A Dihydroxylation Based Approach for the Asymmetric Syntheses of Hydroxy-\(\gamma\)-butyrolactones

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Abstract

A method of preparing enantiopure hydroxy-\(\gamma\)-butyrolactones containing multiple contiguous stereocentres in high yield with good diastereoselectivity has been developed. Osmium tetroxide mediated dihydroxylation of a range of \(\beta\)-alkenyl-\(\beta\)-hydroxy-\(N\)-acyloxazolidin-2-ones results in formation of triols that undergo spontaneous intramolecular 5-exo-trig cyclisation reactions to provide hydroxy-\(\gamma\)-butyrolactones. The stereochemistry of these hydroxy-\(\gamma\)-butyrolactones has been established using NOE spectroscopy, which revealed that 1-substituted, 1,1-disubstituted, (\(E\))-1,2-disubstituted, (\(Z\))-1,2-disubstituted, and 1,1,2-trisubstituted alkenes undergo dihydroxylation with anti-diastereoselectivity, whilst 1,2,2-trisubstituted systems afford syn-diastereoisomers. The synthetic utility of this methodology has been demonstrated for the asymmetric synthesis of the natural product 2-deoxy-\(D\)-ribonolactone.
**Introduction**

Enantiomerically pure trisubstituted $\gamma$-butyrolactones are found as fragments in a large number of natural products that display a broad range of biological activities$^1$ and a wide range of methodology has been developed for their asymmetric synthesis.$^2$ Hydroxy-$\gamma$-butyrolactones represent an important subset of this type of natural product$^3$ and they have also been shown to be important chiral building blocks for natural product synthesis.$^4$ For example, Nicolaou et al. have employed a substituted 5-hydroxy-$\gamma$-butyrolactone as an intermediate for the synthesis of the antibiotic abyssomicin C.$^{4c}$ Shioiri et al. also employed a trisubstituted $\gamma$-butyrolactone as a key intermediate for the stereoselective synthesis of the $C_{20}-C_{25}$ subunit of calyculin A.$^{4f}$ Chamberlin et al. used functionalised hydroxy-$\gamma$-butyrolactones as key chiral building blocks for the enantioselective synthesis of the polyketide 9S-dihydroerythronolide A seco acid.$^{4g}$

A number of asymmetric methods exist for the synthesis of highly substituted hydroxy-$\gamma$-butyrolactones,$^5$ with a number of these approaches based upon the diastereoselective reaction of substituted enolates with appropriately substituted electrophiles. For example, Johnson et al. prepared substituted silyl-protected 3-hydroxy-$\gamma$-butyrolactones via double Reformatsky reactions, which involved reaction of a zinc propionate enolate with silyl glyoxylates to afford a new zinc enolate intermediate that then reacts further with an aryl ketone electrophile.$^5d$ Baba et al. have shown that indium enolates of $\alpha$-substituted-$\alpha$-bromo esters undergo diastereoselective Reformatsky reactions with $\alpha$-hydroxy ketones to form 3-hydroxy-$\gamma$-butyrolactones that contain three contiguous stereocentres in good yield and with high diastereoselectivity.$^5i$ Luo and Gong et al. prepared trisubstituted 2-hydroxy-$\gamma$-
butyrolactones by performing enantioselective aldol reactions between ketones and \( \alpha \)-keto acids using a proline derived organocatalyst, with subsequent diastereoselective reduction of the resulting ketone functionality to afford the desired \( \gamma \)-butyrolactones with high levels of diastereocontrol.\(^{5f}\)

Another common method of forming highly substituted hydroxy-\( \gamma \)-butyrolactones is through dihydroxylation of \( \gamma,\delta \)-unsaturated carbonyl systems, with spontaneous intramolecular ring-closure then occurring to afford a \( \gamma \)-butyrolactone skeleton. For example, Woerpel \textit{et al.} carried out osmium tetroxide (OsO\(_4\)) catalysed directed dihydroxylation reactions of \( \alpha \)-hydroxy-\( \gamma,\delta \)-unsaturated acids to afford hydroxy-\( \gamma \)-butyrolactones as single diastereoisomers in good yield.\(^ {5c}\) Brückner \textit{et al.} have used Sharpless asymmetric dihydroxylation reactions of disubstituted\(^ {5m}\) and trisubstituted\(^ {5g}\) \( \beta,\gamma \)-unsaturated esters to prepare substituted 3-hydroxy-\( \gamma \)-butyrolactones in reasonable yield with low to moderate levels of enantiomeric excess (ee). Jenkinson \textit{et al.} prepared synthetically useful and highly functionalised sugar-lactones using directed osmium dihydroxylations of chain extended ribulose and erythrose derivatives.\(^ {5b}\)

We have previously reported that \( \beta \)-alkenyl-\( \beta \)-hydroxy-\( N \)-acyloxazolidin-2-ones (1) undergo efficient epoxidation/lactonisation reactions with catalytic VO(acac)\(_2\) and a stoichiometric equivalent of \textit{tert}-butylhydroperoxide to afford hydroxy-\( \gamma \)-butyrolactones (3) (Scheme 1). It is proposed that an unstable epoxide (2) is generated with high levels of diastereocontrol, which is then ring-opened by intramolecular nucleophilic attack of the exocyclic carbonyl fragment that gives clean inversion of configuration at the \( C_5 \) position. Hydrolysis of the
resulting iminium species affords a highly functionalised hydroxy-\(\gamma\)-butyrolactone skeleton containing multiple contiguous stereocentres.⁶

**Scheme 1.** Epoxidation/lactonisation sequence with inversion of configuration at \(C_5\) to form a hydroxy-\(\gamma\)-butyrolactone 3 containing three contiguous stereocentres.

As this epoxidation/lactonisation sequence leads to inversion of configuration at the \(C_5\) position, it was decided to investigate an osmium catalysed dihydroxylation/lactonisation protocol in order to access complementary diastereoisomers of this type of hydroxy-\(\gamma\)-butyrolactone (Scheme 2). For example, dihydroxylation of the alkene fragment of the generic aldol substrate 1 with *anti*-diastereoselectivity to its \(\beta\)-hydroxyl group would afford a triol (5), which would spontaneously lactonise to afford a diastereomeric hydroxy-\(\gamma\)-butyrolactone.
Therefore, we now report herein a highly diastereoselective dihydroxylation based approach for the synthesis of functionalised hydroxy-γ-butyrolactones containing multiple contiguous stereocentres, where the major diastereoisomer of the lactone produced is controlled by the alkene substitution pattern.

**Results and Discussion**

The configuration of hydroxy-γ-butyrolactone 3, formed from the epoxidation/lactonisation reaction of aldol 1a had previously been unequivocally assigned as (3S,4S,5S) using X-ray crystallographic analysis. Consequently, it was decided to investigate the corresponding dihydroxylation/lactonisation reaction of aldol 1a to confirm that a different diastereoisomer of hydroxy-γ-butyrolactone would be produced. Therefore, unsaturated aldol 1a was treated under standard Upjohn conditions with 10 mol% OsO₄ and N-methylmorpholine-N-oxide (NMO) in acetone:H₂O (8:1) at room temperature to produce a new hydroxy-γ-butyrolactone 6a in 69% yield and in >49:1 dr (Scheme 3a). ¹H NOE spectroscopic analysis of 6a showed a strong interaction between the C₃ proton and the methylene protons of the C₅ ethyl group, as well as a strong interaction between the C₄ proton and the C₅ CH₂OH methylene protons (Scheme 3b), indicating a (3S,4S,5R) configuration. This assignment is consistent with the
expected suprafacial dihydroxylation of unsaturated aldol 1a with anti-diastereoselectivity with respect to its β-hydroxyl group. Thus, whilst our previously reported epoxidation/lactonisation sequence produces (3S,4S,5S)-hydroxy-γ-butyrolactone 3, this dihydroxylation/lactonisation sequence provides its complementary C₅ diastereoisomer (6a) in high dr.

Scheme 3. a) Dihydroxylation/lactonisation of unsaturated aldol 1a to form hydroxy-γ-butyrolactone 6a. b) Strong ¹H NOE interactions in γ-butyrolactone 6a confirm a (3S,4S,5R) configuration.

To further investigate the scope and effect of the alkene substitution pattern on the stereochemical outcome of this dihydroxylation/lactonisation protocol, a series of syn-aldols (1b-j) was prepared in good yield and high dr by reaction of the boron enolate of 5,5-dimethyl-N-propionyl-oxazolidin-2-one (7a) with the corresponding α,β-unsaturated aldehydes (Scheme 4). These syn-aldols (1b-j) were then treated with 10 mol% OsO₄ and NMO in acetone:H₂O (8:1) at room temperature to afford a series of hydroxy-γ-butyrolactones (6b-j) in good yield and generally high diastereoselectivity (Table 1, entries 1-9).
Reaction of 1,1-disubstituted aldol 1b, which contains a terminal O-benzyl substituent, with 10 mol% OsO₄ and NMO proceeded with good levels of anti-diastereoselectivity to form hydroxy-γ-butyrolactone 6b in high yield (Table 1, entry 1). The stereochemistry of hydroxy-γ-butyrolactone 6b was unequivocally assigned as (3S,4S,5R) via X-ray crystallographic analysis (see supporting information). The terminal O-benzyl fragment of this type of lactone makes it particularly useful as a bifunctional synthetic building block for the synthesis of polyketide inspired synthetic targets. The stereochemistry of the remaining lactones (6) was determined by ¹H NOE spectroscopic analysis as well as by comparison with literature precedent for each of the different substitution patterns (see below).
Table 1. Dihydroxylation of aldols 1b-k to afford hydroxy-γ-butyrolactones 6b-k.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Aldol (1b-k)</th>
<th>Triol (5b-k) (not isolated)</th>
<th>Lactone (6b-k)</th>
<th>dr</th>
<th>Yield (%)</th>
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<tr>
<td>1</td>
<td>1b</td>
<td>OHOHOBn</td>
<td>OHOBn</td>
<td>10:1</td>
<td>93</td>
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<td></td>
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<td>2</td>
<td>1c</td>
<td>OHOHOBn</td>
<td>OHOBn</td>
<td>3:1</td>
<td>79</td>
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<td></td>
<td></td>
<td>53%, &gt;95% de</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>1d</td>
<td>OHOHBn</td>
<td>OHOBn</td>
<td>9:1</td>
<td>81</td>
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<td></td>
<td>78%, &gt;95% de</td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>4</td>
<td>1e</td>
<td>OHOHOBn</td>
<td>OHOBn</td>
<td>5:1</td>
<td>83</td>
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<td></td>
<td></td>
<td>91%, &gt;95% de</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1f</td>
<td>OHOHOBn</td>
<td>OHOBn</td>
<td>4:1</td>
<td>77</td>
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<td>89%, &gt;95% de</td>
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<tr>
<td>6</td>
<td>1g</td>
<td>OHOHOBn</td>
<td>OHOBn</td>
<td>2:1</td>
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<td>88%, &gt;95% de</td>
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<td>7</td>
<td>1h</td>
<td>OHOHOBn</td>
<td>OHOBn</td>
<td>&gt;49:1</td>
<td>82</td>
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<td>82%, &gt;95% de</td>
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<tr>
<td>8</td>
<td>1i</td>
<td>OHOHOBn</td>
<td>OHOBn</td>
<td>&gt;49:1</td>
<td>93</td>
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<tr>
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<td></td>
<td>75%, &gt;95% de</td>
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*a*Major diastereoisomer formed. *b*Configuration of hydroxyl-γ-butyrolactones confirmed by 1H NOE spectroscopic analysis. *c*Determined by analysis of the crude 1H NMR spectra. *d*Yields after purification by column chromatography.
The dihydroxylation/lactonisation reaction of acrolein aldol 1c was less diastereoselective, giving a 3:1 mixture of diastereoisomers, with the major diastereoisomer (6c) being formed from dihydroxylation with anti-diastereoocontrol in 79% yield (Table 1, entry 2). It was found that (E)-1,2-disubstituted aldols derived from cinnamaldehyde and crotonaldehyde (1d and 1e respectively) underwent dihydroxylation with greater levels of anti-diastereoselectivity to give hydroxy-γ-butyrolactones 6d (9:1 dr) and 6e (5:1 dr) in good yields (Table 1, entries 3 and 4). Pleasingly, the (E)-1,2-disubstituted aldol 1f containing an O-benzyl group also underwent dihydroxylation/lactonisation under standard Upjohn conditions to form the hydroxy-γ-butyrolactone 6f in 77% yield with 4:1 diastereoselectivity (Table 1, entry 5). The related (Z)-1,2-disubstituted O-benzyl aldol 1g was found to undergo dihydroxylation with poor levels of anti-diastereoselectivity (2:1 dr), with the corresponding hydroxy-γ-butyrolactone 6g being formed with the opposite C₆ configuration to that observed for (E)-1,2-disubstituted aldol 1f (Table 1, entry 6). Reaction of (E)-1,1,2-trisubstituted aldol 1h under standard dihydroxylation/lactonisation conditions proceeded with excellent levels of anti-diastereoselectivity to afford hydroxy-γ-butyrolactone 6h in 82% yield as a single diastereoisomer (Table 1, entry 7). The related O-benzyl (E)-1,1,2-trisubstituted aldol 1i also underwent dihydroxylation/lactonisation with similar levels of high anti-diastereoselectivity, providing the synthetically useful O-benzyl-γ-butyrolactone 6i in 93% yield as a single diastereoisomer (Table 1, entry 8). However, the reaction of 1,2,2-trisubstituted aldol 1j derived from 3-methyl-2-butenal proceeded with reduced diastereoselectivity, with the major hydroxy-γ-butyrolactone 6j diastereoisomer having the opposite configuration at C₅ to that observed for the previous examples. Therefore, it follows that the 1,2,2-trisubstituted aldol 1j must preferentially undergo dihydroxylation syn to its β-hydroxyl group (5:1 dr) before lactonisation to afford (3S,4S,5R)-hydroxy-γ-butyrolactone 6j in 41% yield (Table 1, entry 9). We then decided to investigate the effect of varying the α-substituent of the unsaturated aldol
on the dihydroxylation/lactonisation reaction. The α-phenyl 1,1-disubstituted aldol 1k was prepared using our standard boron aldol protocol and subjected to the standard dihydroxylation/lactonisation conditions. It was found that α-phenyl aldol 1k underwent dihydroxylation with good levels of anti-diastereoselectivity (9:1 dr), allowing the corresponding hydroxy-γ-butyrolactone 6k to be isolated in 75% yield (Table 1, entry 10).

