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New Strategy for the Preparation of Nitrogen- and Phosphorus-Containing Chiral Polyfunctional Secondary Alcohols

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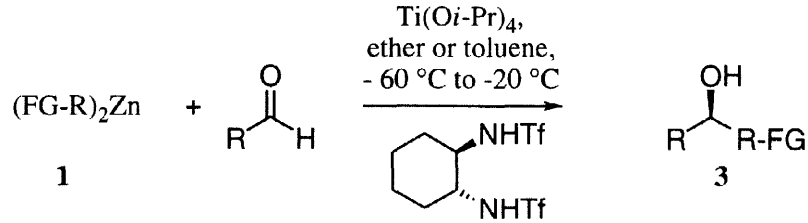
Abstract: The use of borane-derived protecting groups for aldehydes containing pyridine and phosphine functionalities allows the performance of highly enantioselective additions of functionalized diorganozincs leading to polyfunctional chiral hydroxy-pyridines and -phosphines with excellent enantioselectivity.

Introduction

Recently, we have shown that functionalized diorganozincs ($(FG\text{-}R)_2Zn$; **1**)[1] can be added to various aliphatic and aromatic aldehydes in the presence of $Ti(OR)_4$ and the chiral catalyst (1*R*,2*R*)-*bis*(trifluoromethanesulfonamido)cyclohexane[2] **2** leading to polyfunctional secondary alcohols **3** with high enantioselectivity (Scheme 1).[3] Although many oxygen-containing functionalities like esters and ethers are well tolerated in this reaction, the presence of nitrogen-functionalities either in the zinc reagent or in the aldehyde leads to considerable loss of reactivity and enantioselectivity. This is a result of the strong coordinating ability of amino functions to the titanium metal center which deactivates the chiral catalyst and favours non-asymmetric addition pathways.



Scheme 1

Herein, we wish to report a new protective group strategy allowing the highly enantioselective addition to pyridyl aldehydes and phosphinyl substituted aldehydes. It had been shown that the complexation of a pyridyl nitrogen atom with boron derivatives modifies considerably the chemical reactivity of the heterocycle allowing selective reductions[4] or metalations.[5] Similarly, the complexation of phosphines with borane considerably improves their stability towards oxidation and greatly facilitates the purification of polyfunctional trialkylphosphines.[6] We have envisioned that the complexation of pyridyl- or quinolyl-aldehydes with BEt_3, such as **4**, and the use of borane protected phosphinyl aldehydes, like **5**, will allow the asymmetric addition of diorganozincs without the interference of the basic nitrogen or phosphorus functionality. Below we report the successful results obtained with this strategy.

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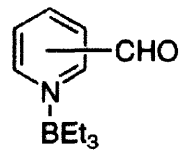

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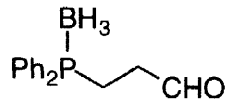

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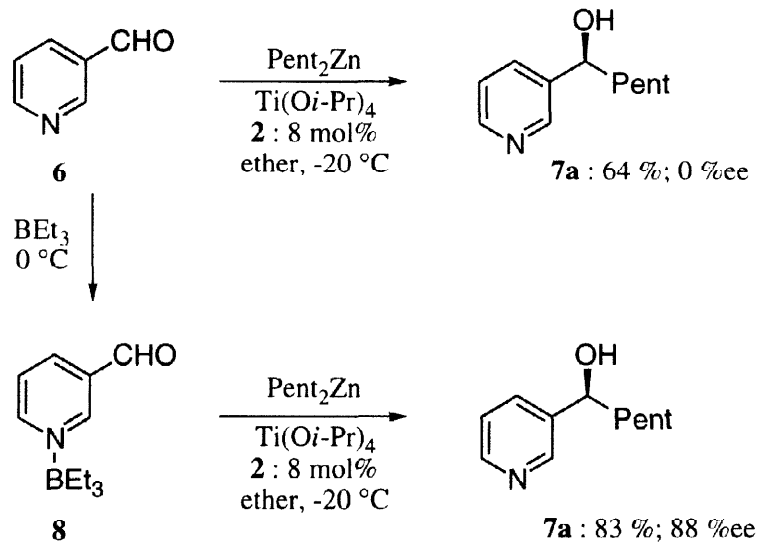
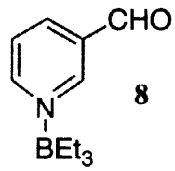
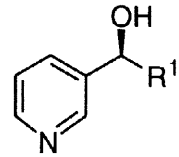
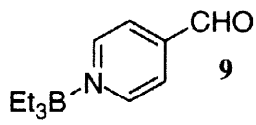
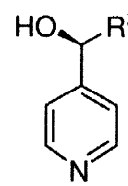
Results and Discussion

