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Opening of Carbohydrate 5,6-Epoxides with Chiral Acetate and Propionate Enolate Equivalents Attached to the Iron Chiral Auxiliary [(C5H5)Fe(CO)(PPh3)].

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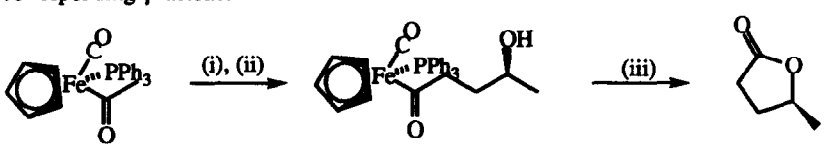
Abstract: The lithium enolate derived from the chiral iron acetyl complex (*RS*)-[(C5H5)Fe(CO)(PPh3)COCH3] (*RS*)-**1** opens, in the presence of boron trifluoride etherate, the carbohydrate 5,6-epoxides, 5,6-anhydro-3-*O*-benzyl-1,2-*O*-isopropylidene-α-D-allofuranose **3**, 5,6-anhydro-3-*O*-benzyl-1,2-*O*-isopropylidene-β-L-talonofuranose **4**, 5,6-anhydro-3-*O*-benzyl-1,2-*O*-isopropylidene-α-D-glucofuranose **5**, and 5,6-anhydro-3-*O*-benzyl-1,2-*O*-isopropylidene-β-L-idofuranose **6** to generate after decomplexation the doubly homologated γ-lactones 3-*O*-benzyl-6,7-dideoxy-1,2-*O*-isopropylidene-α-D-*allo*-octafuranurono-5,8-lactone **15**, 3-*O*-benzyl-6,7-dideoxy-1,2-*O*-isopropylidene-β-L-*talono*-octafuranurono-5,8-lactone **16**, 3-*O*-benzyl-6,7-dideoxy-1,2-*O*-isopropylidene-α-D-*gluco*-octafuranurono-5,8-lactone **17**, and 3-*O*-benzyl-6,7-dideoxy-1,2-*O*-isopropylidene-β-L-*ido*-octafuranurono-5,8-lactone **18** respectively. The lithium enolate derived from the homochiral iron propionyl complexes (*R*)-[(C5H5)Fe(CO)(PPh3)COCH2CH3] (*R*)-**2** and (*S*)-[(C5H5)Fe(CO)(PPh3)COCH3] (*S*)-**2** convert after decomplexation 5,6-anhydro-3-*O*-benzyl-1,2-*O*-isopropylidene-α-D-glucofuranose **5** to 7(*R*)-methyl-3-*O*-benzyl-6,7-dideoxy-1,2-*O*-isopropylidene-α-D-*gluco*-octafuranurono-5,8-lactone **20** and 7(*S*)-methyl-3-*O*-benzyl-6,7-dideoxy-1,2-*O*-isopropylidene-α-D-*gluco*-octafuranurono-5,8-lactone **22** respectively.

The iron chiral auxiliary [(C5H5)Fe(CO)(PPh3)] imparts excellent levels of stereocontrol and enantiomeric recognition in a variety of carbon-carbon bond forming reactions involving the reactions of enolates derived from attached acyl ligands.[1] In particular, the lithium enolate derived from the iron acetyl complex **1** opens simple epoxides such as propylene oxide in the presence of diethyl aluminium chloride at the least substituted end with a high degree of chiral recognition allowing access to the corresponding γ-lactone after decomplexation[2] (Scheme 1). Essentially no chiral recognition is observed if boron trifluoride is employed as the Lewis acid. Both reactions, however, achieve overall the double homologation of a monosubstituted epoxide to the corresponding γ-lactone.

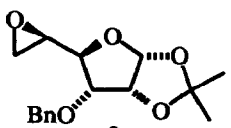


(*RS*)-**1**

Scheme 1:
Reagents (i) BuLi, THF, -78°C; (ii) (*RS*)-propylene oxide, Et_2AlCl, -78°C; (iii) Br_2, CH_2Cl_2, -78°C.

In the case of the enolate derived from the iron propionyl complex [(C5H5)Fe(CO)(PPh3)COCH2CH3] **2** opening epoxides, the configuration of the newly formed stereogenic centre is entirely dependent on the iron

chiral auxiliary not on the epoxide configuration.[3,4] With this information to hand it seemed appropriate to investigate the opening of carbohydrate derived epoxides with the enolates derived from **1** and **2** to determine whether a versatile double homologation methodology could be established. We describe herein our first results in this area where we have investigated the double homologation of the four readily available hexose 5,6-epoxides **3-6**, all derived from D-glucose.



