Aminolysis of cyclic thioxocarbonate of (*R*,*R*)-di-*tert*-butyl tartrate: efficient access to thio- and thiolcarbamates †

Ludovic Faissat, Claude Chavis, Jean-Louis Montéro and Marc Lucas *

ENSCM, Laboratoire de Chimie Biomoléculaire, UMR 5032, 8 Rue de l'Ecole Normale, 34296 Montpellier Cédex 05, France. E-mail: lucas@univ-montp2.fr

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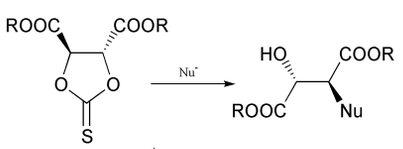
Aminolysis of cyclic thioxocarbonates derived from (*R*,*R*)-dialkyl tartrates with secondary amines is described to afford efficiently thio- and thiolcarbamates in a fast and high yielding reaction. Their stereochemistry and mechanism of formation are discussed.

Introduction

Cyclic carbonates are known to react slowly at room temperature at their carbonyl centre with amines to yield carbamates, but their reactivity can be enhanced in nucleophilic additions by using the more reactive thiocarbonyl group. For example, the cyclic thioxocarbonate of 3-*O*-phenylglycerol reacts with *n*-hexylamine or benzylamine at ambient temperature in dimethyl sulfoxide to afford two hydroxythiourethane isomers (88 : 12) where the secondary alcohol predominates;[1] similarly, the regioselective ring-opening of the 4,6-*O*-benzylidene-α-D-glucopyranoside 2,3-thiocarbonate by liquid ammonia or piperidine produces a mixture of 2- and 3-thiocarbamates in a 3.6 : 1 ratio.[2] Considering cyclic thioxocarbonates derived from C_2-symmetric chiral dialkyl tartrates, the electron-withdrawing carboxylic esters will increase the electrophilic character of the carbinol carbons and consequently nucleophilic substitutions at these positions will be favoured . This possibility has been developed until recently with cyclic thioxocarbonates[3–7] which mimic the corresponding cyclic sulfites and sulfates[8–10] used as epoxide surrogates, in regio- and stereoselective functionalisations or deoxygenation reactions. Thus numerous nucleophiles, except amines, have been reported to open the cyclic thioxocarbonates of dialkyl tartrates with inversion of configuration and with the production of *anti*-α-substituted β-hydroxy diesters (Scheme 1) by an exclusive attack at the two chemically equivalent carbinol carbons.

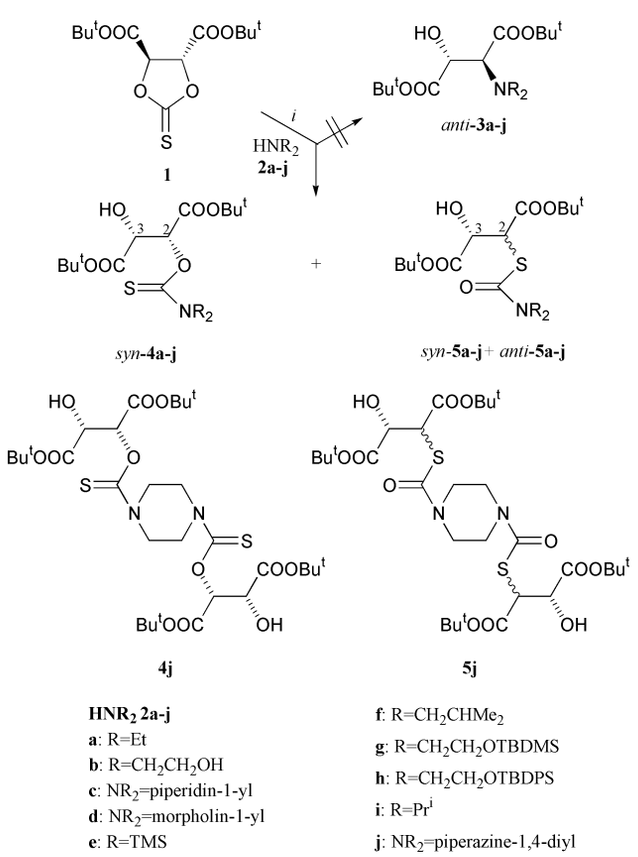


Scheme 1

In this report we focus on the peculiar reactivity of the cyclic thioxocarbonates of dialkyl tartrates as ambident substrates towards secondary amines.

Results and discussion

Surprisingly, we found that when secondary amines **2** reacted with the cyclic thioxocarbonate of (*R*,*R*)-di-*tert*-butyl tartrate **1** in dichloromethane at room temperature, instead of the expected α-amino β-hydroxy succinates *anti*-**3** we obtained the optically active thiocarbamate *syn*-**4** and/or a mixture of *syn*- and *anti*-thiolcarbamates **5**, altogether corresponding to an exclusive primary nucleophilic attack at the thiocarbonyl centre and in a ratio dependent on the amine (Scheme 2, Table 1).



Scheme 2 *Reagents and conditions*: i, thioxocarbonate **1** (1 equiv.), amines **2a**–**i** (2 equiv.) or **2j** (0.5 equiv.), dichloromethane, room temp., 30 min. or 12 h.

It is noteworthy that the reactions reached completion very quickly (30 min) with amines **2a**–**e** or **2j** and much more slowly with others (**2f**–**i**, 12 h). Moreover, when the reaction proceeded rapidly, the thiocarbamates *syn*-**4a**–**e** or the bis(thiocarbamate) *syn*–*syn*-**4j** were exclusively formed with retention of configuration, whereas in the case of the reported slow reactions (amines **2f**–**h**) a diastereomeric mixture of *syn*–*anti*-thiolcarbamates **5** was produced concomitantly with **4**. Finally it

† In this paper thioxocarbonate refers to thiocarbonate-*O*,*O*-diesters and the IUPAC name for thiolcarbamate is thiocarbamate.

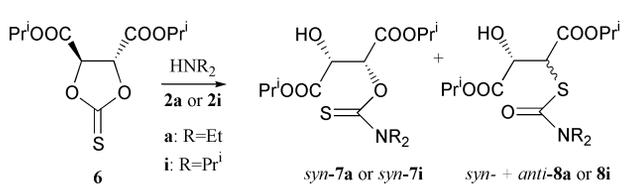
Table 1 Reactions of thioxocarbonate **1** with amines **2a–j** in dichloromethane at room temp.

Run	Amine	Time/h	**4** : **5**	Yield (%) **4** + **5**	*syn*-**4a–j** δH_2, J_{2-3}, δC_2	*syn*- + *anti*-**5a–j** [d,e] δH_2, J_{2-3}, δC_2
1	**2a**	0.5	100 : 0	95		
2			50 : 50 [a]	63 [a]	6.1, 2.3, 78.3	4.75, 2.9, 53.0
3	**2b**	0.5	100 : 0	Quant.	6.1, 2.3, 79.2	
4	**2c**	0.5	100 : 0	Quant.	6.1, 2.3, 77.6	
5	**2d**	0.5	100 : 0	Quant.	6.1, 2.4, 79.2	
6	**2e**	0.5	100 : 0 [b]	Quant.	5.9, 2.5, 79.4	
7	**2f**	12	50 : 50	90	6.0, 2.1, 79.2	4.8, 2.9, 52.9
8	**2g** [c]	12	88 : 12	87		
9			0 : 100 [a]	98 [a]	6.1, 2.3, 79.1	4.7, 3.1, 52.4
10	**2h**	12	39 : 61	64	6.1, 2.3, 79.5	4.7, 2.8, 53.1
11	**2i**	12	0 : 100	70		4.7, 3.0, 52.0
12	**2j**	0.5	100 : 0 [f]	84	6.0, 2.1, 79.5	

[a] DMF was used as the solvent. [b] $NR_2 = NH_2$. [c] See ref 23. [d] Ratio not determined. [e] $J_{2-3anti} \approx J_{2-3syn}$ (see chemical correlation of *anti*-**5i**). [f] The bis(thiocarbamate) *syn–syn* was exclusively formed.