The preparation of chiral pyridyl alcohols is especially important due to the use of these compounds for the synthesis of chiral ligands.[7] Until now, they were usually prepared by the asymmetric reduction of the corresponding ketone[8] or by kinetic resolutions using lipase.[9] The catalytic addition of diorganozincs to pyridyl aldehydes was performed previously using stoichiometric quantities of catalyst or in connection with autocatalytic reactions.[10] Prelimary results in the addition of $Pent_2Zn$ to 3-pyridinecarboxaldehyde **6** in the presence of catalytic amounts of **2** (15 mol%) led to the formation of the pyridyl alcohol **7a** in 64 % yield and 0 % *ee*. However, the treatment of **6** with BEt_3 (ether, 0 °C, 0.5 h) provided the intermediate complex **8** which now reacted with $Pent_2Zn$ under the above conditions providing after aqueous work-up the alcohol **7a** in 83 % yield and 88 % *ee* (Scheme 2). This reaction has some generality and provides general access to pyridyl alcohols **7a-f** in 54-96 % yield and 69-93 % *ee* (entries 1-6, Table 1). Interestingly, functionalized diorganozincs like $Zn((CH_2)_4OPiv)_2$ and $Zn((CH_2)_5OPiv)_2$ give the corresponding pyridyl alcohol in satisfactory yield and excellent enantioselectivity. The corresponding 4-pyridinecarboxaldehyde-BEt_3 complex **9** undergoes the addition of diorganozincs with lower yields (35-88 %) and slightly reduced enantioselectivity (66-91 % *ee*; see entries 7-11 of Table 1).



Scheme 2

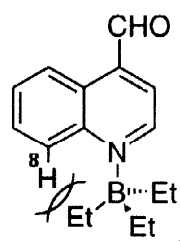
Table 1. Pyridyl alcohols **7a-k** obtained by the enantioselective addition of diorganozincs to the complex of 3-pyridinecarboxaldehyde **8** and 4-pyridinecarboxaldehyde **9**.

Entry	Aldehyde	$(FG\text{-}R)_2Zn$ (FG-R)	Product of type **7**	Yield[a] (%)	ee[b] (%)
	 **8**				
1		Pent	**7a**: R^1=Pent	83	88
2		Et	**7b**: R^1=Et	96	92
3		Bu	**7c**: R^1=Bu	86	84
4		Oct	**7d**: R^1=Oct	90	69
5		$(CH_2)_4OPiv$	**7e**: $R^1=(CH_2)_4OPiv$	61	91
6		$(CH_2)_5OPiv$	**7f**: $R^1=(CH_2)_5OPiv$	54	93
	 **9**				
7		Et	**7g**: R^2=Et	61	91
8		Pent	**7h**: R^2=Pent	88	76
9		Oct	**7i**: R^2=Oct	35	66
10		$(CH_2)_4OPiv$	**7j**: $R^2=(CH_2)_4OPiv$	46	85
11		$(CH_2)_5OPiv$	**7k**: $R^2=(CH_2)_5OPiv$	42	88

[a]Isolated yields of analytically pure products. [b]The enantiomeric excess was determined by derivatisation with (*S*)-(+)-*O*-acetylmandelic acid.