Whilst the vast majority of alkene substitution patterns gave high levels of diastereoselectivity for our dihydroxylation/lactonisation sequence, the (Z)-1,2-disubstituted aldol 1g gave a 2:1 mixture of lactone diastereoisomers. In an attempt to improve the diastereoselectivity, (Z)-1,2-disubstituted aldol 1g was reacted under Sharpless asymmetric dihydroxylation conditions using both AD-mix-α and AD-mix-β (Scheme 5a and b).10 Remarkably, the ‘mismatched’ reaction of (Z)-1,2-disubstituted aldol 1g with AD-mix-α resulted in dihydroxylation/lactonisation with reversal of diastereoselectivity compared with the reaction using the standard Upjohn conditions. The hydroxy-γ-butyrolactones (6g and 8) were obtained in 95% yield as a 4:1 mixture of diastereoisomers, with the major lactone (8) being formed as the result of dihydroxylation with syn-diastereoselectivity with respect to the β-hydroxyl group of 1g (Scheme 5a). This facial selectivity is consistent with that observed previously by Sharpless et al. for reaction of a simplified (Z)-O-benzyl allylic alcohol with AD-mix-α.11 Pleasingly, the use of AD-mix-β resulted in ‘matched’ enhancement of the diastereoselectivity observed for dihydroxylation under Upjohn conditions, affording the hydroxy-γ-butyrolactones (6g and 8) in 95% yield as a 17:1 mixture of diastereoisomers (Scheme 5b). In this case the major diastereoisomer (6g) obtained is the result of dihydroxylation with anti-diastereoselectivity relative to the β-hydroxyl group of 1g, which is
again consistent with the results obtained by Sharpless et al. using AD-mix-β on related substrates.

Scheme 5. Effect of using Sharpless asymmetric dihydroxylation conditions.

Finally, in order to demonstrate the synthetic utility of our dihydroxylation/lactonisation protocol we decided to apply it to the synthesis of 2-deoxy-D-ribonolactone (11), which is a byproduct of oxidatively damaged DNA. 2-Deoxy-D-ribonolactone (11) has also been shown to be a useful synthetic precursor, whilst its nucleoside derivatives are of structural interest because they can potentially act as universal bases and non-hydrogen bonding isosteres of nucleobases for chemical biology applications. Therefore, the boron enolate of α-chloropropionyl-N-acyl-oxaolidin-2-one 7c was reacted with acrolein to afford syn-aldol 9 in a 45% yield and in >95% de. Treatment of the α-chloro-β-vinyl-aldol 9 with zinc dust and ammonium chloride in methanol resulted in dechlorination, providing the desired allylic alcohol 10 in 82% yield. The dechlorinated alcohol 10 was then subjected to the standard Upjohn dihydroxylation/lactonisation conditions, to afford 2-deoxy-D-ribonolactone (11) as a 9:1 mixture of diastereoisomers in 87% yield (Scheme 6), whose spectroscopic data was consistent with that reported previously.
Scheme 6. Asymmetric synthesis of 2-deoxy-D-ribonolactone (11).

Assignment of Stereochemistry

There are many literature examples of directed dihydroxylation reactions of allylic alcohols, with selected examples of dihydroxylations of allylic alcohols with various substitution patterns shown in Scheme 7. Several stereochemical models have been proposed to rationalise the observed diastereoselectivity in dihydroxylation reactions of allylic alcohols, most notably the models described by Kishi, Houk and Vedejs.
Scheme 7. Literature examples of dihydroxylation reactions of allylic alcohols with different alkene substitution patterns.

The configuration of each of the hydroxyl-$\gamma$-butyrolactone (6a-k) prepared in this study has been determined by $^1$H NOE spectroscopic analysis (Figure 1) and the conclusions compared with the literature precedent for dihydroxylation of each of the alkene substitution patterns shown in Scheme 7. The results from dihydroxylation/lactonisation of 1,1-disubstituted (1a and 1b), 1-substituted (1c), and (E)-1,2-disubstituted allylic alcohols (1d-f) are consistent with the anti-diastereoselectivity observed in catalytic osmylation reactions of related
substrates with the same alkene substitution patterns (Scheme 7a-c). The $^1$H NOE spectrum of the $O$-benzyl hydroxy-$\gamma$-butyrolactone 6b, derived from dihydroxylation/lactonisation of 1,1-disubstituted aldol 1b, shows a strong interaction between the $C_3$ proton and the $C_5$ methylene protons of the $O$-benzyl substituent that confirms the configuration of the $C_5$ stereocentre (Figure 1b). The $^1$H NOE spectra of the hydroxy-$\gamma$-butyrolactones 6c-f also show strong interaction between the $C_3$ proton and the $C_5$ proton, confirming that these protons lie on the same face of the lactone ring (Figure 1c-f).

The modest levels of anti-diastereoselectivity (2:1) observed for the reaction of (Z)-1,2-disubstituted aldol 1g are in contrast with the observations of Donohoe et al., who found that simple (Z)-1,2-disubstituted allylic alcohols gave low levels (2:1) of syn-diastereoselectivity when dihydroxylation was carried out under Upjohn conditions (Scheme 7d).$^{23b}$ In our case, the configuration of the $C_5$ stereocentre of the major diastereoisomer of hydroxy-$\gamma$-butyrolactone 6g was confirmed by analysis of the $^1$H NOE spectrum, which showed a strong interaction between the $C_3$ proton and the $C_5$ proton (Figure 1g). However, the low levels of diastereoselectivity observed in both cases suggest that the directing effect of the allylic alcohol in (Z)-1,2-disubstituted systems is limited, therefore it is unsurprising that different substrates result in different diastereoisomers being formed with poor dr.

The high levels of anti-diastereoselectivity observed for the (E)-1,1,2-trisubstituted aldols (1h and 1i) were consistent with the results of Fronza et al. who found that an acetonide protected allylic alcohol gave dihydroxylation with anti-diastereoselectivity when reacted under Sharpless conditions in the absence of a chiral ligand (Scheme 7e).$^{24}$ The configuration of the hydroxy-$\gamma$-butyrolactones (6h and 6i) was confirmed by analysis of the $^1$H NOE
spectra, which showed strong interactions between the proton on C$_3$ and the C$_5$ methyl protons as well as strong interactions between the C$_3$ methyl group and the C$_5$ CHOH proton in both cases (Figure 1h and 2i).

The dihydroxylation/lactonisation of 1,2,2-trisubstituted aldol 1j proceeded with syn-diastereoselectivity, which is consistent with the syn-diastereoselectivity previously observed by Donohoe et. al. for dihydroxylation of 1,2,2-trisubstituted allylic alcohols (Scheme 7f).$^{23b}$ The 5R stereochemistry of the major diastereoisomer of hydroxy-\(\gamma\)-butyrolactone 6j was confirmed by a strong interaction in the $^1$H NOE spectra between the methyl protons on C$_3$ and the C$_5$ proton (Figure 1j), whilst a vicinal coupling constant between the protons on C$_4$ and C$_5$ of $^3J = 7.4$ Hz is indicative of a syn-relationship between these protons.$^{25}$

The $\alpha$-substituent of the aldol product was shown not to affect the stereochemical outcome of the dihydroxylation reaction unduly, with $\alpha$-phenyl 1,1-disubstituted aldol 1k undergoing dihydroxylation with the expected anti-diastereoselectivity (Scheme 7a) to afford hydroxy-\(\gamma\)-butyrolactone 6k, which exhibited the same characteristic interactions in its $^1$H NOE spectrum as the previous examples (Figure 1k).
Figure 1. Strong interactions in the $^1$H NOE spectra of the hydroxyl-$\gamma$-butyrolactones (6a-k).

Of particular relevance to the results described is the previous report of Dias et al., who reported the dihydroxylation/lactonisation of a small series of closely related Evans derived $\beta$-alkenyl-$O$-silyl aldol products (14a-d). Surprisingly, the configuration of the resulting $O$-silyl-$\gamma$-butyrolactones (16a-d) was reported as (3S,4S,5S), which was different to the results we had obtained, with lactones 16b and 16d reported to have arisen from an unprecedented antarafacial dihydroxylation reaction occurring with syn-diastereoselectivity to the $\beta$-$O$-silyl hydroxyl group (Scheme 9).$^{5h,26}$ Therefore, in order to investigate the effect of the $O$-silyl group on these dihydroxylation/lactonisation reactions, unsaturated aldol 1a was $O$-TBS protected using TBS-OTf and 2,6-lutidine and subjected to the standard Upjohn dihydroxylation/lactonisation conditions, which gave $O$-TBS $\gamma$-butyrolactone 13 in a 3:1 dr.
This mixture was then deprotected using TBAF to give hydroxy-γ-butyrolactone 6a in 65% yield and 3:1 dr (Scheme 8), whose $^1$H, $^{13}$C($^1$H), and NOE spectra were identical to those of the lactone we had previously formed from dihydroxylation/lactonisation of the unprotected aldol 1a.

Scheme 8. Dihydroxylation/lactonisation of unprotected aldol 1a and O-TBS aldol 12 afford the same major diastereoisomer of hydroxy-γ-butyrolactone (6a).

In light of this result, we propose that both the free hydroxyl and O-silyl protected unsaturated aldol derivatives of 1a undergo dihydroxylation with anti-diastereoselectivity to the stereodirecting group. We therefore suggest that the stereochemical assignments of the O-silyl-γ-butyrolactones (16a-d) previously reported by Dias et al.$^5h$ are incorrect and propose that the configuration of these lactones be reassigned as shown in Scheme 9.
Scheme 9. a) Dias et al.’s dihydroxylation/lactonisation of O-TBS protected unsaturated aldols (14a-d). b) Proposed reassignment of configuration of the reported O-silyl-γ-butyrolactones (17a-d).

Conclusions

We have developed a method of preparing enantiomerically pure hydroxy-γ-butyrolactones (6a-k) containing multiple contiguous stereocentres through directed dihydroxylation/lactonisation reactions of β-alkenyl-β-hydroxy-N-acyloxazolidin-2-ones (1a-k). The configurations of the resulting hydroxy-γ-butyrolactones (6a-k) have been confirmed by ¹H NOE spectroscopic analysis, which revealed that the diastereoselectivity of these directed dihydroxylation reactions is dependent on the alkene substitution pattern. It was found that 1-substituted, 1,1-disubstituted, (E)-1,2-disubstituted, (Z)-1,2-disubstituted, and
1,1,2-trisubstituted alkenes undergo dihydroxylation with \textit{anti}-diastereoselectivity to their \( \beta \)-hydroxyl groups, whereas a 1,2,2-trisubstituted alkene gave the \textit{syn}-diastereoisomer. The poor levels of diastereoselectivity observed for the dihydroxylation/lactonisation of the (Z)-1,2-disubstituted aldol (1g) could be improved using Sharpless’ asymmetric dihydroxylation conditions, with the ‘matched’ and ‘mismatched’ diastereoisomers being formed dependent on the enantiomer of ligand used. The synthetic utility of this directed dihydroxylation/lactonisation methodology has been demonstrated with a short synthesis of 2-deoxy-D-ribonolactone (11).

**Experimental**

**General:** All reactions were performed using starting materials and solvents obtained from commercial sources without further purification using dry solvents under an atmosphere of nitrogen. \(^1\)H NMR spectra were recorded at 250, 300, 400 and 500 MHz and \(^{13}\)C\(^{1}\)H\) NMR spectra were recorded at 75 MHz. Chemical shifts \( \delta \) are quoted in parts per million and are referenced to the residual solvent peak. NMR peak assignments were confirmed using 2D \(^1\)H COSY where necessary. Chemical shift is reported in parts per million (ppm) and all coupling constants, \( J \), are reported in Hertz (Hz). Infra-red spectra were recorded as thin films or were recorded with internal background calibration in the range 600-4000 cm\(^{-1}\), using thin films on NaCl plates (film), or KBr discs (KBr) as stated. High resolution mass spectra were recorded in either positive or negative mode using electrospray (ES) ionisation. Optical rotations were recorded with a path length of 1 dm; concentrations \((c)\) are quoted in g/100 mL.

