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Explorations of an intramolecular route to pyrrolo[3,4-\textit{b}]isoxazoles: an unexpected retro-Claisen reaction

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Abstract
Potential precursors have been prepared for intramolecular 1,3-dipolar cycloaddition to form a pyrrolo[3,4-\textit{b}]isoxazole. The cycloaddition has not to date been accomplished, however an unexpected retro-Claisen reaction is reported.

Keywords: Acetoacetylation, nitro amine, aza-Henry reaction, retro-Claisen reaction, urea

Introduction

We have reported over a number of years on synthetic approaches to the 3-acyltetramic acid group of metabolites, which display an N-heterocyclic enolised tricarbonyl core, as illustrated in general structure 1 (Figure 1).\textsuperscript{1} These metabolites show a range of biological activities, ranging through antibiotic, antitumour, antifungal and antiviral;\textsuperscript{2} they also have a relationship to the inducers of bacterial quorum sensing.\textsuperscript{3} Over recent years we have focussed on pyrroloisoxazoles 2 and 3 as providing masked forms of the polar enol functionality in the acyltetramic acids.\textsuperscript{4-6}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{structures.png}
\caption{General structure of 3-acyltetramic acids 1, and pyrroloisoxazole masked forms 2 & 3.}
\end{figure}

Most recently we have reported on our 2\textsuperscript{nd} generation approach that employs the 5,6-dihydropyrrolo[3,4-\textit{b}]isoxazol-4-one building block 2 through the route shown in Scheme 1, which involves the 1,3-dipolar cycloaddition of an amino acid-derived nitrile oxide dipole with a \(\beta\)-ketoester enamine as dipolarophile.\textsuperscript{5} One of the less efficient steps in this sequence is the ring closure (lactam formation) of 3-(1-aminoalkyl)-5-methylisoxazole-4-carboxylates to complete...
the pyrroloisoxazole framework 2. We were interested to investigate whether this sequence could be improved by reversing the order of N1-C2 bond formation and cycloaddition, making the amide bond first, which would also have the possible benefit of making the cycloaddition intramolecular. We report here our efforts to date, which generated an intermediate having a nitro group as dipole precursor and a β-keto amide as dipolarophile precursor, but revealed an unexpected retro-Claisen reaction on attempting to generate the dipolarophile.

**Scheme 1.** 2nd Generation isoxazole route to acyltetramic acids. *Reagents*: i, DIBAL-H, toluene, –78 °C; ii, NH₂OH.HCl, NaOAc, EtOH aq., 70 °C; iii, N-chlorosuccinimide, CHCl₃, reflux; iv, Et₃N; v, TFA, 20 °C; 2M HCl; vi, EDCI, N-hydroxysuccinimide, DMF, 0→20 °C.

**Results and Discussion**

Authors, please provide missing symbols

As the desired dipolarophile in the cycloaddition is an enamine prepared from a β-keto acid derivative, an obvious initial approach based on intermediates we had in hand was N-acetoacetylation of an amino acid-derived oxime. The nitrile oxide dipole would be prepared from the aldoxime via C-chlorination and 1,3-dehydrochlorination. Using valine as our test amino acid scaffold, the aldoxime 4a was prepared from N-tert-butyloxy carbonyl-S-valine methyl ester (DIBAL-H, toluene, –78 °C, 2 h; then NH₂OH.HCl, NaOAc, EtOH aq., 70 °C, 10 min) in 89% yield as a 2:1 mixture of geometric isomers (Scheme 2). Acetoacetylation was attempted using 2,2,6-trimethyl-1,3-dioxin-4-one, the diketene-acetone adduct (PPTS, toluene reflux, 3 h). The results were inconsistent, with product 1H NMR spectra sometimes showing loss of the tert-butyloxycarbonyl group and sometimes not. Samples retaining the tert-butyloxy carbonyl group had 1H NMR spectra that implied acylation of the oxime N-atom rather than the amine function, with a signal for the proton NH₄Boc being observed at δ 4.62 (1H, d, J 9.6 Hz). More surprisingly, the NMR spectra suggested the reduced structure 5a, having an unexpected additional CH₂N signal (δ 4.11-4.24, 2H, m; δC 65.6) and no oxime sp²-CHN
signals, although we were unable to fully characterise this material. A test with FeCl$_3$ supported the assignment of a hydroxamate structure.$^8$ The capricious behaviour in the thermolysis led us to switch to the corresponding N-benzylxocarbonyl aldoxime 4b, prepared from N-benzylxocarbonyl-S-valine methyl ester as outlined above for the tert-butyloxycarbonyl compound 4a. Thermolysis with the diketene-acetone adduct, however, again gave a product assigned as the hydroxamate 5b, showing $\delta$ 3.62-3.68 (1H, m, CHNH$_2$), 4.07-4.17 (2H, m, CHCH$_2$N), 4.62 (1H, d, $J$ 9.6 Hz, CHNH$_2$), $\delta$ 8 67.0 (CH$_2$N), and no oxime CH signal. Again, full characterisation could not be accomplished. A redox process is clearly implicated alongside these acylations, but we are unable to identify the reducing agent. Changing the acetoacetylation agent to the more reactive diketene but omitting the acid (toluene reflux, 3 h) led to the same presumed hydroxamates 5a,b from the aldoximes 4a,b, respectively.

Scheme 2. Attempted acetoacylation of $\alpha$-amino oximes. Reagents: i, DIBAL-H, toluene, $-78^\circ$C; ii, NH$_2$OH.HCl, NaOAc, EtOH aq., 70 $^\circ$C; iii, 2,2,6-trimethyl-1,3-dioxen-4-one, pyrH$^+$ OTs, toluene reflux; or diketene, toluene reflux.

These results led us to avoid the oxime as a precursor functional group for the nitrile oxide dipole. Instead we targeted the dehydration of a primary nitro group as the route to the nitrile oxide. Our target thus became an N-protected S-2-methyl-1-nitromethyl-1-propanamine 6a or 6b (Scheme 3), which could be N-acetoacylated. Thus S-valinol 7 (prepared by reduction of S-valine: TMSCl, NaBH$_4$, THF, 0 $^\circ$C, 24 h; $^9$ 78%) was selected as starting material. A good leaving group was now needed at the alcohol function for substitution to generate a primary nitro group, but attempted toluene-4-sulfonylation (TsCl, DCM, 0$\rightarrow$20 $^\circ$C, 17 h) unsurprisingly afforded the N-sulfonylated compound 8 (100%) rather than the desired O-sulfonylated compound. Thus S-valinol 7 was N-protected as the tert-butyloxycarbonyl derivative 9a (Boc$_2$O, Et$_3$N, DCM, 0$\rightarrow$20 $^\circ$C, 17 h; 100%) and benzoyloxycarbonyl derivative 9b (PhCH$_2$OCOCl, NaHCO$_3$, EtOAc-H$_2$O, 0$\rightarrow$20 $^\circ$C, 17 h; 90%). The corresponding mesylate derivatives 10a and 10b were formed by a standard method (methanesulfonyl chloride, Et$_3$N, DCM, 0$\rightarrow$20 $^\circ$C, 4 h) in crude yields of over 90%. Attempts to use these crude materials in a nucleophilic substitution with nitrite were unsuccessful (NaNO$_2$, toluene or DMF, 0$\rightarrow$60 $^\circ$C, 17 h) with the alcohols 9a and 9b being recovered after aqueous workup. The mesylates were instead treated under Finkelstein conditions (NaI, acetone reflux, 17 h) in an attempt to generate the corresponding iodo compounds 11a and 11b, respectively. The N-tert-butyloxycarbonyl derivative 10a
however, underwent protecting group cleavage to afford the cyclic carbamate 12; the N-benzyloxycarbonyl compound 10b did give the iodo compound 11b (42%) along with some cyclic carbamate 12 (7%). It is assumed that anchimeric assistance by the N-protecting group carbonyl oxygen atom is followed by loss of a carbenium ion (to afford the cyclic carbamate) competing with iodide nucleophilic attack. In an alternative direct iodination from alcohol 9a, iodotriphenylphosphonium iodide was prepared (triphenylphosphine, iodine, DCM) to which imidazole and alcohol 9a was added and the mixture heated under reflux for 17 h to afford the iodide 11a (31% after chromatography). The yield and product purification was improved by replacing the triphenylphosphine with a polymer-supported triphenylphosphine, to afford the iodides 11a (43%) and 11b (80%) from the corresponding alcohols 9a and 9b, respectively. Traces of the cyclised by-product 12 were sometimes observed in these reactions. The nitro substitution was undertaken with the iodo compounds, now using sodium nitrite in DMF (20 °C, 20 h) with the addition of phloroglucinol and urea to minimize the formation of nitrite ester. The corresponding N-tert-butyloxycarbonyl and N-benzyloxycarbonyl S-2-methyl-1-nitromethylpropanamines 6a (64%) and 6b (70%) were isolated along with small recoveries of the corresponding alcohols 9a or 9b.

