** (500 mg, 2.0 mmol) in dry THF (3.0 mL) was added. The mixture was stirred at 20 °C for 16 h. Filtration, evaporation and chromatography (hexane/Et_2O, 5:1) gave **9a** (300 mg, 44%) as a pale yellow oil: ^{1}H NMR δ 1.40 (3H, s, Me), 1.44 (3H, s, Me), 3.19 (1H, d, *J*=4.3 Hz, SCH), 3.20 (1H, d, *J*=4.3 Hz, SCH), 3.63 (2H, d, *J*=4.7 Hz, $BnOCH_2$), 4.04–4.09 (2H, m, 4,5-H_2), 4.54 (1H, d, *J*=14.9 Hz, PhCH), 4.57 (1H, d, *J*=14.9 Hz, PhCH), 7.16–7.36 (10H, m, 2×Ph-H_5); ^{13}C NMR δ 27.1 (Me), 27.2 (Me), 36.7 (SCH_2), 70.7 (BnO*C*H_2), 73.5 (Ph*C*H_2), 77.0 (5-C), 79.4 (4-C), 109.7 (*C*Me_2), 126.2 (Ph-C_2), 127.8 (Ph-C_2), 128.4 (Ph-C_2), 128.9 (Ph-C_2), 129.2 (2×Ph 4-C), 135.8 (Ph 1-C), 137.8 (Ph′ 1-C); MS (FAB) *m/z* 345.1522 (M+H) ($C_{20}H_{24}O_3S$ requires 345.1519), 329 (M−CH_3), 109 (PhSH), 91 (Bn); $[\alpha]_D^{20}$ +4.4 (*c* 2.0, $CHCl_3$).

5.6. 4*S*,5*R*-4-(Benzyloxymethyl)-2,2-dimethyl-5-(3-bromophenylthiomethyl)-1,3-dioxolane (9b)

Compound **7** was treated with 3-bromothiophenol, as for the synthesis of **9a**, to give **9b** (69%) as a yellow oil: ^{1}H NMR δ 1.39 (3H, s, Me), 1.43 (3H, s, Me), 3.16–3.19 (2H, m, SCH_2), 3.59–3.66 (2H, m, $BnOCH_2$), 4.03–4.05 (2H, m, 4,5-H_2), 4.57 (2H, s, $PhCH_2$), 7.08 (1H, t, *J*=8.0 Hz, Ar 5-H), 7.22 (1H, ddd, *J*=8.1, 1.8, 1.0 Hz, Ar 6-H), 7.42–7.46 (5H, m, Ph-H_5), 7.48–7.51 (2H, m, Ar 2,4-H_2); ^{13}C NMR δ 27.0 (Me), 27.1 (Me), 36.3 (SCH_2), 70.5 (BnO*C*H_2), 73.6 (Ph*C*H_2), 77.2 (5-C), 79.1 (4-C), 110.0 (*C*Me_2), 122.8 (Ar 3-C), 127.3 (CH), 127.8 (Ph 3,5-C_2), 128.4 (Ph 2,6-C_2), 129.0 (Ph 4-C), 130.2 (Ar-CH), 131.2 (Ar-CH), 132.3 (Ar-CH), 137.7 (Ph 1-C), 138.5 (Ar 1-C); $[\alpha]_D^{20}$ +6.1 (*c* 2.5, $CHCl_3$).

5.7. 4*S*,5*R*,*S*(±)-4-(Benzyloxymethyl)-2,2-dimethyl-5-(phenylsulfinylmethyl)-1,3-dioxolane (10a)