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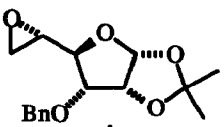

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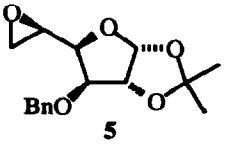

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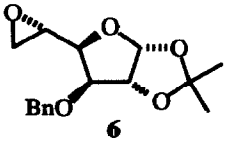

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Results and discussion:

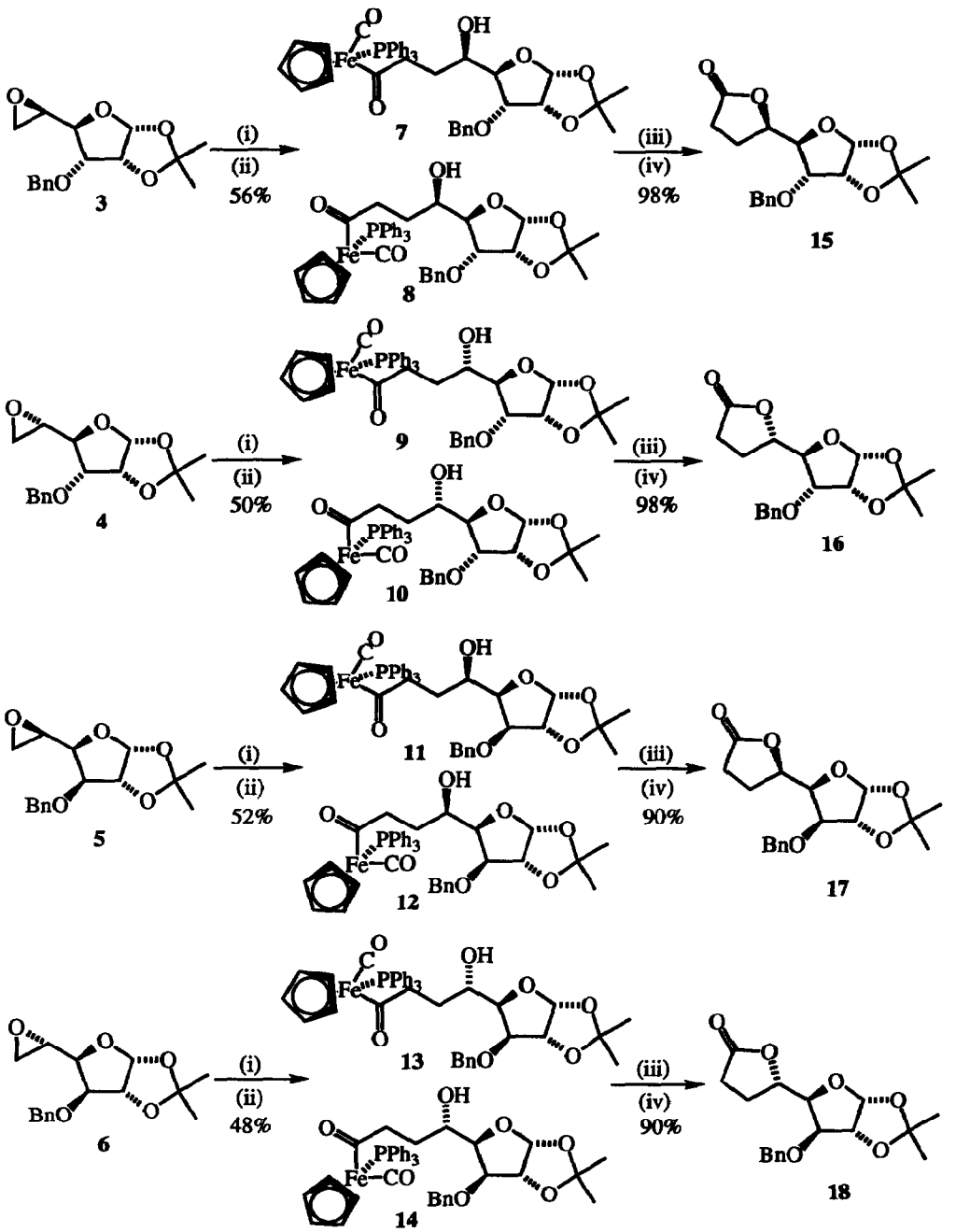
The iron acetyl complex (*RS*)-**1** in tetrahydrofuran at -78°C was treated with butyl lithium to generate the corresponding lithium enolate. No reaction was observed on addition of epoxide **3** with or without the subsequent addition of an excess (5 equivalents) of diethyl aluminium chloride. However, addition of epoxide **3** to the lithium enolate from (*RS*)-**1** followed by three equivalents of boron trifluoride etherate gave, after work up, an inseparable 1:1 mixture of the diastereoisomers **7** and **8**, epimeric at iron (Scheme 2). The ratio was evident from the ^{1}H-nmr spectrum which contained two cyclopentadienyl signals of equal intensity. Treatment of the epoxides **4**, **5** and **6** under similar conditions also generated, in each case, inseparable 1:1 mixtures of the corresponding iron epimers (Scheme 2).

Decomplexation of the mixture of **7** and **8** with bromine generated the lactone **15** in 98% yield (Scheme 2). The high yield of **15** demonstrates that both epimers **7** and **8** generate the same lactone **15** consistent with them being only epimeric at iron. Similar decomplexations of the epimeric mixtures from the other epoxides also generated the corresponding γ-lactones **16**, **17** and **18** in high yields (Scheme 2).