Scheme 3. Preparation of protected S-2-methyl-1-nitromethylpropanamines 6. Reagents: i, TsCl, DCM, 0→20 °C; ii, For 9a: Boc₂O, Et₃N, DCM, 0→20 °C. For 9b: PhCH₂OCOCl, NaHCO₃, EtOAc-H₂O, 0→20 °C; iii, MsCl, Et₃N, DCM, 0→20 °C; iv, NaI, acetone reflux; v, PS-PPh₃, I₂; then imidazole; vi, NaNO₂, DMF, phloroglucinol, urea, 20 °C.

This route to optically active N-protected S-2-methyl-1-nitromethylpropanamines was complemented by a reported approach to the N-tert-butyloxycarbonyl R-compound 6c via the aza-Henry reaction (Scheme 4). Thus, sodium benzenesulfinate in water was added to tert-butyl carbamate (THF, 20 °C), followed by 2-methylpropanal and methanoic acid. After 17 h, the white precipitate was recrystallized to afford the sulfone 13 (75%). Reaction with nitromethane in the presence of potassium hydroxide (toluene, –78→20 °C, 48 h) and catalytic...
benzylquininium chloride led to the nitro compound 6a (72%). Replacing potassium by cesium hydroxide led to incomplete reaction after 48 h, in contrast to one of the earlier reports. The nitro compound prepared by this route was formed highly stereoselectively, whereas the route from S-valine was stereospecific.

Scheme 4. Alternative preparation of R-nitromethylpropanamine 6a. Reagents: i, BocNH₂, PhSO₂Na, THF aq., 20 °C; ii, MeNO₂, KOH, benzylquininium chloride (12 mol %), toluene, –78→20 °C, 48 h.

The next step was N-acetoacetylation of the amino-nitro compound 6a, which was initially attempted as described earlier, using thermolysis of the diketene-acetone adduct (pyridinium toluene-4-sulfonate, toluene reflux, 3 h), but starting material was recovered. As an alternative acylating agent we employed S-tert-butyl 3-oxobutanthioate 14, itself generated by base treatment of 2-methylpropane-2-thiol (NaH, THF, –15→0 °C) followed by addition of diketene to the thiolate at –5 °C.¹³ Thus amino-nitro compound 6a and the thioester 14 were reacted in the presence of silver(I) trifluoroacetate (THF in the dark) but starting carbamate 6a was recovered.¹⁴ We reasoned this was due to reduced nucleophilicity of the carbamate N-atom, so we removed the tert-butyloxy carbonyl group (TFA, followed by 2M hydrochloric acid) to afford the stable amine hydrochloride salt 15 (Scheme 5). Acylation was completed using both protocols described above, to afford the acetoacetamide 16 (68% from diketene-acetone adduct; just 19% from thioester 14). The precursor functionality for generation of the required dipole (nitrile oxide from dehydration of the primary nitro group) and dipolarophile (enamine derived from the β-ketoamide) is present in the acetoacetamide 16. The next step was planned to be the enamine formation, so the amide 16 was treated with pyrrolidine in toluene at reflux under Dean-Stark water removal conditions. After workup, a product was recovered (55%) but the ^1H NMR spectrum was missing the CH₃ and CH signals expected for the enamine 17, although it did show signals for the pyrrolidine ring. The structure was revealed by an X-ray crystal structure determination to be the unexpected mixed urea 18 (Figure 2). The solid-state structure displays two independent molecules in the asymmetric unit, differing in the detailed conformation of the pyrrolidine sub-unit and linked via a strong N–H⋯O hydrogen bond.¹⁵

Authors, we changed the "Figure 1" on page 5 to the "Figure 2" because you have the "Figure 1" on page 1.
Scheme 5. Attempted enamine formation from acetoacetamide 16. Reagents: i, TFA, 20 °C, 4.5 h, then 2M HCl aq., 20 °C, 0.5 h; ii, Et₃N, DCM, then 2,2,6-trimethyl-1,3-dioxin-4-one, pyrH⁺-OTs, toluene reflux; iii, Et₃N, DCM, then MeCOCH₂COSBu¹ 14, CF₃CO₂Ag, THF, –15 °C, 30 min; iv, pyrrolidine, toluene, Dean-Stark reflux.

Figure 2. X-Ray crystal structure of mixed urea 18. The structure comprises two independent molecules differing in conformation of the pyrrolidine unit. N(5)–H(5)···O(1): d(D...A) = 2.917(2) Å, <(DHA) = 155(2)°; N(2)–H(2)...O(4'): d(D...A) = 2.889(2) Å, <(DHA) = 160(2)°, generating chains parallel to b; ′ = –x,y+1/2,–z+1/2.

We propose the mechanism shown in Scheme 6 wherein the iminium ion formed en route to the desired enamine 17, or in equilibrium with it, is attacked by a second pyrrolidine molecule to promote a retro-Claisen reaction, affording the observed urea and presumably the pyrrolidine enamine of propanone as an unusual leaving group, although this was not isolated.
Scheme 6. Possible mechanism for formation of mixed urea 18.

An alternative potential sequence towards an intramolecular dipolar cycloaddition would be nitrile oxide formation and then cycloaddition to the enol form of the β-keto amide. With this in mind we treated the nitro compound 16 under several reported dehydration conditions: di-tert-butyl dicarbonate or ethyl chloroformate (Et$_3$N, 0.1 mol equiv. 4-DMAP, in DCM, acetonitrile or toluene at reflux), but in all cases starting material was recovered unchanged. Likewise, an attempt to form a silyl nitronate as dipole (TMSCl, Et$_3$N, in THF or acetonitrile at reflux) returned starting nitro-amide 16.

Conclusions

In conclusion, based on these explorations we have not been able to form the isoxazole building block 2 via an intramolecular approach, and continued to focus instead on developing the pyrroloisoxazole strategy towards masked acyltetramic acids via the previously reported intermolecular sequence.