**General Procedure for the Acylation of (S)-4-Benzyl-5,5-dimethyl oxazolidin-2-one:** \( n \)-BuLi (1.1 equiv., 2.5 M solution in hexane) was added to a solution of (S)-4-benzyl-5,5-
dimethyloxazolidin-2-one (1 equiv.) in dry THF at -78°C under nitrogen and was stirred for 30 minutes. The appropriate acid chloride (1.1 equiv.) was added in one portion and the resulting solution was stirred for a further two hours. The reaction was quenched with saturated ammonium chloride and allowed to warm to ambient temperature. The THF was evaporated under reduced pressure, the resulting oil was redissolved in dichloromethane and extracted with brine. The combined organic extracts were dried over MgSO₄ and concentrated to afford the crude product.

(S)-4-Benzyl-5,5-dimethyl-3-propionyloxazolidin-2-one, 7a: The title compound was prepared according to the general procedure from n-BuLi (6.43 mL, 16.1 mmol, 2.5 M solution in hexane), (S)-4-benzyl-5,5-dimethyloxazolidin-2-one (3.00 g, 14.6 mmol) and propionyl chloride (1.40 mL, 16.1 mmol) in THF (90 mL). The crude product was purified by recrystallisation from diethyl ether and hexane to afford (S)-4-benzyl-5,5-dimethyl-3-propionyloxazolidin-2-one 7a (3.52 g, 13.4 mmol, 92%) as a white solid. ¹H NMR (300 MHz, CDCl₃): δH 7.31-7.17 (5H, m, Ph), 4.48 (1H, dd, J = 9.6, 3.9 Hz, CHN), 3.12 (1H, dd, J = 14.3, 3.9 Hz, CHH₆Ph), 2.94-2.81 (3H, m, CH₃H₆Ph, COCH₂), 1.34 (3H, s, C(CH₃)(CH₃)), 1.33 (3H, s, C(CH₃)(CH₃)), 1.12 (3H, t, J = 7.33 Hz, CH₂CH₃); ¹³C{¹H} NMR (75 MHz, CDCl₃): δC 174.4, 152.8, 137.1, 129.2, 128.8, 126.9, 82.3, 63.6, 35.5, 29.5, 28.7, 22.4, 8.5; IR cm⁻¹ ν = 1766 (C=Oₓ), 1703 (C=O); HRMS: m/z (ES) 262.1446, C₁₅H₂₀N₂O₃ [M+H]⁺ requires 262.1443; [α]D²¹ = -42.0 (c = 0.50 g/100 mL in CHCl₃).

(S)-4-Benzyl-5,5-dimethyl-3-(2-phenylacetyl)oxazolidin-2-one, 7b: The title compound was prepared according to the general procedure from n-BuLi (1.71 mL, 4.3 mmol, 2.5 M solution in hexane), (S)-4-benzyl-5,5-dimethyloxazolidin-2-one (0.80 g, 3.9 mmol) and phenylacetyl chloride (0.56 mL, 4.3 mmol) in THF (30 mL). The crude product was purified using flash silica chromatography [CH₂Cl₂, Rf 0.61] to afford (S)-4-benzyl-5,5-dimethyl-3-(2-
phenylacetyl)oxazolidin-2-one 7b (0.96 g, 3.0 mmol, 76%) as a colourless oil, which solidified on standing. $^1$H NMR (300 MHz, CDCl$_3$): $\delta$H 7.33-7.15 (10H, m, Ph$_{ox}$, Ph), 4.46 (1H, dd, $J$ = 9.6, 3.8 Hz, CHN), 4.25 (2H, s, COCH$_2$Ph), 3.11 (1H, dd, $J$ = 14.4, 3.8 Hz, CH$_A$H$_B$Ph), 2.82 (1H, dd, $J$ = 14.4, 9.6 Hz, CH$_A$H$_B$Ph), 1.34 (3H, s, C(CH$_3$)(CH$_3$)), 1.29 (3H, s, C(CH$_3$)(CH$_3$)); $^{13}$C{$^1$H} NMR (75 MHz, CDCl$_3$): $\delta$C 171.6, 152.7, 137.0, 133.8, 129.8, 129.2, 128.8, 128.7, 127.3, 126.9, 82.5, 63.9, 41.9, 35.3, 28.7, 22.4; IR cm$^{-1}$ $\nu$ = 1765 (C=O$_{ox}$), 1712 (C=O); HRMS: m/z (ES) 324.1605, C$_{20}$H$_{22}$NO$_3$ [M+H]$^+$ requires 324.1599; $[\alpha]_{D}^{21}$ = -36.0 ($c$ = 0.50 g/100 mL in CHCl$_3$).

Non-Commercially Available Aldehydes

$(E)$-4-(Benzyloxy)but-2-enal: Based on a literature procedure,$^{27}$ oxalyl chloride (0.26 mL, 3.1 mmol) was dissolved in dry dichloromethane (10 mL) at -55 °C under nitrogen. Dimethylsulphoxide (0.39 mL, 5.6 mmol) was added and the resulting solution was stirred for two minutes. (Z)-4-(Benzyloxy)but-2-en-1-ol (0.50 g, 2.8 mmol) in dichloromethane (1 mL) was added dropwise to the solution to form a light yellow cloudy mixture, which was stirred for 15 minutes at -55 °C. Triethylamine (1.96 mL, 14.0 mmol) was then added and the resulting solution was stirred for a further 15 minutes at -55 °C. The thick white slurry was warmed to room temperature and was quenched with the addition of water (10 mL). The layers were separated and the aqueous layer was extracted three times with dichloromethane (20 mL). The combined organic layers were washed with 1 M HCl (10 mL) and saturated NaHCO$_3$ before being dried over MgSO$_4$ and concentrated. The crude product was purified using flash silica chromatography [1:8 EtOAc:Petroleum ether, $R_f$ 0.25] to predominantly afford the cis alkene (0.42 g, 2.4 mmol, 84%) as a colourless liquid. The pure material was dissolved in dichloromethane (1 mL) with a catalytic amount of p-TSA and left at room temperature overnight to isomerise to the trans isomer $(E)$-4-(benzyloxy)but-2-enal in a 99:1
ratio. $^1$H NMR (300 MHz, CDCl$_3$): $\delta$H 9.58 (1H, d, $J = 7.9$ Hz, CHO), 7.39-7.28 (5H, m, Ph), 6.85 (1H, dt, $J = 15.8$, 4.1 Hz, CH=CHCHO), 6.41 (1H, ddt, $J = 15.8$, 7.9, 1.9 Hz, CHCHO), 4.60 (2H, s, OCH$_2$Ph), 4.29 (2H, dd, $J = 4.1$, 1.9 Hz, CH$_2$OBn); $^{13}$C{$_1$H} NMR (75 MHz, CDCl$_3$): $\delta$C 193.4, 153.2, 137.5, 131.9, 128.6, 128.1, 127.8, 73.1, 68.7; IR cm$^{-1}$ $\nu = 1682$ (C=O); HRMS: $m/z$ (ES) 199.0737, C$_{11}$H$_{12}$NaO$_2$ [M+Na]$^+$ requires 199.0734.

4-(Benzyloxy)butanal: Oxalyl chloride (1.03 mL, 12.2 mmol) was dissolved in dry dichloromethane (50 mL) at -55 °C under nitrogen. Dimethylsulphoxide (1.58 mL, 22.2 mmol) was added and the resulting solution was stirred for 2 minutes. 4-(Benzyloxy)butan-1-ol (2.00 g, 11.1 mmol) in dichloromethane (5 mL) was added dropwise to the solution to form a light yellow cloudy mixture, which was stirred for 15 minutes at -55 °C. Triethylamine (7.73 mL, 55.5 mmol) was then added and the resulting solution was stirred for a further 15 minutes at -55 °C. The thick white slurry was warmed to room temperature and was quenched with the addition of water (50 mL). The layers were separated and the aqueous layer was extracted three times with dichloromethane (50 mL). The combined organic layers were washed with 1 M HCl (10 mL) and saturated NaHCO$_3$ before being dried over MgSO$_4$ and concentrated. The crude product was purified using flash silica chromatography [1:9 EtOAc:Petroleum ether, R$_f$ 0.63] to afford 4-(benzylxy)butanal (1.48 g, 8.3 mmol, 75%) as a colourless liquid. $^1$H NMR (300 MHz, CDCl$_3$): $\delta$H 9.68 (1H, s, CHO), 7.30-7.18 (5H, m, Ph), 4.41 (2H, s, OCH$_2$Ph), 3.43 (2H, t, $J = 6.1$ Hz, CH$_2$OBn), 2.45 (2H, t, $J = 7.1$ Hz, CHOCH$_2$), 1.87 (2H, app. quintet, $J = 6.6$ Hz, CH$_2$CH$_2$CH$_2$OBn); $^{13}$C{$_1$H} NMR (75 MHz, CDCl$_3$): $\delta$C 202.1, 138.3, 128.3, 127.5, 72.8, 69.0, 40.8, 22.5; IR cm$^{-1}$ $\nu = 1721$ (C=O); HRMS: $m/z$ (ES) 201.0894, C$_{11}$H$_{14}$NaO$_2$, [M+Na]$^+$ requires 201.0891.

4-(Benzyloxy)-2-methylenebutanal: 4-(Benzyloxy)butanal (0.50 g, 2.8 mmol) was dissolved in 37% aqueous formaldehyde solution (0.27 mL, 3.7 mmol). Dimethyamine hydrochloride (0.30 g, 3.7 mmol) was added and the mixture was heated at 70 °C for 24
hours. The reaction was cooled to room temperature, quenched with saturated NaHCO₃, extracted into hexane and the combined organic fractions were washed with water, dried over MgSO₄ and concentrated. The crude product was purified using flash silica chromatography [1:9 EtOAc:Petroleum ether, Rₜ 0.31] to afford 4-(benzyloxy)-2-methylenebutanal (0.41 g, 2.2 mmol, 78%) as a colourless liquid. ¹H NMR (300 MHz, CDCl₃): δH 9.46 (1H, s, CHO), 7.30-7.19 (5H, m, Ph), 6.31 (1H, s, C=CHₐHₜ), 6.00 (1H, s, C=CHₐHₜ), 4.43 (2H, s, OCH₂Ph), 3.53 (2H, t, J = 6.4 Hz, CH₂OBn), 2.51 (2H, t, J = 6.4 Hz, CH₂=CCH₂); ¹³C{¹H} NMR (75 MHz, CDCl₃): δC 194.4, 146.9, 138.2, 135.7, 128.4, 127.6, 127.5, 72.8, 67.9, 28.2; IR cm⁻¹ ν = 1686 (C=O); HRMS: m/z (ES) 213.0912, C₁₂H₁₄NaO₂, [M+Na]⁺ requires 213.0886.

**General Procedure for the Synthesis of β-Alkenyl-β-hydroxy-N-acyloxazolidin-2-ones:**

Acylated (S)-4-benzyl-5,5-dimethyloxazolidin-2-one 7a or 7b (1 equiv.) was dissolved in dry dichloromethane at 0 °C under nitrogen and was stirred for 30 minutes. 9-Borabicyclo[3.3.1]nonyl trifluoromethanesulfonate (9-BBN-OTf) (1.1 equiv., 0.5 M solution in hexanes) or dibutylboron triflate (1.1 equiv., 1.0 M in dichloromethane) was added dropwise. After 30 minutes, N,N-diisopropylethylamine (1.3 equiv.) was added and the resulting solution was stirred for 30 minutes before the reaction was cooled to -78 °C. The appropriate aldehyde (1.3 equiv.) was added in one portion and the reaction was allowed to warm to ambient temperature overnight. The reaction was quenched with pH 7 buffer solution (Na₂PO₄/NaH₂PO₄) (10 mL) and was stirred for ten minutes. Hydrogen peroxide (4 mL) and methanol (8 mL) were then added and the solution was stirred for a further two hours. The methanol was evaporated, the solution diluted with dichloromethane and washed with saturated NaHCO₃ and brine. The combined organic extracts were dried over MgSO₄ and concentrated to afford crude product.
(S)-4-Benzyl-3-((2S,3S)-3-hydroxy-2-methyl-4-methylenehexanoyl)-5,5-dimethyloxazolidin-2-one, 1a: The title compound was prepared according to the general procedure from 9-BBN-OTf (9.46 mL, 4.7 mmol), (S)-4-benzyl-5,5-dimethyl-3-propionyloxazolidin-2-one 7a (1.08 g, 4.3 mmol), N,N-diisopropylethylamine (0.94 mL, 5.4 mmol) and ethacrolein (0.45 g, 5.4 mmol) in dichloromethane (90 mL) to afford a crude product as a pale yellow oil. The crude product was purified using flash silica chromatography to afford (S)-4-benzyl-3-((2S,3S)-3-hydroxy-2-methyl-4-methylenehexanoyl)-5,5-dimethyloxazolidin-2-one 1a (1.19 g, 3.4 mmol, 80%) as a colourless oil. 

\[ \text{1H NMR (300 MHz, CDCl}_3 \]: } \delta_H 7.34-7.20 (5H, m, Ph), 5.16 (1H, app. t, \( J = 1.0 \) Hz, \( CH_{cis}H_{trans}=C \)), 4.98 (1H, app. t, \( J = 1.0 \) Hz, \( CH_{cis}H_{trans}=C \)), 4.53 (1H, dd, \( J = 9.0, 4.0 \) Hz, \( CHN \)), 4.40 (1H, d, \( J = 3.5 \) Hz, \( CHOH \)), 3.96 (1H, qd, \( J = 7.0, 3.5 \) Hz, \( CH \)), 3.84 (1H, qd, \( J = 7.0, 3.5 \) Hz, \( CH \)), 3.08 (1H, dd, \( J = 14.0, 4.0 \) Hz, \( CH_AH_BPh \)), 2.91 (1H, dd, \( J = 14.0, 9.5 \) Hz, \( CH_AH_BPh \)), 2.91 (1H, br. s, \( OH \)), 2.02 (2H, m, \( CH_2CH_3 \)), 1.40 (3H, s, (\( CH_3 \)C(CH_3))), 1.38 (3H, s, (\( CH_3 \)C(CH_3))), 1.11 (3H, d, \( J = 7.0 \) Hz, \( CHJCH \)), 1.07 (3H, t, \( J = 7.0 \) Hz, \( CHJCH \)); 

\[ \text{13C\{1H} \] NMR (75 MHz, CDCl_3): \delta_C 177.5, 152.6, 150.3, 137.0, 129.5, 129.1, 127.3, 109.9, 82.7, 74.1, 63.8, 41.1, 35.8, 28.8, 25.7, 22.6, 12.5, 11.1; IR cm\(^{-1}\) \( v = 3497 \) (br. OH), 1773 (C=O\text{ox}), 1700 (C=O); HRMS: m/z (ES) 346.2014, C_{20}H_{28}NO_4 [M+H]^+ requires 346.2013; 

\[ [\alpha]_D^{21} = -36.0 \] (c = 1.00 g/100 mL in CHCl_3).