appeared that thiolcarbamates **5** were the only products obtained with diisopropylamine **2i**. As can be seen, the results so far obtained obviously rule out either the influence of the amine basicity or the presence of a silicon moiety on the reaction outcome, favouring thiolcarbamate *versus* thiocarbamate formation. In fact the silylated bis(2-hydroxyethyl)amines **2g** (*O*-TBDMS) and **2h** (*O*-TBDPS) yielded 12 and 61% of the thiolcarbamoyl derivatives **5g** and **5h**, respectively while diisopropylamine **2i** gave the thiolcarbamate **5i** exclusively. On the other hand, piperidine, diethylamine and diisopropylamine which exhibit essentially very similar basicities produced the thiocarbamate **4** for the first two reactions and inversely the *syn*- and *anti*-thiolcarbamates **5** for the last one, and conversely, piperidine and morpholine which are compounds characterised by a similar bulkiness but a substantial difference in their basic character, solely produced thiocarbamates **4c** and **4d**. At this stage, it is obvious that the bulkiness of the amine, associated with its nucleophilic properties take a prominent role in the mechanism of the reaction; the following order (**2c**, **2d** < **2a** < **2b**) < (**2g** < **2h** < **2f** < **2i**) < **2e** depicts schematically the increasing steric hindrance around the nitrogen atom, and it appears that the more hindered the amine is, the more favoured is the thiolcarbamate formation: the first pool of amines **2a–d** afford exclusively the corresponding thiocarbamates **4a–d** (100%) and the following group **2f–i**, yields together with **4f–i**, the thiolcarbamates **5f–i** (12 to 100%). The case of HMDS **2e** is more peculiar since it is a known silylating agent and is theoretically more crowded than diisopropylamine **2i**. The results may be explained by an initial *in situ* desilylation of this reagent to afford ammonia which reacts with the cyclic thioxocarbonate **1**; the *O*-TMS thiocarbamoyl derivative (NR_2=NH_2) was isolated as a stable intermediate which afforded compound **4e** after acidic hydrolysis.

Since the cyclic thioxocarbonate **6** of (*R*,*R*)-diisopropyl tartrate was reported[4] to react normally with nucleophiles at its carbinol centres, could the steric hindrance of the ester moiety possibly be responsible for the preferred nucleophilic attack of the incoming amine at the thiocarbonyl carbon instead of the electrophilic carbinol carbons? To investigate this, we subjected **6** to a reaction with diethylamine **2a** and diisopropylamine **2i** using the same experimental conditions as above (Scheme 3 and Table 2) and observed the exclusive formation of the thiocarbamate *syn*-**7a** with the reactive amine **2a**, and that of the *syn*-and *anti*-thiolcarbamates **8i** with the hindered amine **2i**, suggesting that secondary amines behave similarly when faced with any cyclic thioxocarbonate derived from dialkyl tartrates.

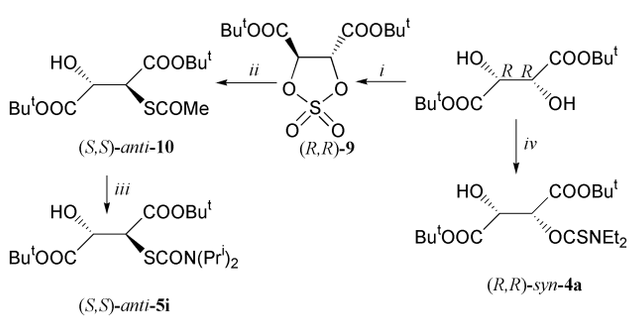


Scheme 3 *Reagents and conditions*: thioxocarbonate **6** (1 equiv.), amine **2a** or **2i** (2 equiv.), dichloromethane, room temp., 30 min or 12 h.

Structural assignment of the reaction products, thiocarbamates (**4a–j**, **7a**) and thiolcarbamates (**5a–j**, **8i**), was easily achieved using ^1H and ^{13}C NMR spectroscopies (Tables 1 and 2): thiocarbamates (UV absorbing) being characterised by upfield signals for 2-H (6.1 ppm, J_{2-3} 2.1–2.5 Hz) and 2-C (78–79 ppm), whereas the thiolcarbamates exhibited downfield signals for 2-H (4.7–4.8 ppm) and 2-C (52–53 ppm) and a slightly larger coupling constant (J_{2-3} 2.8–3.1 Hz) (we presume that the J_{syn} and J_{anti} values are very similar as we found 3.0 Hz in the case of the pure thiolcarbamate *anti*-**5i** compared with 3.1 Hz for the mixture of *syn*-and *anti*-**5i**). It is worth noting that any diastereomeric mixtures of *syn*-and *anti*-thiolcarbamates were inseparable and appeared as single products by ^1H NMR spectroscopy, whereas ^{13}C NMR showed a splitting of several signals (weak differences of *ca.* 40 Hz) and thus allowed us to distinguish what was assumed to be the two epimers at 2-C.

In order to ascertain both the structure and the relative configuration of all the products, we prepared unequivocally the thiocarbamate *syn*-**4a** and the thiolcarbamate *anti*-**5i**. Thiocarbamate *syn*-**4a** was easily obtained, although in very low yield, by direct reaction of (*R*,*R*)-di-*tert*-butyl tartrate[11] with sodium hydride in DMF and diethylthiocarbamoyl chloride (Scheme 4); it exhibited analytical data and optical rotation in good agreement with those obtained for **4a** generated from the cyclic thioxocarbonate **1**.

The cyclic sulfate **9** of (*R*,*R*)-di-*tert*-butyl tartrate was used as a starting material for the preparation of the thiolcarbamate



Scheme 4 *Reagents and conditions*: i, $SOCl_2$, Et_3N, CH_2Cl_2, 0 °C, then $RuCl_3 \cdot H_2O$, $NaIO_4$, CCl_4, CH_3CN, H_2O, 0 °C, 82%; ii, a) MeC(=O)SK, acetone, room temp., b) conc. H_2SO_4 (cat.), H_2O (0.5–1.0 equiv.), THF, quant.; iii, a) $NH_2NH_2 \cdot AcOH$, DMF, room temp., b) $(Pr^i)_2NC(=O)Cl$, Et_3N, CH_2Cl_2, room temp., 27%; iv, NaH, $Et_2NC(=S)Cl$, DMF, 90 °C, 7%.

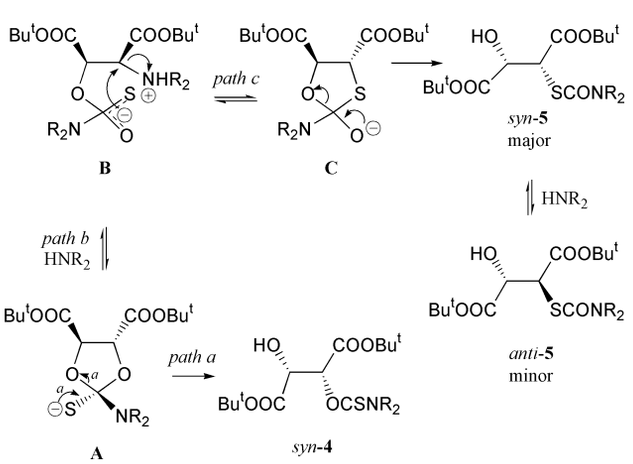
Table 2 Reactions of thioxocarbonate **6** with amine **2a** or **2i** in dichloromethane at room temp.

