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Synthesis of novel chiral phosphines from α,α-trehalose

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Abstract

New disaccharide chiral phosphines, such as 4,6-*O*-benzylidene-2-(diphenylphosphino)-2-deoxy-α-D-altropyranosyl-(1,1)-4,6-*O*-benzylidene-2-(diphenylphosphino)-2-deoxy-α-D-altropyranoside **1** and 2-(diphenylphosphino)-2-deoxy-4,6-*O*-isopropylidene-α-D-altropyranosyl-(1,1)-2-(diphenylphosphino)-2-deoxy-4,6-*O*-isopropylidene-α-D-altropyranoside **9**, were prepared from α,α-trehalose. We also succeeded in the synthesis of polyhydroxy chiral diphosphine 2-(diphenylphosphino)-2-deoxy-α-D-altropyranosyl-(1,1)-2-(diphenylphosphino)-2-deoxy-α-D-altropyranoside **5** by deprotection of isopropylidene groups.

1. Introduction

The design and synthesis of chiral ligands are of significant importance in the development of transition metal-catalyzed asymmetric reactions.[1] Carbohydrates, especially monosaccharides, have received a great deal of attention as a chiral source of ligands, because they exist widely in nature and have some advantages for asymmetric synthesis, such as ready availability and many stereogenic centers in their skeletons. While many phosphine and phosphinite ligands derived from monosaccharides have been reported,[2] the types of chiral phosphines in which the phosphorus atoms are attached directly to the secondary carbons of a sugar are few in number. They are somewhat difficult to make, since the introduction of a phosphorus atom on the secondary carbon of sugars by the nucleophilic replacement competes with undesired elimination reactions. Recently, the groups of Wardell[3] and Shi[4] reported the preparation of 2- and 3-phosphinosugars in high yields by the nucleophilic ring-opening reactions of methyl 2,3-anhydro-4,6-*O*-benzylidene-α-D-allopyranoside and methyl 2,3-anhydro-4,6-*O*-benzylidene-α-D-mannopyranoside, respectively.

In contrast to many excellent ligands derived from monosaccharides, disaccharide chiral ligands have been less studied.[5] Recently, we reported a new preparative method of novel disaccharide phosphinites

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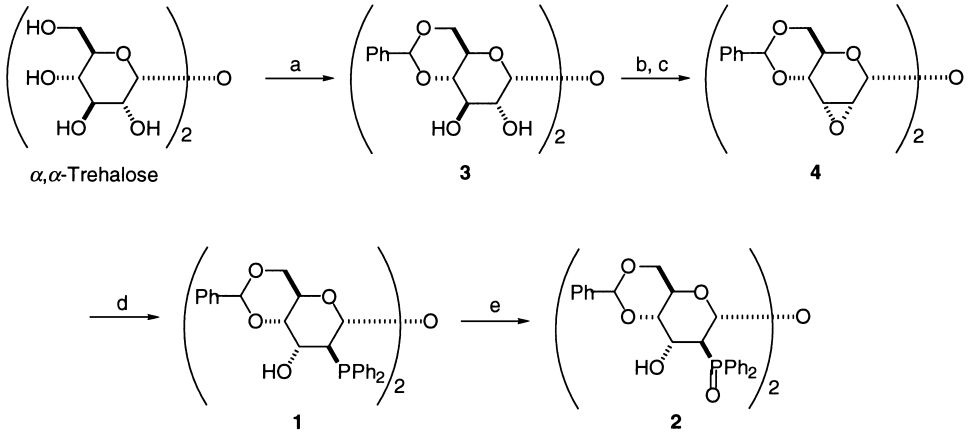
from α,α-trehalose which functioned as chiral ligands for asymmetric Rh-catalyzed hydrogenation of enamides to afford both enantiomers of amino acid derivatives.[6] We also succeeded in a preparation of water-soluble disaccharide phosphinite chiral ligands having polyhydroxy groups from α,α- and β,β-trehaloses and their application to Rh-catalyzed hydrogenations of dehydroamino acids and their esters in water.[7] In this paper, we describe the synthesis of novel chiral disaccharide *phosphine* ligands from α,α-trehalose in which phosphorus atoms are directly linked at 2,2′-positions. These ligands are expected to coordinate metals more effectively than phosphinite ligands, because the distances between stereogenic centers of ligands and a metal center are shorter than those in the case of phosphinite ligands. Furthermore, we tried to prepare 2,2′-bisphosphine bearing polyhydroxy groups by the removal of protecting groups. The hydroxy groups in the ligand usually play an important role in the transition metal-catalyzed asymmetric reactions.[8] For example, they can make the complex water-soluble, so that phosphines bearing polyhydroxy groups deserve investigation.