(S)-4-Benzyl-3-((2S,3S)-6-(benzhyloxy)-3-hydroxy-2-methyl-4-methylenehexanoyl)-5,5-dimethyloxazolidin-2-one, 1b: The title compound was prepared according to the general procedure from dibutylboron triflate (1.78 mL, 1.8 mmol), (S)-4-benzyl-5,5-dimethyl-3-propionyloxazolidin-2-one 7a (0.423 g, 1.6 mmol), N,N-diisopropylethylamine (0.36 mL, 2.1 mmol) and 4-(benzhyloxy)-2-methylenebutanal (0.40 g, 2.1 mmol) in dichloromethane (5 mL) to afford a crude product as a pale yellow oil. The crude product was purified using flash silica chromatography [1:4 EtOAc:Petroleum ether, R_f 0.27] to afford (S)-4-benzyl-3-((2S,3S)-6-(benzhyloxy)-3-hydroxy-2-methyl-4-methylenehexanoyl)-5,5-dimethyloxazolidin-
2-one 1b (0.57 g, 1.3 mmol, 78%) as a colourless oil. $^1$H NMR (300 MHz, CDCl$_3$): $\delta_H$ 7.27-7.16 (10H, m, Ph, Ph$_{ox}$), 5.11 (1H, s, C=CH$_A$H$_B$), 4.95 (1H, s, C=CH$_A$H$_B$), 4.45-4.40 (3H, m, OCH$_2$Ph, CHN), 4.32 (1H, br. d, $J = 5.8$ Hz, CHOH), 4.00 (1H, app. quintet, $J = 6.6$ Hz, CHCH$_3$), 3.62-3.48 (2H, m, CH$_2$OBn), 3.18 (1H, br. s, OH), 2.99 (1H, dd, $J = 14.4$, 4.3 Hz, CH$_A$H$_B$Ph), 2.83 (1H, dd, $J = 14.1$, 8.7 Hz, CH$_A$H$_B$Ph), 2.44-2.35 (1H, m, CH$_A$H$_B$OBn), 2.29-2.21 (1H, m, CH$_A$H$_B$OBn), 1.31 (3H, s, C(CH$_3$)(CH$_3$)), 1.26 (3H, s, C(CH$_3$)(CH$_3$)), 1.12 (3H, d, $J = 6.9$ Hz, CHCH$_3$); $^{13}$C{$^1$H} NMR (75 MHz, CDCl$_3$): $\delta_C$ 176.3, 152.2, 146.8, 137.9, 136.7, 129.1, 128.6, 128.4, 127.7, 127.6, 126.8, 113.3, 82.2, 74.5, 73.0, 70.0, 63.3, 41.5, 35.3, 32.7, 28.2, 22.1, 12.0; IR cm$^{-1}$ $\nu = 3467$ (OH), 1770 (C=O$_{ox}$), 1694 (C=O); HRMS: m/z (ES) 452.2458, C$_{27}$H$_{34}$NO$_5$ [M+H]$^+$ requires 452.2436; $[\alpha]_D^{17}$ = -30.0 ($c = 0.50$ g/100 mL in CHCl$_3$).

(S)-4-Benzyl-3-((2S,3R)-3-hydroxy-2-methylpent-4-enoyl)-5,5-dimethyloxazolidin-2-one, 1c: The title compound was prepared according to the general procedure from 9-BBN-OTf (3.78 mL, 1.9 mmol), (S)-4-benzyl-5,5-dimethyl-3-propionyloxazolidin-2-one 7a (0.40 g, 1.7 mmol), N,N-diisopropylethylamine (0.43 ml, 2.5 mmol) and acrolein (0.16 mL, 2.5 mmol) in dichloromethane (90 mL) to afford a crude product as a pale yellow oil. The crude product was purified using flash silica chromatography to afford (S)-4-benzyl-3-((2S,3R)-3-hydroxy-2-methylpent-4-enoyl)-5,5-dimethyloxazolidin-2-one 1c (0.26 g, 0.9 mmol, 53%) as a colourless oil. $^1$H NMR (300 MHz, CDCl$_3$): $\delta_H$ 7.26-7.12 (5H, m, Ph), 5.83-5.70 (1H, ddd, $J = 10.5$, 5.5, 5.3 Hz, CH=CH$_2$), 5.25 (1H, dt, $J = 1.5$ Hz, CH$_{cis}$H$_{trans}$=C), 5.13 (1H, dt, $J = 10.5$, 1.5 Hz, CH$_{cis}$H$_{trans}$=C), 4.49 (1H, dd, $J = 9.0$, 4.5 Hz, CHN), 4.38 (1H, m, CHOH), 3.85 (1H, dq, $J = 7.0$, 4.0 Hz, CHCH$_3$), 3.0 (1H, dd, $J = 14.5$, 4.5 Hz, CH$_A$H$_B$Ph), 2.85 (1H, dd, $J = 14.5$, 9.0 Hz, CH$_A$H$_B$Ph), 2.65 (1H, br. s, OH), 1.33 (3H, s, (CH$_3$)C(CH$_3$)), 1.31 (3H, s, (CH$_3$)C(CH$_3$)), 1.10 (3H, d, $J = 7.0$ Hz, CH$_3$CH); $^{13}$C{$^1$H} NMR (75 MHz, CDCl$_3$): $\delta_C$ 176.9, 152.8, 137.7, 137.0, 129.5, 129.1, 127.3, 116.8, 82.8, 73.2, 63.8, 42.85, 35.9, 28.8, 22.6, 11.7;
IR cm⁻¹ ν = 3501 (br. OH), 1754 (C=O), 1702 (C=O ox); HRMS: m/z (ES) 340.1577, C₁₈H₂₃NNaO₄ [M+Na]^+ requires 340.1519; [α]_D^{22} = -26.0 (c = 0.60 g/100 mL in CHCl₃).

(S)-4-Benzyl-3-((2S,3R,E)-3-hydroxy-2-methyl-5-phenylpent-4-enoyl)-5,5-dimethyloxazolidin-2-one, 1d: The title compound was prepared according to the general procedure from 9-BBN-OTf (10.10 mL, 5.0 mmol), (S)-4-benzyl-5,5-dimethyl-3-propionyloxazolidin-2-one 7a (1.20 g, 4.6 mmol), N,N-diisopropylethylamine (1.03 mL, 5.9 mmol) and (E)-cinnimaldehyde (0.76 mL, 5.9 mmol) in dichloromethane (30 mL) to afford a crude product as a pale yellow oil. The crude product was purified using flash silica chromatography to afford (S)-4-benzyl-3-((2S,3R,E)-3-hydroxy-2-methyl-5-phenylpent-4-enoyl)-5,5-dimethyloxazolidin-2-one 1d (1.41 g, 3.6 mmol, 78%) as a colourless oil. mp = 147–149 °C (Et₂O); ¹H NMR (300 MHz, CDCl₃): δ_H 7.36–7.13 (10H, m, Ph), 6.59 (1H, dd, J = 16.0, 1.5 Hz, CH=CHPh), 6.12 (1H, dd, J = 16.0 Hz, 6.0 Hz, CH=CHPh), 4.54 (1H, m, CHOH), 4.47 (1H, dd, J = 9.0, 5.0 Hz, CHN), 3.94 (1H, qd, J = 7.0, 4.0 Hz, COCH), 3.00 (1H, dd J = 14.0, 5.0 Hz, CH₅H₅Ph), 2.84 (1H, dd, J = 14.0, 9.0 Hz, CH₂CH₅Ph), 2.74 (1H, br. s, OH), 1.32 (3H, s, (CH₃)C(CH₃)), 1.30 (3H, s, (CH₃)C(CH₃)), 1.13 (3H, d, J = 7.0 Hz, CH₃CH); ¹³C{¹H} NMR (75 MHz, CDCl₃): δ_C 177.1, 152.6, 137.7, 134.1, 129.3, 129.2, 129.1, 127.3, 82.7, 73.4, 63.8, 43.3, 35.9, 32.7, 32.2, 29.6, 29.5, 23.1, 14.5, 12.0; IR cm⁻¹ ν = 3443 (OH), 1768 (C=O), 1684 (C=O ox); HRMS: m/z (ES) 416.1821, C₂₄H₂₇NNaO₄ [M+Na]^+ requires 416.1838; [α]_D^{23} = +6.0 (c = 0.89 g/100 mL in CHCl₃).

(S)-4-Benzyl-3-((2S,3R,E)-3-hydroxy-2-methylhex-4-enoyl)-5,5-dimethyl-oxazolidin-2-one, 1e: The title compound was prepared according to the general procedure from 9-BBN-OTf (5.56 mL, 2.8 mmol), (S)-4-benzyl-5,5-dimethyl-3-propionyloxazolidin-2-one 7a (0.61 g, 2.3 mmol), N,N-diisopropylethylamine (0.53 ml, 3.0 mmol) and (E)-crotonaldehyde (0.25 mL, 3.0 mmol) in dichloromethane (50 mL) to afford a crude product as a pale yellow oil.
The crude product was purified using flash silica chromatography to afford (S)-4-benzyl-3-((2S,3R,E)-3-hydroxy-2-methylhex-4-enoyl)-5,5-dimethyloxazolidin-2-one 1e (0.70 g, 2.1 mmol, 91%) as a clear oil. $^1$H NMR (300 MHz, CDCl$_3$): $\delta$H 7.39-7.17 (5H, m, Ph), 5.74 (1H, dqd, $J$ = 15.5, 6.5, 1.0 Hz, CH=CHCH$_3$), 5.48 (1H, ddd, $J$ = 15.5, 6.5, 1.0 Hz, CH=CHCH$_3$), 4.60 (1H, dd, $J$ = 9.0, 4.5 Hz, CHN), 4.53 (1H, m, CHOH), 3.91 (1H, qd, $J$ = 7.0, 4.5 Hz, COCH), 3.05 (1H, dd $J$ =14.5, 4.5 Hz, CH$_A$H$_B$Ph), 2.90 (1H, dd, $J$ = 14.5, 9.0 Hz, CH$_A$H$_B$Ph), 2.60 (1H, d, $J$ = 2.5 Hz, OH), 1.70 (3H, d, $J$ = 7.0 Hz, CH$_3$CH=CH), 1.39 (3H, s, (CH$_3$)C(CH$_3$)), 1.38 (3H, s, (CH$_3$)C(CH$_3$)), 1.15 (3H, d, $J$ = 7.0 Hz, CH$_3$CH); $^{13}$C{[1H] NMR (75 MHz, CDCl$_3$): $\delta$C 176.9, 152.9, 137.1, 130.5, 129.5, 129.1, 128.9, 127.3, 82.7, 73.6, 63.8, 43.2, 35.9, 28.7, 22.5, 18.2, 12.1; IR cm$^{-1}$ ν = 3508 (br. OH), 1775 (C=O ox), 1696 (C=O); HRMS: m/z (ES) 332.1855, C$_{19}$H$_{26}$NO$_4$ [M+H]$^+$ requires 332.1856; $[\alpha]_D^{21}$ = -14.0 (c = 0.84 g/100 mL in CHCl$_3$).