Amine	Time/h	**7** : **8**	Yield (%) **7** + **8**	*syn*-**7a** δH_2, $J_{2\text{-}3}$, δC_2	*syn*- + *anti*-**8i** δH_2, $J_{2\text{-}3}$, δC_2
2a	0.5	100 : 0	93	6.1, 2.4, 78.6	
2i	12	0 : 100	58		4.8, 3.3, 51.8

anti-**5i**. Ring-opening[8] of **9** with inversion of configuration by potassium thioacetate in acetone gave the corresponding thioacetate *S*-ester *anti*-**10** (quant.). Treatment of **10** with hydrazinium acetate followed by the *in situ* regioselective reaction of the resulting thiol with diisopropylcarbamyl chloride afforded the expected thiolcarbamate *anti*-**5i** (27%, two steps from **10**). All attempts to synthesise the pure *syn*-**5i** epimer failed; furthermore the ring opening of **9** with tetrabutylammonium bromide gave the corresponding bromohydrin with a net inversion of configuration, but any nucleophilic substitution (*i.e.* potassium thioacetate) on the *O*-protected bromohydrin in order to carry out the second inversion proceeded non stereospecifically and afforded a mixture of *syn*- and *anti*-isomers; an observation in accordance with some non pure S_N2 processes reported on related tartrate[12,13] and malate[14] structures. Nevertheless, compounds *syn*-**4a** and *anti*-**5i** thus obtained by unequivocal syntheses enabled us to ascertain the chemical structures proposed for the thio- and thiolcarbamates obtained by reaction of cyclic thioxocarbonates **1** and **6** with secondary amines. From the known ^{13}C NMR spectrum of *anti*-**5i** and a careful examination of the corresponding spectra of all mixtures of *syn*- and *anti*-thiolcarbamates **5a**–**j**, we were able to conclude that the *syn*-isomer predominated in all cases (*ca.* 70–80% as tentatively estimated by integration of signals on the ^{13}C NMR spectra).

In order to find a reasonable mechanism of formation for thio- and thiolcarbamates, we checked that when the pure thiocarbamate *syn*-**4f** was reacted with diisobutylamine **2f** using the standard experimental conditions the corresponding thiolcarbamates **5f** were not produced (*syn* + *anti*), and conversely the thiocarbamate *syn*-**4f** was not formed from the thiolcarbamates **5f** (*syn* + *anti*) and diisobutylamine **2f**. Furthermore, we observed (^{13}C NMR monitoring) that the thiolcarbamate *anti*-**5i** isomerised into a mixture of *syn*- and *anti*-**5i** (*anti*-**5i** > *syn*-**5i**) when one equivalent of diisopropylamine in dichloromethane was added during a 12 h reaction. This valuable information allows us access to a better understanding of the reaction mechanism. Castro *et al.*[15–19] have investigated kinetic studies on the aminolysis of alicyclic thioxocarbonates and proposed the formation of a zwitterionic tetrahedral intermediate which undergoes a deprotonation step with amine R_2NH to afford the anionic tetrahedral intermediate **A** (Scheme 5).

At this stage, three conceivable competitive pathways can occur according to the nature of the amine reagent. In the case of reactive amines, the thiolate anion normally expels the alcoholate (better leaving group than amide) from the unstable anionic intermediate **A** (*path a*) in a fast reaction to provide the thiocarbamate *syn*-**4**. In contrast to this *path a* remains disfavoured with hindered amines for reasons unclear to us; so we firstly envisioned the nucleophilic attack of the thiolate ion on one carbinol carbon bearing the carboxylate ester to afford thiolcarbamates, but this disfavoured 4-*endo*-*tet* process[20] was dismissed.[21] Since a breaking of the acetalic C–O bond is necessary to explain the thiolcarbamate formation, we hypothesise the formation of the unstrained opened intermediate **B** from the reaction of a second molecule of amine on **A** with inversion of configuration (*path b*), followed by the ring closure (second inversion) with the more nucleophilic thiolate ion to give the intermediate **C** (*path c*); the latter is able to afford the thiolcarbamate **5**-*syn* (major isomer formed) which isomerises into the *anti*-isomer by an equilibrating process probably *via* a transient enolate intermediate at the 2-C centre. The double inversion mechanism leading to **C** is closely related to the proposed pathway invoked for the rearrangement of cyclic thioxocarbonates into corresponding cyclic thiolcarbonates with bromine ions.[4,22]



Scheme 5

Path c of this mechanism could be strengthened by the very marked solvent effect we found in substituting dichloromethane for the polar aprotic solvent, DMF: thus in the case of the reactive diethylamine **2a**, the ratio of **4a** : **5a** changed from 100 : 0 (run 1) to 1 : 1 (run 2, DMF), whereas the silylated amine **2g** (*O*-TBDMS) gave the thiolcarbamate **5g** [0 : 100 (run 9, DMF) *vs.* 88 : 12 (run 8)] exclusively. These results firstly exemplified the well known anion nucleophilicity enhancer properties of DMF applied in our case to a thiolate ion, and secondly they may be used to take advantage of this solvent effect in order to partially direct the synthesis towards thiolcarbamate formation in the case of very reactive amines.

In conclusion, we have shown that secondary amines react initially exclusively at the thiocarbonyl centre of the cyclic thioxocarbonates derived from (*R*,*R*)-dialkyl tartrates to afford either the *syn*-thiocarbamates with retention of configuration and/or the diastereomeric mixture of *syn*-and *anti*-thiolcarbamates. The efficient and high yielding formation of both thio- and thiolcarbamates by this method obviates their cumbersome and non straightforward synthesis. Our findings should be of value in further synthetic work in this area.

Experimental

Elemental analyses were performed by the 'Service de Microanalyse de l'Ecole Supérieure de Chimie de Montpellier'. ^1H NMR spectra were determined on a Bruker 200 spectrometer (200 MHz frequency) and ^{13}C NMR spectra on a Bruker AC 400 spectrometer (100.6 MHz frequency). Mass spectra were obtained with a JEOL JMS-DX-300 instrument by the FAB ionisation method (positive mode) with *p*-nitrobenzyl alcohol (NBA) as the matrix; specific optical rotations were measured in a 0.1 dm cell on a Perkin-Elmer 241 polarimeter in units of 10^{-1} deg cm^2 g^{-1}. Petroleum ether refers to the fraction boiling in the range 40–65 °C.

(4*R*,5*R*)-2-Thioxo-4,5-bis-(*tert*-butyloxycarbonyl)-1,3-dioxolane **1**

To a stirred solution of (*R*,*R*)-di-*tert*-butyl tartrate[11] (5 g, 19 mmol) in THF (80 cm^3) was added dropwise at 0 °C thiocarbonyldiimidazole (9.4 g, 47.5 mmol) in THF (150 cm^3). After 12 h at

room temp. diethyl ether was added and the organic phase was successively washed with an aqueous solution of citric acid (5%), a saturated solution of $NaHCO_3$, a saturated solution of NaCl and dried over Na_2SO_4 and the solvents evaporated under reduced pressure. Chromatography on silica gel and elution with petroleum ether–ethyl acetate (6 : 1) afforded the title compound as a solid (3.5 g, 60%); mp 124–127 °C; R_f 0.57 [petroleum ether–ethyl acetate (6 : 2)]; $[\alpha]_D^{20}$ − 57.4 ± 0.1 (*c* 1.0, chloroform); δ_H (200 MHz; $CDCl_3$) 1.54 (18 H, s, 2 × Bu^t) and 5.14 (2 H, s, 2 × CH); δ_C (100 MHz; $CDCl_3$) 28.2 (6 C, 2 × C*Me*$_3$), 80.2 (2 C, 2 × *C*Me$_3$), 85.9 (2 C, 2 × CH), 164.6 (2 C, 2 × CO), and 189.1 (1 C, CS); *m*/*z* (NBA) 305 $[M + H]^+$ (Found: C, 51.1; H, 6.4. $C_{13}H_{20}O_6S$ requires C, 51.3; H, 6.6%).

N,*N*-Bis(*tert*-butyldiphenylsilyloxyethyl)amine 2h

To a stirred mixture of *tert*-butylchlorodiphenylsilane (17.8 cm^3, 68.5 mmol) and imidazole (9.7 g, 142.6 mmol) dissolved in anhydrous dimethylformamide (DMF) (55 cm^3) was added dropwise bis(hydroxyethyl)amine (diethanolamine) (2 g, 19 mmol). After 30 min at room temp. and addition of dichloromethane, the organic phase was washed with brine, dried over Na_2SO_4 and evaporated under reduced pressure. Chromatography on silica gel with methanol (0 to 2%) in dichloromethane afforded quantitatively the title compound as a white solid (11 g); R_f 0.84 [dichloromethane–methanol (95 : 5)]; mp 64–66 °C; δ_H (200 MHz; $CDCl_3$) 1.40 (18 H, s, 2 × Bu^t), 2.79 (4 H, t, J_{CH2CH2} 5.4 Hz, 2 × CH_2N), 3.60 (4 H, t, J_{CH2CH2} 5.4 Hz, 2 × CH_2O) and 7.35 (20 H, m, aromatics); δ_C (100 MHz; $CDCl_3$) 27.3 (3 C, C*Me*$_3$), 52.1 (1 C, CH_2N), 63.9 (1 C, CH_2O), 78.1 (1 C, *C*Me$_3$), 128.1 (4 C, C_m aromatics), 130.0 (2 C, C_p aromatics); 134.1 (2 C, C_q aromatics) and 136.0 (4 C, C_o aromatics); *m*/*z* (NBA) 582 $[M + H]^+$ (Found: C, 74.5; H, 8.2. $C_{36}H_{47}NO_2Si_2$ requires C, 74.3; H, 8.1%).