The above results show that the carbohydrate 5,6-epoxides **3-6** are relatively unsusceptible to opening by the enolate from the iron acetyl complex **1** even in the presence of excess Lewis acid presumably because of the alternative coordination sites available to the Lewis acid. However excess of the strong Lewis acid boron trifluoride etherate and prolonged reaction times do effect the epoxide opening. As expected regioselective opening at the 6-position is observed with no chiral discrimination being observed in any of the four cases studied.[2] The generation of iron epimers could have been avoided by the use of homochiral iron acetyl complex **1**, however, this was unnecessary as the auxiliary is removed in the decomplexation step to generate, with overall double homologation of the starting epoxides, the corresponding γ-lactones.

In contrast to the case of the iron acetyl complex (*RS*)-**1**, opening of carbohydrate 5,6-epoxides with the enolate derived from the iron propionyl complex [$(C_5H_5)Fe(CO)(PPh_3)COCH_2CH_3$] **2** generates a new stereogenic centre at C-7. Previous work with *cis*- and *trans*-but-2-ene oxides[3,4] had shown that the new stereogenic centre is controlled entirely by the iron chiral auxiliary and not by the epoxide configurations. It would therefore be inappropriate to use racemic **2** as this would inevitably lead to C-7 epimeric γ-lactone products after removal of the iron auxiliary.

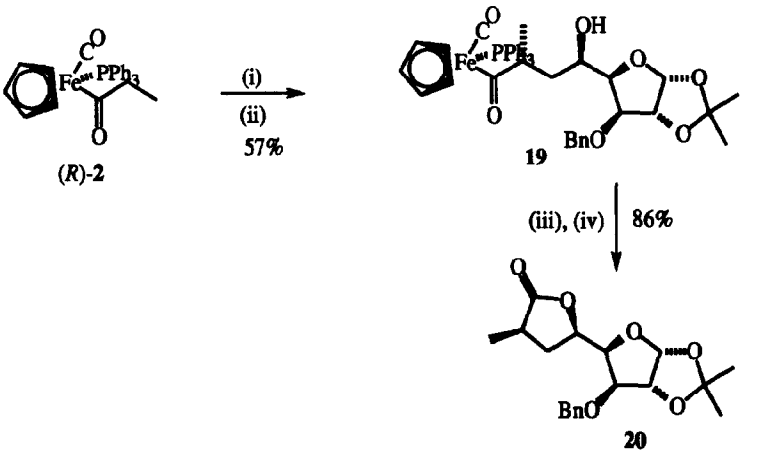
Treatment of the lithium enolate from homochiral (*R*)-**2** with epoxide **5** in the presence of boron trifluoride etherate generated complex **19** as a single diastereoisomer (Scheme 3). The ^{1}H nmr spectrum of **19** contained only one singlet for the cyclopentadienyl ligand and only one methyl doublet for the C-7 methyl group. The appearance of the methyl group at δ 0.38 is characteristic of the (*R*)-configuration at C-7 relative to



Scheme 2:

Reagents: (i) (*RS*)-1/BuLi, -78°C, THF; (ii) $BF_3.Et_2O$ (3 equiv.); (iii) Br_2, -78°C; (iv) Et_3N, -78°C.

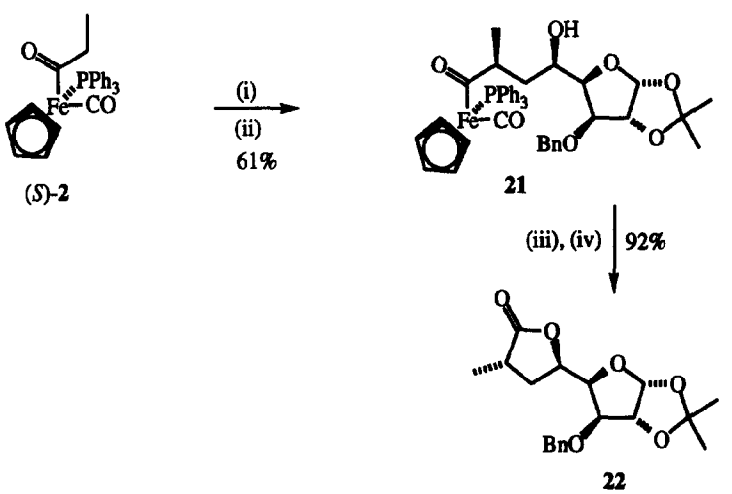
the known absolute (*R*)-configuration at iron.[5] Since all the other stereogenic centres in **19** derive unchanged from epoxide **5** the structure of **19** is established. Decomplexation of **19** generated the *cis*-γ-lactone **20** (Scheme 3).



Scheme 3:

Reagents: (i) BuLi, THF, -78°C; (ii) epoxide **5**; (iii) Br_2, -78°C; (iv) Et_3N, -78°C.

Treatment of the lithium enolate from homochiral (*S*)-**2** with epoxide **5** in the presence of boron trifluoride etherate generated complex **21** as a single diastereoisomer (Scheme 4). The ^1H nmr spectrum of **21** contained only one doublet for the cyclopentadienyl ligand and only one methyl doublet for the C-7 methyl group. Again the appearance of the methyl group at δ 0.38 allows the assignment of the (*S*)-configuration at C-7 relative to the known absolute (*S*)-configuration at iron.[5] Since all the other stereogenic centres in **21** derive unchanged from epoxide **5** the structure of **21** is established. Decomplexation of **21** generated the *trans*-γ-lactone **22** (Scheme 4).