Compound **9a** (180 mg, 0.52 mmol) was stirred with 3-chloroperoxybenzoic acid (111 mg, 0.52 mmol) in CH_2Cl_2 (15 mL) at −78 °C for 5 h. The mixture was washed (aq $NaHCO_3$, water). Drying and evaporation gave **10a** (180 mg, 96%) as a 1:1 mixture of diastereoisomers as a pale yellow oil: IR ν_{max} 1265 cm^{-1}; ^{1}H NMR δ 1.37 (1.5H, s, Me), 1.45 (1.5H, s, Me), 1.46 (1.5H, s, Me), 1.47 (1.5H, s, Me), 2.84 (0.5H, dd, *J*=13.2, 9.8 Hz, SCH (isomer A)), 3.04 (0.5H, dd, *J*=13.2, 4.2 Hz, SCH (isomer B)), 3.06 (0.5H, dd, *J*=13.2, 2.2 Hz, SCH (isomer A)), 3.22 (0.5H, dd, *J*=13.2, 7.2 Hz, SCH (isomer B)), 3.51 (0.5H, dd, *J*=10.1, 5.7 Hz, BnOCH (isomer B)), 3.55 (0.5H, dd, *J*=9.8, 5.7 Hz, BnOCH (isomer A)), 3.62 (0.5H, dd, *J*=9.8, 4.9 Hz, BnOCH (isomer B)), 3.68 (0.5H, dd, *J*=9.5, 5.3 Hz, BnOCH (isomer A)), 3.91 (0.5H, dt, *J*=5.3, 8.3 Hz, 4-H (isomer A)), 3.97 (0.5H, m, 5-H (isomer B)), 4.15 (0.5H, dt, *J*=5.3, 8.3 Hz, 4-H (isomer B)), 4.41 (0.5H, ddd, *J*=9.8, 8.3, 2.3 Hz, 5-H (isomer A)), 4.50 (0.5H, d, *J*=12.1 Hz, PhCH), 4.52 (0.5H, d, *J*=12.1 Hz, PhCH), 4.55 (1H, s, $PhCH_2$), 7.23–7.35 (5H, m, Ph-H_5), 7.50–7.53 (3H, m, S-Ph 3,4,5-H_3), 7.65–7.67 (2H, m, S-Ph 2,6-H_2); ^{13}C NMR δ 26.8 (Me), 26.9 (Me), 27.0 (Me), 27.2 (Me), 60.2 (SCH_2 (isomer B)), 62.2 (SCH_2 (isomer A)), 69.6 (BnO*C*H_2 (isomer B)), 70.0 (BnO*C*H_2 (isomer A)), 73.2 (5-C (isomer A)), 73.5 (Ph*C*H_2 (isomer B)), 73.7 (Ph*C*H_2 (isomer A)), 73.9 (5-C (isomer B)), 78.6 (4-C (isomer B)), 79.0 (4-C (isomer A)), 110.0 (*C*Me_2), 110.2 (*C*Me_2), 123.8 (CH), 124.3 (CH), 127.6 (CH), 127.7 (CH), 127.8 (CH), 128.4 (CH), 129.2 (CH), 129.3 (CH), 131.2 (S-Ph 4-CH), 131.3 (S-Ph 4-CH), 137.6 (C-Ph 1-C), 137.7 (C-Ph 1-C), 143.5 (S-Ph 1-C (isomer B)), 144.5 (S-Ph 1-C (isomer A)); MS (FAB) *m/z* 361 (M+H), 303 (M+H−Me_2CO); $[\alpha]_D^{20}$ +4.4 (*c* 2.0, $CHCl_3$).

5.8. 4*S*,5*R*,*S*(±)-4-(Benzyloxymethyl)-2,2-dimethyl-5-(3-bromophenylsulfinylmethyl)-1,3-dioxolane (10b)