(S)-4-Benzyl-3-((2S,3R,E)-6-(benzyloxy)-3-hydroxy-2-methylhex-4-enoyl)-5,5-dimethyl oxazolidin-2-one, 1f: Based on a literature procedure, (S)-4-benzyl-5,5-dimethyl-3-propionyloxazolidin-2-one 7a (1.95 g, 7.5 mmol) was dissolved in dry dichloromethane (50 mL) at -10 °C under nitrogen and was stirred for 20 minutes. Dibutylboron triflate (8.97 mL, 9.0 mmol, 1.0 M in dichloromethane) was added dropwise followed by triethylamine (1.35 mL, 9.7 mmol) and the resulting solution was stirred for 30 minutes at 0 °C. The reaction was cooled to -78 °C and (E)-4-(benzyloxy)but-2-enal (1.45 g, 8.2 mmol) was added dropwise. The solution was stirred at -78 °C for 45 minutes and then warmed to 0 °C and stirred for a further 3 hours. The reaction was cooled to -10 °C and pH 7 buffer solution (Na$_2$PO$_4$/NaH$_2$PO$_4$) (30 mL) was added followed by methanol (24 mL) and hydrogen peroxide (12 mL). The methanol was evaporated, the solution diluted with dichloromethane and washed with saturated NaHCO$_3$ and brine. The combined organic extracts were dried over MgSO$_4$ and concentrated. The crude product was purified using flash silica
chromatography [1:4 EtOAc:Petroleum ether, Rf 0.19] to afford $(S)$-4-benzyl-3-((2$S$,3$R$,E)-6-(benzyloxy)-3-hydroxy-2-methylhex-4-enoyl)-5,5-dimethyloxazolidin-2-one 1f (2.91 g, 6.7 mmol, 89%) as a yellow oil. $^1$H NMR (300 MHz, CDCl$_3$): $\delta$H 7.27-7.15 (10H, m, Ph, Ph$_{ox}$), 5.83 (1H, dtd, $J = 15.6, 5.4, 1.0$ Hz, CH=CHCH$_2$OBn), 5.68 (1H, dd, $J = 15.6, 5.4$ Hz, CH=CHCH$_2$OBn), 4.48-4.38 (4H, m, CH$_2$OBn, CHN, CHOH), 3.96 (2H, d, $J = 5.4$ Hz, CH$_2$OBn), 3.86 (1H, qd, $J = 7.0, 4.2$ Hz, CH$_2$OBn), 2.99 (1H, dd, $J = 14.2, 4.6$ Hz, CH$_A$H$_B$Ph), 2.82 (1H, dd, $J = 14.4, 9.0$ Hz, CH$_A$H$_B$Ph), 2.76 (1H, broad s, OH), 1.30 (3H, s, C(C$_H$$_3$)(CH$_3$)), 1.28 (3H, s, C(CH$_3$)(CH$_3$)), 1.10 (3H, d, $J = 7.1$ Hz, CHCH$_3$); $^{13}$C{$_1^H$} NMR (75 MHz, CDCl$_3$): $\delta$C 176.3, 152.4, 138.2, 136.6, 132.0, 129.1, 128.7, 128.6, 128.3, 127.7, 127.6, 126.8, 82.3, 72.2, 72.1, 70.0, 63.3, 42.7, 35.4, 28.3, 22.1, 11.6; IR cm$^{-1}$ $\nu = 3474$ (OH), 1771 (C=O$_{ox}$), 1693 (C=O); HRMS: $m/z$ (ES) 460.2064, C$_{26}$H$_{31}$NNaO$_5$ [M+Na]$^+$ requires 460.2099; [$\alpha$]$^D_{25} = -28.0$ (c = 0.50 g/100 mL in CHCl$_3$).

$(S)$-4-Benzyl-3-((2$S$,3$R$,Z)-6-(benzyloxy)-3-hydroxy-2-methylhex-4-enoyl)-5,5-dimethyl oxazolidin-2-one, 1g: Based on a literature procedure,$^{27}$ $(S)$-4-benzyl-5,5-dimethyl-3-propionyloxazolidin-2-one 7a (0.50 g, 1.9 mmol) was dissolved in dry dichloromethane (20 mL) at -10 °C under nitrogen and was stirred for 20 minutes. Dibutylboron triflate (2.29 mL, 2.3 mmol, 1.0 M in dichloromethane) was added dropwise followed by triethylamine (0.35 mL, 2.5 mmol) and the resulting solution was stirred for 30 minutes at 0 °C. The reaction was cooled to -78 °C and (Z)-4-(benzyloxy)but-2-enal (0.37 g, 2.1 mmol) was added dropwise. The solution was stirred at -78 °C for 45 minutes and then warmed to 0 °C and stirred for a further three hours. The reaction was cooled to -10 °C and pH 7 buffer solution (Na$_2$PO$_4$/NaH$_2$PO$_4$) (10 mL) was added followed by methanol (8 mL) and hydrogen peroxide (4 mL). The methanol was evaporated, the solution diluted with dichloromethane and washed with saturated NaHCO$_3$ and brine. The combined organic extracts were dried over MgSO$_4$ and concentrated. The crude product was purified using flash silica chromatography [1:2
EtOAc:Petroleum ether, Rf 0.63] to afford (S)-4-benzyl-3-((2S,3R,Z)-6-(benzyloxy)-3-hydroxy-2-methylhex-4-enoyl)-5,5-dimethyloxazolidin-2-one 1g (0.74 g, 1.7 mmol, 88%) as a colourless gum, which crystallised on standing. \(^{1}H\) NMR (300 MHz, CDCl\(_3\)): \(\delta\) \(H\) 7.29-7.12 (10H, m, Ph), 5.71-5.52 (2H, m, \(CH=CH\)), 4.63-4.49 (1H, m, CHO), 4.44-4.39 (3H, m, CH\(_2\)OBn, CHN), 4.10 (1H, ddd, \(J = 12.7, 6.5, 1.3\) Hz, CH\(_3\)H\(_8\)OBn), 4.00 (1H, ddd, \(J = 12.6, 5.5, 1.3\) Hz, CH\(_3\)H\(_8\)Ph), 3.87 (1H, m, CH\(_3\)H\(_8\)), 2.97 (1H, dd, \(J = 14.3, 4.5\) Hz, CH\(_3\)H\(_8\)), 2.81 (1H, dd, \(J = 14.3, 9.0\) Hz, CH\(_3\)H\(_8\)), 2.73 (1H, broad s, OH), 1.30 (3H, s, C(CH\(_3\))(CH\(_3\))), 1.26 (3H, s, C(CH\(_3\))(CH\(_3\))), 1.11 (3H, d, \(J = 7.0\) Hz, CHCH\(_3\)), \(^{13}C\){\(^{1}H\) NMR (75 MHz, CDCl\(_3\)): \(\delta\) \(C\) 175.9, 152.6, 138.1, 136.7, 132.1, 129.6, 129.2, 128.7, 128.5, 127.9, 127.8, 126.9, 82.4, 72.5, 69.0, 66.2, 63.4, 43.1, 35.5, 28.4, 22.2, 12.4; IR cm\(^{-1}\) \(\nu = 3477\) (OH), 1771 (C=O\(_{ox}\)), 1692 (C=O); HRMS: \(m/z\) (ES) 460.2097, C\(_{26}\)H\(_{31}\)NNaO\(_5\) [M+Na\(^+\) requires 460.2099; \([\alpha\]\(^D\))\(^{25}\) = -12.0 (c = 0.50 g/100 mL in CHCl\(_3\)).

(S)-4-Benzyl-3-((2S,3S,E)-3-hydroxy-2,4-dimethylhept-4-enoyl)-5,5-dimethyloxazolidin-2-one, 1h: The title compound was prepared according to the general procedure from 9-BBN-OTf (7.08 mL, 3.5 mmol), (S)-4-benzyl-5,5-dimethyl-3-propionyloxazolidin-2-one 7a (0.84 g, 3.2 mmol), \(N,N\)-diisopropylethylamine (0.73 mL, 4.2 mmol) and 2-methyl-pentenal (0.48 mL, 4.2 mmol) in dichloromethane (100 mL) to afford a crude product as a pale yellow oil. The crude product was purified using flash silica chromatography to afford (S)-4-benzyl-3-((2S,3S,E)-3-hydroxy-2,4-dimethylhept-4-enoyl)-5,5-dimethyloxazolidin-2-one 1h (0.95 g, 2.6 mmol, 82%) as a colourless oil. \(^{1}H\) NMR (300 MHz, CDCl\(_3\)): \(\delta\) \(H\) 7.27-7.12 (5H, m, Ph), 6.51 (1H, tt, \(J = 7.0, 1.5\) Hz, C=CH\(_3\)), 4.45 (1H, dd, \(J = 9.0, 4.5\) Hz, CHN), 4.23 (1H, br. s, CHOH), 3.91 (1H, dq, \(J = 7.0, 4.0\) Hz, COCH\(_3\)), 3.10 (1H, dd \(J = 14.5, 4.5\) Hz, CH\(_3\)CH\(_3\)), 2.84 (1H, dd, \(J = 14.5, 9.0\) Hz, CH\(_3\)CH\(_3\)), 2.84 (1H, br. d, OH), 2.10 - 1.92 (2H, m, CH\(_2\)CH\(_3\)), 1.53 (3H, s, CH\(_3\)C=CH), 1.32 (3H, s, (CH\(_3\))C(CH\(_3\))), 1.29 (3H, s, (CH\(_3\))C(CH\(_3\))), 1.00 (3H, d, \(J = 7.0\) Hz, CH\(_3\)CH), 0.90 (3H, t, \(J = 7.5\) Hz, CH\(_2\)CH\(_3\)); \(^{13}C\){\(^{1}H\) NMR (75 MHz,
CDCl₃: δC 177.3, 152.7, 137.1, 133.4, 129.5, 129.0, 128.8, 127.2, 82.67, 76.1, 63.8, 41.1, 35.8, 28.7, 22.5, 21.3, 14.4, 13.5, 11.5; IR cm⁻¹ ν = 3493 (br. OH), 1777 (C=O), 1680 (C=O); HRMS: m/z (ES) 382.1977, C₂₁H₂₉NNaO₄ [M+Na]⁺ requires 382.1994; [α]D²⁵ = -5.0 (c = 1.00 g/100 mL, CHCl₃).

(S)-4-Benzyl-3-((2S,3S,E)-6-(benzylkoxy)-3-hydroxy-2,4-dimethylhex-4-enoyl)-5,5-dimethyloxazolidin-2-one, 1i: The title compound was prepared according to the general procedure from dibutylboron triflate (1.50 mL, 1.5 mmol), (S)-4-benzyl-5,5-dimethyl-3-propionyloxazolidin-2-one 7a (0.36 g, 1.4 mmol), N,N-diisopropylethylamine (0.31 mL, 1.8 mmol) and (E)-4-(benzylkoxy)-2-methylbut-2-enal²⁸ (0.34 g, 1.8 mmol) in dichloromethane (3 mL) to afford a crude product as a pale yellow oil. The crude product was purified using flash silica chromatography [1:9 EtOAc:Petroleum ether, Rf 0.24] to afford (S)-4-benzyl-3-((2S,3S,E)-6-(benzylkoxy)-3-hydroxy-2,4-dimethylhex-4-enoyl)-5,5-dimethyloxazolidin-2-one 1i (0.28 g, 0.6 mmol, 46%) as a colourless oil. ¹H NMR (300 MHz, CDCl₃): δH 7.27-7.15 (10H, m, Ph, Ph ox), 5.71 (1H, br. t, J = 6.3 Hz, C=CH), 4.46-4.43 (3H, m, OC₂H₂Ph, (CH₃)₂N), 4.28 (1H, d, J = 3.7 Hz, CHOH), 4.02 (2H, d, J = 6.6 Hz, CH₂OBn), 3.96-3.91 (1H, m, CH₃CH₃), 3.01 (1H, dd, J = 14.3, 4.0 Hz, CH₄H₃Ph), 2.82 (2H, dd, broad s, J = 14.3, 9.1 Hz, CH₃H₃Ph, OH), 1.57 (3H, s, CH₃C=CH), 1.30 (3H, s, C(CH₃)(CH₃)), 1.26 (3H, s, C(CH₃)(CH₃)), 1.05 (3H, d, J = 7.4 Hz, CHCH₃); ¹³C{¹H} NMR (75 MHz, CDCl₃): δC 176.6, 152.3, 138.3, 138.1, 136.7, 129.1, 128.6, 128.4, 127.8, 127.6, 126.9, 122.9, 82.4, 75.2, 72.1, 66.2, 63.5, 40.6, 35.3, 28.3, 22.1, 13.6, 10.9; IR cm⁻¹ ν = 3481 (OH), 1771 (C=O); HRMS: m/z (ES) 452.2446, C₂₇H₃₄NO₅ [M+H]⁺ requires 452.2436; [α]D²⁰ = -42.0 (c = 0.50 g/100 mL in CHCl₃).