In the case of 2-pyridinecarboxaldehyde-BEt_3 complex no addition reaction was observed due to the steric hindrance resulting of the complexation with BEt_3. In order to extend the method to related heterocycles we have examined the addition of diorganozincs to 4-quinolinecarboxaldehyde **10** and 4-isoquinolinecarboxaldehyde **11** as well as to the corresponding borane complexes respectively **12** and **13** (Table 2).

The importance of the steric hindrance at the sp^2-hybridized nitrogen center explains the results. Thus, the unprotected quinolinecarboxaldehyde **10** adds Et_2Zn and $Pent_2Zn$ with good yields and 72-81 % *ee*. Surprisingly, the use of the corresponding BEt_3 complex **12** led to disappointing yields and enantioselectivities. This may be explained by the lower stability of the BEt_3 adduct due to the steric repulsion between the BEt_3 and the hydrogen at position 8 (see **12**).



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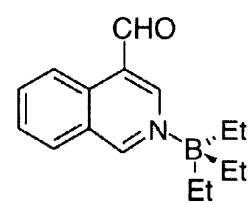

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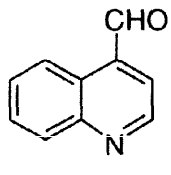
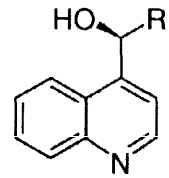
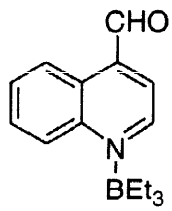
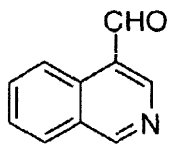
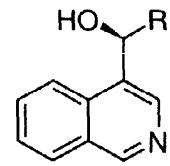
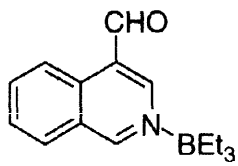
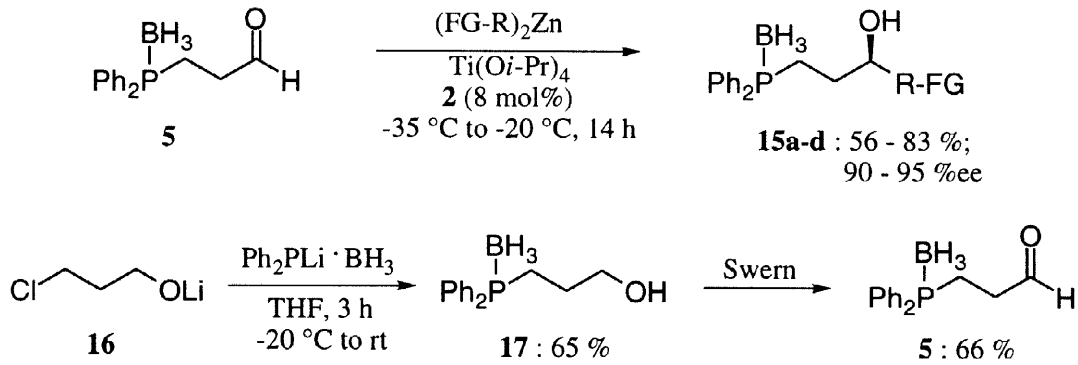
Table 2. Quinolyl- and isoquinolyl-alcohols **14a-d** obtained by the enantioselective addition of diorganozincs to the aldehydes **10-13**.