Compound **9b** was treated with 3-chloroperoxybenzoic acid, as for the synthesis of **10a**, to give **10b** (68%) as a 3:2 mixture of diastereoisomers as a yellow oil: ^{1}H NMR δ 1.16 (1.8H, Me), 1.21 (1.2H, Me), 1.25 (1.8H, Me), 1.26 (1.2H, Me), 3.42 (dd, *J*=9.6, 6.8 Hz) and 3.43 (dd, *J*=9.7, 6.8 Hz) (BnOC*H*H), 3.65 (dd, *J*=10.7, 4.7 Hz) and 3.66 (dd, *J*=10.2, 4.7 Hz) (BnOCH*H*), 3.79 (dd, *J*=14.1, 8.6 Hz) and 3.81 (dd, *J*=14.4, 9.7 Hz) (SC*H*H), 3.86–3.92 (1H, m, 4-H), 3.99 (dd, *J*=11.2, 2.3 Hz) and 4.03 (dd, *J*=11.2, 2.2 Hz) (SCH*H*), 4.14–4.19 (1H, m, 5-H), 4.49 (2H, s, $PhCH_2$), 7.23–7.37 (5H, m, Ph-H_5), 7.54–7.60 (2H, m, S-Ph 3,5-H_2), 7.70 (1H, t, *J*=8 Hz, S-Ph 4-H), 7.94 (2H, d, *J*=8 Hz, S-Ph 2,6-H_2); ^{13}C NMR δ 26.4 (Me), 26.6 (Me), 58.5 (SCH_2), 59.3 (SCH_2), 69.6 ($BnOCH_2$), 69.7 ($BnOCH_2$), 72.9 (5-C), 73.3 (5-C), 73.6 ($PhCH_2$), 73.7 ($PhCH_2$), 78.1 (4-C), 78.2 (4-C), 110.8 (*C*Me_2), 127.7 (CH), 127.8 (CH), 127.9 (C-Ph 2,6-C_2), 128.0 (CH), 128.2 (S-Ph 2,6-C_2), 128.3 (CH), 128.47 (CH), 128.49 (CH), 128.53 (C-Ph 3,5-C_2), 129.0 (CH), 129.5 (S-Ph 3,5-C_2), 134.6 (S-Ph 4-C), 134.8 (S-Ph 4-C), 135.3 (S-Ph 1-C), 135.4 (S-Ph 1-C), 137.32 (C-Ph 1-C), 137.35 (C-Ph 1-C); ^{19}F NMR δ −76.0 (1.8F, s), −75.9 (1.2F, s); $[\alpha]_D^{20}$ +3.7 (*c* 2.0, $CHCl_3$).

5.9. 4*S*,5*R*,*S*(±)-4-(Benzyloxymethyl)-2,2-dimethyl-5-(*N*-(trifluoroacetyl)phenylsulfonimidoylmethyl)-1,3-dioxolane (11a)

$PhI(OAc)_2$ (242 mg, 0.75 mmol) was stirred vigorously with **10a** (180 mg, 0.5 mmol), CF_3CONH_2 (113 mg, 1.0 mmol), MgO (81 mg, 2.0 mmol) and $Rh_2(OAc)_4$ (5.5 mg, 2.5 mol %) in CH_2Cl_2 (10 mL) for 6 days. Filtration (Celite®), evaporation and chromatography (hexane/Et_2O, 1:1) afforded **11a** (176 mg, 75%) as a 3:2 mixture of diastereoisomers as a pale yellow oil: IR ν_{max} 1422, 1265, 1173 cm^{-1}; ^{1}H NMR δ 1.16 (1.8H, Me), 1.21 (1.2H, Me), 1.25 (1.8H,