(S)-4-Benzyl-3-((2S,3R)-3-hydroxy-2,5-dimethylhex-4-enoyl)-5,5-dimethyloxazolidin-2-one, 1j: The title compound was prepared according to the general procedure from 9-BBN-
OTf (8.05 mL, 4.0 mmol), (S)-4-benzyl-5,5-dimethyl-3-propionyloxazolidin-2-one 7a (0.96 mg, 3.7 mmol), N,N-diisopropylethylamine (0.83 ml, 4.8 mmol) and 3-methyl-2-butenal (0.46 mL, 4.8 mmol) in dichloromethane (100 mL) to afford a crude product as a pale yellow oil. The crude product was purified using flash silica chromatography to afford (S)-4-benzyl-3-((2S,3R)-3-hydroxy-2,5-dimethylhex-4-enoyl)-5,5-dimethyloxazolidin-2-one 1j (1.28 g, 3.7 mmol, 92%) as a white solid.

\[ \text{1H NMR (300 MHz, CDCl}_3\text{)}: \delta_H 7.35-7.17 (5H, m, Ph), 5.23 (1H, d, \text{J} = 9.0 \text{ Hz, CHC=C}), 4.60 (1H, m, C\text{HCOH}), 4.52 (1H, dd, \text{J} = 9.0, 4.5 \text{ Hz, CHN}), 3.93 (1H, qd, \text{J} = 7.0, 5.0 \text{ Hz, COCH}), 3.05 (1H, dd, \text{J} = 14.5, 4.5 \text{ Hz, } CH_ACH_BPh), 2.90 (1H, dd, \text{J} = 14.5, 9.0 \text{ Hz, } CH_AH_BPh), 2.35 (1H, br. s, OH), 1.72 (3H, s, C=C(CH_3)A(CH_3)B), 1.68 (3H, s, C=C(CH_3)A(CH_3)B), 1.39 (3H, s, (CH_3)C(CH_3)A), 1.37 (3H, s, (CH_3)C(CH_3)B), 1.18 (3H, d, \text{J} = 7.0 \text{ Hz, CH}_3CH); \]

\[ \text{13C\{}^1\text{H}\text{NMR (75 MHz, CDCl}_3\text{): } \delta_C 176.7, 153.0, 137.2, 137.1, 129.5, 129.1, 127.3, 124.5, 82.6, 69.9, 63.8, 43.4, 35.9, 28.6, 26.4, 22.5, 18.8, 12.6; \text{IR cm}^{-1}\nu = 3479 (\text{br. OH}), 1769 (\text{C=O}), 1681 (\text{C=O}); \text{HRMS: } m/z (\text{ES}) 346.2011, \text{C}_{20}\text{H}_{28}\text{NO}_4 [\text{M}+\text{H}]^+ \text{requires 346.2013; } [\alpha]_{D}^{21} = -27.0 (c = 1.00 \text{ g/100 mL in CHCl}_3). \]

**(S)-4-Benzyl-3-((2S,3S)-3-hydroxy-4-methyl-2-phenylpent-4-enoyl)-5,5-dimethyloxazolidin-2-one, 1k:** The title compound was prepared according to the general procedure from 9-BBN-OTf (0.45 mL, 0.9 mmol), (S)-4-benzyl-5,5-dimethyl-3-(2-phenylacetyl)oxazolidin-2-one 7b (0.27 g, 0.8 mmol), N,N-diisopropylethylamine (0.17 ml, 1.0 mmol) and methacrolein (0.08 mL, 1.0 mmol) in dichloromethane (70 mL) to afford a crude product as a pale yellow oil. The crude product was purified using flash silica chromatography to afford (S)-4-benzyl-3-((2S,3S)-3-hydroxy-4-methyl-2-phenylpent-4-enoyl)-5,5-dimethyloxazolidin-2-one 1k (0.24 g, 0.6 mmol, 75%) as a colourless oil. \[ \text{1H NMR (300 MHz, CDCl}_3\text{): } \delta_H 7.42-7.20 (5H, m, Ph), 7.14-6.98 (5H, m, Ph), 5.27 (1H, d, \text{J} = 7.0 \text{ Hz, PhCH}) 4.92 (1H, m, CH_AH_{trans}=C), 4.85 (1H, br. app. pent., \text{J} = 1.5 \text{ Hz, CH_AH_{trans}=C}), 4.69 (1H, d, \text{J} = 8.0 \text{ Hz, CHOH}), 4.43 (1H, dd, \text{J} = 9.0, 4.0 \text{ Hz, CHN}), 2.82 (1H, dd \text{J} = 14.0, 4.0 Hz, CH_AH_BPh), 2.63 (1H, dd, J =
14.0, 9.0 Hz, CH₄CH₂Ph), 2.05 (1H, br. s, OH), 1.74 (3H, s, CH₂=CCH₃), 1.27 (3H, s, (CH₃)C(CH₃)), 1.24 (3H, s, (CH₃)C(CH₃)); ¹³C{¹H} NMR (75 MHz, CDCl₃): δC 172.9, 152.5, 144.8, 136.9, 134.7, 130.2, 129.4, 129.1, 128.9, 128.4, 127.1, 114.2, 82.5, 63.7, 53.4, 35.3, 28.7, 22.5, 18.7; IR cm⁻¹ ν = 3489 (OH), 1768 (C=O), 1671 (C=O ox); HRMS: m/z (ES) 394.2019, C₂₄H₂₈NO₄ [M+H]+ requires 394.2018; [α]D²⁵ = -89.9 (c = 1.00 g/100 mL, CHCl₃).

General Procedure for the Synthesis of (3S,4S)-Hydroxy-γ-lactones (6a-6k, 11): Osmium tetroxide (OsO₄) (0.1 equiv.) was added in one portion to a stirring solution of the appropriate β-alkenyl-β-hydroxy-N-acyloxazolidin-2-one 1a-1k (1.0 equiv.) in acetone/water (8:1 ratio) under nitrogen. After five minutes, NMO (N-methylmorpholine N-oxide, 60% by weight in water, 1.1 equiv.) was added in one portion and stirred for 24 hours. The resulting reaction mixture was concentrated under reduced pressure and immediately purified via column chromatography.

(3S,4S,5R)-5-Ethyl-4-hydroxy-5-(hydroxymethyl)-3-methylidihydrofuran-2(3H)-one, 6a: OsO₄ (22 mg, 0.09 mmol) was added to a solution of 1a (305 mg, 0.88 mmol) in acetone/water (8:1, 3 mL) followed by addition of NMO (60% by weight in water, 0.16 mL, 0.97 mmol) according to the general procedure to afford the crude product as black oil. Purification via column chromatography afforded 6a (120 mg, 0.61 mmol, 69%, 49:1 dr). ¹H NMR (500 MHz, MeOD): δH 4.24 (1H, d, J = 9.4 Hz, CHO), 3.74 (1H, d, J = 12.1 Hz, CH₃OH), 3.52 (1H, d, J = 12.2 Hz, CH₃OH), 2.68 (1H, qd, J = 9.4, 7.1 Hz, CHCO), 1.81 (1H, dq, J = 15.0, 7.5 Hz, CH₃OH), 1.71 (1H, dq, J = 15.0, 7.5 Hz, CH₃OH), 1.28 (3H, d, J = 7.5 Hz, CH₃), 1.01 (3H, t, J = 7.5 Hz, CH₂CH₃); ¹³C{¹H} NMR (75 MHz, MeOD): δC 179.6, 90.2, 76.5, 64.7, 44.2, 25.0, 13.9, 8.6; IR cm⁻¹ ν = 3368 (br. OH), 1751 (C=O); HRMS: m/z (ES) 175.0957, C₈H₁₃O₄ [M+H]+ requires 175.0970; [α]D²⁵ = -3.4 (c = 0.88 g/100 mL in CHCl₃).
(3S,4S,5R)-5-(2-(Benzyloxy)ethyl)-4-hydroxy-5-(hydroxymethyl)-3-methyldihydrofuran-2(3H)-one, 6b: OsO₄ (8 mg, 0.03 mmol) was added to a solution of 1b (140 mg, 0.31 mmol) in acetone/water (8:1, 1.5 mL) followed by addition of NMO (60% by weight in water, 0.07 mL, 0.34 mmol) according to the general procedure to afford the crude product as black oil. Purification via column chromatography afforded 6b (80 mg, 0.28 mmol, 93%, 10:1 dr). ¹H NMR (300 MHz, CDCl₃): δ H 7.31-7.18 (5H, m, Ph), 4.43 (2H, s, OC₂H₂Ph), 4.12 (1H, br. s, O), 3.96 (1H, d, J = 8.4 Hz, C₂H₂OH), 3.59-3.49 (4H, m, C₂H₂OBn, C₂H₂OH), 2.80 (1H, br. s, OH), 2.49 (1H, app. quintet, J = 7.4 Hz, CHCH₃), 2.07-1.91 (2H, m, C₂H₂CH₂OBn), 1.20 (3H, d, J = 7.4 Hz, CHC₂H₃), 2.19 (1H, dt, J = 5.8, 3.7 Hz, CHCH₂OH), 1.30 (3H, d, J = 7.5 Hz, CH₃). ¹³C{¹H} NMR (75 MHz, CDCl₃): δ C 177.4, 136.5, 128.8, 128.5, 128.3, 87.8, 76.5, 73.9, 66.4, 64.8, 42.9, 30.3, 13.7; IR cm⁻¹ ν = 3402 (OH), 1754 (C=O); HRMS: m/z (ES) 303.1210, C₁₅H₂₀NaO₅, [M+Na]⁺ requires 303.1208; [α]₂⁴ = +18.0 (c = 0.50 g/100 mL in CHCl₃).

(3S,4S,5R)-4-Hydroxy-5-(hydroxymethyl)-3-methyldihydrofuran-2(3H)-one, 6c: OsO₄ (15 mg, 0.06 mmol) was added to a solution of 1c (150 mg, 0.52 mmol) in acetone/water (8:1, 5 mL) followed by addition of NMO (60% by weight in water, 0.09 mL, 0.52 mmol) according to the general procedure to afford the crude product as black oil. Purification via column chromatography afforded a diastereomeric mixture of 6c major and 6c minor (60 mg, 0.41 mmol, 79%, 3:1 dr). The two diastereoisomers were analysed as a mixture. ¹H NMR (500 MHz, MeOD): δ H 4.19-4.17 (1H, m, CHCH₂OH), 4.02 – 3.99 (1H, m, CHOH), 3.94 (1H, dd, J = 12.8, 2.5 Hz, CH₃CH₂OH), 3.72 (1H, dd, J = 12.8, 4.8 Hz, CH₃CH₂OH), 2.66 (1H, dq, J = 8.9, 7.1 Hz, CHCH₃), 1.30 (3H, d, J = 7.3 Hz, CH₃); ¹³C{¹H} NMR (75 MHz, MeOD): δ C 180.0, 86.8, 75.6, 62.0, 45.7, 13.6; (3S,4S,5S)-minor: ¹H NMR (500 MHz, CDCl₃): δ H 4.57 (1H, dt, J = 5.8, 3.7 Hz, CHCH₂OH), 4.27 (1H, t, J = 6.0 Hz, CHOH), 3.90 (2H, d, J = 3.7 Hz, CH₃CH₂OH), 2.71 (1H, dt, J = 13.6, 7.6 Hz, CHCH₃), 1.29 (3H, d, J = 7.5 Hz, CH₃); ¹³C{¹H} NMR (75 MHz, MeOD): δ C 181.6, 84.1,
76.2, 62.2, 45.5, 14.4; IR cm⁻¹ ν = 3377 (br. OH), 2934 (br. OH), 1763 (C=O); HRMS: m/z (ES) 147.0650, C₆H₁₁O₄ [M+H]⁺ requires 147.0657; [α]D²⁴ = +4.0 (c = 0.50 g/100 mL in MeOH).

(3S,4S,5S)-4-Hydroxy-5-((S)-hydroxy(phenyl)methyl)-3-methyldihydrofuran-2(3H)-one, 6d: OsO₄ (13 mg, 0.05 mmol) was added to a solution of 1d (198 mg, 0.50 mmol) in acetone/water (8:1, 3 mL) followed by addition of NMO (60% by weight in water, 0.1 mL, 0.55 mmol) according to the general procedure to afford the crude product as black oil. Purification via column chromatography afforded 6d (90 mg, 0.41 mmol, 81%, 9:1 dr). ¹H NMR (500 MHz, CDCl₃): δH 7.41-7.25 (5H, m, Ph), 4.76 (1H, d, J = 5.7, CHPh), 4.22 (1H, dd, J = 9.2, 7.5 Hz, CHCH₂Ph), 3.95 (1H, dd, J = 9.2, 7.5 Hz, CHOH), 2.56 (1H, dq, J = 9.2, 7.2 Hz, CHCO), 1.19 (3H, d, J = 6.9 Hz, CH₃CHOH); ¹³C{¹H} NMR (75 MHz, CDCl₃): δC 178.4, 134.5, 129.1, 128.7, 127.4, 80.1, 74.9, 70.9, 43.1, 14.1; IR cm⁻¹ ν = 3358 (br. OH), 1753 (C=O); HRMS: m/z (ES) 223.0964, C₁₂H₁₅O₄ [M+H]⁺ requires 223.0970; [α]D²³ = +44.0 (c = 1.62 g/100 mL in CHCl₃).

(3S,4S,5R)-4-Hydroxy-5-((S)-1-hydroxyethyl)-3-methyldihydrofuran-2(3H)-one, 6e: OsO₄ (13 mg, 0.05 mmol) was added to a solution of 1e (164 mg, 0.50 mmol) in acetone/water (8:1, 3 mL) followed by addition of NMO (60% by weight in water, 0.09 mL, 0.54 mmol) according to the general procedure to afford the crude product as black oil. Purification via column chromatography afforded a diastereomeric mixture of 6e major and 6e minor (66 mg, 0.41 mmol, 83%, 5:1 dr). The two diastereoisomers were analysed as a mixture. (3S,4S,5R)-major: ¹H NMR (500 MHz, CDCl₃): δH 4.11 (1H, dd, J = 8.8, 7.0 Hz, CHOH), 4.04-3.95 (2H, m, CHOCO, CHOCH₃), 2.68 (1H, dq, J = 9.1, 7.1 Hz, CHCO), 1.37 (3H, d, J = 6.5 Hz, CH₃CHOH), 1.32 (3H, d, J = 7.1 Hz, CH₃CH); ¹³C{¹H} NMR (75 MHz, CDCl₃): δC 176.8, 86.4, 74.9, 66.6, 44.2, 19.9, 12.8; (3S,4S,5S)-minor: ¹H NMR (500
MHz, CDCl$_3$) $\delta_H$ 4.35-4.32 (1H, m, CHOH), 4.32 – 4.27 (2H, m, CHOCO, CHOCH$_3$), 2.76 (1H, dq, $J = 7.7$, 5.3 Hz, CHCO), 1.39 (3H, d, $J = 6.7$ Hz, CH$_3$CHOH), 1.32 (3H, d, $J = 7.5$ Hz, CH$_3$CH); $^{13}$C{${^1}$H} NMR (75 MHz, CDCl$_3$) $\delta_C$ 177.3, 82.9, 76.3, 67.1, 44.6, 19.8, 14.0; IR cm$^{-1}$ $\nu = 3356$ (br. OH), 1754 (C=O); HRMS: $m/z$ (ES) 183.0613, C$_7$H$_{12}$NaO$_4$ [M+Na]$^+$ requires 183.0628.