Scheme 4:

Reagents: (i) BuLi, THF, -78°C; (ii) epoxide **5**; (iii) Br_2, -78°C; (iv) Et_3N, -78°C.

Thus the carbohydrate 5,6-epoxide **5** can be doubly homologated by the enolate from the iron propionyl complex **2** with the new C-7 stereogenic centre being completely controlled by the iron chiral auxiliary allowing access selectively, by appropriate choice of the configuration of the chiral auxiliary, to the *cis*- and *trans*-γ-lactones **20** and **22** epimeric at C-7.

Experimental:

^{1}H nmr spectra were recorded on a Bruker WH 300 (300.13 MHz) spectrometer in $CDCl_3$ solutions, unless otherwise stated. ^{13}C and ^{31}P nmr spectra were recorded on a Bruker AM250 (62.90 MHz and 101.26 MHz respectively) spectrometer in $CDCl_3$ solutions. ^{1}H and ^{13}C nmr spectra were referenced to tetramethylsilane using internal solvent peaks. ^{31}P nmr spectra were referenced to external 85% orthophosphoric acid. In the experimental section, ^{13}C and ^{31}P nmr data are described in terms of the proton decoupled (broad band) spectra. All chemical shifts are quoted as δ values, and coupling constants (*J*) given in Hertz. Mass spectra were obtained on a V.G. Micromass ZAB IF instrument, using field desorption techniques unless otherwise stated. F.A.B. refers to fast atom bombardment techniques. Elemental microanalyses were carried out by Mrs. V. Lamburn of the Dyson Perrins Laboratory. Optical rotations were measured on a Perkin-Elmer 241 polarimeter. Epoxides **3**, **4**, **5** and **6** were prepared by literature methods[6] and the iron acyl complexes (*RS*)-**1**, (*R*)-**2** and (*S*)-**2** are commercially available.[7]

General procedure for the reaction of the iron acyls (RS)-**1**, (R)-**2** *and* (S)-**2** *with epoxides* **3**, **4**, **5** *and* **6**.

Butyl lithium (1.32 mmol) was added to the iron acyl (1.10 mmol) in THF (15 ml) at -78°C. The resulting dark red solution was stirred at -78°C for 1.5 hrs. The epoxide (1.10 mmol) was then added, followed by dropwise addition of the $BF_3.OEt_2$ (3.30 mmol). The reaction mixture was stirred for 8 hrs at -78°C and then quenched with methanol (1 ml), followed by addition of alumina (grade V, 2.5 g). Removal of the solvent under reduced pressure gave an orange powder. This powder was loaded onto the top of a silica gel column and flash chromatography was performed eluting with a 10:1 mixture of petroleum ether/ether. Removal of the solvent under reduced pressure yielded the product as an orange solid.

General method for the decomplexation of γ-hydroxy iron complexes to γ-lactones.

A solution of the iron complex in THF was cooled to -78°C; bromine (1.2 eq) was added and the resultant green solution allowed to stir at -78°C for 1 hr. Excess triethylamine was then added, and the solution was then allowed to warm to ambient temperature. Removal of solvents under reduced pressure followed by extraction of the solid residue with ether resulted in a green solution. Standing in air for 3 days typically led to the precipitation of a brown solid; filtering through a small plug of flash silica gave a pale yellow solution, which on removal of the solvent gave the desired γ-lactone as a yellow oil. Final purification was performed by flash chromatography on silica gel, eluting with petrol/ether, or by Kugelröhr distillation.

Reaction of 5,6-anhydro-3-O-benzyl-1,2-O-isopropylidene-α-D-allofuranose **3** *with iron acetyl* (RS)-**1**

Treatment of the enolate from (*RS*)-**1** with epoxide **3** as above generates a 1:1 mixture of **7** and **8** (56% combined yield); (Found C 67.43, H 6.03%. $C_{42}H_{43}FeO_7P$ requires C 67.57, H 5.81%); υ_{max} 3450 (OH), 1910 (CO), 1600 (C=O) cm^{-1}; δ_H 7.60-7.31 (20H, m, 4 x C_6H_5), 5.71 (1H, d, *J* 2.4, H-1), 4.81-4.50 (3H, m, H-2 and CH_2Ph), 4.44 (5H, d, J_{PH} 1.1, C_5H_5), 4.41 (5H, s, C_5H_5), 3.90 (2H, m, H-3 and H-4), 3.52-2.73 (4H, m, H-5, OH and 2 x H-7), 1.59 (3H, s, CH_3), 1.25 (3H, s, CH_3), 1.25 (2H, m, 2 x H-6); δ_C 138.1 (s, C_6H_5, C_{ipso}), 136.3 (d, J_{PC} 42.0, PPh_3, C_{ipso}), 133.4 (d, J_{PC} 10.0, PPh_3, C_{ortho}), 128.4, 128.3, 128.1, 127.9 (4 x s, 4 x C_{aryl}), 112.8 (s, $C(CH_3)_2$), 104.0 (s, CH(OH)), 62.8 (s, C-7), 27.6 (s, CH_3), 26.8 (s, CH_3), 26.6 (s, CH_3); *m/z* 747 $(M+H)^+$, 746 (M^+).