Me), 1.26 (1.2H, Me), 3.42 (dd, J=9.6, 6.8 Hz) and 3.43 (dd, J=9.7, 6.8 Hz) (BnOC*H*H), 3.65 (dd, J=10.7, 4.7 Hz) and 3.66 (dd, J=10.2, 4.7 Hz) (BnOCH*H*), 3.79 (dd, J=14.1, 8.6 Hz) and 3.81 (dd, J=14.4, 9.7 Hz) (SC*H*H), 3.86–3.92 (1H, m, 4-H), 3.99 (0.5H, dd, J=11.2, 2.3 Hz) and 4.03 (0.5H, dd, J=11.2, 2.2 Hz) (SCH), 4.14–4.19 (1H, m, 5-H), 4.49 (2H, s, $PhCH_2$), 7.23–7.37 (5H, m, Ph-H_5), 7.54–7.60 (2H, m, S-Ph 3,5-H_2), 7.70 (1H, t, J=8 Hz, S-Ph 4-H), 7.94 (2H, d, J=8 Hz, S-Ph 2,6-H_2); ^{13}C NMR δ 26.4 (Me), 26.6 (Me), 58.5 (SCH_2), 59.3 (SCH_2), 69.6 (BnO*C*H_2), 69.7 (BnO*C*H_2), 72.9 (4-C), 73.3 (4-C), 73.6 (Ph*C*H_2), 73.7 (Ph*C*H_2), 78.1 (5-C), 78.2 (5-C), 110.8 (*C*Me_2), 127.7 (Ph-CH), 127.8 (Ph-CH), 127.9 (C-Ph 2,6-C_2), 128.0 (Ph-CH), 128.2 (S-Ph 2,6-C_2), 128.3 (Ph-CH), 128.47 (Ph-CH), 128.49 (Ph-CH), 128.53 (C-Ph 3,5-C_2), 129.0 (Ph-CH), 129.5 (S-Ph 3,5-C_2), 134.8 (Ph 1-C), 135.3 (Ph 1-C), 135.4 (Ph 1-C), 138.0 (Ph 1-C); ^{19}F NMR δ −76.0 (1.8F, s), −75.9 (1.2F, s); MS (FAB) m/z 472.1382 (M+H) ($C_{22}H_{25}NO_5F_3S$ requires 472.1406), 472 (M+H−O), 414 (M+H−Me_2CO); $[\alpha]_D^{20}$ +5.1 (c 2.6, $CHCl_3$).

5.10. 4*S*,5*R*,*S*(±)-4-(Benzyloxymethyl)-2,2-dimethyl-5-(*N*-trifluoroacetyl-3-bromophenylsulfonimidoyl-methyl)-1,3-dioxolane (11b)

Compounds **10b** were treated with trifluoroacetamide, $PhI(OAc)_2$ and $Rh_2(OAc)_4$, as for the synthesis of **11a**, to give **11b** (83%) as a 1:1 mixture of diastereoisomers as a pale yellow oil: IR ν_{max} 1746, 1216, 1176 cm^{-1}; ^{1}H NMR δ 1.15 (1.5H, s, Me), 1.21 (1.5H, s, Me), 1.26 (1.5H, s, Me), 1.28 (1.5H, s, Me), 3.49 (1H, m, BnOCH), 3.66 (0.5H, dd, J=8.2, 4.8 Hz, BnOCH), 3.68 (0.5H, dd, J=8.2, 4.8 Hz, BnOCH), 3.70–3.75 (0.5H, m, SCH), 3.76 (0.5H, dd, J=14.6, 9.8 Hz, SCH), 3.87 (1H, m, 4-H), 4.05 (0.5H, dd, J=10.0, 2.2 Hz, SCH), 4.09 (0.5H, dd, J=9.9 Hz, 2.3 Hz, SCH), 4.14–4.22 (1H, m, 5-H), 4.51 (2H, s, $PhCH_2$), 7.27–7.40 (5H, m, Ph-H_5), 7.43 (1H, dt, J=1.9, 8.0 Hz, Ar 5-H), 7.72–7.85 (2H, m, Ar 4,6-H_2), 8.08 (0.5H, t, J=1.6 Hz, Ar 2-H), 8.11 (0.5H, t, J=1.9 Hz, Ar 2-H); ^{13}C NMR δ 26.4 (Me), 26.5 (Me), 26.6 (Me), 58.6 (SCH_2), 59.4 (SCH_2), 69.5 (BnO*C*H_2), 69.6 (BnO*C*H_2), 72.9 (5-C), 73.4 (5-C), 73.8 (Ph*C*H_2), 77.97 (4-C), 78.02 (4-C), 110.8 (*C*Me_2), 110.9 (*C*Me_2), 123.3 (Ar 3-C), 126.7, 126.8, 127.8, 128.0, 128.1, 128.5, 128.6, 130.83 (Ar 5-C), 130.85 (Ar 5-C), 131.3 (Ar 2-CH), 131.4 (Ar 2-C), 137.2 (Ph 1-C), 137.3 (Ph 1-C), 137.4 (Ar 1-C), 137.5 (Ar 1-C), 137.7, 137.8; ^{19}F NMR δ −76.0 (1.5F, s, CF_3), −75.9 (1.5F, s, CF_3); $[\alpha]_D^{20}$ +4.3 (c 1.4, $CHCl_3$).