2. Results and discussion

First, we prepared 4,6-*O*-benzylidene-2-(diphenylphosphino)-2-deoxy-α-D-altropyranosyl-(1,1)-4,6-*O*-benzylidene-2-(diphenylphosphino)-2-deoxy-α-D-altropyranoside **1** from α,α-trehalose as shown in Scheme 1.

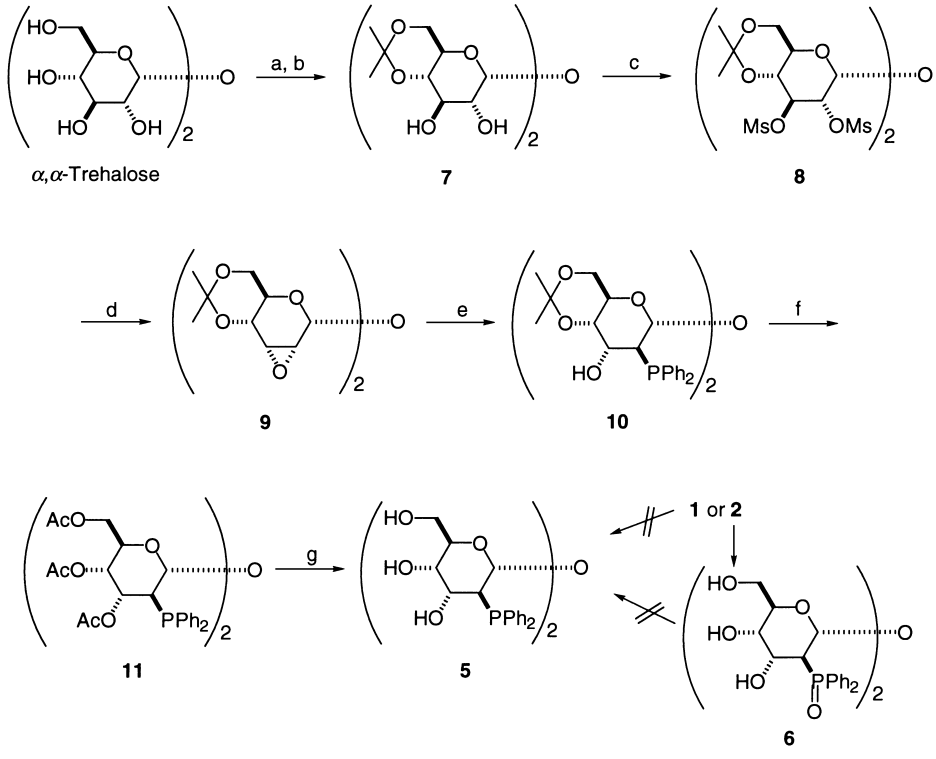


Scheme 1. (a) Benzaldehyde dimenthyl acetal, *P*-TsOH·H_2O, DMF, 100°C, 2 h, 91%; (b) mesyl chloride, pyridine, 0°C–rt, 24 h, 80%; (c) MeONa, acetone–MeOH, rt, 48 h, 61%; (d) PH_2PNa, DMF, 50°C, 10 min, 70%; (e) 30% H_2O_2, CH_2Cl_2, 24 h, 98%

Protection of the 4,6:4′,6′-positions of α,α-trehalose with the benzylidene groups[9] and the mesylation of 2,3:2′,3′-positions followed by treatment with sodium methoxide gave 2,3-anhydro-4,6-*O*-benzylidene-α-D-allopyranosyl-(1,1)-2,3-anhydro-4,6-*O*-benzylidene-α-D-allopyranoside **4**.[10] Although compound **4** was insoluble in most organic solvents, we succeeded in the preparation of the compound **1** by treatment of **4** with Ph_2PNa in DMF at 50°C. Oxidation of **1** with H_2O_2 gave rise to diphosphine oxide **2**.