General procedure for the ring opening of thioxocarbonates 1 or 6 by amines 2

To a solution of thioxocarbonate **1** or **6** (0.2 mmol) in anhydrous dichloromethane (or DMF in two cases specified in the text) (2 cm^3) was added under nitrogen at room temp. amine **2a**–**i** (0.4 mmol) and the solution stirred for 30 min for amines **2a**–**e**,**j** and 12 h for amines **2f**–**i**. After concentration under vacuum the crude residue was chromatographed on silica gel with ethyl acetate (0 to 4%) in petroleum ether to afford the expected thiocarbamates **4a**–**j**, **7a** (UV absorbing at 254 nm) and thiolcarbamates **5a**–**j**, **8i**.

(2*R*,3*R*)-Di-*tert*-butyl 2-diethylthiocarbamoyloxy-3-hydroxysuccinate *syn*-4a. *Method A via* the thioxocarbonate ***1***. The title compound was obtained as a colourless oil according to the aforementioned procedure (95% yield).

Method B via direct thiocarbamoylation of (*R*,*R*)-di-*tert*-butyl tartrate. To the di-*tert*-butyl tartrate (100 mg, 0.38 mmol) dissolved in DMF (2 cm^3) was added at 0 °C sodium hydride (19 mg, 0.76 mmol) and the solution stirred for 1.5 h at room temp.. Diethylthiocarbamoyl chloride (91 mg, 0.57 mmol) was then added and the reaction maintained at room temp. for 5 h and warmed to 90 °C for 1 h. After concentration under reduced pressure and chromatography on silica gel (see general procedure) the title compound was obtained as a colourless oil (10 mg, 7%); R_f 0.44 [petroleum ether–ethyl acetate (8 : 2)]; $[\alpha]_D^{20}$ − 73.5 ± 0.9 (*c* 1.2, chloroform); δ_H (200 MHz; $CDCl_3$) 1.21 (6 H, t, *J* 7.3 Hz, 2 × CH_2CH_3), 1.45 (9 H, s, Bu^t), 1.49 (9 H, s, Bu^t), 3.16 (1 H, d, J_{OH-3} 6.9 Hz, OH), 3.49 (2 H, q, *J* 7.3 Hz, CH_2Me), 3.68 (1 H, m, CH_aMe), 3.90 (1 H, m, CH_bMe), 4.65 (1 H, dd, J_{3-OH} 6.9, J_{3-2} 2.3 Hz, 3-H) and 6.10 (1 H, d, J_{2-3} 2.3 Hz, 2-H); δ_C (100 MHz; $CDCl_3$) 12.1 (1 C, CH_2Me), 13.5 (1 C, CH_2Me), 28.2 (3 C, C*Me*$_3$), 28.4 (3 C, C*Me*$_3$), 44.2 (1 C, CH_2N), 48.5 (1 C, CH_2N), 71.6 (1 C, 3-C), 78.3 (1 C, 2-C), 83.2 (1 C, *C*Me$_3$), 84.3 (1 C, *C*Me$_3$), 166.4 (1 C, CO_2), 170.9 (1 C, CO_2) and 186.0 (1 C, OC=S); *m*/*z* (NBA) 378 $[M + H]^+$, 400 $[M + Na]^+$ (Found: C, 54.4; H, 8.5. $C_{17}H_{31}NO_6S$ requires C, 54.1; H, 8.3%).

(3*S*)-Di-*tert*-butyl 2-diethylcarbamoylsulfanyl-3-hydroxysuccinates *syn*- and *anti*-5a. The title compounds were obtained as an oil according to the aforementioned procedure in DMF (63% overall yield) together with the thiocarbamate isomer **4a** in a 1 : 1 ratio; R_f 0.15 [petroleum ether–ethyl acetate (85 : 15)]; δ_H (200 MHz; $CDCl_3$) 1.25 (6 H, m, 2 × CH_3CH_2), 1.45 (9 H, s, Bu^t), 1.50 (9 H, s, Bu^t), 3.39 (4 H, m, 2 × CH_2Me), 3.50 (1 H, d, J_{OH-3} 6.8 Hz, OH), 4.40 (1 H, dd, J_{3-OH} 6.8, J_{3-2} 2.9 Hz, 3-H) and 4.75 (1 H, d, J_{2-3} 2.9 Hz, 2-H); δ_C(100 MHz; $CDCl_3$) 12.2 (1 C, CH_2Me), 13.5 (1 C, CH_2Me), 28.2 (3 C, C*Me*$_3$), 28.5 (3 C, C*Me*$_3$), 44.3 (1 C, *C*H_2Me), 48.6 (1 C, *C*H_2Me), 52.9 (1 C, 2-C_{syn}), 53.1 (1 C, 2-C_{anti}), 71.9 (1 C, 3-C_{anti}), 72.8 (1 C, 3-C_{syn}), 83.3 (1 C, *C*Me$_3$), 84.6 (1 C, *C*Me$_3$), 166.1 (1 C, CO_{2anti}), 166.2 (1 C, CO_{2syn}), 168.7 (1 C, SC=O_{syn}), 169.0 (1 C, SC=O_{anti}), 170.8 (1 C, CO_{2anti}) and 171.1 (1 C, CO_{2syn}); *m*/*z* (NBA) 378 $[M + H]^+$, 400 $[M + Na]^+$ (Found: C, 54.0; H, 8.1. $C_{17}H_{31}NO_6S$ requires C, 54.1; H, 8.3%).

(2*R*,3*R*)-Di-*tert*-butyl 2-[bis(2-hydroxyethyl)]thiocarbamoyloxy-3-hydroxysuccinate *syn*-4b. The title compound was obtained quantitatively as an oil according to the aforementioned procedure; R_f 0.62 [ethyl acetate–methanol (98 : 2)]; $[\alpha]_D^{20}$ − 65.6 ± 0.4 (*c* 2.6, chloroform); δ_H (200 MHz; $CDCl_3$, D_2O) 1.48 (9 H, s, Bu^t), 1.53 (9 H, s, Bu^t), 3.43–4.25 (8 H, m, 2 × CH_2N and 2 × CH_2OH), 4.65 (1 H, d, J_{3-2} 2.3 Hz, 3-H) and 6.10 (1 H, d, J_{2-3} 2.3 Hz, 2-H); δ_C (100 MHz; $CDCl_3$) 28.2 (3 C, C*Me*$_3$), 28.4 (3 C, C*Me*$_3$), 54.4 (1 C, CH_2N), 58.5 (1 C, CH_2N), 60.7 (1 C, CH_2O), 61.0 (1 C, CH_2O), 71.4 (1 C, 3-C), 79.2 (1 C, 2-C), 84.2 (1 C, *C*Me$_3$), 84.6 (1 C, *C*Me$_3$), 166.9 (1 C, CO_2), 170.7 (1 C, CO_2) and 188.1 (1 C, OC=S); *m*/*z* (NBA) 410 $[M + H]^+$ (Found: C, 50.3; H, 7.8. $C_{17}H_{31}NO_8S$ requires C, 49.9; H, 7.6%).