(3S,4S,5S)-5-((S)-2-(Benzyloxy)-1-hydroxyethyl)-4-hydroxy-3-methyldihydrofuran-2(3H)-one, 6f: OsO$_4$ (6 mg, 0.02 mmol) was added to a solution of 1f (100 mg, 0.22 mmol) in acetone/water (8:1, 1.2 mL) followed by addition of NMO (60% by weight in water, 0.04 mL, 0.25 mmol) according to the general procedure to afford the crude product as black oil. Purification via column chromatography afforded 6f (47 mg, 0.17 mmol, 77%, 4:1 dr). $^1$H NMR (300 MHz, CDCl$_3$): $\delta_H$ 7.33-7.20 (5H, m, Ph), 4.50 (2H, s, OCH$_2$Ph), 4.04-3.90 (3H, m, CH$_3$CHC$_2$H$_5$, COOC$_2$H$_5$, OCH$_2$C$_2$H$_5$), 3.63-3.52 (3H, m, CH$_2$OBn, OH), 2.95 (1H, d, $J = 4.3$ Hz, OH), 2.61-2.51 (1H, m, CH$_2$CH$_3$), 1.22 (3H, d, $J = 7.0$ Hz, CH$_2$CH$_3$); $^{13}$C{${^1}$H} NMR (75 MHz, CDCl$_3$): $\delta_C$ 176.6, 137.1, 128.8, 128.4, 128.1, 84.3, 74.6, 74.0, 71.1, 69.3, 43.2, 12.4; IR cm$^{-1}$ $\nu = 3396$ (OH), 1760 (C=O); HRMS: $m/z$ (ES) 289.1041, C$_{14}$H$_{18}$NaO$_5$, [M+Na]$^+$ requires 289.1051; $[\alpha]_D^{24} = +4.0$ ($c = 0.50$ g/100 mL in CHCl$_3$).

(3S,4S,5S)-5-((R)-2-(Benzyloxy)-1-hydroxyethyl)-4-hydroxy-3-methyldihydrofuran-2(3H)-one, 6g: OsO$_4$ (6 mg, 0.02 mmol) was added to a solution of 1g (100 mg, 0.22 mmol) in acetone/water (8:1, 1.2 mL) followed by addition of NMO (60% by weight in water, 0.04 mL, 0.25 mmol) according to the general procedure to afford the crude product as black oil. Purification via column chromatography afforded the product in 74% yield, 2:1 dr, 6g major (28 mg, 0.11 mmol, 45%), 6g minor (13 mg, 0.05 mmol, 21%) and a mixture of 6g major and 6g minor (4 mg, 0.15 mmol, 7%). (3S,4S,5R)-5-(S)-major: $^1$H NMR (300 MHz, 50:50 CDCl$_3$:C$_6$H$_6$): $\delta_H$ 7.32-21 (5H, m, Ph), 4.43 (1H, d, $J = 11.6$ Hz, OCH$_2$H$_3$Ph), 4.36 (1H, d, $J = 11.6$ Hz, OCH$_2$H$_3$Ph)
= 11.6 Hz, OCH$_A$H$_B$Ph), 4.03 (1H, dd, $J = 9.9, 7.3$ Hz, CH$_2$CHCHOH), 3.85 (1H, dd, $J = 7.3,
5.1$ Hz, COOCH), 3.79-3.75 (1H, m, OCH$_2$CHOH), 3.51 (1H, dd, $J = 10.3, 3.3$ Hz, CH$_A$-
H$_B$OBn), 3.46 (1H, dd, 10.3, 4.2 Hz, CH$_A$H$_B$OBn), 3.21 (1H, br. s, OH), 2.59 (1H, br. s, OH),
2.50 (1H, dq, 9.9, 7.1 Hz, CHCH$_3$), 1.25 (3H, d, $J = 7.1$ Hz, CHCH$_3$); $^{13}$C{$_^1$H} NMR (75 MHz, CDCl$_3$):
$\delta_C$ 176.5, 136.9, 128.8, 128.5, 128.2, 83.1, 74.5, 74.3, 70.9, 70.4, 42.7, 12.6;
IR cm$^{-1}$ $\nu = 3418.67$ (OH), 1759.65 (C=O); HRMS: m/z (ES) 289.1042, C$_{14}$H$_{18}$NaO$_5$,
[M+Na]$^+$ requires 289.1051; [$\alpha$]$^D_{24} = -2.0$ (c = 0.50 g/100 mL in CHCl$_3$).

(3S,4S,5S,6h: OsO$_4$ (15 mg, 0.06 mmol) was added to a solution of 1h (209 mg, 0.58 mmol) in acetone/water (8:1, 3 mL) followed by addition of NMO (60% by weight in water, 0.11 mL, 0.64 mmol) according to the general procedure to afford the crude product as black oil. Purification via column chromatography afforded (3S,4S,5S)-4-hydroxy-5-((S)-1-hydroxypropyl)-3,5-dimethylidihydrofuran-2(3H)-one,

$^{1}$H NMR (300 MHz, CDCl$_3$): $\delta_H$ 7.40-7.30 (5H, m, Ph), 4.59 (2H, s, OC$_H_2$Ph), 4.43
(1H, dd, $J = 8.0, 4.7$ Hz, COOCH), 4.32 (1H, dd, $J = 4.7, 2.6$ Hz, CH$_2$CHCHOH), 4.18-4.13
(1H, m, OCH$_2$CHOH), 3.79 (1H, dd, $J = 9.9, 3.3$ Hz, CH$_A$H$_B$OBn), 3.69 (1H, dd, $J = 9.9, 5.0$
Hz, CH$_A$H$_B$OBn), 3.11 (1H, br. s, OH), 2.87 (1H, br. s, OH), 2.68 (1H, dq, $J = 7.8, 2.5$ Hz,
CHCH$_3$), 1.30 (3H, d, $J = 7.8$ Hz, CHCH$_3$); $^{13}$C{$_^1$H} NMR (75 MHz, CDCl$_3$): $\delta_C$ 178.4,
137.3, 128.8, 128.3, 128.1, 79.2, 75.0, 73.9, 71.0, 69.1, 43.8, 13.8; IR cm$^{-1}$ $\nu = 3421$ (OH),
1774 (C=O); HRMS: m/z (ES) 289.1032, C$_{14}$H$_{18}$NaO$_5$, [M+Na]$^+$ requires 289.1051; [$\alpha$]$^D_{24} = -6.0$ (c = 0.50 g/100 mL in CHCl$_3$).
(3H, t, J = 7.3 Hz, CH₂CH₃); ¹³C{¹H} NMR (75 MHz, CDCl₃): δC 178.0, 89.1, 75.6, 75.2, 41.6, 24.1, 16.4, 12.8, 11.3; IR cm⁻¹ ν = 3356 (br. OH), 1748 (C=O); HRMS: m/z (ES) 189.1120, C₉H₁₇O₄[M+H]⁺ requires 189.1127; [α]D²³ = -5.4 (c = 1.30 g/100 mL in CHCl₃).

(3S,4S,5S)-5-((S)-2-(Benzyloxy)-1-hydroxyethyl)-4-hydroxy-3,5-dimethylidihydrofuran-2(3H)-one, 6i: OsO₄ (4 mg, 0.02 mmol) was added to a solution of 1i (75 mg, 0.17 mmol) in acetone/water (8:1, 0.7 mL) followed by addition of NMO (60% by weight in water, 0.03 mL, 0.18 mmol) according to the general procedure to afford the crude product as black oil. Purification via column chromatography afforded 6i (43 mg, 0.15 mmol, 93%, >49:1 dr). ¹H NMR (300 MHz, CDCl₃): δH 7.31-7.17 (5H, m, Ph), 4.49 (1H, d, J = 11.6 Hz, OCH₂H₂Ph), 4.43 (1H, d, J = 11.6 Hz, OCH₂H₂Ph), 3.86 (1H, d, J = 10.5 Hz, CH₂CH₃CH₂OH), 3.77 (1H, dd, J = 7.6, 6.2 Hz, CHOHCH₂OBn), 3.54 (1H, dd, J = 10.0, 6.2 Hz, CH₂H₂OBn), 3.47 (1H, dd, J = 9.8, 7.8 Hz, CH₂H₂OBn), 3.42 (1H, br. s, OH), 2.90 (1H, br. s, OH), 2.65-2.53 (1H, m, CH₂CH₃), 1.20-1.16 (6H, m, CH₂CH₃, CCH₃); ¹³C{¹H} NMR (75 MHz, CDCl₃): δC 175.9, 136.6, 128.9, 128.6, 128.3, 87.7, 76.8, 74.3, 74.0, 70.0, 40.6, 13.9, 12.7; IR cm⁻¹ ν = 3420 (OH), 1761 (C=O); HRMS: m/z (ES) 281.1368, C₁₅H₂₁O₅, [M+H]⁺ requires 281.1388; [α]D²³ = -12.0 (c = 0.50 g/100 mL in CHCl₃).

(3S,4S,5R)-4-Hydroxy-5-(2-hydroxypropan-2-yl)-3-methylidihydrofuran-2(3H)-one, 6j: OsO₄ (14 mg, 0.05 mmol) was added to a solution of 1j (184 mg, 0.53 mmol) in acetone/water (8:1, 3 mL) followed by addition of NMO (60% by weight in water, 0.10 mL, 0.59 mmol) according to the general procedure to afford the crude product as black oil. Purification via column chromatography afforded 6j (38 mg, 0.22 mmol, 41%, 5:1 dr) as a pale oil. ¹H NMR (300 MHz, CDCl₃): δH 4.94 (1H, d, J = 4.1 Hz, OH), 4.26 (1H, app. dt, J = 3.9, 1.5 Hz, CHOH), 4.09 (1H, d, J = 4.1 Hz, CHOCO), 2.96 (1H, br. s, OH), 2.68 (1H, qd, J = 7.8, 1.5 Hz, CH₂(CH₃)₂OH), 1.38 (3H, s, (CH₃)C(CH₃)), 1.36 (3H, s, (CH₃)C(CH₃)), 1.19
(3H, d, J = 7.8 Hz, CH$_3$CH); $^{13}$C($^1$H) NMR (75 MHz, CDCl$_3$): $\delta$C 179.5, 84.0, 76.3, 73.0, 46.9, 28.7, 25.0, 13.5; IR cm$^{-1}$ ν = 3295 (br. OH), 1754 (C=O); HRMS: $m/z$ (ES) 175.0970, C$_8$H$_{15}$O$_4$ [M+H]$^+$ requires 175.0970; [α]$_D^{23}$ = -55.6 (c = 0.99 g/100 mL in CHCl$_3$).

(3S,4S,5R)-4-Hydroxy-5-(hydroxymethyl)-5-methyl-3-phenyldihydrofuran-2(3H)-one, 6k: OsO$_4$ (6 mg, 0.03 mmol) was added to a solution of 1k (94 mg, 0.25 mmol) in acetone/water (8:1, 3 mL) followed by addition of NMO (60% by weight in water, 0.06 mL, 0.26 mmol) according to the general procedure to afford the crude product as black oil. Purification via column chromatography afforded 6k (42 mg, 0.19 mmol, 75%, 9:1 dr) as a pale oil. $^1$H NMR (400 MHz, CDCl$_3$): $\delta$H 7.29-7.23 (3H, m, Ph), 7.18-7.13 (2H, m, Ph), 4.62 (1H, d, J = 10.5 Hz, CH$_2$OH), 3.80 (1H, d, J = 10.5 Hz, CH$_2$CO), 3.70 (1H, d, J = 12.6 Hz, CH$_2$OH), 1.32 (3H, s, CH$_3$); $^{13}$C($^1$H) NMR (75 MHz, CDCl$_3$): $\delta$C 174.3, 135.1, 129.4, 129.0, 128.4, 86.5, 75.3, 65.5, 53.8, 16.9; IR IR cm$^{-1}$ ν = 3308 (br. OH), 1745 (C=O); HRMS: $m/z$ (ES) 223.0961, C$_{12}$H$_{15}$O$_4$ [M+H]$^+$ requires 223.0970; [α]$_D^{23}$ = -9.1 (c = 0.83 g/100 mL in MeOH).