Next, we tried to synthesize 2-(diphenylphosphino)-2-deoxy-α-D-altropyranosyl-(1,1)-2-(diphenylphosphino)-2-deoxy-α-D-altropyranoside **5** as shown in Scheme 2. We attempted to convert **1** into the corresponding phosphine **5** bearing polyhydroxy functionalities via deprotection of benzylidene groups using: (i) acids, e.g. CH_3COOH or conc. HCl; or (ii) catalytic and stoichiometric palladium on carbon under hydrogen.[11] However, all attempts to cleave the protecting groups failed, probably due to the decomposition of product under acidic conditions before complete deprotection of benzylidene groups and undesired complexation between phosphorus and palladium under

hydrogenolysis conditions. This was also the case when compound **2** was used as a starting material. Although we succeeded in the deprotection of the benzylidene groups of **2** using conc. HCl, we could not reduce the obtained phosphine oxide, 2-(diphenylphosphinooxyl)-2-deoxy-α-D-altropyranosyl-(1,1)-2-(diphenylphosphinooxyl)-2-deoxy-α-D-altropyranoside **6**, to **5** using trichlorosilane together with triethylamine due to the insolubility of phosphine oxide under such reduction conditions.



Scheme 2. (a) 2,2-Dimenthoxypropane, *p*-TsOH·H_2O, DMF, rt, 2 h, then Ac_2O, pyridine, rt, 12 h, 60%; (b) K_2CO_3, MeOH, rt, 1 h, 80%; (c) mesyl chloride, pyridine, 0°C–rt, 24 h, 81%; (d) MeONa, CH_2Cl_2, rt, 24 h, 58%; (e) Ph_2PLi, THF, −23°C, 30 min, 69%; (f) pyridinium *p*-toluenesulfonate (PPTS), MeOH:CH_2Cl_2=1:2, rt, 24 h, then Ac_2O, pyridine, cat. 4-(dimethylamino)pyridine, rt 6 h, 38%; (g) K_2CO_3, MeOH, rt, 1 h, 60%

Thus, we replaced the benzylidene groups with isopropylidene ones in the 4,6:4′,6′-positions because the latter are labile under acidic conditions by one order of magnitude owing to steric and electronic effects.[12] Protection of 4,6:4′6′-positions of α,α-trehalose with isopropylidene groups,[13] and the mesylation of 2,3:2′,3′-positions followed by treatment with sodium methoxide gave 2,3-anhydro-4,6-*O*-isopropylidene-α-D-allopyranosyl-(1,1)-2,3-anhydro-4,6-*O*-isopropylidene-α-D-allopyranoside **9**. Compound **9** was easily converted into 2-(diphenylphosphino)-2-deoxy-4,6-*O*-isopropylidene-α-D-altropyranosyl-(1,1)-2-(diphenylphosphino)-2-deoxy-4,6-*O*-isopropylidene-α-D-altropyranoside **10** using Ph_2PLi in THF at −23°C. As expected, the cleavage of isopropylidene groups of **10** occurred smoothly in the presence of pyridinium *p*-toluenesulfonate (PPTS)[14] in MeOH:CH_2Cl_2=1:2 at room temperature to give crude 2-(diphenylphosphino)-2-deoxy-α-D-altropyranosyl-(1,1)-2-(diphenylphosphino)-2-deoxy-α-D-altropyranoside **5**. Acetylation of crude **5** with Ac_2O/pyridine leading to 3,4,6-tri-*O*-acetyl-2-(diphenylphosphino)-2-deoxy-α-D-altropyranosyl-(1,1)-3,4,6-tri-*O*-acetyl-2-(diphenylphosphino)-2-deoxy-α-D-altropyranoside **11** followed by deacetylation in the usual manner (K_2CO_3/MeOH) afforded pure **5**.

In the ^{31}P NMR of rhodium complex **12** prepared in situ from an equimolar amount of $[Rh(cod)_2]BF_4$ and **5** in CD_3OD, a single resonance peak of a phosphorus nucleus was observed as a doublet: δ 41.6

ppm (J_{Rh-P}=152.6 Hz). This result shows that the diphosphine **5** coordinates to rhodium in a bidentate fashion.[15] Unfortunately, neither the diphosphine **5** nor its rhodium complex **12** were appreciably soluble in water, and we could not apply the complex to asymmetric hydrogenation of methyl α-acetamidocinnamate in water.[16]

In summary, we prepared novel chiral disaccharide phosphines **1** and **10** from α,α-trehalose in which the phosphorus atoms are directly linked at the 2,2′-positions. We also succeeded in a deprotection of the isopropylidene groups in **10** to give **5** bearing polyhydroxy groups, although it was only slightly soluble in water. However, since the hydroxy group in the ligand can sometimes powerfully support the stereodiscriminating ability of a metal catalyst,[8] the ligand reported here may find application in the other asymmetric reactions.