Decomplexation of the mixture of **7** and **8** generates *3-O-benzyl-6,7-dideoxy-1,2-O-isopropylidene-α-D-allo-octafuranurono-5,8-lactone* **15** (98%); m.p. 149.5-150.5°C; (Found C 64.79, H 6.94%. $C_{18}H_{22}O_6$ requires C 64.66, H 6.63%); $[\alpha]_D^{20}$ +61.4 (*c* 0.07, $CHCl_3$); υ_{max} 1760 (C=O) cm^{-1}; δ_H 7.35 (5H, m, C_6H_5), 5.75 (1H, d, *J* 3.6, H-1), 4.84-4.54 (4H, m, CH_2Ph, H-5 and H-2), 4.28 (1H, dd, *J* 2.0 and 2.2, H-4), 3.72 (1H, dd, *J* 4.3 and 4.2, H-3), 2.45 (2H, m, 2 x H-7), 2.15 (2H, m, 2 x H-6), 1.61 (3H, s, CH_3), 1.38 (3H, s, CH_3); δ_C 177.0 (s, C=O), 137.1 (s, C_6H_5, C_{ipso}), 128.8 (s, C_6H_5, C_{ortho}), 128.5 (s, C_6H_5, C_{meta}), 128.4 (s, C_6H_5, C_{para}), 113.5 (s, $C(CH_3)_2$), 104.0 (s, C-1), 78.6 (s, C-2), 77.7 (s, C-3), 77.1 (s, C-4), 76.9 (s, C-5), 72.1 (s, CH_2Ph), 27.9 (s, C-6), 26.7 (s, CH_3), 26.4 (s, CH_3), 21.0 (s, C-7); *m/z* 352 $(M+NH_4)^+$, 335 $(M+H)^+$.

Reaction of 5,6-anhydro-3-O-benzyl-1,2-O-isopropylidene-β-L-talonofuranose **4** *with iron acetyl (RS)-***1**

Treatment of the enolate from (*RS*)-**1** with epoxide **4** as above generates a 1:1 mixture of **9** and **10** (50% combined yield); (Found C 67.32, H 5.77%. $C_{42}H_{43}FeO_7P$ requires C 67.57, H 5.81%); υ_{max} 3500 (OH), 1910 (CO), 1610 (C=O) cm^{-1}; δ_H 7.60-7.20 (20H, m, 4 x C_6H_5), 5.71 (1H, d, *J* 2.9, H-1), 4.81-4.53 (3H, m, H-2 and CH_2Ph), 4.42 (5H, d, J_{PH} 1.3, C_5H_5), 4.34 (5H, s, C_5H_5), 3.96-3.71 (3H, m, H-4, H-3 and H-5), 3.41-2.90 (3H, m, 2 x H-7 and OH), 1.85 (1H, m, H-6), 1.63 (3H, s, CH_3), 1.34 (3H, s, CH_3), 1.30 (1H, m, H-6); δ_C 138.0 (s, C_6H_5, C_{ipso}), 136.1 (d, J_{PC} 43.0, PPh_3, C_{ipso}), 133.1 (s, PPh_3, C_{ortho}), 129.8 (s, PPh_3, C_{para}), 128.3, 128.1, 128.0, 127.9 (4 x s, 4 x C_{aryl}), 112.6 (s, $C(CH_3)_2$), 104.3 (s, C-1), 85.0 (s, C_5H_5), 78.2 (s, C-2), 78.0 (s, C-3), 77.6 (s, C-4), 71.4 (s, CH_2Ph), 63.2 (s, CH(OH)), 62.9 ($COCH_2$), 29.4 (s, C-6), 26.71 (s, CH_3), 26.3 (s, CH_3); *m/z* 747 $(M+H)^+$, 746 (M^+).

Decomplexation of the mixture of **9** and **10** generates *3-O-benzyl-6,7-dideoxy-1,2-O-isopropylidene-β-L-talono-octafuranurono-5,8-lactone* **16** (98%); m.p. 137-138°C; (Found C 64.84, H 6.90%. $C_{18}H_{22}O_6$ requires C 64.66, H 6.63%); $[\alpha]_D^{20}$ +63.6 (*c* 0.12, $CHCl_3$); υ_{max} 1765 (C=O) cm^{-1}; δ_H 7.32 (5H, m, C_6H_5), 5.70 (1H, d, *J* 3.7, H-1), 4.79-4.52 (4H, m, CH_2Ph, H-5 and H-2), 4.07 (1H, m, H-4), 3.95 (1H, dd, *J* 4.1 and 4.3, H-3), 2.66 (2H, m, 2 x H-7), 2.35 (2H, m, 2 x H-6), 1.59 (3H, s, CH_3), 1.36 (3H, s, CH_3); δ_C 177.9 (s, C=O), 135.5 (s, C_6H_5, C_{ipso}), 128.6 (s, C_6H_5, C_{ortho}), 128.2 (s, C_6H_5, C_{meta}), 127.0 (s, C_6H_5, C_{para}), 113.3 (s, $C(CH_3)_2$), 104.3 (s, C-1), 80.3 (s, C-2), 77.4(s, C-4), 76.5 (s, C-5), 27.7 (s, C-6), 26.7 (s, CH_3), 26.3 (s, CH_3), 24.2 (s, C-7); *m/z* 352 $(M+NH_4)^+$, 335 $(M+H)^+$.