Experimental Section

General. Commercial dry solvents were used in all reactions except for light petroleum and EtOAc, distilled from CaCl$_2$, and CH$_2$Cl$_2$ distilled over P$_2$O$_5$. THF was distilled from sodium and benzophenone. Light petroleum refers to the b.p. 40-60 °C fraction. Sodium hydride was obtained as 60% dispersion in oil and washed with light petroleum. Melting points were determined on a Leica Galen III hot stage apparatus. $^1$H (250 MHz), $^1$H (400 MHz) and $^{13}$C (100 MHz) NMR spectra were recorded on Bruker AC-250 or AC-400 spectrometers in CDCl$_3$ solutions with Me$_4$Si or (CD$_3$)$_2$SO as internal standard unless otherwise specified. Chemical shifts δ are given in parts per million (ppm) and $^1$H coupling constants $J$ in Hz, with multiplicities: s (singlet), d (doublet), t (triplet) and m (multiplet). Mass spectra were recorded on a JEOL SX102 spectrometer, or carried out by the EPSRC National Mass Spectrometry Service Centre (Swansea) or on a ZQ2000 spectrometer with Waters 600 series liquid handling system, dual wavelength UV and ELS detectors at Novartis, Horsham UK. MicroMass LCT was detected.
using a TOF spectrometer with Agilent 1100 series HPLC and Gilson 215 liquid handling; diode array and CAD detectors; Platform LC spectrometers with Agilent 1100 series HPLC diode array and ELS detectors; ThermoElectron LTQ Linear Quadrupole Ion Trap MS with ESI probe and APCI source were used for MS/MS; ThermoElectron DSQ MS with TRACE GC, at Novartis. GCMS was carried out on a Fisons 8000 series instrument using a 15 m x 0.25 mm DB-5 column and an EI low resolution MS at Novartis. IR spectra were recorded on a Perkin-Elmer Paragon 1000 FT-IR spectrophotometer on NaCl plates, in the range 4000–600 cm⁻¹. Elemental analyses were determined on a Perkin Elmer 2400 CHN Elemental Analyser in conjunction with a Perkin Elmer AD-4 Autobalance, or on a LECO CHNS-932 Analyst, at Novartis. TLC using silica gel as absorbent was carried out on aluminium backed plates coated with silica gel (Merck Kieselgel 60 F₂₅₄), and TLC using alumina as absorbent was carried out on aluminium backed plates coated with neutral aluminium oxide (Merck 150 F₂₅₄, Type T). Silica gel (Merck Kieselgel 60 H silica) was used for column chromatography unless otherwise specified. Column chromatography using alumina was carried out with Aldrich aluminium oxide, activated neutral, Brockmann 1, STD Grade, 150 mesh sizes. Preparative TLC was carried out using aluminium oxide (Merck 60 F₂₅₄, Type E).

**S-2-tert-Butyloxycarbonylamino-3-methylbutanaldoxime (4a).** DIBAL-H (1.0M in toluene, 22 mL, 21.73 mmol) was added dropwise over 1 h to a suspension of N-tert-butyloxycarbonylamino-S-valine methyl ester (2.0 g, 8.69 mmol) in dry toluene (10 mL) under nitrogen with stirring at –78 °C. After stirring the reaction mixture at –78 °C for a further 30 min, MeOH (approx. 7 mL) was added to the mixture and it was poured into a solution of Rochelle salt (50 g) in water (100 mL) and stirred vigorously for 2 h. The aqueous phase was separated, extracted with EtOAc (3 x 50 mL), and the combined organic layers were washed with saturated brine (2 x 50 mL), dried (MgSO₄) and concentrated under reduced pressure to yield S-2-tert-butyloxycarbonylamino-3-methylbutanal (2.0 g, 100%) as a colourless oil that was used directly. IR (νₛₑ₃, CHCl₃/cm⁻¹), 3350, 2967, 2931, 1700, 1367, 1248, 1044, 1019. ¹H NMR (400 MHz; CDCl₃), δH 0.94-1.04 (6H, 2 x d, J₆.₈, CH(C₃H₃)₂), 1.45 (9H, s, C(CH₃)₃), 2.25-2.32 (1H, m, CH(CH₃)₂), 4.24-4.28 (1H, m, CHNH), 5.14-5.21 (1H, d, J₈, CHN), 9.64 (1H, broad, CHO). ¹³C NMR (100 MHz; CDCl₃), δC 17.6, 18.9 (CH(CH₃)₂), 28.4 (C(CH₃)₃), 29.0 (CH(CH₃)₂), 64.7 (CHNH), 78.9 (C(CH₃)₃), 155.9 (OCONH), 200.5 (CHO).

To the crude aldehyde (1.5 g, 6.94 mmol) in EtOH (10 mL) was added hydroxylamine hydrochloride (0.96 g, 13.88 mmol) and NaOAc (2.28 g, 27.76 mmol) in water (10 mL). A few drops of EtOH were added to dissolve the precipitate and the solution was warmed to 70 °C for 10 min, cooled and stored in a refrigerator overnight. The white precipitate formed was filtered. The remaining mixture was extracted with EtOAc (3 x 70 mL) and the combined organic layers were dried (MgSO₄) and concentrated under reduced pressure to yield the *title compound* 4a (1.34 g, 89%) as a white solid, syn:anti 2:1, m.p. 117-124 °C, [α]D²⁰ +23.4 (c 12.8, MeOH). IR (νₛₑ₃, Nujol/cm⁻¹), 3342, 2955, 1722, 1682, 1459, 1376, 1312, 1016. ¹H NMR (400 MHz; (CD₃)₂SO), δH 0.77-.0.83 (6H, 2 x d, J 7.2, CH(CH₃)₂), 1.37 (9H, s, C(CH₃)₃), 1.72-1.78 (1H, m,
2,2,6-trimethyl-1,3-dioxin-4-one (145 mg, 133 μmol), NaOAc (22.59 g, 275.41 mmol) in water (50 mL) and worked up to afford the crude aldehyde (16.2 g, 68.85 mmol) was treated with hydroxylamine hydrochloride (9.57 g, 10.9 mmol) in MeOH (15 mL), Rochelle salt (150 g) in water (300 mL) to afford 2-tert-butyl oxycarbonylamino-3-methylbutanaldoxime (4a).

The crude aldehyde (16.2 g, 68.85 mmol) was treated with hydroxylamine hydrochloride (9.57 g, 10.9 mmol) in MeOH (15 mL), Rochelle salt (150 g) in water (300 mL) to afford 2-tert-butyl oxycarbonylamino-3-methylbutanaldoxime (4a).

2-Benzyloxycarbonylamino-3-methylbutanaldoxime (4b). Prepared by the same method as oxime 4a but using N-benzyloxycarbonylamino-S-valine methyl ester (18.3 g, 68.98 mmol) in dry toluene (100 mL) and DIBAL-H (1.0M in toluene, 173 ml, 172.4 mmol), and worked-up using MeOH (15 mL), Rochelle salt (150 g) in water (300 mL) to afford 2-benzyloxycarbonylamino-3-methylbutanal (17.0 g, 100%) as a colourless oil that was used directly. 

1H NMR (400 MHz; CDCl3), δH 0.92-1.03 (6H, 2 x d, J 6.8, CH(CH3)}, 2.27-2.35 (1H, m, CH(CH3)}, 4.31-4.34 (1H, dd, J 3.6, 10.9, CHN)}, 5.11 (2H, s, CH2Ph), 5.46-5.47 (1H, d, J 7.8, CHNH), 7.26-7.36 (5H, m, Ar-H), 9.62 (1H, s, CHO). 