(2*R*,3*R*)-Di-*tert*-butyl 2-(piperidinothiocarbonyloxy)-3-hydroxysuccinate *syn*-4c. The title compound was obtained quantitatively according to the aforementioned general procedure as a colourless oil; R_f 0.73 [petroleum ether–ethyl acetate (97 : 3)]; $[\alpha]_D^{20}$ −42.3 ± 0.5 (*c* 1.8, chloroform); δ_H (200 MHz; $CDCl_3$, D_2O) 1.47 (9 H, s, Bu^t), 1.52 (9 H, s, Bu^t), 1.70 (6 H, m, 3 × CH_2), 3.48–4.18 (4 H, m, 2 × CH_2N), 4.65 (1 H, d, J_{3-2} 2.3 Hz, 3-H) and 6.10 (1 H, d, J_{2-3} 2.3 Hz, 2-H); δ_C (100 MHz; $CDCl_3$) 23.2–24.8 (3 C, 3 × CH_2), 27.0 (6 C, 2 × C*Me*$_3$), 45.7–50.6 (2 C, 2 × CH_2N), 70.1 (1 C, 3-C), 77.6 (1 C, 2-C), 81.8 (1 C, *C*Me$_3$), 82.9 (1 C, *C*Me$_3$), 164.9 (1 C, CO_2), 169.4 (1 C, CO_2) and 184.2 (1 C, OC=S); *m*/*z* (NBA) 390 $[M + H]^+$, 412 $[M + Na]^+$ (Found: C, 55.8; H, 8.3. $C_{18}H_{31}NO_6S$ requires C, 55.5; H, 8.0%).

(2*R*,3*R*)-Di-*tert*-butyl 2-(morpholinothiocarbonyloxy)-3-hydroxysuccinate *syn*-4d. The title compound was obtained quantitatively according to the aforementioned general procedure as a colourless oil; R_f 0.48 [petroleum ether–ethyl acetate (7 : 3)]; $[\alpha]_D^{20}$ −36.5 ± 0.9 (*c* 1.0, chloroform); δ_H (200 MHz; $CDCl_3$) 1.47 (9 H, s, Bu^t), 1.51 (9 H, s, Bu^t), 3.53–4.10 (8 H, m, 4 × CH_2), 3.22 (1 H, d, J_{OH-3} 6.5 Hz, OH), 4.66 (1 H, dd, J_{3-OH} 6.5, J_{3-2} 2.4 Hz, 3-H) and 6.06 (1 H, d, J_{2-3} 2.4 Hz, 2-H); δ_C (100 MHz; $CDCl_3$) 28.4 (6 C, 2 × C*Me*$_3$), 46.6 (1 C, CH_2N), 50.5 (1 C, CH_2N), 66.5 (1 C, CH_2O), 66.7 (1 C, CH_2O), 71.4 (1 C, 3-C), 79.2 (1 C, 2-C), 83.5 (1 C, *C*Me$_3$), 84.4 (1 C, *C*Me$_3$), 166.0 (1 C, CO_2), 170.7 (1 C, CO_2) and 186.7 (1 C, OC=S); *m*/*z* (NBA) 392 $[M + H]^+$ (Found: C, 51.9; H, 7.3. $C_{17}H_{29}NO_7S$ requires C, 52.2; H, 7.5%).

(2*R*,3*R*)-Di-*tert*-butyl 2-thiocarbamoyloxy-3-hydroxysuccinate *syn*-4e. The *O*-TMS-derivative was obtained

according to the aforementioned general procedure, followed by an acidic treatment THF–HCl 0.5 M (1.2 cm^3) for 30 min to afford after neutralisation, extraction with THF, drying of organic phases and concentration under vacuum then chromatography on silica gel as described in the general procedure, the title compound as a colourless oil (quant.); R_f 0.51 [petroleum ether–ethyl acetate (7 : 3)]; $[\alpha]_D^{20}$ −37.9 ± 0.7 (*c* 1.4, chloroform); δ_H (200 MHz; $CDCl_3$) 1.47 (9 H, s, Bu^t), 1.50 (9 H, s, Bu^t), 3.79 (1 H, br s, OH), 4.67 (1 H, d, J_{3-2} 2.5 Hz, 3-H), 5.92 (1 H, d, J_{2-3} 2.5 Hz, 2-H), 6.60 (1 H, br s, NH) and 6.73 (1 H, br s, NH); δ_C (100 MHz; $CDCl_3$) 28.2 (3 C, C*Me*$_3$), 28.4 (3 C, C*Me*$_3$), 71.5 (1 C, 3-C), 79.4 (1 C, 2-C), 83.9 (1 C, *C*Me$_3$), 84.8 (1 C, *C*Me$_3$), 166.6 (1 C, CO_2), 170.7 (1 C, CO_2) and 191.5 (1 C, SC=O); *m*/*z* (NBA) 322 [M + H]$^+$ (Found: C, 48.9; H, 7.4. $C_{13}H_{23}NO_6S$ requires C, 48.6; H, 7.2%).

Di-*tert*-butyl (2*R*)-[4-(1*R*,2*R*)-bis-(*tert*-butoxycarbonyl-2-hydroxyethoxythiocarbonyl)piperazinothiocarbonyloxy]-(3*R*)-hydroxysuccinate *syn*–*syn*-4j. The title compound was obtained according to the aforementioned general procedure [piperazine **2j** (1 equiv.), thioxocarbonate **1** (2 equiv.)] as a colourless oil (84%); R_f 0.29 [petroleum ether–ethyl acetate (8 : 2)]; $[\alpha]_D^{20}$ −36.4 ± 0.5 (*c* 0.2, chloroform); δ_H (200 MHz; $CDCl_3$) 1.42 (18 H, s, 2 × Bu^t), 1.48 (18 H, s, 2 × Bu^t), 3.20 (2 H, d, J_{CHOH} 6 Hz, 2 × OH), 3.47–4.26 (8 H, m, 4 × CH_2N), 4.63 (2 H, dd, J_{3-2} 2.1, J_{CHOH} 6 Hz, 2 × C*H*OH) and 6.01 (2 H, d, J_{2-3} 2.1 Hz, 2 × CHOCS); δ_C (100 MHz; $CDCl_3$) 28.2–28.8 (12 C, 4 × C*Me*$_3$), 45.0 (1 C, CH_2N), 45.1 (1 C, CH_2N), 49.1 (1 C, CH_2N), 49.2 (1 C, CH_2N), 71.2 (1 C, CHOH), 71.3 (1 C, CHOH), 79.5 (2 C, *C*HOCS), 83.6 (1 C, *C*Me$_3$), 83.7 (1 C, *C*Me$_3$), 84.3 (1 C, *C*Me$_3$), 84.5 (1 C, *C*Me$_3$), 166.0 (2 C, 2 × CO_2), 170.5 (1 C, CO_2), 170.6 (1 C, CO_2) and 187.0 (2 C, 2 × OC=S); *m*/*z* (NBA) 695 [M + H]$^+$, 717 [M + Na]$^+$ (Found: C, 51.6; H, 7.0. $C_{30}H_{50}N_2O_{12}S_2$ requires C, 51.9; H, 7.2%).

(2*R*,3*R*)-Di-*tert*-butyl 2-diisobutylthiocarbamoyloxy-3-hydroxysuccinate *syn*-4f and (3*S*)-di-*tert*-butyl 2-diisobutylcarbamoylsulfanyl-3-hydroxysuccinates *syn*- and *anti*-5f. The title compounds were obtained as colourless oils according to the aforementioned procedure in 90% overall yield in a 1 : 1 ratio.