5.11. 4*S*,5*R*,*S*(*R*)-4-(Benzyloxymethyl)-2,2-dimethyl-5-(phenylsulfonimidoylmethyl)-1,3-dioxolane (12a*R*) and 4*S*,5*R*,*S*(*S*)-4-(benzyloxymethyl)-2,2-dimethyl-5-(phenylsulfonimidoylmethyl)-1,3-dioxolane (12a*S*)

Compounds **11a** (176 mg, 0.37 mmol) were stirred with NH_3 (35% in water, 2.0 mL) in MeOH (5.0 mL) for 16 h. Evaporation and chromatography (EtOAc/hexane, 2:3) yielded **12a*R*** (42 mg, 30%) as a pale yellow oil: IR ν_{max} 3332, 733 cm^{-1}; ^{1}H NMR δ 1.33 (3H, s, Me), 1.37 (3H, s, Me), 3.10 (1H, br s, NH), 3.30 (1H, dd, J=13.6, 8.7 Hz, SCH), 3.45 (1H, dd, J=13.6, 2.9 Hz, SCH), 3.53 (1H, dd, J=9.8, 5.8 Hz, BnOCH), 3.67 (1H, dd, J=9.8, 5.3 Hz, BnOCH), 3.90 (1H, dt, J=7.7, 5.3 Hz, 4-H), 4.45 (1H, dt, J=2.9, 8.7 Hz, 5-H), 4.51 (2H, s, $PhCH_2$), 7.27–7.35 (5H, m, Ph-H_5), 7.50 (2H, m, S-Ph 3,5-H_2), 7.59 (1H, m, S-Ph 4-H), 8.00 (2H, m, S-Ph 2,6-H_2); ^{13}C NMR δ 26.8 (Me), 26.9 (Me), 61.3 (SCH_2), 70.0 (BnO*C*H_2), 73.6 (Ph*C*H_2), 73.7 (5-C), 78.7 (4-C), 110.4 (*C*Me_2), 127.6 (Ph 3,5-C_2), 127.7 (Ph 4-C), 128.4 (Ph 3,5-C_2), 128.5 (Ph 2,6-C_2), 129.0 (Ph 2,6-C_2), 133.1 (Ph 4-C), 137.6 (Ph 1-C), 141.5 (Ph 1-C); MS (FAB) m/z 376 (M+H); MS (ES) m/z 775 (2M+Na), 399 (M+Na), 375 (M); $[\alpha]_D^{20}$ +8.4 (c 2.3, $CHCl_3$). Further elution gave **12a*S*** (47 mg, 34%) as a white solid: mp 86–88 °C; IR ν_{max} 3332, 734 cm^{-1}; ^{1}H NMR δ 1.21 (3H, s, Me trans to CH_2OBn), 1.29 (3H, s, Me cis to CH_2OBn), 3.39 (1H, dd, J=14.2, 8.2 Hz, SCH), 3.50–3.54 (2H, m, SCH+BnOCH), 3.64 (1H, dd, J=9.7, 5.3 Hz, BnOCH), 3.93 (1H, dt, J=7.6, 5.3 Hz, 4-H), 4.31 (1H, dt, J=3.4, 8.2 Hz, 5-H), 4.51 (2H, s, $PhCH_2$), 7.26–7.35 (5H, m, Ph-H_5), 7.48 (2H, m, S-Ph 3,5-H_2), 7.58 (1H, m, S-Ph 4-H), 7.96 (2H, m, S-Ph 2,6-H_2); ^{13}C NMR δ 26.7 (Me), 26.8 (Me), 61.0 (SCH_2), 69.9 (BnO*C*H_2), 73.5 (5-C), 73.6 (Ph*C*H_2), 78.6 (4-C), 110.1 (*C*Me_2), 127.6 (Ph 3,5-C_2), 127.7 (Ph 4-C), 128.4 (Ph 3,5-C_2), 128.5 (Ph 2,6-C_2), 128.8 (Ph 2,6-C_2), 133.0 (Ph 4-C), 137.6 (Ph 1-C), 141.5 (Ph 1-C); MS (FAB) m/z 376 (M+H); $[\alpha]_D^{20}$ +7.8 (c 2.3, $CHCl_3$).