3. Experimental

3.1. General

Tetrahydrofuran (THF) was distilled from sodium benzophenone ketyl under argon. Dichloromethane, triethylamine, and *N*,*N*-dimethylformamide (DMF) were distilled from calcium hydride. Methanol was distilled from $Mg(OMe)_2$. Analytical thin-layer chromatographies (TLC) were performed with silica gel 60 Merck F-254 plates. Column chromatographies were performed with Merck silica gel 60. NMR spectra were measured on JEOL EX-400, JEOL JNM-AL300, and JEOL JNM-GSX270 spectrometers for solutions in $CDCl_3$ or CD_3OD with Me_4Si as an internal standard (^1H and ^{13}C) or with $P(OMe)_3$ as an external standard (^{31}P). IR spectra were recorded with a Nicolet Impact 400 FT-IR spectrometer. Optical rotations were measured on JASCO DIP-1000. Melting points are uncorrected. High-resolution mass spectra (FAB HRMS) were obtained with a JEOL JMX-SX 102A spectrometer. α,α-Trehalose dihydrate was purchased from Hayashibara Corporation.

*3.2. 4,6-O-Benzylidene-2-(diphenylphosphino)-2-deoxy-α-D-altropyranosyl-(1,1)-4,6-O-benzylidene-2-(diphenylphosphino)-2-deoxy-α-D-altropyranoside **1***

To a stirred mixture of Ph_2PH (0.52 mL, 3.0 mmol) and sodium hydride (0.068 g, 2.8 mmol) in dry DMF (35 mL) was added the compound **4** (0.48 g, 1.0 mmol) in one portion under Ar and the mixture was stirred for 10 min at 50°C. After the complete consumption of **4** was confirmed by TLC, NH_4Cl (0.16 g, 3.0 mmol) was added to the above solution, and the mixture was stirred for 30 min. The solvent was removed under vacuum and the residue was subjected to column chromatography on SiO_2 with $CHCl_3$:AcOEt (v/v=6:1) as an eluent to give the compound **1** (0.60 g, 0.70 mmol, 70%), as a white solid: mp 128.0–130.0°C. $[\alpha]_D^{25}$ =+28.4 (*c* 0.5, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ 3.23 (m, 2H), 3.71 (t, *J*=9.8 Hz, 2H), 3.86 (m, 2H), 4.06–4.22 (m, 6H), 4.72 (d, *J*=5.4 Hz, 2H), 5.62 (s, 2H), 7.30–7.60 (m, 30H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 44.8 (d, *J*=14.7 Hz), 59.3, 66.5 (d, *J*=18.3 Hz), 69.0, 77.4, 93.6 (d, *J*=20.2 Hz), 102.2, 126.3, 128.2, 128.98, 129.0 (d, *J*=9.2 Hz), 129.1 (d, *J*=9.2 Hz), 129.7, 130.0, 133.0 (d, 20.2 Hz), 133.6 (d, *J*=20.2 Hz), 134.7 (d, *J*=12.8 Hz), 135.3 (d, *J*=14.7 Hz), 137.2; ^{31}P NMR (161.9 MHz, $CDCl_3$) δ −21.4; IR (KBr) 509 (w), 697 (s), 749 (s), 959 (s), 1006 (s), 1089 (s), 1121 (s), 1281 (w), 1380 (m), 1435 (m), 1724 (m), 1814 (w), 1893 (w), 1957 (w), 2860 (m), 2931 (m), 3069 (w), 3510 (m) cm^{-1}; HRMS (FAB) calcd for $C_{50}H_{49}O_9P_2$ ($M+H^+$): 855.2852. Found: 855.2816.

3.3. 4,6-O-Benzylidene-2-(diphenylphosphinooxyl)-2-deoxy-α-D-altropyranosyl-(1,1)-4,6-O-benzylidene-2-(diphenylphosphinooxyl)-2-deoxy-α-D-altropyranoside **2**