*Thiocarbamate syn-**4f**.* R_f 0.74 [petroleum ether–ethyl acetate (85 : 15)]; $[\alpha]_D^{20}$ −38.6 ± 0.9 (*c* 1.1, chloroform); δ_H (200 MHz; $CDCl_3$) 0.92 (12 H, m, 4 × Me), 1.48 (9 H, s, Bu^t), 1.51 (9 H, s, Bu^t), 2.21 (2 H, m, 2 × C*H*Me$_2$), 3.09 (1 H, d, J_{OH-3} 6.7 Hz, OH), 3.50 (4 H, m, 2 × CH_2N), 4.65 (1 H, dd, J_{3-OH} 6.7, J_{3-2} 2.1 Hz, 3-H) and 6.04 (1 H, d, J_{2-3} 2.1 Hz, 2-H); δ_C (100 MHz; $CDCl_3$) 20.56 (1 C, Me), 20.58 (1 C, Me), 20.84 (1 C, Me), 20.88 (1 C, Me), 26.8 (1 C, *C*HMe$_2$), 27.8 (1 C, *C*HMe$_2$), 28.3 (6 C, 2 × C*Me*$_3$), 58.7 (1 C, CH_2N), 62.2 (1 C, CH_2N), 71.6 (1 C, 3-C), 79.2 (1 C, 2-C), 83.1 (1 C, *C*Me$_3$), 84.2 (1 C, *C*Me$_3$), 166.4 (1 C, CO_2), 171.1 (1 C, CO_2) and 187.4 (1 C, OC=S); *m*/*z* (NBA) 434 [M + H]$^+$, 456 [M + Na]$^+$ (Found: C, 58.0; H, 9.3. $C_{21}H_{39}NO_6S$ requires C, 58.2; H, 9.1%).

*Thiolcarbamates syn- and anti-**5f**.* R_f 0.57 [petroleum ether–ethyl acetate (85 : 15)]; δ_H (200 MHz; $CDCl_3$) 0.9 (12 H, m, 4 × Me), 1.46 (9 H, s, Bu^t), 1.52 (9 H, s, Bu^t), 2.0 (2 H, m, 2 × C*H*Me$_2$), 3.33 (4 H, m, 2 × CH_2N), 3.50 (1 H, d, J_{OH-3} 7.0 Hz, OH), 4.39 (1 H, dd, J_{3-OH} 7.0, J_{3-2} 2.9 Hz, 3-H) and 4.79 (1 H, d, J_{2-3} 2.9, 2-H); δ_C (100 MHz; $CDCl_3$) 20.5 (4 C, 4 × Me), 27.1 (1 C, *C*HMe$_2$), 27.9 (1 C, *C*HMe$_2$), 28.3 (6 C, 2 × C*Me*$_3$), 52.5 (1 C, 2-C$_{syn}$), 52.9 (1 C, 2-C$_{anti}$), 55.7 (1 C, CH_2N), 56.0 (1 C, CH_2N), 71.9 (1 C, 3-C$_{anti}$), 72.8 (1 C, 3-C$_{syn}$), 83.1 (2 C, 2 × *C*Me$_3$), 166.4 (1 C, 1-CO_{2anti}), 166.7 (1 C, 1-CO_{2syn}), 168.8 (1 C, SC=O$_{syn}$), 169.2 (1 C, SC=O$_{anti}$), 171.3 (1 C, CO_{2anti}) and 171.4 (1 C, CO_{2syn}); *m*/*z* (NBA) 434 [M + H]$^+$, 456 [M + Na]$^+$ (Found: C, 58.3; H, 9.4. $C_{21}H_{39}NO_6S$ requires C, 58.2; H, 9.1%).

(2*R*,3*R*)-Di-*tert*-butyl 2-[bis(*tert*-butyldimethylsilyloxyethyl)-thiocarbamoyloxy]-3-hydroxysuccinate *syn*-4g and (3*S*)-di-*tert*-butyl 2-[bis(*tert*-butyldimethylsilyloxyethyl)carbamoylsulfanyl]-3-hydroxysuccinates *syn*- and *anti*-5g. The title compounds were obtained (87% overall yield) according to the aforementioned procedure in a 88 : 12 ratio.

*Thiocarbamate syn-**4g**.* R_f 0.87 [petroleum ether–ethyl acetate (8 : 2)]; mp 89–90 °C; $[\alpha]_D^{20}$ −34.3 ± 0.7 (*c* 1.3, chloroform); δ_H (200 MHz; $CDCl_3$) 0.06 (3 H, s, SiMe), 0.07 (3 H, s, SiMe), 0.08 (6 H, s, 2 × SiMe), 0.89 (9 H, s, SiBu^t), 0.90 (9 H, s, SiBu^t), 1.47 (9 H, s, Bu^t), 1.51 (9 H, s, Bu^t), 3.14 (1 H, d, J_{OH-3} 6.8 Hz, OH), 3.95 (8 H, m, 2 × CH_2N and 2 × CH_2O), 4.65 (1 H, dd, J_{3-OH} 6.8, J_{3-2} 2.3 Hz, 3-H) and 6.12 (1 H, d, J_{2-3} 2.3 Hz, 2-H); δ_C (100 MHz; $CDCl_3$) −5.0 (2 C, 2 × SiMe), −4.9 (2 C, 2 × SiMe), 26.3 (6 C, 2 × C*Me*$_3$), 28.3 (3 C, OC*Me*$_3$), 28.4 (3 C, OC*Me*$_3$), 53.9 (1 C, CH_2N), 57.6 (1 C, CH_2N), 60.8 (1 C, CH_2O), 61.6 (1 C, CH_2O), 71.5 (1 C, 3-C), 79.1 (1 C, 2-C), 83.2 (2 C, 2 × *C*Me$_3$), 84.3 (2 C, 2 × *C*Me$_3$), 166.2 (1 C, CO_2), 170.9 (1 C, CO_2) and 187.4 (1 C, OC=S); *m*/*z* (NBA) 638 [M + H]$^+$, 660 [M + Na]$^+$ (Found: C, 54.4; H, 9.1. $C_{29}H_{59}NO_8SSi_2$ requires C, 54.6; H, 9.3%).

*Thiolcarbamates syn- and anti-**5g**.* colourless oil; R_f 0.59 [petroleum ether–ethyl acetate (85 : 15)]; δ_H (200 MHz; $CDCl_3$) 0.06 (3 H, s, SiMe), 0.07 (3 H, s, SiMe), 0.08 (6 H, s, 2 × SiMe), 0.86 (18 H, s, 2 × SiBu^t), 1.49 (9 H, s, Bu^t), 1.50 (9 H, s, Bu^t), 3.45 (1 H, d, J_{OH-3} 7.0 Hz, OH), 3.48–3.82 (8 H, m, 2 × NCH_2-CH_2O), 4.36 (1 H, dd, J_{3-2} 3.1, J_{3-OH} 7.0 Hz, 3-H) and 4.72 (1 H, d, J_{2-3} 3.1 Hz, 2-H); δ_C (100 MHz; $CDCl_3$) −5.02 (1 C, SiMe), −4.99 (1 C, SiMe), −4.96 (2 C, 2 × SiMe), 26.1 (6 C, 2 × SiC*Me*$_3$), 28.3 (6 C, 2 × OC*Me*$_3$), 52.2 (2 C, 2 × CH_2N), 52.4 (1 C, 2-C$_{syn}$), 53.1 (1 C, 2-C$_{anti}$), 61.7 (2 C, 2 × CH_2O), 72.0 (1 C, 3-C$_{anti}$), 72.7 (1 C, 3-C$_{syn}$), 83.2 (4 C, 4 × *C*Me$_3$), 166.1 (1 C, CO_{2anti}), 166.4 (1 C, CO_{2syn}), 168.4 (1 C, SC=O$_{syn}$), 168.8 (1 C, SC=O$_{anti}$), 171.2 (1 C, CO_{2syn}) and 171.3 (1 C, CO_{2anti}); *m*/*z* (NBA) 638 [M + H]$^+$; 660 [M + Na]$^+$ (Found: C, 54.3; H, 9.0. $C_{29}H_{59}NO_8SSi_2$ requires C, 54.6; H, 9.3%).

(2*R*,3*R*)-Di-*tert*-butyl 2-[bis(*tert*-butyldiphenylsilyloxyethyl)-thiocarbamoyloxy]-3-hydroxysuccinate *syn*-4h and (3*S*)-di-*tert*-butyl 2-[bis-(*tert*-butyldiphenylsilyloxyethyl)carbamoylsulfanyl]-3-hydroxysuccinates *syn*- and *anti*-5h. The title compounds were obtained as colourless oils according to the aforementioned procedure (64% overall yield) in a 39 : 61 ratio.