5.12. 4*S*,5*R*,*S*(*R*)-4-(Benzyloxymethyl)-2,2-dimethyl-5-(3-bromophenylsulfonimidoylmethyl)-1,3-dioxolane (12b*R*) and 4*S*,5*R*,*S*(*S*)-4-(benzyloxymethyl)-2,2-dimethyl-5-(3-bromophenylsulfonimidoylmethyl)-1,3-dioxolane (12b*S*)

Compounds **11b** were treated with NH_3, as for the synthesis of **12a*R*** and **12a*S*** except that the chromatographic eluant was EtOAc/hexane (7:3), to give **12b*R*** (29%) as a pale yellow oil: ^{1}H NMR δ 1.22 (3H, s, Me), 1.32 (3H, s, Me), 3.34 (1H, dd, J=14.5, 9.0 Hz, SCH), 3.46 (1H, dd, J=14.5, 2.7 Hz, SCH), 3.52 (1H, dd, J=9.8, 6.3 Hz, BnOCH), 3.69 (1H, dd, J=9.8, 5.1 Hz, BnOCH), 3.86 (1H, ddd, J=7.8, 6.3, 4.7 Hz, 4-H), 4.31 (1H, ddd, J=8.6, 7.8, 2.7 Hz, 5-H), 4.53 (2H, s, $PhCH_2$), 7.29–7.37 (5H, m, Ph-H_5), 7.38 (1H, t, J=7.8 Hz, Ar 5-H), 7.75 (1H, ddd, J=7.8, 2.0, 0.8 Hz, Ar 4-H or Ar 6-H), 7.82 (1H, ddd, J=7.8, 2.0, 0.8 Hz, Ar 6-H or Ar 4-H), 8.08 (1H, t, J=1.9 Hz, Ar 2-H); ^{13}C NMR δ 26.7 (Me), 26.8 (Me), 59.7 (SCH_2), 69.9 ($BnOCH_2$), 73.6 (5-CH), 73.7 (Ph*C*H_2), 78.4 (4-C), 110.3 (*C*Me_2), 122.8 (Ar 3-C), 126.9, 127.7, 127.9, 128.5, 130.4, 131.6, 136.7, 137.5 (Ph 1-C), 141.6 (Ar 1-C); MS (ES) m/z 456.0642 (M+H) ($C_{20}H_{25}{}^{81}BrNO_4S$ requires 456.0668), 455.0585 (M) ($C_{20}H_{24}{}^{81}BrNO_4S$ requires 456.0590), 454.0669 (M+H) ($C_{20}H_{25}{}^{79}BrNO_4S$ requires 454.0682), 453.0604 (M) ($C_{20}H_{24}{}^{79}BrNO_4S$ requires 453.0610); $[\alpha]_D^{20}$ +3.2 (c 1.5, $CHCl_3$). Further elution gave **12b*S*** (32%) as a white solid: mp 75–77 °C; ^{1}H NMR δ 1.20 (3H, s, Me), 1.31 (3H, s, Me), 2.32 (1H, br s, NH), 3.38 (1H, dd, J=14.3, 8.7 Hz, SCH), 3.52 (1H, dd, J=9.5, 6.3 Hz, BnOCH), 3.54 (1H, dd, J=14.3, 3.0 Hz, SCH), 3.66 (1H, dd, J=9.5, 5.1 Hz, BnOCH), 3.89 (1H, ddd, J=8.0, 6.3, 5.1 Hz, 4-H), 4.33 (1H, ddd, J=8.5, 8.0, 2.9 Hz, 5-H), 4.53 (2H, s, $PhCH_2$), 7.27–7.39 (5H, m, Ph-H_5), 7.36 (1H, t, J=8.0 Hz, Ar 5-H), 7.70 (1H, ddd, J=8.0, 2.1, 1.0 Hz, Ar 4-H or Ar 6-H), 7.90 (1H, ddd, J=8.0, 2.1, 1.0 Hz, Ar 6-H or Ar 4-H), 8.14 (1H, t, J=1.9 Hz, Ar 2-H); ^{13}C NMR δ 26.7 (Me), 26.8 (Me), 61.0 (SCH_2), 69.9 (BnO*C*H_2), 73.7