Reaction of 5,6-anhydro-3-O-benzyl-1,2-O-isopropylidene-α-D-glucofuranose **5** *with iron acetyl (RS)-***1**

Treatment of the enolate from (*RS*)-**1** with epoxide **5** as above generates a 1:1 mixture of **11** and **12** (52% combined yield); (Found C 67.84, H 5.56%. $C_{42}H_{43}FeO_7P$ requires C 67.57, H 5.81%); υ_{max} 3400 (OH), 1915 (CO), 1600 (C=O) cm^{-1}; δ_H 7.60-7.20 (20H, m, 4 x C_6H_5), 5.88 (1H, d, *J* 3.8, H-1), 4.66 (2H, s, CH_2Ph), 4.50 (1H, dd, *J* 3.8 and 3.7, H-2), 4.44 (5H, d, J_{PH} 1.1, C_5H_5), 4.43 (5H, d, *J* 1.1, C_5H_5), 4.04 (1H, m, H-4), 3.84-3.75 (1H, m, H-3), 3.68-3.06 (4H, m, 2 x H-7, H-5 and OH), 1.48 (3H, s, CH_3), 1.30 (3H, s, CH_3), 1.27-1.24 (2H, m, 2 x H-6); δ_C 219.9 (s, CO), 138.1 (s, C_6H_5, C_{ipso}), 136.3 (d, J_{PC} 43.0, PPh_3, C_{ipso}), 133.3 (d, J_{PC} 9.5, PPh_3, C_{ortho}), 129.7 (s, PPh_3, C_{para}), 128.4, 128.1, 127.9, 127.7, 127.6 (5 x s, 5 x C_{aryl}), 111.4 (s, $C(CH_3)_2$), 105.1 (s, C-1), 85.2 (s, C_5H_5), 84.6 (s, C-2), 82.8 (s, C-3), 82.1 (s, C-4), 72.4 (s, CH_2Ph), 68.4 (s, C(OH)), 62.9 (s, $COCH_2$), 29.7 (s, C-6), 26.8 (s, CH_3), 26.3 (s, CH_3); δ_C 72.20 (s, PPh_3); *m/z* 747 $(M+H)^+$, 746 (M^+).

Decomplexation of the mixture of **11** and **12** generates *3-O-benzyl-6,7-dideoxy-1,2-O-isopropylidene-α-D-gluco-octafuranurono-5,8-lactone* **17** (90%); (Found C 64.95, H 6.78%. $C_{18}H_{22}O_6$ requires C 64.66, H 6.63%); $[\alpha]_D^{20}$ -50.3 (*c* 4.10, $CHCl_3$); υ_{max} 1765 (C=O) cm^{-1}; δ_H 7.32 (5H, m, C_6H_5), 5.92 (1H, d, *J*

3.7, H-1), 4.80 (1H, m, H-5), 4.65 (3H, m, CH_2Ph and H-2), 4.20 (1H, dd, *J* 7.3 and 7.1, H-4), 4.06 (1H, d, *J* 3.3, H-3), 2.53 (2H, m, 2 x H-7), 2.36 (2H, m, 2 x H-6), 1.48 (3H, s, CH_3), 1.31 (3H, s, CH_3); δ_C 177.5 (s, C=O), 137.5 (s, C_6H_5, C_{ipso}), 128.7 (s, C_6H_5, C_{ortho}), 128.2 (s, C_6H_5, C_{meta}), 127.9 (s, C_6H_5, C_{para}), 112.2 (s, $C(CH_3)_2$), 105.4 (s, C-1), 82.5(s, C-2), 81.8 (s, C-3), 81.3 (s, C-4), 76.6 (s, C-5), 72.5 (s, CH_2Ph), 27.9 (s, C-7), 26.7 (s, CH_3), 26.1 (s, CH_3), 24.7 (s, C-6); *m/z* 352 $(M+NH_4)^+$, 335 $(M+H)^+$.

Reaction of 5,6-anhydro-3-O-benzyl-1,2-O-isopropylidene-β-L-idofuranose **6** *with iron acetyl (RS)-***1**

Treatment of the enolate from (*RS*)-**1** with epoxide **6** as above generates a 1:1 mixture of **13** and **14** (48%); (Found C 67.71, H 5.60%. $C_{42}H_{43}FeO_7P$ requires C 67.57, H 5.81%); υ_{max} 3450 (OH), 1910 (CO), 1600 (C=O) cm^{-1}; δ_H 7.60-7.21 (20H, m, 4 x C_6H_5), 5.95 (1H, d, *J* 3.8, H-1), 5.93 (1H, d, *J* 3.8, H-1'), 4.73-4.50 (3H, m, CH_2Ph and H-2), 4.44 (5H, d, J_{PH} 1.1, C_5H_5), 3.92-3.80 (2H, m, H-4 and H-3), 3.21-2.60 (4H, m, 2 x H-7, H-5 and OH), 1.48 (3H, m, CH_3), 1.32 (3H, m, CH_3), 1.42-1.22 (2H, m, 2 x H-6); δ_C 138.0 (s, C_6H_5, C_{ipso}), 136.4 (d, J_{PC} 44.0, PPh_3, C_{ipso}), 133.4 (s, PPh_3, C_{ortho}), 129.8 (s, PPh_3, C_{meta}), 129.4 (s, PPh_3, C_{para}), 128.4, 128.2, 128.0, 127.7 (4 x s, 4 x C_{aryl}), 111.5 (s, $C(CH_3)_2$), 105.1 (s, C-1), 85.3 (s, C_5H_5), 84.8 (s, C-2), 82.8 (s, C-3), 82.3 (s, C-4), 72.6 (s, CH_2Ph), 69.1 (s, CH(OH)), 63.3 (s, $COCH_2$), 29.5 (s, C-6), 26.9 (s, CH_3), 26.4 (s, CH_3); δ_P 72.40 (s, PPh_3); *m/z* 747 $(M+H)^+$, 746 (M^+).