A 30% aqueous hydrogen peroxide (5 mL) was added at room temperature to the solution of the compound **1** (0.85 g, 1.0 mmol) in CH_2Cl_2 (10 mL) and the mixture was stirred overnight. The solution was washed with aqueous $Na_2S_2O_3$ solution and the organic layer was dried over $MgSO_4$. After the solvent was removed under vacuum, the residue was subjected to column chromatography on SiO_2 with CH_2Cl_2:acetone (v/v=2:1) as an eluent to give the compound **2** (0.87 g, 0.98 mmol, 98%), as a white solid: mp 201.3–202.0°C. $[\alpha]_D^{25}$=+28.9 (*c* 0.5, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.19 (d, *J*=11.2 Hz, 2H), 3.63–3.73 (m, 4H), 4.05–4.10 (m, 2H), 4.31–4.37 (m, 4H), 5.11 (d, *J*=8.3 Hz, 2H), 5.67 (s, 2H), 7.36–7.91 (m, 30 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 45.9 (d, *J*=66.2 Hz), 58.4, 64.6, 68.7, 76.5, 90.8, 102.0, 126.3–137.2 (8 carbons); ^{31}P NMR (161.9 MHz, $CDCl_3$) δ 25.0; IR (KBr) 554 (s), 699 (s), 753 (s), 870 (m), 974 (s), 1006(s), 1120 (s), 1188 (s), 1381 (w), 1438 (m), 1637 (w), 2866 (w), 3011 (w), 3059 (w), 3399 (m) cm^{-1}; HRMS (FAB) calcd for $C_{50}H_{49}O_{11}P_2$ (M+H$^+$): 887.2750. Found: 887.2720.

3.4. 4,6-O-Isopropylidene-2,3-di-O-mesyl-α-D-glucopyranosyl-(1,1)-4,6-O-isopropylidene-2,3-di-O-mesyl-α-D-glucopyranoside **8**

To a solution of the compound **7** (15.8 g, 37.4 mmol) in dry pyridine (200 mL) was slowly added methanesulfonyl chloride (17 mL, 224 mmol) at 0°C. The solution was left standing at room temperature overnight, then poured into ice-water, whereupon the product was precipitated. Filtration and recrystallization of crystalline compound from acetone–methanol gave the compound **8** (22.3 g, 30.4 mmol, 81%), as a white solid: mp 152.1–153.3°C. $[\alpha]_D^{24}$=+88.2 (*c* 0.5, $CHCl_3$); ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.46 (s, 6H), 1.50 (s, 6H), 3.16 (s, 6H), 3.20 (s, 6H), 3.67 (m, 2H), 3.80 (t, *J*=9.6 Hz, 2H), 3.99–4.10 (m, 4H), 4.65 (dd, *J*=4.1, 9.6 Hz, 2H), 4.93 (t, *J*=9.6 Hz), 5.29 (d, *J*=4.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.4, 28.7, 38.9, 61.4, 64.0, 71.8, 75.7, 78.0, 95.2, 100.1; IR (KBr) 757 (m), 838 (s), 965 (s), 998 (m), 1040 (s), 1190 (s), 1362 (s), 1620 (w), 2943 (w), 2995 (w), 3024 (w), 3485 (m) cm^{-1}; HRMS (FAB) calcd for $C_{22}H_{39}O_{19}S_4$ (M+H$^+$): 735.0968. Found: 735.0956.

3.5. 2,3-Anhydro-4,6-O-isopropylidene-α-D-allopyranosyl-(1,1)-2,3-anhydro-4,6-O-isopropylidene-α-D-allopyranoside **9**

To a solution of the compound **8** (10 g, 13.6 mmol) in dry CH_2Cl_2 (160 mL) was added 2 M sodium methoxide–methanol solution (55 mL) and the mixture was stirred for 24 h. After the mixture was diluted with CH_2Cl_2, the organic layer was washed with water and dried over $MgSO_4$. The solvent was removed under vacuum and the residue was subjected to column chromatography on SiO_2 with $CHCl_3$:AcOEt (v/v=1:2) as an eluent to give the compound **9** (3.0 g, 7.9 mmol, 58%), as a white solid: mp 197.6–198.1°C. $[\alpha]_D^{25}$=+90.4 (*c* 0.5, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.44 (s, 6H), 1.51 (s, 6H), 3.40 (m, 2H), 3.45 (dd, *J*=2.8, 4.4 Hz, 2H), 3.62–3.70 (m, 2H), 3.79–3.84 (m, 2H), 3.99–4.03 (m, 4H), 5.28 (d, *J*=2.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 18.9, 28.9, 50.9, 53.0, 61.5, 62.2, 70.3, 89.7, 100.1; IR (KBr) 773 (m), 843 (m), 879 (s), 920 (s), 939 (s), 1004 (s), 1067 (s), 1107 (s), 1197 (s), 1268 (m), 1375 (m), 2892 (w), 2961 (w), 2995 (m) cm^{-1}; HRMS (FAB) calcd for $C_{18}H_{27}O_9$ (M+H$^+$): 387.1655. Found: 387.1667.