(PhCH_2+5-C), 78.4 (4-C), 110.3 (CMe_2), 122.7 (Ar 3-C), 127.2, 127.7 (Ph 3,5-C_2), 127.9, 128.5 (Ph 2,6-C_2), 130.3 (Ar 5-C), 131.8 (Ar 2-C), 136.0, 137.5 (Ph 1-C), 144.3 (Ar 1-C). Anal. Calcd for $C_{20}H_{24}BrNO_4S$: C, 52.87; H, 5.32; N, 3.08. Found: C, 52.82; H, 5.22; N, 3.06; $[\alpha]_D^{20}$ +2.6 (*c* 1.5, $CHCl_3$).

5.13. 2*S*,3*R*,*S*(*R*)-1-(Benzyloxy)-4-(phenylsulfonimidoyl)butane-2,3-diol (13a*R*)

Compound **12a*R*** (38 mg, 0.1 mmol) was stirred with aq HCl (9 M, 1.0 mL) in MeOH (5.0 mL) for 4 h. Evaporation and chromatography (EtOAc/MeOH, 7:3) afforded **13a*R*** (37 mg, 100%) as a pale yellow oil: IR ν_{max} 3305 cm^{-1}; ^{1}H NMR δ 2.68 (1H, br, OH), 3.13 (1H, dd, *J*=13.8, 1.7 Hz, SCH), 3.45 (1H, dd, *J*=13.8, 10.1 Hz, SCH), 3.59–3.63 (2H, m, $BnOCH_2$), 3.69 (1H, m, 3-H), 4.54–4.56 (3H, m, $PhCH_2$+4-H), 7.27–7.35 (5H, m, Ph-H_5), 7.56 (2H, m, S-Ph 3,5-H_2), 7.64 (1H, m, S-Ph 4-H), 7.98 (2H, m, S-Ph 2,6-H_2); ^{13}C NMR δ 59.8 (SCH_2), 66.4 (4-C), 71.0 (1-C), 72.4 (3-C), 73.5 (PhCH_2), 127.7 (Ph 3,5-C_2), 127.8 (Ph 4-C), 128.1 (Ph 3,5-C_2), 128.5 (Ph 2,6-C_2), 129.4 (Ph 2,6-C_2), 133.5 (Ph 4-C), 137.7 (Ph 1-C), 142.6 (Ph 1-C); MS (FAB) *m*/*z* 336 (M+H); MS (ES^+) *m*/*z* 693 (2M+Na), 671 (2M+H), 336.1264 (M+H) ($C_{17}H_{23}NO_4S$ requires 336.1264); MS (ES^-) *m*/*z* 372/370 (M+Cl); MS (EI) *m*/*z* 336 (M+H), 244 (M−Bn), 214 (M−$BnOCH_2$), 91 (Bn); $[\alpha]_D^{20}$ +5.5 (*c* 1.3, $CHCl_3$).