Entry	Aldehyde	$(FG\text{-}R)_2Zn$ (FG-R)	Product of type **14**	Yield[a] (%)	ee[b] (%)
					
1	**10**	Et	**14a**: R = Et	71	72
2	**10**	Pent	**14b**: R = Pent	64	81
					
3	**12**	Et	**14a**: R = Et	33	66
4	**12**	Pent	**14b**: R = Pent	23	25
					
5	**11**	Et	**14c**: R = Et	71	0
6	**11**	Pent	**14d**: R = Pent	44	0
					
7	**13**	Et	**14c**: R = Et	50	93
8	**13**	Pent	**14d**: R = Pent	86	92

[a]Isolated yields of analytically pure products. [b]The enantiomeric excess was determined by derivatisation with (*S*)-(+)-*O*-acetylmandelic acid.

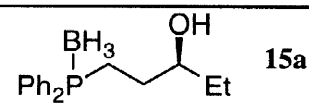
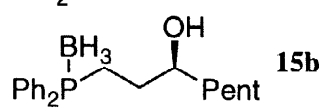
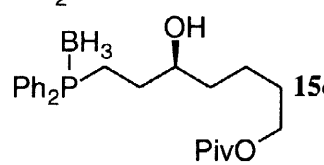
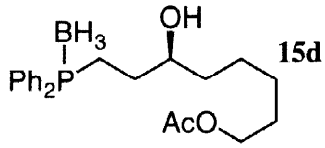
The presence of free BEt_3 has also been supported by the formation of a substantial amount of ethylated product **14a** during the addition of $Pent_2Zn$ to the quinoline-BEt_3 complex **12** (ratio **14a**:**14b** = 1.8:1). Thus, the reaction of BEt_3 with $Pent_2Zn$ leads to an equilibration resulting in the formation of mixed trialkylboranes and mixed dialkylzincs, explaining the low yields and moderate enantioselectivity. On the other hand, the isoquinolinecarboxaldehyde **11** behaves as expected. Its reaction with Et_2Zn or $Pent_2Zn$ under standard conditions produces the addition product in 44-71 % in racemic form. By using the corresponding BEt_3 complex **13**, satisfactory yields and enantioselectivities over 92 % *ee* were obtained showing the utility of the protecting group strategy.

Like the nitrogen atom of amines, the phosphorus center of phosphines is strongly basic and hampers the enantioselective addition of diorganozincs to aldehydes. γ-Hydroxyphosphines of type **15** are important precursors for the preparation of chiral phosphines. We have decided to investigate the reaction of the protected phosphinyl aldehyde **5** with diorganozincs in the presence of the catalyst **2** (Scheme 3 and Table 3). The enantioselectivity of the addition reaction was surprisingly high and polyfunctional hydroxyphosphines like **15c** and **15d** were obtained in over 94 % *ee* (see entries 3 and 4 of Table 3). The preparation of the starting aldehyde **5** was achieved in two steps using the reaction of the lithiated 3-chloropropanol **16** with $Ph_2PLi{\cdot}BH_3$ providing the alcohol **17** in 65 % yield. Swern oxidation of **17** provides the aldehyde **5** in 66 % yield (Scheme 3).



Scheme 3

Table 3. Preparation of the γ-hydroxyphosphine-BH_3 complexes **15a-d** by the addition of diorganozincs to the aldehyde **5**.

Entry	$(FG\text{-}R)_2Zn$ (FG-R)	Product of type **15**	Yield[a] (%)	ee[b] (%)
1	Et	 **15a**	83	90
2	Pent	 **15b**	72	93
3	$(CH_2)_4OPiv$	 **15c**	61	95
4	$(CH_2)_5OAc$	 **15d**	56	94

[a]Isolated yields of analytically pure products. [b]The enantiomeric excess was determined by derivatisation with (*S*)-(+)-*O*-acetylmandelic acid.

Conclusion

In summary, we have shown that the use of boranes as protecting groups allows the addition of various diorganozincs to pyridylcarboxaldehydes and related heterocycles as well as to the phosphinylaldehyde **5** with good to excellent enantioselectivities. The role of the added borane is to neutralize the complexation ability of the basic nitrogen or phosphorus centers. Extension of these methods to aminoaldehydes is currently underway in our laboratory.