*Thiocarbamate syn-**4h**.* R_f 0.65 [petroleum ether–ethyl acetate (9 : 1)]; $[\alpha]_D^{20}$ −33.6 ± 1.0 (*c* 1.1, chloroform); δ_H (200 MHz; $CDCl_3$) 1.08 (18 H, s, 2 × SiBu^t), 1.39 (9 H, s, Bu^t), 1.48 (9 H, s, Bu^t), 3.05 (1 H, d, J_{OH-3} 7.0 Hz, OH), 4.05 (8 H, m, 2 × CH_2N and 2 × CH_2OSi), 4.61 (1 H, dd, J_{3-OH} 7.0, J_{3-2} 2.3 Hz, 3-H), 6.08 (1 H, d, J_{2-3} 2.3 Hz, 2-H) and 7.55 (20 H, m, aromatics); δ_C (100 MHz; $CDCl_3$) 27.2 (6 C, 2 × C*Me*$_3$), 28.3 (6 C, 2 × C*Me*$_3$), 53.5 (1 C, CH_2N), 57.3 (1 C, CH_2N), 61.9 (1 C, CH_2O), 62.6 (1 C, CH_2O), 71.5 (1 C, 3-C), 79.2 (1 C, 2-C), 83.1 (1 C, *C*Me$_3$), 84.2 (2 C, 2 × *C*Me$_3$), 85.6 (1 C, *C*Me$_3$), 128.2 (8 C, C$_m$ aromatics), 130.1 (4 C, C$_p$ aromatics), 133.7 (4 C, C$_q$ aromatics), 136 (8 C, C$_o$ aromatics), 166.1 (1 C, CO_2), 170.9 (1 C, CO_2) and 187.4 (1 C, OC=S); *m*/*z* (NBA) 886 [M + H]$^+$, 908 [M + Na]$^+$ (Found: C, 66.1; H, 7.4. $C_{49}H_{67}NO_8SSi_2$ requires C, 66.4; H, 7.6%).

*Thiolcarbamates syn- and anti-**5h**.* R_f 0.51 [petroleum ether–ethyl acetate (9 : 1)]; δ_H (200 MHz; $CDCl_3$) 1.08 (18 H, s, 2 × SiBu^t), 1.39 (9 H, s, Bu^t), 1.48 (9 H, s, Bu^t), 3.50 (1 H, d, J_{OH-3} 7.0 Hz, OH), 3.74 (8 H, m, 2 × CH_2N and 2 × CH_2OSi), 4.33 (1 H, dd, J_{3-OH} 7.0, J_{3-2} 2.8 Hz, 3-H), 4.73 (1 H, d, J_{2-3} 2.8, 2-H) and 7.55 (20 H, m, aromatics); δ_C (100 MHz; $CDCl_3$) 28.3 (6 C, 2 × C*Me*$_3$), 30.1 (6 C, 2 × C*Me*$_3$), 51.5 (2 C, 2 × CH_2N), 52.8 (1 C, 2-C$_{syn}$), 53.1 (1 C, 2-C$_{anti}$), 62.6 (2 C, 2 × CH_2O), 72.7 (1 C, 3-C$_{anti}$), 72.8 (1 C, 3-C$_{syn}$), 83.3 (2 C, 2 × *C*Me$_3$), 83.6 (1 C, *C*Me$_3$), 83.7 (1 C, *C*Me$_3$), 128.2 (8 C, C$_m$ aromatics), 130.2 (4 C, C$_p$ aromatics), 133.5 (4 C, C$_q$ aromatics), 135.9 (8 C, C$_o$ aromatics), 166.50 (1 C, CO_{2anti}), 166.55 (1 C, CO_{2syn}), 168.34 (1 C,

SC=O_{syn}), 168.39 (1 C, SC=O_{anti}), 171.2 (1 C, CO_{2anti}) and 171.3 (1 C, CO_{2syn}); *m*/*z* (NBA) 886 $[M + H]^+$, 908 $[M + Na]^+$ (Found: C, 66.2; H, 7.3. $C_{49}H_{67}NO_8SSi_2$ requires C, 66.4; H, 7.6%).

(3*S*)-Di-*tert*-butyl 2-diisopropylcarbamoylsulfanyl-3-hydroxysuccinates *syn*- and *anti*-5i. The title compounds were obtained in 70% overall yield according to the aforementioned general procedure as a colourless oil; R_f 0.56 [petroleum ether–ethyl acetate (8 : 2)]; δ_H (200 MHz; $CDCl_3$) 1.47 (9 H, s, Bu^t), 1.52 (9 H, s, Bu^t), 1.53 (12 H, m, 4 × Me), 3.54 (1 H, m, C*H*Me_2), 3.57 (1 H, d, $J_{OH\text{-}3}$ 7.1 Hz, OH), 4.17 (1 H, m, C*H*Me_2), 4.41 (1 H, d, $J_{3\text{–}2}$ 3.0, $J_{3\text{-}OH}$ 7.1 Hz, 3-H) and 4.71 (1 H, d, $J_{2\text{–}3}$ 3.0 Hz, 2-H); δ_C (100 MHz; $CDCl_3$) 20.9 (2 C, CHMe_2), 21.0 (2 C, CHMe_2), 28.3–28.5 (6 C, 2 × CMe_3), 46.7 (1 C, *C*HMe$_3$), 49.7 (1 C, *C*HMe$_3$), 52.0 (1 C, 2-C_{syn}), 52.5 (1 C, 2-C_{anti}), 72.0 (1 C, 3-C_{anti}), 72.6 (1 C, 3-C_{syn}), 83.0 (1 C, *C*Me$_3$), 83.6 (1 C, *C*Me$_3$), 163.3 (1 C, CO_{2anti}), 163.6 (1 C, CO_{2syn}), 168.9 (1 C, SC=O_{syn}), 169.3 (1 C, SC=O_{anti}), 171.47 (1 C, CO_{2anti}) and 171.50 (1 C, CO_{2syn}); *m*/*z* (NBA) 406 $[M + H]^+$, 428 $[M + Na]^+$ (Found: C, 56.5; H, 8.9. $C_{19}H_{35}NO_6S$ requires C, 56.3; H, 8.7%).

(2*R*,3*R*)-Diisopropyl 2-diethylthiocarbamoyloxy-3-hydroxysuccinate *syn*-7a. The title compound was obtained in 93% yield according to the aforementioned general procedure as a colourless oil; R_f 0.26 [petroleum ether–ethyl acetate (85 : 15)]; $[\alpha]_D^{20}$ −69.1 ± 0.4 (*c* 2.7, chloroform); δ_H (200 MHz; $CDCl_3$) 1.16–1.30 (18 H, m, 6 × Me), 3.12 (1 H, d, $J_{OH\text{-}3}$ 7.3 Hz, OH), 3.49 (2 H, q, $J_{CH_2\text{-}Me}$ 7.0 Hz, CH_2Me), 3.77 (2 H, m, CH_2Me), 4.70 (1 H, dd, $J_{3\text{-}OH}$ 7.3, $J_{3\text{–}2}$ 2.4 Hz, 3-H), 5.11 (2 H, m, 2 × CO_2CH) and 6.14 (1 H, d, $J_{2\text{–}3}$ 2.4 Hz, 2-H); δ_C (100 MHz; $CDCl_3$) 12.1 (1 C, CH_2*Me*), 13.4 (1 C, CH_2*Me*), 21.9 (1 C, Me), 22.1 (1 C, Me), 22.2 (1 C, Me), 44.3 (1 C, *C*H_2Me), 48.6 (1 C, *C*H_2Me), 70.0 (1 C, CO_2CH), 70.2 (1 C, CO_2CH), 71.5 (1 C, 3-C), 78.6 (1 C, 2-C), 166.9 (1 C, CO_2), 171.2 (1 C, *C*O_2) and 186.0 (1 C, OC=S); *m*/*z* (NBA) 350 $[M + H]^+$ (Found: C, 51.7; H, 7.6. $C_{15}H_{27}NO_6S$ requires C, 51.6; H, 7.8%).