13C NMR (100 MHz; CDCl3), δC 28.2 (C(CH3)}, 39.4 (CH(CH3)}, 50.2 (CHNH), 79.0 (C(CH3}}, 149.9 (CHN), 155.2 (OCONH). HRMS: Calcd for C10H20N2O3: M+ 217.1557; found: M+, 217.1557. Anal. Calcd for C10H20N2O3: C, 55.53; H, 9.32; N, 12.95%; Found: C, 55.51; H, 9.14; N, 13.01%.

**S-2-Benzyloxycarbonylamino-3-methylbutanaldoxime (4b).** Prepared by the same method as oxime 4a but using N-benzyloxycarbonylamino-S-valine methyl ester (18.3 g, 68.98 mmol) in dry toluene (100 mL) and DIBAL-H (1.0M in toluene, 173 ml, 172.4 mmol), and worked-up using MeOH (15 mL), Rochelle salt (150 g) in water (300 mL) to afford 2-benzyloxycarbonylamino-3-methylbutanal (17.0 g, 100%) as a colourless oil that was used directly. 

1H NMR (400 MHz; CDCl3), δH 0.92-1.03 (6H, 2 x d, J 6.8, CH(CH3)}, 2.27-2.35 (1H, m, CH(CH3)}, 4.31-4.34 (1H, dd, J 3.6, 10.9, CHN)}, 5.11 (2H, s, CH2Ph), 5.46-5.47 (1H, d, J 7.8, CHNH), 7.26-7.36 (5H, m, Ar-H), 9.62 (1H, s, CHO).

13C NMR (100 MHz; CDCl3), δC 28.2 (C(CH3)}, 39.4 (CH(CH3)}, 50.2 (CHNH), 79.0 (C(CH3}}, 149.9 (CHN), 155.2 (OCONH). HRMS: Calcd for C10H20N2O3: M+ 217.1557; found: M+, 217.1557. Anal. Calcd for C10H20N2O3: C, 55.53; H, 9.32; N, 12.95%; Found: C, 55.51; H, 9.14; N, 13.01%.

**Attempted N-acylation of S-2-tert-butyloxycarbonylamino-3-methylbutanaldoxime (4a).** S-2-tert-Butyloxycarbonylamino-3-methylbutanaldoxime (0.2 g, 0.93 mmol) 4a was added to 2,2,6-trimethyl-1,3-dioxin-4-one (145 mg, 133 μL, 1.02 mmol) in dry toluene (20 mL) and followed by PPTS (256 mg, 1.02 mmol). The mixture was heated under reflux for 3 h and then concentrated under reduced pressure. The residue was partitioned between EtOAc (30 mL) and water (30 mL) and the aqueous phase extracted with EtOAc (2 x 30 mL). The combined extracts were dried (MgSO4) and concentrated under reduced pressure. The residue was subjected to column chromatography eluting with light petroleum : EtOAc (1:3 v/v) to yield an orange oil (94.4 mg) identified as S-1-hydroxy-3-oxobutanoylaminomethyl-2-methylpropyl]carbamic acid tert-butyl ester 5a based on its 1H NMR spectrum. A test with FeCl3 supported the assignment of a hydroxamate structure, but complete characterization was not possible. 1H NMR (400 MHz; CDCl3), δH 0.93-0.97 (6H, 2 x d, J 6.8, CH(CH3)}, 1.44 (9H, s, C(CH3)}, 1.77-1.82 (1H, m, CH(CH3)}, 2.28 (3H, s, CH3CO), 3.49 (2H, s, CH2), 3.66-3.68 (1H, m, CHNH), 4.11-4.24 (2H, m, CHCH2)}, 4.59-4.64 (1H, d, J 9.6 Hz, CHNH). 13C NMR (100 MHz; CDCl3), δC 13.0, 18.4, 19.4 (CH(CH3)}, 28.4 (C(CH3)}, 30.1 (CH(CH3)}, 30.2 (CH3CO), 49.9 (CH2), 54.6 (CHNH), 65.6 (CH2), 79.9 (C(CH3)}, 155.8 (OCONH), 167.1 (CONOH), 200.6 (CH3CO).
**Attempted N-acylation of S-2-benzyloxy carbonylamino-3-methylbutanal doxime (4b).**

**Method A.** Performed by the same method as for S-2-ter t-butyloxy carbonylamino-3-methylbutanal doxime 4a but using 2-benzyloxy carbonylamino-3-methylbutanal doxime 4b (200 mg, 0.80 mmol), 2,2,6-trimethyl-1,3-dioxin-4-one (125 mg, 115 µL, 0.88 mmol), dry toluene (20 mL) and PPTS (221 mg, 0.88 mmol) to yield an orange oil (53.8 mg) identified as S-(1-hydroxy-3-oxobutanoylaminomethyl-2-methylpropyl)car bamic acid benzyl ester 5b based on its $^1$H NMR spectrum. A test with FeCl$_3$ supported the assignment of a hydroxamate structure, but complete characterization was not possible. $^1$H NMR (400 MHz; CDCl$_3$), $\delta_H$ 83.8-0.87 (6H, 2 x d, J 7.2, C(CH$_3$)$_2$), 1.69-1.76 (1H, m, CH(CH$_3$)$_2$), 2.14 (3H, s, CH$_3$CO), 3.34 (2H, s, CH$_2$), 3.62-3.68 (1H, m, CHNH), 4.07-4.17 (2H, m, CHC$_2$), 4.94-4.96 (1H, d, J 9.6, CHNH), 5.02 (2H, s, CH$_2$Ph), 7.22-7.29 (5H, m, Ar-H). $^{13}$C NMR (100 MHz; CDCl$_3$), $\delta_C$ 18.5, 19.4 (CH(CH$_3$)$_2$), 29.6 (CH(CH$_3$)$_2$), 30.4 (CH$_3$), 49.9 (CH$_2$), 55.4 (CHNH), 67.0 (CH$_2$), 68.1 (CH$_2$Ph), 128.3, 128.5, 128.8 (Ar-CH), 136.6 (Ar-C), 156.4 (OCONH), 172.4 (CONOH), 200.6 (CH$_2$CO).

**Method B.** Performed as Method A but using 2-benzyloxy carbonylamino-3-methylbutanal doxime 4b (500 mg, 2.00 mmol) and diketene (180 mg, 160 µL, 2.10 mmol) in dry toluene (20 mL) to yield a yellow oil (94.6 mg) whose NMR data were identical to a sample prepared by Method A above.