Experimental

General considerations

All reactions with organometallic reagents were carried out under argon. Solvents (toluene, ether) were dried and freshly distilled from sodium/benzophenone. CH_2Cl_2 and DMF were freshly distilled over CaH_2. Reactions were monitored by gas-liquid-phase chromatography (GC) and thin-layer chromatography (TLC) analysis of hydrolyzed aliquots. ^{1}H- and ^{13}C-NMR spectra were recorded on Bruker ARX 200 and AC 300. IR-spectra were recorded on Perkin-Elmer 281 and Nicolet 511. Optical rotations were measured with Perkin-Elmer 241. Mass spectra were recorded on Varian MAT CH 7 A. Elemental analyses were performed by the *Microanalytical Service Laboratory of the Fachbereich Chemie (Marburg).*

Starting materials

$Ti(O\textit{i}\text{-}Pr)_4$ was distilled before use. The following starting materials were prepared according to literature procedures: Bu_2Zn[11], $Pent_2Zn$[11], (*R,R*)-1,2-bis(trifluoromethanesulfonamido)cyclohexane[2a]. The alkyl iodides required for the preparation of the corresponding dialkylzincs were prepared by standard methods: 4-iodobutyl pivalate[12], 5-iodopentyl pivalate[12], 5-iodopentyl acetate[12].

Isoquinoline-4-carboxaldehyde **11**

n-Butyllithium (14.0 mL of a 1.43 M solution in hexane) was placed in a three-necked flask, equipped with an argon inlet, a low-temperature thermometer, a magnetic stirring bar and a rubber septum. The solution was concentrated to ca. 2 mL in vacuo. The remaining viscous solution was diluted with THF/ether (90 mL; 1:1) and cooled to -70 °C. A solution of 4-bromoisoquinoline (2.08 g, 10 mmol) in THF (2 mL) was slowly added and stirred for further 15 min. A red suspension was obtained to which a precooled (-70 °C) solution of DMF (7.7. mL) in THF (15 mL) was added. After stirring for further 10 min the mixture was quenched with ethanol (10 mL) and warmed to 20 °C. After adding sat. aq. NH_4Cl the product was extracted with ether and dried over $MgSO_4$. After removal of the solvents the crude product was recrystallized from ethanol. After filtration and drying in vacuo the product was obtained in 65 % yield (1.02 g). M.p. 96 °C; IR (neat): 1687 (s), 1490, (s), 1080 (s), 895 (s); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 10.32 (s, 1 H), 9.36 (s, 1 H), 9.12 (d, J = 12 Hz, 1 H), 8.86 (s, 1 H), 8.00 (d, J = 8 Hz, 1 H), 7.84 (m, 1 H), 7.66 (m, 1 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 192.4, 157.8, 152.5, 133.1, 131.9, 128.0, 127.9, 124.4, 124.1; MS (EI): m/z 157 (100, M^+), 128 (83), 102 (26), 77 (14), 75 (15), 51 (18); $C_{10}H_7NO$ (157.17); calcd C 76.41, H 4.49, N 8.91; found C 76.55, H 4.63, N 8.68.

(3-Hydroxypropyl)diphenylphosphine-borane complex **17**[13]

To a solution of diphenylchlorophosphine (8.70 g, 39.4 mmol) in THF (20 mL) was added borane-dimethylsulfide complex (3.15 g, 39.4 mmol) at 0 °C. The reaction mixture was stirred at room temperature for 2 h. Then it was cooled and dropwise added with vigorous stirring to a solution of lithium naphthalenide (prepared from lithium (0.56 g, 80.7 mmol) and naphthalene (10.3 g, 80.0 mmol) in THF (40 mL)) carefully monitoring the reaction temperature, which should not exceed -50 °C. The resulting dark red reaction mixture was stirred for 10 min at -50 °C and then added slowly to a suspension of lithium 3-chloropropan-1-ol in THF (20 mL) at -20 °C. The resulting yellow solution was stirred at 0 °C for 1 h and then further 2 h at 20 °C. The solvents were removed under reduced pressure. To the residue were added ether (100 mL) and sat. aq. NH_4Cl. The aqueous layer was extracted several times with ether and the combined organic phase was washed with brine and dried over $MgSO_4$. After filtration and evaporation of the solvents, the residue was purified by flash chromatography using mixtures of hexane and ether (1:3) yielding phosphinoalcohol **17** as a clear viscous sirup (6.59 g, 65 %). IR (neat): 3380 (br), 2940 (m), 2370 (s), 1440 (s), 1060 (s), 740 (s), 700