(3*S*)-Diisopropyl 2-diisopropylcarbamoylsulfanyl-3-hydroxysuccinates *syn*- and *anti*-8i. The title compounds were obtained in 58% overall yield according to the aforementioned general procedure as a colourless oil; R_f 0.28 [petroleum ether–ethyl acetate (85 : 15)]; δ_H (200 MHz; $CDCl_3$, D_2O) 1.16–1.31 (24 H, m, 8 × Me), 4.48 (1 H, d, $J_{3\text{–}2}$ 3.3 Hz, 3-H), 4.76 (1 H, d, $J_{2\text{–}3}$ 3.3 Hz, 2-H), 4.82 (2 H, m, 2 × NC*H*Pr^i) and 5.16 (2 H, m, 2 × CO_2C*H*Pr^i); δ_C (100 MHz; $CDCl_3$) 20.9–22.3 (4 C, 4 × Me), 46.3 (1 C, NCH), 50.3 (1 C, NCH), 51.4 (1 C, 2-C_{syn}), 51.8 (1 C, 2-C_{anti}), 69.8 (1 C, CO_2CH), 70.2 (1 C, CO_2CH), 71.7 (1 C, 3-C_{anti}), 72.4 (1 C, 3-C_{syn}), 163.1 (1 C, CO_{2anti}), 163.4 (1 C, CO_{2syn}), 169.1 (1 C, SC=O_{syn}), 169.5 (1 C, SC=O_{anti}), 171.7 (1 C, CO_{2syn}) and 171.9 (1 C, CO_{2anti}); *m*/*z* (NBA) 378 $[M + H]^+$ (Found: C, 54.3; H, 8.4. $C_{17}H_{31}NO_6S$ requires C, 54.1; H, 8.3%).

(4*R*,5*R*)-Di-*tert*-butyl 2,2-dioxo-1,3,2-dioxathiolane-4,5-dicarboxylate 2,2-dioxide 9

To a stirred solution of (*R*,*R*)-di-*tert*-butyl tartrate (5 g, 19.1 mmol) and triethylamine (10.6 cm^3, 76.2 mmol) dissolved in dichloromethane (60 cm^3) was added dropwise under nitrogen at 0 °C thionyl chloride (2.1 cm^3, 28.5 mmol) in dichloromethane (5 cm^3). After 1.5 h at room temp. cold diethyl ether (200 cm^3) was added and the organic phase was washed with cold water and a cold saturated solution of NaCl and the solvent evaporated under reduced pressure to afford the intermediate cyclic sulfite as a brown oil. To the crude sulfite dissolved in a cold mixture of carbon tetrachloride–acetonitrile–water [200 cm^3, (1.2 : 1.2 : 1.7)] were added at 0 °C $RuCl_3 \cdot H_2O$ (20 mg, 0.1 mmol, 0.5%) and $NaIO_4$ (8.15 g, 38 mmol). The mixture was vigorously stirred for 30 min at room temp. and filtered on a celite pad; the filtrates were extracted with diethyl ether, washed with a saturated solution of NaCl and the organic phases dried over Na_2SO_4. The solvent was evaporated under reduced pressure. Chromatography on silica gel and elution with dichloromethane afforded the title compound as a white solid (5 g, 82%); mp 52–54 °C; R_f 0.74 (dichloromethane); $[\alpha]_D^{20}$ −67.1 ± 0.6 (*c* 1.7, chloroform); δ_H (200 MHz; $CDCl_3$) 1.56 (18 H, s, 2 × Bu^t) and 5.29 (2 H, s, 2 × CH); δ_C (100 MHz; $CDCl_3$) 28.2 (6 C, 2 × CMe_3), 78.1 (2 C, 2 × *C*Me$_3$), 86.4 (2 C, 2 × CH) and 163.7 (2 C, 2 × CO); *m*/*z* (NBA) 325 $[M + H]^+$, 347 $[M + Na]^+$, 269 $[M + H - Bu^t]^+$, 210 $[M + H - 2\ Bu^t]^+$ (Found: C, 44.7; H, 6.3. $C_{12}H_{20}O_8S$ requires C, 44.4; H, 6.2%).

(*S*,*S*)-Di-*tert*-butyl 2-acetylsulfanyl-3-hydroxysuccinate *anti*-10

To the cyclic sulfate **9** (300 mg, 0.9 mmol) dissolved in acetone (5 cm^3) was added at room temp. potassium thioacetate (127 mg, 1.1 mmol) and the solution stirred at room temp. for 30 min followed by the addition at 0 °C of conc.H_2SO_4 (cat.) and water (17 µl, 0.9 mmol). The reaction was stirred for 3 h at room temp. and concentrated under vacuum, dissolved in dichloromethane (10 cm^3), neutralised with a 5% solution of $NaHCO_3$ and the organic phase was dried, concentrated to give quantitatively the pure title compound (295 mg) as a white solid; mp 52–54 °C; R_f 0.40 [petroleum ether–ethyl acetate (85 : 15)]; $[\alpha]_D^{20}$ −66.1 ± 0.6 (*c* 1.6, chloroform); δ_H (200 MHz; $CDCl_3$, D_2O) 1.43 (9 H, s, Bu^t), 1.49 (9 H, s, Bu^t), 2.46 (3 H, s, Ac), 4.29 (1 H, d, $J_{3\text{–}2}$ 3.1 Hz, 3-H) and 4.69 (1 H, d, $J_{2\text{–}3}$ 3.1 Hz, 2-H); δ_C (100 MHz; $CDCl_3$) 28.3 (3 C, CMe_3), 28.4 (3 C, CMe_3), 30.6 (1 C, *Me*CO), 51.3 (1 C, 2-C), 72.2 (1 C, 3-C), 83.7 (1 C, *C*Me$_3$), 84.1 (1 C, *C*Me$_3$), 167.7 (1 C, CO_2), 171.1 (1 C, CO_2) and 193.9 (1 C, SC=O); *m*/*z* (NBA) 321 $[M + H]^+$, 343 $[M + Na]^+$ (Found: C, 52.3; H, 7.7. $C_{14}H_{24}O_6S$ requires C, 52.5; H, 7.5%).

(*S*,*S*)-Di-*tert*-butyl 2-diisopropylcarbamoylsulfanyl-3-hydroxysuccinate *anti*-5i from 10

To the thioacetate **10** (250 mg, 0.8 mmol) in DMF (1 cm^3) was added hydrazine acetate (93 mg, 1 mmol) and the solution stirred at room temp. for 15 min. Then triethylamine (652 µl, 4.7 mmol) and diisopropylcarbamyl chloride (638 mg, 3.9 mmol) in dichloromethane (2 cm^3) were added and the reaction maintained at room temp. for 12 h. The solution was extracted with dichloromethane and the organic phase was washed with brine, dried and evaporated under reduced pressure. After a chromatography on silica gel with ethyl acetate (0 to 6%) in petroleum ether, the title compound (86 mg, 27%) was obtained as a colourless oil; R_f 0.56 [petroleum ether–ethyl acetate (8 : 2)]; $[\alpha]_D^{20}$ −34.5 ± 0.9 (*c* 1.1, chloroform); δ_H (200 MHz; $CDCl_3$, D_2O) 1.45 (9 H, s, Bu^t), 1.52 (9 H, s, Bu^t), 1.53 (12 H, m, 4 × Me), 3.57 (1 H, m, C*H*Me_2), 4.16 (1 H, m, C*H*Me_2), 4.38 (1 H, d, $J_{3\text{–}2}$ 3.1 Hz, 3-H) and 4.71 (1 H, d, $J_{2\text{–}3}$ 3.1 Hz, 2-H); δ_C (100 MHz; $CDCl_3$) 20.5 (2 C, CHMe_2), 20.7 (2 C, CHMe_2), 27.8 (3 C, CMe_3), 28.0 (3 C, CMe_3), 46.7 (1 C, NCH), 49.7 (1 C, NCH), 52.0 (1 C, 2-C), 72.1 (1 C, 3-C), 83.1 (1 C, *C*Me$_3$), 83.2 (1 C, *C*Me$_3$), 163.0 (1 C, CO_2), 168.9 (1 C, SC=O) and 171.0 (1 C, CO_2); *m*/*z* (NBA) 406 $[M + H]^+$, 428 $[M + Na]^+$ (Found: C, 56.2; H, 8.5. $C_{19}H_{35}NO_6S$ requires C, 56.3; H, 8.7%).

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