5.14. 2*S*,3*R*,*S*(*R*)-1-(Benzyloxy)-4-(3-bromophenylsulfonimidoyl)butane-2,3-diol (13b*R*)

Compound **12b*R*** was treated with aq HCl, as for the synthesis of **13a*R***, to give **13b*R*** (100%) as a pale yellow solid: mp 73–76 °C; IR ν_{max} 3425 cm^{-1}; ^{1}H NMR δ 3.00 (2H, br, 2×OH), 3.13 (1H, d, *J*=14 Hz, SCH), 3.45 (1H, dd, *J*=13.9, 10.1 Hz, SCH), 3.59–3.64 (2H, m, $BnOCH_2$), 3.70 (1H, m, 2-H), 4.52 (1H, d, *J*=11.7 Hz, PhCH), 4.54 (1H, d, *J*=11.7 Hz, PhCH), 4.55 (1H, br d, *J*=10 Hz, 3-H), 7.27–7.36 (5H, m, Ph-H_5), 7.43 (1H, t, *J*=7.9 Hz, Ar 5-H), 7.75 (1H, ddd, *J*=8.0, 1.9, 0.8 Hz, Ar 4-H or Ar 6-H), 7.91 (1H, ddd, *J*=8.0, 1.9, 0.8 Hz, Ar 6-H or Ar 4-H), 8.12 (1H, t, *J*=1.8 Hz, Ar 2-H); ^{13}C NMR δ 59.9 (SCH_2), 66.5 (3-C), 71.0 (1-C), 72.3 (2-C), 73.6 (PhCH_2), 123.4 (Ar 3-C), 126.7, 127.9 (Ph 3,5-C_2), 128.0, 128.6 (Ph 2,6-C_2), 130.9, 131.1, 136.7, 137.6 (Ph 1-C), 141.0 (Ar 1-C). Anal. Calcd for $C_{17}H_{20}BrNO_4S$: C, 49.28; H, 4.87; N, 3.38. Found: C, 49.48; H, 4.61; N, 2.95; $[\alpha]_D^{20}$ +2.5 (*c* 1.7, $CHCl_3$).

5.15. Crystal data for 12a*S*

Crystals of quality suitable for X-ray crystallography were grown from EtOH/hexane. $C_{20}H_{25}NO_4S$, *M*=375.47, orthorhombic, *a*=5.5540(1), *b*=18.4970(3), *c*=19.2410(4) Å, *U*=1976.67(6) Å^3, *T*=150(2) K, space group=$P2_12_12_1$, *Z*=4, μ(Mo Kα)=0.188 mm^{-1}, 4490 reflections (R_{int}=0.04977), *R*1=0.03581 and *wR*2=0.0772 based on 3837 F^2 with $F_o \geq 4\sigma(F_o)$. Software used: SHELXS,[19] SHELXL-97[20] and ORTEX.[21] Atoms C14–C20 disordered in 1:1 ratio with C14A–C20A, respectively. H1 located and refined at 0.89 Å from N1. CCDC 654427.

5.16. Crystal data for 12b*S*

Crystals of quality suitable for X-ray crystallography were grown from EtOH/hexane. $C_{20}H_{24}NO_4SBr$, *M*=454.37, monoclinic, *a*=12.3520(2), *b*=5.5440(1), *c*=15.7540(3) Å, β=103.459(1)°, *U*=1049.20(3) Å^3, *T*=150(2) K, space group=$P2_1$, *Z*=2, μ(Mo Kα)=2.083 mm^{-1}, 5447 reflections (R_{int}=0.0506), *R*1=0.0347 and *wR*2=0.0731 based on 4752 F^2 with $F_o \geq 4\sigma(F_o)$. Software used: SHELXS,[19] SHELXL-97[20] and ORTEX.[21] H1 located and refined at 0.89 Å from N1. CCDC 654428.

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