3.6. 2-(Diphenylphosphino)-2-deoxy-4,6-O-isopropylidene-α-D-altropyranosyl-(1,1)-2-(diphenylphosphino)-2-deoxy-4,6-O-isopropylidene-α-D-altropyranoside **10**

A solution of the compound **9** (0.4 g, 1.0 mmol) in anhydrous THF (6 mL) was added dropwise under N_2 to a stirred solution of Ph_2PLi (3.0 mmol) in anhydrous THF (4 mL) at −23°C. After the complete consumption of **9** was confirmed by TLC, NH_4Cl (0.16 g, 3.0 mmol) was added to the above solution, and the mixture was stirred for 30 min. The solvent was removed under vacuum and the residue was subjected to column chromatography on SiO_2 with $CHCl_3$:AcOEt (v/v=2:1) as an eluent to give the compound **10** (0.52 g, 0.69 mmol, 69%), as a white solid: mp 120.9–121.5°C. $[\alpha]_D^{25}$=+37.5 (*c* 0.5, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.44 (s, 6H), 1.50 (s, 6H), 3.17 (m, 2H), 3.46 (dd, *J*=5.4, 10.3 Hz, 2H), 3.67 (t, *J*=10.3 Hz, 2H), 3.87 (m, 2H), 3.99 (m, 2H), 4.11 (dd, *J*=2.9, 9.8 Hz, 2H), 4.68 (d, *J*=5.4 Hz, 2H), 7.35–7.58 (m, 20H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.4, 29.2, 44.5 (d, *J*=14.7 Hz), 60.0, 62.3, 66.8 (d, *J*=16.6 Hz), 69.9, 93.7 (d, *J*=22.0 Hz), 100.0, 126.3, 128.3–129.9 (2 carbons), 133.0 (d, *J*=20.2 Hz), 133.5 (d, *J*=22.1 Hz), 133.5 (d, *J*=22.1 Hz), 135.1 (d, *J*=12.9 Hz), 135.4 (d, *J*=14.8 Hz); ^{31}P NMR (161.9 MHz, $CDCl_3$) δ −20.4; IR (KBr) 697 (s), 750 (s), 895 (m), 942 (s), 962 (s), 1002 (s), 1082 (s), 1121 (s), 1197 (s), 1269 (w), 1374 (m), 1382 (m), 1435 (s), 1481 (w), 2937 (m), 2992 (m), 3054 (m), 3435 (s) cm^{-1}; HRMS (FAB) calcd for $C_{42}H_{49}O_9P_2$ ($M+H^+$): 759.2852. Found: 759.2842.

3.7. 3,4,6-Tri-O-acetyl-2-(diphenylphosphino)-2-deoxy-α-D-altropyranosyl-(1,1)-3,4,6-tri-O-acetyl-2-(diphenylphosphino)-2-deoxy-α-D-altropyranoside **11**

Pyridinium *p*-toluenesulfonate (0.9 g, 3.6 mmol) was added to a solution of the compound **10** (1.4 g, 1.8 mmol) in MeOH:CH_2Cl_2=1:2 (10 mL) and the mixture was stirred overnight. The solution was neutralized by $NaHCO_3$ (43 mg, 3.6 mmol) and the solvent was removed under vacuum. The residue was subjected to column chromatography on SiO_2 with $CHCl_3$:CH_3OH (v/v=10:1) as an eluent to give the crude compound of **5**. After the crude **5** was dissolved in CH_2Cl_2:Et_3N=2:1 (7.5 mL), Ac_2O (1.5 mL, 16 mmol) and a catalytic amount of 4-(dimethylamino)pyridine was added to this solution, and the mixture was stirred at rt for 6 h. The mixture was diluted with CH_2Cl_2 and washed with aqueous $NaHCO_3$ solution and dried over $MgSO_4$. The solvent was removed under vacuum and the residue was subjected to column chromatography on SiO_2 with $CHCl_3$:AcOEt (v/v=10:1) as an eluent to give the compound **11** (0.64 g, 0.69 mmol, 38%), as a white solid: mp 65.6–66.0°C. $[\alpha]_D^{25}$=+69.7 (*c* 0.5, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.93 (s, 6H), 2.01 (s, 6H), 2.11 (s, 6H), 3.23 (d, *J*=2.4 Hz, 2H), 3.54 (dd, *J*=1.9, 11.3 Hz, 2H), 3.94 (m, 2H), 4.04 (dd, *J*=3.9, 11.3 Hz, 2H), 4.90 (d, *J*=6.84 Hz, 2H), 5.01 (m, 2H), 5.33 (dd, *J*=2.9, 9.8 Hz, 2H), 7.36–7.61 (m, 20H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.7, 21.1, 41.6 (d, *J*=18.4 Hz), 65.1, 65.3, 65.4, 69.1 (d, *J*=20.2 Hz), 92.1 (d, *J*=22.1 Hz), 128.7 (d, *J*=7.4 Hz), 128.8 (d, *J*=7.3 Hz), 129.7, 130.0, 133.4 (d, *J*=7.9 Hz), 133.7 (d, *J*=7.3 Hz), 134.3 (d, *J*=12.9 Hz), 134.9 (d, *J*=14.7 Hz), 169.2, 170.1, 170.7; ^{31}P NMR (161.9 MHz, $CDCl_3$) δ −18.7; IR (KBr) 698 (s), 748 (m), 968 (s), 1036 (s), 1059 (m), 1129 (m), 1225 (s), 1372 (m), 1436 (m), 1482 (w), 1635 (w), 1744 (s), 1890 (w), 1972 (w), 2955 (w), 3056 (w) cm^{-1}; HRMS (FAB) calcd for $C_{48}H_{53}O_{15}P_2$ ($M+H^+$): 931.2859. Found: 931.2842.