**S-(1-Hydroxymethyl-2-methylpropyl)car bamic acid tert-butyl ester (9a).** Di-tert-butyl dicarbonate (2.22 g, 10.18 mmol) in CH$_2$Cl$_2$ (10 mL) was added dropwise to S-valinol 7 (1.0 g, 9.69 mmol) in CH$_2$Cl$_2$ (25 mL) at 0 °C. Et$_3$N (1.03 g, 1.42 mL, 10.18 mmol) was then added dropwise to the reaction mixture. The mixture was stirred at 20 °C for 17 h, washed with citric acid solution (1M, 50 mL) and saturated brine (2 x 50 mL), dried (MgSO$_4$) and concentrated under reduced pressure to afford a colourless oil that was purified by column chromatography eluting with light petroleum : EtOAc (2:1 v/v) to yield the title compound 9a (1.31 g, 66%) as a colourless oil, $[\alpha]_D^{20}$ +24.8 (c 10, CHCl$_3$), lit.$^{10}$ $[\alpha]_D^{20}$ +17 (c 1.68, CHCl$_3$), IR ($\nu_{\text{max}}$ CHCl$_3$/cm$^{-1}$, 3337, 3032, 2962, 1714, 1315, 1234, 1150. $^1$H NMR (400 MHz; CDCl$_3$), $\delta_H$ 0.88-0.92 (6H, 2 x d, J 6.8, CH(CH$_3$)$_2$), 1.40 (9H, s, C(CH$_3$)$_3$), 1.75-1.86 (1H, m, CH(CH$_3$)$_2$), 3.01 (1H, br, OH), 3.33-3.41 (1H, m, CHNH), 3.51-3.68 (1H, m, CHCH$_2$), 4.80-4.89 (1H, broad, CHNH). $^{13}$C NMR (100 MHz; CDCl$_3$), $\delta_C$ 18.5, 19.5 (CH(CH$_3$)$_2$), 28.4 (C(CH$_3$)$_3$), 29.2 (CH(CH$_3$)$_2$), 59.2 (CHNH), 63.2 (CHCH$_2$), 79.4 (C(CH$_3$)$_3$), 156.8 (OCONH). HRMS: Calcd for C$_{10}$H$_{21}$NO$_3$: MH$^+$ 204.1594; found: MH$^+$ 204.1589.

**S-(1-Hydroxy methyl-2-methylpropyl)car bamic acid benzyl ester (9b).** Benzyl chloroformate (1.82 g, 1.52 mL, 10.66 mmol) was added dropwise to a bi-phase solution of S-valinol 7 (1 g, 9.69 mmol) and NaHCO$_3$ (3.42 g, 40.71 mmol) in water (50 mL) and CH$_2$Cl$_2$ (50 mL) at 0 °C. The mixture was stirred for 17 h and the aqueous phase was then acidified to pH 1 with 2M hydrochloric acid and extracted with CH$_2$Cl$_2$ (2 x 50 mL). The combined extracts were washed with saturated brine (50 mL), dried (MgSO$_4$) and concentrated under reduced pressure to afford a colourless oil that was purified by column chromatography eluting with light petroleum : EtOAc (2:1 v/v) to yield the title compound 9b (2.06 g, 90%) as a white solid, mp 50-52 °C, $[\alpha]_D^{20}$ +20.67 (c 12, CHCl$_3$), IR ($\nu_{\text{max}}$ CHCl$_3$/cm$^{-1}$, 3322, 3031, 2963, 2875, 1700, 1541, 1235, 1177. $^1$H
NMR (400 MHz; CDCl₃). δ_H 0.89-0.94 (6H, 2 x d, J 6.8, CH(CH₃)$_{2}$), 1.80-1.87 (1H, m, CH(CH₃)$_{2}$), 2.96 (1H, br, OH), 2.45-2.51 (1H, m, CH(NH)), 3.58-3.68 (2H, m, CHCH₂), 5.07-5.11 (1H, m, CH₂), 5.16-5.18 (1H, d, J 8.8, CHNH), 7.27-7.36 (5H, m, Ar-H). $^{13}$C NMR (100 MHz; CDCl₃), δ_C 18.5, 19.5 (CH(CH₃)$_{2}$), 29.3 (CH(CH₃)$_{2}$), 58.6 (CHNH), 63.6 (CH$_{2}$OH), 66.9 (CH$_{2}$Ph), 127.8, 128.2, 128.5 (Ar-CH), 136.5 (Ar-C), 157.2 (OCONH). HRMS: Calcd for C$_{13}$H$_{19}$NO$_{3}$: MH$^{+}$ 238.1438; found: MH$^{+}$ 238.1447.

**S-2-tert-Butyoxycarbonylamino-3-methylbutyl methanesulfonate (10a).** Et$_{3}$N (305 mg, 420 μL, 3.01 mmol) was added to S-(1-hydroxymethyl-2-methylpropyl)carbamic acid tert-butyl ester 9a (510 mg, 2.51 mmol) in CH$_{2}$Cl$_{2}$ (20 mL) at 0 °C under nitrogen followed by methanesulfonyl chloride (345 mg, 233 μL, 3.01 mmol). The mixture was stirred at 20 °C for 4 h, then washed with water (30 mL), citric acid solution (1M, 30 mL) and saturated brine (30 mL), dried (MgSO$_{4}$) and concentrated under reduced pressure to yield the title compound 10a (735.1 mg, 100%) as a white solid that was used directly. $^{1}$H NMR (400 MHz; CDCl$_{3}$), δ_H 0.93-0.99 (6H, 2 x d, J 6.8, CH(CH$_{3}$)$_{2}$), 1.44 (9H, s, (C(CH$_{3}$)$_{3}$), 1.83-1.88 (1H, m, CH(CH$_{3}$)$_{2}$), 3.02 (3H, s, SCH$_{3}$), 3.59-3.63 (1H, m, CHNH), 4.24-4.27 (2H, m, CHCH$_{2}$), 4.64-4.65 (1H, br, CHNH). $^{13}$C NMR (100 MHz; CDCl$_{3}$), δ_C 18.5, 19.4 (CH(CH$_{3}$)$_{2}$), 28.4 (C(CH$_{3}$)$_{3}$), 29.1 (CH(CH$_{3}$)$_{2}$), 37.4 (SCH$_{3}$), 58.2 (CHNH), 69.7 (CH$_{2}$), 79.8 (C(CH$_{3}$)$_{3}$), 155.6 (OCONH).

**S-2-Benzylxocarbonylamino-3-methylbutyl methanesulfonate (10b).** Prepared as for S-2-tert-Butyoxycarbonylamino-3-methylbutyl methanesulfonate 10a but using Et$_{3}$N (0.24 g, 0.32 mL, 2.32 mmol), S-(1-hydroxymethyl-2-methylpropyl)carbamic acid benzyl ester 9b (0.5 g, 2.11 mmol) in CH$_{2}$Cl$_{2}$ (20 mL) and methanesulfonyl chloride (0.27 g, 2.32 mmol) to yield the title compound 10b (0.62 g, 93%) as a white solid that was used directly. $^{1}$H NMR (400 MHz; CDCl$_{3}$), δ_H 0.96-1.03 (6H, 2 x d, J 6.8, CH(CH$_{3}$)$_{2}$), 1.85-1.92 (1H, m, CH(CH$_{3}$)$_{2}$), 2.96 (3H, s, SCH$_{3}$), 3.69-3.75 (1H, m, CHNH), 4.28-4.29 (2H, d, J 4.4, CHCH$_{2}$), 4.85-4.88 (1H, d, J 9.2, CHNH), 5.11-5.12 (2H, s, CH$_{2}$Ph), 7.30-7.37 (5H, m, Ar-H). $^{13}$C NMR (100 MHz; CDCl$_{3}$), δ_C 18.5, 19.4 (CH(CH$_{3}$)$_{2}$), 29.1 (CH(CH$_{3}$)$_{2}$), 37.4 (SCH$_{3}$), 56.0 (CHNH), 67.0 (CH$_{2}$), 69.4 (CH$_{2}$Ph), 128.2, 128.3, 128.6 (Ar-C), 136.4 (Ar-C), 156.1 (OCONH).