(3S,4S,5S)-5-((R)-2-(benzylxy)-1-hydroxyethyl)-4-hydroxy-3-methylidihydrofuran-2(3H)-one, 6g: AD-mix-β (252 mg, 1.4 g/mmol of allylic alcohol) was dissolved in a 1:1 mixture of $^1$BuOH and water (1.8 mL, 10 mL/mmol of allylic alcohol). MeSO$_2$NH$_2$ (17 mg, 0.18 mmol) was added and the biphasic suspension was cooled to 0 °C. (S)-4-Benzyl-3-((2S,3R,Z)-6-(benzylxy)-3-hydroxy-2-methylhex-4-enoyl)-5,5-dimethylazolidin-2-one (80 mg, 0.18 mmol) dissolved in CH$_2$Cl$_2$ (1 mL) was added dropwise via syringe to the stirring suspension followed by OsO$_4$ (4.5 mg, 0.18 mmol). The suspension was stirred vigorously whilst slowly warming to room temperature. After 48 hours, the reaction was quenched with solid sodium sulfite (100 mg) at room temperature. The suspension was filtered through a pad of Celite®/Florisil®, eluting with ethyl acetate before the solution was
dried over MgSO₄ and concentrated. The crude product was purified via column chromatography [1:1 EtOAc:Petroleuem ether, Rf 0.15] to afford (3S,4S,5S)-5-((R)-2-(benzyloxy)-1-hydroxyethyl)-4-hydroxy-3-methyldihydrofuran-2(3H)-one 6g (46 mg, 0.17 mmol, 95%, 17:1 dr) as a white oil.

(3S,4S,5R)-5-((S)-2-(Benzyloxy)-1-hydroxyethyl)-4-hydroxy-3-methyldihydrofuran-2(3H)-one, 8: AD-mix-α (252 mg, 1.4 g/mmol of allylic alcohol) was dissolved in a 1:1 mixture of tBuOH and water (1.8 mL, 10 mL/mmol of allylic alcohol). MeSO₂NH₂ (17 mg, 0.18 mmol) was added and the biphasic suspension was cooled to 0 ºC. (S)-4-Benzyl-3-((2S,3R,Z)-6-(benzyloxy)-3-hydroxy-2-methylhex-4-enoyl)-5,5-dimethyloxazolidin-2-one (80 mg, 0.18 mmol) dissolved in CH₂Cl₂ (1 mL) was added dropwise via syringe to the stirring suspension followed by OsO₄ (4.5 mg, 0.18 mmol). The suspension was stirred vigorously whilst slowly warming to room temperature. After 48 hours, the reaction was quenched with solid sodium sulfite (100 mg) at room temperature. The suspension was filtered through a pad of Celite®/Florisil®, eluting with ethyl acetate before the solution was dried over MgSO₄ and concentrated. The crude product was purified using via column chromatography [1:1 EtOAc:Petroleuem ether, Rf 0.15] to afford (3S,4S,5R)-5-((S)-2-(benzyloxy)-1-hydroxyethyl)-4-hydroxy-3-methyldihydrofuran-2(3H)-one 8 (46 mg, 0.17 mmol, 95%, 4:1 dr) as a white oil.

Synthesis of 2-Deoxy-d-ribonolactone

(S)-4-Benzyl-3-(2-chloroacetyl)-5,5-dimethyloxazolidin-2-one, 7c: The title compound was prepared according to the general procedure from n-BuLi (10.7 mL, 26.8 mmol, 2.5 M solution in hexane), (S)-4-benzyl-5,5-dimethyloxazolidin-2-one (5.00 g, 24.3 mmol) and chloroacetyl chloride (2.07 mL, 26.8 mmmol) in THF (150 mL). The crude product was purified using flash silica chromatography [1:9 EtOAc:Petroleuem ether, Rf 0.50] to afford
(S)-4-benzyl-3-(2-chloroacetyl)-5,5-dimethylxazolidin-2-one 7c (5.69 g, 20.1 mmol, 83%) as a colourless oil that solidified on standing. ¹H NMR (300 MHz, CDCl₃): δ 7.32-7.20 (5H, m, Ph), 4.76 (1H, d, J = 15.8 Hz, COCH₃H₂Cl), 4.64 (d, J = 15.8 Hz, COCH₃H₂Cl), 4.49 (1H, dd, J = 9.7, 3.9 Hz, CHN), 3.20 (1H, dd, J = 14.4, 3.8 Hz, CHH₃H₂Ph), 2.88 (1H, dd, J = 14.4, 9.8 Hz, CHH₃H₂Ph), 1.38 (3H, s, C(CH₃)(CH₃)), 1.36 (3H, s, C(CH₃)(CH₃)); ¹³C{'¹H} NMR (75 MHz, CDCl₃): δ 166.4, 152.4, 136.5, 129.1, 128.9, 127.1, 83.7, 64.1, 44.0, 35.0, 28.7, 22.4; IR cm⁻¹ v = 1769 (C=O ox), 1709 (C=O); HRMS: m/z (ES) 304.0722, C₁₄H₁₆ClNNaO₃ [M+Na]⁺ requires 304.0716; [α]_D²⁵ = -32.0 (c = 0.50 g/100 mL in CHCl₃).

(S)-4-Benzyl-3-((2S,3R)-2-chloro-3-hydroxypent-4-enoyl)-5,5-dimethylxazolidin -2-one, 9: The title compound was prepared according to the general procedure from dibutylboron triflate (7.70 mL, 7.7 mmol), (S)-4-benzyl-3-(2-chloroacetyl)-5,5-dimethylxazolidin-2-one 7c (1.97g, 7.0 mmol), N,N-diisopropylethylamine (1.58 mL, 9.1 mmol) and acrolein (0.61 mL, 9.1 mmol) in dichloromethane (15 mL) to afford a crude product as a pale yellow oil. The crude product was purified using flash silica chromatography [1:4 EtOAc:Petroleum ether, Rf 0.27] to afford (S)-4-benzyl-3-((2S,3R)-2-chloro-3-hydroxypent-4-enoyl)-5,5-dimethylxazolidin-2-one 9 (1.07g, 3.2 mmol, 45%) as a colourless oil. ¹H NMR (300 MHz, CDCl₃): δ 7.31-7.17 (5H, m, Ph), 5.88 (1H, ddd, J = 17.3, 10.5, 5.8 Hz, CH=CH₂), 5.72 (1H, d, J = 5.1 Hz, CHCl), 5.40 (1H, dt, J = 17.3, 1.3 Hz, CH=CH₂H₂B), 5.28 (1H, dt, J = 10.5, 1.2 Hz, CH=CH₂H₂B), 4.59 (1H, app. t, J = 5.5 Hz, CHOH), 4.48 (1H, dd, J = 9.5, 3.8 Hz, CHN), 3.14 (1H, dd, J = 14.4, 3.8 Hz CH₂H₂BPh), 3.00 (1H, br. s, OH), 2.88 (1H, dd, J = 14.4, 9.5 Hz, CH₂H₂BPh), 1.36 (3H, s, C(CH₃)(CH₃)), 1.33 (3H, s, C(CH₃)(CH₃)); ¹³C{'¹H} NMR (75 MHz, CDCl₃): δ 167.9, 152.0, 136.4, 135.0, 129.1, 128.8, 127.0, 118.9, 83.3, 72.9, 64.0, 59.1, 34.9, 28.5, 22.2; IR cm⁻¹ v = 3496 (OH), 1771 (C=O ox), 1703 (C=O); HRMS: m/z (ES) 338.1149, C₁₇H₂₂ClNO₄ [M+H]⁺ requires 338.1159; [α]_D²⁴ = -12.0 (c = 1.00 g/100 mL in CHCl₃).
(S)-4-Benzyl-3-((S)-3-hydroxypent-4-enoyl)-5,5-dimethyloxazolidin-2-one, 10: (S)-4-
Benzyl-3-((2S,3R)-2-chloro-3-hydroxypent-4-enoyl)-5,5-dimethyloxazolidin-2-one 9 (1.08 g,
3.2 mmol) was dissolved in dry methanol (12 mL) under nitrogen. Zinc dust (0.83 g, 12.8
mmol) and ammonium chloride (0.69 g, 12.8 mmol) were added and the reaction was stirred
for one hour. The suspension was filtered through Celite and concentrated to afford the crude
product as a yellow oil. The crude product was purified using flash silica chromatography
[1:4 EtOAc:Petroleum ether, Rf 0.18] to afford (S)-4-benzyl-3-((S)-3-hydroxypent-4-enoyl)-
5,5-dimethyloxazolidin-2-one 10 (0.79 g, 2.6 mmol, 82%) as a colourless oil. \[^{1}\text{H} \text{NMR} (300
MHz, CDCl}_3): \delta \text{H} 7.33-7.24 (5H, m, Ph), 5.89 (1H, ddd, J = 17.3, 10.5, 5.4 Hz, CH=CH}_2),
5.32 (1H, d, J = 17.3 Hz, CH=CHB), 5.15 (1H, d, J = 10.5 Hz, CH=CHB)), 4.58-4.50
(2H, m, CHO, CHN), 3.16-3.09 (3H, m, CHA,BPh, CHO), 2.93-2.85 (2H, m,
CHA,BPh, CHO), 1.39 (3H, s, C(CH}_3)CH}_3), 1.37 (3H, s, C(CH}_3)(CH}_3)); \[^{13}\text{C} \{^{1}\text{H}\} \text{NMR}
(75 MHz, CDCl}_3): \delta \text{C} 172.3, 152.7, 138.8, 136.8, 129.1, 128.9, 127.0, 115.5, 82.7, 68.9, 63.5,
42.6, 35.6, 28.6, 22.3; IR cm\(^{-1}\) \nu = 3483 (OH), 1771 (C=O), 1694 (C=O\(\text{am})\); HRMS: \text{m/z} (ES)
304.1511, [M+H]^+ requires 304.1548; \[^{20}\alpha \]D \ = \ -52.0 (c = 0.50 g/100 mL in
CHCl}_3).

2-Deoxy-d-ribonolactone - (4S,5R)-4-Hydroxy-5-(hydroxymethyl)dihydrofuran-2(3H)-
one, 11: OsO\(_4\) (16 mg, 0.06 mmol) was added to a solution of 10 (200 mg, 0.66 mmol) in
acetone/water (8:1, 2.5 mL) followed by addition of NMO (60% by weight in water, 0.12
mL, 0.73 mmol) according to the general procedure to afford the crude product as black oil.
Purification via column chromatography afforded 11 (76 mg, 0.57 mmol, 87%, 9:1 dr).
(4S,5R)-major: \[^{1}\text{H} \text{NMR} (500 MHz, MeOD): \delta \text{H} 4.46 (1H, dt, J = 6.7, 2.3 Hz, CHOH),
4.40-4.39 (1H, m, CHCH}_2OH), 3.79 (1H, dd, J = 12.4, 3.3 Hz, CHA,BOH), 3.72 (1H, dd, J =
12.4, 3.7 Hz, CHA,BOH), 2.94 (1H, dt, J = 17.9, 6.8 Hz, CHA,BC=O), 2.40 (1H, dd, J =
17.9, 2.5 Hz, CHA,BC=O); \[^{13}\text{C} \{^{1}\text{H}\} \text{NMR} (75 MHz, MeOD): \delta \text{C} 179.5, 91.0, 70.6, 63.4,
40.0; (4S,5S)-minor: $^1$H NMR (500 MHz, MeOD): δ$_H$ 4.63-4.50 (2H, m, CHOH & CHCH$_2$OH), 3.90 (2H, dd, $J = 5.4$, 1.6 Hz, CH$_2$OH), 2.93 (1H, dd, $J = 17.6$, 5.9 Hz, CH$_A$H$_B$C=O), 2.45 (1H, dd, $J = 17.7$, 1.6 Hz, CH$_A$CH$_B$C=O); $^{13}$C($^1$H) NMR (75 MHz, MeOD): δ$_C$ 179.5, 87.4, 69.8, 62.1, 40.9; IR cm$^{-1}$ ν = 3356 (OH), 1749 (C=O); HRMS: $m/z$ (ES) 155.0333, C$_5$H$_8$NaO$_4$, [M+Na]$^+$ requires 155.0320; [$\alpha$]$^D_{25}$ = +4.0 ($c = 0.50$ g/100 mL in MeOH) [lit: [$\alpha$]$^D_{25}$ = +2.17 ($c = 0.6$ g/100 mL in MeOH)].$^{12a}$

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**Supporting Information**

$^1$H, $^{13}$C($^1$H), spectra of all aldol products (1a-k, 9) and hydroxy-$\gamma$-butyrolactones (6a-k, 8, 11) as well as $^1$H NOE spectra of all lactones. This material is available free of charge via the Internet at http://pubs.acs.org.

**References**


(17) The observed diastereoselectivity is consistent with that observed for dihydroxylation of acrolein aldol 1c. Studies on the effect of the α-substituent indicate that performing the dihydroxylation reaction on unsaturated aldol 10 should have little effect on the diastereoselectivity.


(25) A vicinal coupling constant between the \( C_3 \) proton and the \( C_5 \) proton of \( ^3J = 4.0 \) Hz was observed for the minor 5S diastereoisomer, which is consistent with an anti-relationship between these protons in this diastereoisomer.

(26) In a subsequent publication Dias et al. reported (3S,4S,5R)-stereochemistry for \( \gamma \)-butyrolactone 16a derived from the dihydroxylation/lactonisation of aldol 14a, which is different to that reported in his original paper (ref. 5h), but is consistent with our results, see: Dias, L. C.; Finelli, F. G.; Conegero, L. S.; Krogh, R.; Andricopulo, A. D. *Eur. J. Org. Chem.* 2010, 6748-6759.