3.8. 2-(Diphenylphosphino)-2-deoxy-α-D-altropyranosyl-(1,1)-2-(diphenylphosphino)-2-deoxy-α-D-altropyranoside **5**

To a solution of the compound **11** (0.36 g, 0.38 mmol) in CH_3OH was added K_2CO_3 (26 mg, 0.19 mmol) under N_2 and the mixture was stirred for 1 h. After the complete consumption of **11** was confirmed by TLC, the solvent was removed under vacuum and the residue was subjected to column chromatography on SiO_2 with $CHCl_3$:CH_3OH(v/v=10:1) as an eluent to give the compound **5** (0.16 g,

0.23 mmol, 60%), as a white solid: mp 127.2–128.0°C. $[\alpha]_D^{25}$=+45.0 (*c* 0.5, CH_3OH); ^1H NMR (400 MHz, CD_3OD) δ 3.23 (m, 2H), 3.42 (dd, *J*=2.3, 12.0 Hz, 2H), 3.69 (dd, 3.7, 12.0 Hz, 2H), 3.77–3.84 (m, 4H), 4.09 (dd, *J*=3.3, 10.2 Hz, 2H), 4.75 (d, *J*=5.5 Hz, 2H), 7.36–7.59 (m, 20H); ^{13}C NMR (100 MHz, CD_3OD) δ 46.5 (d, *J*=14.5 Hz), 63.3, 66.7 (d, *J*=6.8 Hz), 70.7, 71.1, 95.8 (d, *J*=19.7 Hz), 129.9 (d, *J*=9.2 Hz), 130.0 (d, *J*=7.3 Hz), 130.7, 130.8, 134.4 (d, *J*=21.4 Hz), 134.7 (d, *J*=22.0 Hz), 137.1 (d, *J*=16.6 Hz), 137.4 (d, *J*=12.9 Hz); ^{31}P NMR (161.9 MHz, CD_3OD) δ −21.6; IR (KBr) 697 (s), 742 (s), 960 (s), 1045 (s), 1065 (s), 1126 (s), 1435 (m), 1481 (w), 1636 (w), 2924 (m), 3071 (w), 3408 (s) cm^{-1}; HRMS (FAB) calcd for $C_{36}H_{41}O_9P_2$ ($M+H^+$): 679.2226. Found: 679.2228.

*3.9. Synthesis of rhodium complex **12***

$[Rh(cod)_2]BF_4$ (12 mg, 3.0×10^{-2} mmol) and **5** (20 mg, 3.0×10^{-2} mmol) were dissolved in degassed dry MeOH (1.0 mL) and the mixture was stirred under Ar. After 20 min, degassed dry Et_2O (10 mL) was added, and the complex precipitated. The supernatant solution was decanted, and degassed dry Et_2O (5.0 mL) was again added to the obtained solid. The product was separated by filtration, washed with degassed dry Et_2O (10 mL), and dried under vacuum to give **12** as an orange powder (14.6 mg, 1.5×10^{-2} mmol, 50%): mp (decomposition) 210.5–211.3°C; ^{31}P NMR δ 41.6 ppm (J_{Rh-P}=152.6 Hz).