**4-(2-Propyl)oxazolidin-2-one (12).** Method A. NaI (339 mg, 2.26 mmol) was added to S-2-tert-Butyoxycarbonylamino-3-methylbutyl methanesulfonate 10a (199 mg, 0.71 mmol) in acetone (20 mL). The mixture was heated under reflux for 17 h and then concentrated under reduced pressure to leave a residue that was partitioned between EtOAc (30 mL) and water (30 mL) and the aqueous phase was extracted with EtOAc (2 x 30 mL). The combined organic layers were washed with sodium thiosulfate solution (10 % w/v, 30 mL), water (30 mL) and saturated brine (30 mL), dried (Na$_{2}$SO$_{4}$) and concentrated under reduced pressure to yield the title compound 12 (162 mg, 100%) as a white solid, mp 63-65 °C (lit. $^{18}$ 67-70 °C, [α]$_{D}^{20}$ +17.1 (c 12, CHCl$_{3}$) [lit.$^{18}$ [α]$_{D}^{26}$ +16.5 (c 10.4, CHCl$_{3}$)]. $^{1}$H NMR (400 MHz; CDCl$_{3}$), δ_H 0.83-0.91 (6H, 2 x d, J 6.8, CH(CH$_{3}$)$_{2}$), 1.63-1.71 (1H, m, CH(CH$_{3}$)$_{2}$), 3.52-3.58 (1H, dd, J 6.4, 16.0, CHNH), 4.02-4.06 (1H, dd, J 6.4, 8.7, CH$_{2}$), 4.36-4.40 (1H, t, J 8.7, 16.0, CH$_{2}$), 6.26 (1H, br, CHNH). $^{13}$C NMR (100 MHz; CDCl$_{3}$), δ_C 18.1, 18.5 (CH(CH$_{3}$)$_{2}$), 33.1 (CH(CH$_{3}$)$_{2}$), 58.8 (CHNH), 69.0 (CH$_{2}$CH$_{2}$), 160.6 (OCONH).
When the same procedure was applied to S-2-benzyloxy carbonylamino-3-methylbutyl methanesulfonate 10b (64 mg, 0.2 mmol) using NaI (97 mg, 0.65 mmol) in acetone (10 mL), the title compound 12 (53 mg, 7%) was isolated along with S-(1-iodomethyl-2-methylpropyl)carbamoyl acid benzyl ester 11b (29.6 mg, 42%), data as reported below.

**S-(1-Iodomethyl-2-methylpropyl)carbamoyl acid tert-butyl ester (11a).** Method A. Iodine (2.75 g, 10.82 mmol) was added to a suspension of polystyrene-triphenylphosphine (5.19 g, 10.33 mmol) in CH2Cl2 (100 mL) and the mixture stirred at 20 °C under nitrogen for 15 min. Imidazole (827 mg, 12.30 mmol) was then added and the mixture stirred for 15 min before S-(1-hydroxymethyl-2-methylpropyl)carbamoyl acid tert-butyl ester 9a (1.0 g, 4.92 mmol) was added and the mixture heated under reflux for 20 h, then cooled and filtered. The filtrate was washed with sodium thiosulfate solution (10% w/v, 70 mL), water (70 mL) and saturated brine (70 mL). The organic layer was dried (Na2SO4) and concentrated under reduced pressure to afford a yellow solid (897 mg) that was purified by column chromatography eluting with light petroleum : EtOAc (2:1 v/v) to yield the title compound 11a (668 mg, 43%) as a yellow solid, mp 62-65 °C (lit.10 mp 48-51 °C), [α]D²⁰ -20.8 (c 12.5, CHCl₃) [lit.10 [α]D²⁰ -18.7 (c 2.1, CHCl₃)], IR (vmax CHCl₃/cm⁻¹), 3292, 2962, 2870, 1691, 1365, 1258, 1168. ¹H NMR (400 MHz; CDCl₃), δH 0.92-0.97 (6H, 2 x d, J 6.8, CH(CH₃)₂), 1.45 (9H, s, C(CH₃)₃), 1.75-1.80 (1H, m, CH(CH₃)₂), 3.09-3.13 (1H, m, CHNH), 3.31-3.35 (1H, dd, J 4.8, 10.4, CHCHH), 3.40-3.43 (1H, dd, J 3.6, 10.4, CHCHH), 4.53-4.58 (1H, br, CHNH). ¹³C NMR (100 MHz; CDCl₃), δC 12.5 (CH₂), 17.9, 18.3 (CH(CH₃)₂), 27.3 (C(CH₃)₃), 31.3 (CH(CH₃)₂), 54.4 (CHNH), 78.9 (C(CH₃)₃), 159.1 (OCONH). HRMS: Calcd for C₁₀H₂₀INO₂⁺: MH⁺ 314.0613; found: MH⁺ 314.0627. Anal. Calcd for C₁₀H₂₀INO₂: C, 38.35; H, 6.44; N, 4.47%. Found: C, 38.67; H, 6.41; N, 4.73%.

Method B. Iodine (2.75 g, 10.82 mmol) was added to triphenylphosphine (2.84 g, 10.82 mmol) in CH₂Cl₂ (100 mL) and the mixture stirred at 20 °C under nitrogen for 15 min. Imidazole (827 mg, 12.30 mmol) was then added and the mixture stirred for 15 min before S-1-(hydroxymethyl-2-methylpropyl)carbamoyl acid tert-butyl ester 9a (1 g, 4.92 mmol) was added and the mixture heated under reflux for 20 h, then worked up as method A to afford a yellow solid (3.74 g) that was purified by column chromatography eluting with light petroleum : EtOAc (2:1 v/v) to yield the title compound 11a as a yellow solid (471 mg, 31%) whose data were identical to those reported above.

**S-(1-Iodomethyl-2-methylpropyl)carbamoyl acid benzyl ester (11b).** Prepared as in method A for S-(1-iodomethyl-2-methylpropyl)carbamoyl acid tert-butyl ester 11a but using iodine (2.35 g, 8.85 mmol), polystyrene-triphenylphosphine (4.45 g, 8.85 mmol), imidazole (0.72 g, 10.54 mmol) and S-(1-hydroxymethyl-2-methylpropyl)carbamoyl acid benzyl ester 9b (1 g, 4.21 mmol) to afford a yellow solid (1.26 g) that was purified by column chromatography eluting with light petroleum : EtOAc (2:1 v/v) to yield the title compound 11b (1.17 g, 80%) as a light yellow solid, mp 76-77.5 °C, [α]D²⁰ -22.5 (c 10.3, CHCl₃), IR (vmax CHCl₃/cm⁻¹), 3338, 2960, 2872, 1689, 1532, 1239, 1182. ¹H NMR (400 MHz; CDCl₃), δH 0.86-0.91 (6H, 2 x d, J 6.8, CH(CH₃)₂), 1.68-1.77 (1H, m, CH(CH₃)₂), 3.08-3.15 (1H, m, CHNH), 3.26-3.30 (1H, dd, J 5.9, 10.4, CHCH₂), 3.34-3.38 (1H, dd, J 4, 10.4, CHCH₂), 4.72-4.75 (1H, d, J 8.4, CHNH), 5.04 (2H, s, H).
CH2Ph), 7.24-7.31 (5H, m, Ar-H). 13C NMR (100 MHz; CDCl3), δC 12.0 (CH2), 17.3, 18.2 (CH(CH3)2), 31.3 (CH(CH3)2), 55.1 (CHNH), 65.9 (CH2Ph), 127.1, 127.2, 127.5 (Ar-CH), 136.4 (Ar-C), 157.1 (OCONH). HRMS: Calcd for C13H18NO2: MH+ 238.0837; found: MH+ 238.0864.