Decomplexation of the mixture of **13** and **14** generates *3-O-benzyl-6,7-dideoxy-1,2-O-isopropylidene-β-L-*ido*-octafuranurono-5,8-lactone* **18** (90%); (Found C 64.45, H 6.87%. $C_{18}H_{22}O_6$ requires C 64.66, H 6.63%); $[\alpha]_D^{20}$ -71.7 (*c* 0.18, $CHCl_3$); υ_{max} 1760 (C=O) cm^{-1}; δ_H 7.35 (5H, m, C_6H_5), 6.01 (1H, d, *J* 3.8, H-1), 4.90-4.40 (4H, m, CH_2Ph, H-5 and H-2), 4.22 (1H, dd, *J* 3.7 and 3.9, H-4), 4.03 (1H, d, *J* 3.7, H-3), 2.50 (2H, m, 2 x H-7), 2.15 (2H, m, 2 x H-6), 1.50 (3H, s, CH_3), 1.35 (3H, s, CH_3); δ_C 176.9 (s, C=O), 136.9 (s, C_6H_5, C_{ipso}), 128.8 (s, C_6H_5, C_{ortho}), 128.4 (s, C_6H_5, C_{meta}). 128.1 (s, C_6H_5, C_{para}), 112.3 (s, $C(CH_3)$), 105.7 (s, C-1), 82.2 (s, C-2), 81.9 (s, C-3), 81.6 (s, C-4), 78.8 (s, C-5), 71.8 (s, CH_2Ph), 28.0 (s, C-7), 26.8 (s, CH_3), 26.3 (s, CH_3), 23.5 (s, C-6); *m/z* 352 $(M+NH_4)^+$, 335 $(M+H)^+$.

Reaction of 5,6-anhydro-3-O-benzyl-1,2-O-isopropylidene-α-D-glucofuranose **5** *with iron propionyl (R)-***2**

Treatment of the enolate from (*R*)-**2** with epoxide **5** as above generates **19** (57%); (Found C 67.76, H 6.15%. $C_{43}H_{45}FeO_7P$ requires C 67.90, H 5.96%); $[\alpha]_D^{20}$ -121.3 (*c* 0.07, CH_2Cl_2); υ_{max} 3400 (OH), 1910 (CO), 1605 (C=O) cm^{-1}; δ_H 7.69-7.27 (20H, m, 4 x C_6H_5), 5.94 (1H, d, *J* 3.4, H-1), 4.72-4.60 (3H, m, H-2 and CH_2Ph), 4.45 (5H, s, C_5H_5), 4.14 (1H, bs, H-4), 4.02-3.98 (2H, m, H-5 and H-3), 3.50 (1H, m, H-7), 2.4 (1H, bs, OH), 1.49 (3H, s, CH_3), 1.32 (3H, m, CH_3), 1.51-1.42 (2H, m, 2 x H-6), 0.38 (3H, d, *J* 6.9, CH_3); δ_C 222.0 (s, CO), 137.4 (s, C_6H_4, C_{ipso}), 136.7 (d, J_{PC} 42.3, PPh_3, C_{ipso}), 133.4 (d, J_{PC} 9.4, PPh_3, C_{ortho}), 129.6 (s, PPh_3, C_{para}), 128.6 (s, C_{aryl}), 128.0 (d, J_{PC} 9.1, C_{meta}), 127.8 (s, C_{aryl}), 111.6 (s, $C(CH_3)_2$), 105.1 (s, C-1), 85.3 (s, C_5H_5), 83.2 (s, C-2), 82.6 (s, C-3), 82.2 (s, C-4), 72.3 (s, CH_2Ph), 67.8 (s, C(OH)), 64.3 (s, COCH), 37.4 (s, C-6), 26.8 (s, CH_3), 26.3 (s, CH_3), 15.2 (s, CH_3); δ_P 71.53 (s, PPh_3); *m/z* 761 $(M+H)^+$, 760 (M^+).