References

1. For recent overviews, see: (a) Noyori, R. *Asymmetric Catalysis in Organic Synthesis*; John Wiley: New York, 1994. (b) Ojima, I. *Asymmetric Synthesis*; Verlag: New York, 1993.
2. (a) RajanBabu, T. V.; Radetich, B.; You, K. K.; Ayers, T. A.; Casalnuovo, A. L.; Calabrese, J. C. *J. Org. Chem*. **1999**, *64*, 3429. (b) Yonehara, K.; Hashizume, T.; Mori, K.; Ohe, K.; Uemura, S. *Chem. Commun*. **1999**, 415. (c) Boog-Wick, K.; Pregosin, P. S.; Wörle, M.; Albinati, A. *Helv. Chim. Acta* **1998**, *81*, 1622. (d) Gläser, B.; Kunz, H. *Synlett* **1998**, 53. (e) RajanBabu, T. V.; Ayers, T. A.; Halliday, G. A.; You, K. K.; Calabrese, J. C. *J. Org. Chem*. **1997**, *62*, 6012. (f) Selke, R.; Ohff, M.; Riepe, A. *Tetrahedron* **1996**, *52*, 15079. (g) Berens, U.; Selke, R. *Tetrahedron: Asymmetry* **1996**, *7*, 2055. (h) Casalnuovo, A. L.; RajanBabu, T. V.; Ayers, T. A.; Warren, T. H. *J. Am. Chem. Soc*. **1994**, *116*, 9869. (i) Selke, R.; Facklam, C.; Foken, H.; Heller, D. *Tetrahedron: Asymmetry* **1993**, *4*, 369. (j) Selke, R. *J. Organomet. Chem*. **1989**, *370*, 249. (k) Selke, R.; Pracejus, H. *J. Mol. Catal*. **1986**, *37*, 213. (l) Yamashita, M.; Hiramatsu, K.; Yamada, M.; Suzuki, N.; Inokawa, S. *Bull. Chem. Soc. Jpn*. **1982**, *55*, 2917. (m) Johnson, T. H.; Rangarajan, G. *J. Org. Chem*. **1980**, *45*, 62. (n) Jackson, R.; Thompson, D. J. *J. Organomet. Chem*. **1978**, *159*, C29. (o) Cullen, W. R.; Sugi, Y. *Tetrahedron Lett*. **1978**, 1635.
3. Brown, M. A.; Cox, P. J.; Howie, R. A.; Melvin, O. A.; Taylor, O. J.; Wardell, J. L. *J. Organomet. Chem*. **1995**, *498*, 275.
4. Shi, J.-C.; Hong, M.-C.; Wu, D.-X.; Liu, Q.-T.; Kang, B.-S. *Chem. Lett*. **1995**, 685.
5. (a) RajanBabu, T. V.; Casalnuovo, A. L.; Ayers, T. A. *Adv. Catal. Proc*. **1997**, *2*, 1. (b) Gilbertson, S. R.; Chang, C.-W. T. *J. Org. Chem*. **1995**, *60*, 6226. (c) Brown, J. M.; Cook, S. J.; Khan, R. *Tetrahedron* **1986**, *42*, 5105.
6. Yonehara, K.; Hashizume, T.; Ohe, K.; Uemura, S. *Bull. Chem. Soc. Jpn*. **1998**, *71*, 1967.
7. Yonehara, K.; Hashizume, T.; Mori, K.; Ohe, K.; Uemura, S. *J. Org. Chem*. **1999**, *64*, 5593.
8. For an overview, see: Holz, J.; QuirmBach, M.; Börner, A. *Synthesis* **1997**, 983, and references cited therein.
9. Baer, H. H.; Radatus, B. *Carbohydr. Res*. **1984**, *128*, 165.
10. Hough, L.; Munroe, P. A.; Richardson, A. C. *J. Chem. Soc. (C)* **1971**, 1090.
11. Greene T. A.; Wuts, P. G. M. *Protective Groups in Organic Synthesis*, 2nd Ed.; John Wiley: New York, 1991.
12. (a) De Belder, A. N. *Adv. in Carbohydr. Chem. Biochem*. **1977**, *34*, 179. (b) De Belder, A. N. *Adv. in Carbohydr. Chem*. **1965**, *20*, 219.
13. Wallace, P. A.; Minnikin, D. E. *Carbohydr. Res*. **1994**, *263*, 43.
14. Van Rijsbergen, R.; Anteunis, M. J. O.; De Bruyn, A. *J. Carbohydr. Chem*. **1983**, *2*, 395.
15. At present we cannot rule out the possibility that the complex **12** contains a two phosphine ligands bridge between two rhodium metal centers (Rh:ligand=2:2). The unambiguous structure of **12** has not yet been clarified.
16. Hydrogenation of methyl α-acetamidocinnamate in MeOH using the rhodium complex **12** gave the (*S*)-hydrogenated product with 12% ee.