**S-(2-Methyl-1-nitromethylpropyl)carbamic acid tert-butyl ester (6a).** NaNO2 (490 mg, 7.09 mmol), phloroglucinol (447 mg, 3.55 mmol) and urea (490 mg, 7.09 mmol) were added to S-(1-iodomethyl-2-methylpropyl)carbamic acid tert-butyl ester 11a (1.01 g, 3.22 mmol) in dry DMF under nitrogen, the mixture was stirred at 20 °C for 20 h and washed with water (30 mL), sodium thiosulfate solution (10% w/v, 30 mL), KHCO3 solution (10% w/v, 30 mL) and saturated brine (30 ml). The organic layer was dried (Na2SO4) and concentrated under reduced pressure to afford a yellow solid (998 mg) that was purified by column chromatography eluting with light petroleum : EtOAc (2:1 v/v) to yield the title compound (6a) (487 mg, 64%) as a light yellow solid, mp 84-86.5 °C (lit. 80-83 °C for R-isomer), [α]D20 −24 (c 10, CHCl3) [lit.2a [α]D25 +34.8 (c 1.0, CH2Cl2) for R-isomer], IR (νmax CHCl3/cm−1), 3349, 2979, 1681, 1536, 1369, 1248, 1163. 1H NMR (400 MHz; CDCl3), δH 0.89-0.94 (6H, 2 x d, J 7.2, CH(CH3)2), 1.37 (9H, s, C(CH3)3), 1.78-1.87 (1H, m, CH(CH3)2), 3.87-3.90 (1H, m, CHNH), 4.54-4.57 (2H, m, CHCH2), 4.73-4.76 (1H, br, CHN). 13C NMR (100 MHz; CDCl3), δC 18.5, 19.5 (CH(CH3)2), 28.3 (C(CH3)3), 30.0 (CH(CH3)2), 55.0 (CHNH), 74.5 (CHCH2), 76.9 (C(CH3)3), 155.6 (OCONH). HRMS: Calcd for C16H20N2O4: MH+ 310.1339; found: MH+ 310.1360.

**S-(2-Methyl-1-nitromethylpropyl)carbamic acid benzyl ester (6b).** Prepared as for S-(2-methyl-1-nitromethylpropyl)carbamic acid tert-butyl ester 6a but using NaNO2 (430 mg, 6.24 mmol), phloroglucinol (393 mg, 3.12 mmol), urea (374 mg, 6.24 mmol) and S-(1-iodomethyl-2-methylpropyl)carbamic acid benzyl ester 11b (984 mg, 2.83 mmol) to afford a yellow solid (862 mg) that was purified by column chromatography eluting with light petroleum : EtOAc (2:1 v/v) to yield the title compound (6b) (628 mg, 70%) as a light yellow solid, mp 66 °C, [α]D20 −32.4 (c 10, CHCl3). IR (νmax CHCl3/cm−1), 3324, 2964, 1696, 1554, 1381, 1244. 1H NMR (400 MHz; CDCl3), δH 0.91-0.95 (6H, 2 x d, J 6.8, CH(CH3)2), 1.82-1.87 (1H, m, CH(CH3)2), 3.91-4.00 (1H, m, CHNH), 4.46-4.52 (2H, m, CHCH2), 4.98-5.02 (1H, br, CHN), 5.04 (2H, s, CH2Ph), 7.24-7.32 (5H, m, Ar-H). 13C NMR (100 MHz; CDCl3), δC 19.1, 19.8 (CH(CH3)2), 30.4 (CH(CH3)2), 55.6 (CHNH), 67.6 (CH2Ph), 75.9 (CHCH2), 128.6, 128.7, 129.0 (Ar-CH), 136.4 (Ar-C), 156.2 (OCONH). HRMS: Calcd for C17H20N2O4: MH+ 267.1339; found: MH+ 267.1338.

**(1-Benzensulfonyl-2-methylpropyl)carbamic acid tert-butyl ester (13).** To tert-butyl carbamate (1.32 g, 11.27 mmol) in THF (4 mL) at 20 °C was added benzenesulfinic acid sodium salt (2.03 g, 12.39 mmol) in water (10 mL), followed by 2-methylpropanal (0.89 g, 1.13 mL, 12.39 mmol) and then formic acid (2.5 mL). The mixture was stirred for 17 h and the white precipitate formed (3.68 g) was filtered and recrystallised from 2-methylpentane : EtOAc (4:1 v/v) to yield the title compound (13) (2.64 g, 75%) as a white solid, mp 122.5-123.5 °C, IR (νmax CHCl3/cm−1), 3353, 2974, 1703, 1644, 1367, 1307, 1168, 1142, 1082. 1H NMR (400 MHz; CDCl3), δH 1.00-1.08 (6H, 2 x d, J 6.8, CH(CH3)2), 1.16 (9H, s, C(CH3)3), 2.68-2.76 (1H, m, CH(CH3)2), 4.66-4.69 (1H, dd, J 3.4, 11.2, CHNH), 5.04-5.07 (1H, d, J 11.2, CHNH), 7.48-7.57 (3H, m, Ar-H), 7.82-7.84 (2H, d, J 7.4, Ar-H). 13C NMR (100 MHz; CDCl3), δC 17.3, 21.0
(CH(CH$_3$)$_2$), 27.3 (CH(CH$_3$)$_2$), 28.4 (C(CH$_3$)$_3$), 74.7 (CHNH), 81.2 (C(CH$_3$)$_3$), 129.3, 129.6, 134.1 (Ar-CH), 138.5 (Ar-C), 154.5 (OCNH). HRMS: Calcd for C$_{15}$H$_{23}$NO$_4$S: MH$^+$ 314.1420; found: MH$^+$ 314.1434. Anal. Calcd for C$_{15}$H$_{23}$NO$_4$S: C, 57.48; H, 7.40; N, 4.47, S, 10.23%. Found: C, 57.28; H, 7.69; N, 4.71; S, 9.93%.

**R-(2-Methyl-1-nitromethylpropyl)carbamic acid tert-butyl ester (6c).** N-Benzylquininium chloride (35 mg, 0.08 mmol, 12 mol %) was added to (1-benzenesulfonyl-2-methylpropyl)carbamic acid tert-butyl ester 13 (200 mg, 0.64 mmol) and KOH (186 mg, 3.32 mmol) in toluene (5 mL) at –78 °C under nitrogen. Nitromethane (203 mg, 180 µL, 3.32 mmol) was added dropwise and the mixture allowed to reach 20 °C and stirred for 48 h. The mixture was concentrated under reduced pressure, the residue partitioned between EtOAc (30 mL) and water (30 mL) and the aqueous layer extracted with EtOAc (2 x 30 mL). The combined organic layers were washed with water (30 mL) and saturated brine (30 mL), dried (MgSO$_4$) and concentrated under reduced pressure to yield a yellow oil (151 mg) that was purified by column chromatography eluting with EtOAc : 2-methylpentane (2:3 v/v) to yield the title compound 6c (107 mg, 72%) as a light yellow solid, data identical to those reported above for S-isomer 6a with the exception of an opposite sign of optical rotation, $\alpha$$_{D}$$^20$ +25 (c 10, CHCl$_3$) [lit.$^{12a}$ $\alpha$$_{D}$$^25$ +34.8 (c 1.0, CH$_2$Cl$_2$)].