Decomplexation of **19** generates *7*(R)-methyl-*3-O-benzyl-6,7-dideoxy-1,2-O-isopropylidene-α-D-*gluco*-octafuranurono-5,8-lactone* **20** (86%); (Found C 65.80, H 7.07%. $C_{19}H_{24}O_6$ requires C 65.50, H 6.94%); $[\alpha]_D^{20}$ +37.5 (*c* 3.2 $CHCl_3$); υ_{max} 1765 (C=O) cm^{-1}; δ_H 7.36 (5H, m, C_6H_5), 5.92 (1H, d, *J* 3.7, H-1), 4.65 (4H, m, H-2, H-5 and CH_2Ph), 4.09 (2H, m, H-3 and H-4), 2.60 (2H, m, H-7 and H-6), 1.88 (1H,

m, H-6), 1.50 (3H, s, CH_3), 1.33 (3H, s, CH_3), 1.30 (3H, d, *J* 6.7, CH_3); δ_C 179.1 (s, C=O), 137.3 (s, C_6H_5, C_{ipso}), 128.5, 128.3, 128.0 (3 x s, C_6H_5, $C_{ortho, meta, para}$), 112.1 (s, $C(CH_3)_2$), 105.2 (s, C-1), 82.6 (s, C-5), 82.2 (s, C-4), 81.8 (s, C-3), 73.9 (s, C-2), 72.7 (s, CH_2Ph), 35.0 (s, C-7), 34.6 (s, C-6), 26.9 (s, CH_3), 26.3 (s, CH_3), 15.3 (s, CH_3); *m/z* 366 $(M+NH_4)^+$, 349 $(M+H)^+$.

Reaction of 5,6-anhydro-3-O-benzyl-1,2-O-isopropylidene-α-D-glucofuranose **5** *with iron propionyl (S)-2.*

Treatment of the enolate from (*S*-**2** with epoxide **5** as above generates **21** (61%); (Found C 67.77, H 6.03%. $C_{43}H_{45}FeO_7P$ requires C 67.90, H 5.96%); $[\alpha]_D^{20}$ +114.0 (*c* 0.05, CH_2Cl_2); υ_{max} 3400 (OH), 1910 (CO), 1600 (C=O) cm^{-1}; δ_H 7.56-7.30 (20H, m, 4 x C_6H_5), 5.94 (1H, d, *J* 3.9, H-1), 4.73-4.47 (3H, m, H-2 and CH_2Ph), 4.45 (5H, d, J_{PH} 0.9, C_5H_5), 4.14 (1H, d, *J* 2.9, H-4), 4.05-3.94 (2H, m, H-3, H-5), 3.49 (1H, d, *J* 7.1, OH), 3.44 (1H, m, COCH), 1.88 (1H, m, H-6), 1.50 (3H, s, CH_3), 1.35 (1H, m, H-6), 1.32 (3H, s, CH_3), 0.38 (3H, d, *J* 6.9 Hz, CH_3); δ_C 286.5 (s, C=O), 220.9 (d, J_{PC} 31.0, CO), 137.5 (s, C_6H_5, C_{ipso}), 136.5 (d, J_{PC} 42.9, PPh_3, C_{ipso}), 133.6 (s, PPh_3, C_{ortho}), 133.4 (s, PPh_3, C_{meta}), 129.6, 128.5, 128.0, 127.9(4 x s, 4 x C_{aryl}), 111.4 (s, $C(CH_3)_2$), 105.0 (s, C-1), 85.3 (s, C_5H_5), 82.8 (s, C-2), 82.5 (s, C-1), 72.4 (s, CH_2Ph), 67.9 (s, C(OH)), 64.3 (s, COCH), 36.7 (s, C-6), 26.7 (s, CH_3), 26.3 (s, CH_3), 14.6 (s, CH_3); δ_P 72.10 (s, PPh_3); *m/z* 761 $(M+H)^+$.

Decomplexation of **21** generates *7*(S)-methyl-*3-O-benzyl-6,7-dideoxy-1,2-O-isopropylidene-α-D*-gluco-*octafuranurono-5,8-lactone* **22** (92%); (Found C 65.23, H 6.66%. $C_{19}H_{24}O_6$ requires C 65.50, H 6.94%); $[\alpha]_D^{20}$ -40.8 (*c* 1.95, CH_2Cl_2); υ_{max} 1760 (C=O) cm^{-1}; δ_H 7.34 (5H, m, C_6H_5), 5.93 (1H, d, *J* 3.6, H-1), 4.79-4.62 (4H, m, H-2, H-5 and CH_2Ph), 4.22-4.05 (2H, m, H-4 and H-3), 2.89-2.55 (2H, m, H-7, H-6), 2.13-1.96 (1H, m, H-6), 1.49 (3H, s, CH_3), 1.33 (3H, m, CH_3), 1.29 (3H, d, *J* 7.0, CH_3); δ_C 179.7 (s, C=O), 137.4 (s, C_6H_5, C_{ipso}), 128.5, 128.0, 127.7 (3 x s, C_6H_5, $C_{ortho, meta, para}$), 112.1 (s, $C(CH_3)_2$), 105.3 (s, C-1), 82.7 (s, C-5), 82.0 (s, C-4), 80.8 (s, C-3), 74.3 (s, C-2), 72.7 (s, CH_2Ph), 33.4 (s, C-7), 32.5 (s, C-6), 26.9 (s, CH_3), 26.2 (s, CH_3), 15.7 (s, CH_3); *m/z* 366 $(M+NH_4)^+$, 349 $(M+H)^+$.

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