**S-2-Methyl-1-nitromethylpropylamine hydrochloride (15).** TFA (14.82 g, 9.66 mL, 130.01 mmol) was added to S-(2-methyl-1-nitromethylpropyl)carbamic acid tert-butyl ester 6a (1.51 mg, 6.50 mmol), the mixture was stirred at 20 °C for 4.5 h and then concentrated under reduced pressure. Hydrochloric acid (2M, 65 mL, 130.01 mmol) was added to the residue and the mixture was stirred at 20 °C for 0.5 h and then concentrated under reduced pressure to leave a residue that was dissolved in water (30 mL) and washed with EtOAc (2 x 30 mL). The aqueous phase was evaporated to dryness to yield the title compound 15 (0.99 g, 90%) as a light yellow solid, mp 137-141 °C, $\alpha$$_{D}$$^20$ –11.2 (c 10, MeOH), IR (v$_{max}$ CHCl$_3$/cm$^{-1}$), 3424, 2974, 1558. $^1$H NMR (400 MHz; (CD$_3$)$_2$SO), $\delta$H 0.94-0.98 (6H, 2 x d, J 6.8, CH(C(CH$_3$)$_2$)), 2.00-2.05 (1H, m, CH(CH$_3$)$_2$), 3.67-3.71 (1H, m, CHNH), 4.77-4.79 (1H, dd, J 8, 15.4, CHCH$_2$), 4.96-4.97 (1H, dd, J 3.2, 15.4, CHCHH), 8.48 (3H, br, NH$_3$). $^{13}$C NMR (100 MHz; (CD$_3$)$_2$SO), $\delta$C 17.4, 18.1 (CH(CH$_3$)$_2$), 28.2 (CH(CH$_3$)$_2$), 52.9 (CHNH), 74.3 (CHCH$_2$). HRMS: Calcd for C$_5$H$_{12}$N$_2$O$_2$: MH$^+$ 133.0971; found: MH$^+$ 133.0977.

**N-(S-2-Methyl-1-nitromethylpropyl)-3-oxobutanamide (16).** Et$_3$N (937 mg, 1.29 mL, 9.26 mmol) was added to S-2-methyl-1-nitromethylpropylamine hydrochloride 15 (1.42 g, 8.42 mmol) in CH$_2$Cl$_2$ (20 mL), the mixture stirred at 20 °C for 30 min then concentrated under reduced pressure to afford a residue that was dissolved in toluene (25 mL) and 2,2,6-trimethyl-1,3-dioxin-4-one (1.32 g, 1.21 mL, 9.26 mmol) and PPTS (2.33 g, 9.26 mmol, 1.1 eq) were added. The mixture was heated at reflux under Dean-Stark conditions for 3 h and then concentrated under reduced pressure to leave a residue that was partitioned between water (30 mL) and EtOAc (30 mL) and the aqueous phase was extracted with EtOAc (2 x 30 mL). The combined organic extracts were washed with saturated NaHCO$_3$ solution (30 mL) and saturated brine (30 mL), dried (MgSO$_4$) and concentrated under reduced pressure to afford a brown oil
(2.38 g) that was purified by column chromatography eluting with light petroleum : EtOAc (1:2 v/v) to yield the title compound 16 (1.23 g, 68%) as a brown oil, [α]D20 –36 (c 10, CHCl3), IR (νmax CHCl3/cm−1), 3299, 3073, 2966, 1716, 1556, 1382. 1H NMR (400 MHz; CDCl3), δH 0.99-1.03 (6H, 2 x d, J 7.2, CH(CH3)2), 1.92-1.98 (1H, m, CH(CH3)2), 2.28 (3H, s, CH3CO), 3.42 (2H, s, COCH3), 4.32-4.39 (1H, m, CHNH), 4.52-4.56 (1H, dd, J 4.8, 12.6, CHCHH), 4.56-4.61 (1H, dd, J 6.8, 12.6, CHCHH), 7.44-7.46 (1H, d, J 7.6, CHNH). 13C NMR (100 MHz; CDCl3), δC 18.5, 19.4 (CH(CH3)2), 29.7 (CH(CH3)2), 31.2 (CH3CO), 48.9 (CH2CH2), 53.2 (CHNH), 76.5 (COCH3), 165.6 (CONH), 204.8 (CO). HRMS: Calcd for C9H16N2O4: MH+ 217.1183; found: MH+ 217.1188.

N-(S-2-Methyl-1-nitromethylpropyl)-N’-(tetramethylethlenyl)urea (18). To N-(S-2-methyl-1-nitromethylpropyl)-3-oxobutanamide 16 (48 mg, 0.22 mmol) in toluene (20 mL) was added pyrrolidine (18 mg, 20 µl, 0.24 mmol) dropwise and the mixture heated to reflux under Dean-Stark conditions for 3 h, then cooled and the solvent removed under reduced pressure. The residue was partitioned between water (30 mL) and EtOAc (30 mL), the aqueous phase extracted with EtOAc (2 x 30 mL) and the combined organic layers were dried (MgSO4) and concentrated under reduced pressure to leave a dark brown oil (163 mg) that was purified by column chromatography eluting with light petroleum : EtOAc (1:2 v/v) to yield the title compound 18 (28 mg, 55%) as a brown oil, recrystallised from Et2O–hexane to afford colourless crystals, [α]D20 –6.96 (c 10, CHCl3), IR (νmax CHCl3/cm−1), 3423, 2964, 2872, 1635, 1552. 1H NMR (400 MHz; CDCl3), δH 0.99-1.04 (6H, 2 x d, J 6.8, CH(CH3)2), 1.86-1.94 (5H, m, CH(CH3)2 & 2 x CH2), 3.33-3.36 (4H, m, 2 x NCH2), 4.06-4.13 (1H, m, CHNH), 4.56-4.60 (2H, dd & br, J 4, 12, CHCHH & CHNH), 4.65-4.69 (1H, dd, J 5.6, 12.4, CHCHH). 1H NMR (100 MHz; CDCl3), δC 19.3, 19.6 (CH(CH3)2), 25.5 (CH2), 30.0 (CH(CH3)2), 45.5 (NCH2), 54.5 (CHNH), 76.7 (CH2CH2), 155.8 (NCON). HRMS: Calcd for C10H19N3O5: MH+ 230.1499; found: MH+ 230.1499.

Crystal data for urea (18). C10H19N3O5, M = 229.28, orthorhombic, a = 9.3464(17), b = 14.504(3), c = 18.094(3) Å, U = 2453.0(8) Å3, T = 150(2) K, space group P212121, Mo-Kα radiation, λ = 0.71073 Å, Z = 8, Dc = 1.242 Mg m−3, F(000) = 992, crystal dimensions 0.47 × 0.15 × 0.09 mm, μ(Mo-Kα) = 0.092 mm−1, 3.60 < 2θ < 56.66°, 25509 reflections measured, 3449 unique reflections. Solved by direct methods and refined by full-matrix least-squares on F2.20 The final cycle (for 299 parameters) converged with wR2 = 0.0969 (for all data) and R1 = 0.0393 [F2 > 2σ]. Friedel pairs were merged due to the absence of any significant anomalous scattering. The enantiomer was assigned from an unchanging chiral centre {C(6) & C(15)}.

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15. Crystal data for urea 18 are given in the Experimental Section. Complete crystallographic data (including structure factors) have been deposited at the Cambridge Crystallographic Data Centre, deposition number CCDC 893686. Free copies of the data can be obtained via http://www.ccdc.cam.ac.uk/conts/retrieving.html (or from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge, CB2 1EZ, UK; Fax: +44 1223 336033; e-mail: deposit@ccdc.cam.ac.uk).

Graphical Abstract
A series of chemical reactions involving amino acids and their derivatives, with steps indicated by an arrow.