(s); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 7.72 - 7.28 (m, 10 H), 3.56 (m, 2 H), 2.83 (s, 1 H), 2.37 - 2.20 (m, 2 H), 1.80 - 1.61 (m, 2 H), 1.60 - 0.40 (m, 3 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 131.8 (d, *J* = 9.1 Hz), 130.9 (d, *J* = 2.2 Hz), 129.0 (d, *J* = 55.4 Hz), 128.6 (d, *J* = 9.9 Hz), 62.2 (d, *J* = 14.9 Hz), 25.8, 21.7 (d, *J* = 38.5 Hz); MS (EI): m/z 257 (5), 244 (38), 199 (100), 183 (27), 108 (22), 91 (21), 36 (21); $C_{15}H_{20}BOP$ (258.09); calcd C 69.80; H 7.81; found C 69.61; H 7.90.

(3-Oxopropyl)diphenylphosphine-borane complex **5**[13,14]
This phosphinylaldehyde was prepared from hydroxyphosphine **17** by a conventional Swern oxidation using oxalyl chloride. Yield: 66 %. IR (neat): 2920 (w), 2840 (w), 2740 (w), 2380 (s), 1740 (s), 1490 (s), 1110 (s), 1060 (s), 740 (s), 690 (s); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 9.72 (d, *J* = 2.7 Hz, 1 H), 7.72 - 7.47 (m, 10 H), 2.76 - 2.64 (m, 2 H), 2.56 - 2.47 (m, 2 H), 1.95 - 0.40 (m, 3 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 199.2 (d, *J* = 13.7 Hz), 132.0 (d, *J* = 9.2 Hz), 131.4 (d, *J* = 2.3 Hz), 128.9 (d, *J* = 10.1 Hz), 128.6 (d, *J* = 58.1 Hz), 37.4, 17.8 (d, *J* = 39.9 Hz); MS (EI): m/z 256 (2), 255 (8), 242 (42), 199 (18), 186 (100), 183 (33), 108 (73); $C_{15}H_{18}BOP$ (256.07); calcd C 70.35; H 7.08; found C 70.32; H 7.12.

General Procedure 1 for the Preparation of Functionalized Dialkylzinc Compounds via Iodine-Zinc-Exchange Reaction[15]
A 100 mL two-necked flask with argon inlet, a magnetic stirring bar, a dropping funnel and a septum cap was charged with an iodoalkane (50 mmol) and CuI (29 mg, 0.3 mol %). Et_2Zn (7.7 mL, 75 mmol, 1.5 equiv) was transferred via cannula to the dropping funnel and was dropwise added to the iodoalkane at 25 °C. The reaction mixture was heated to 50-75 °C for several hours. The conversion of the iodoalkane was checked by gas chromatographical analysis (GC) of hydrolyzed and iodolyzed aliquots. Finally, the reaction flask was connected to a short-path distillation apparatus and the formed EtI and excess Et_2Zn were condensed off in vacuo (0.1 Torr, 55 °C). Two cooling traps cooled with liquid nitrogen were connected before the vacuum pump. After 2 h, decane (1.5 mL) was added and the evaporation was pursued for 0.5 h. This coevaporation procedure was repeated three times. The resulting dialkylzinc reagent was dissolved in ether (10 mL) and was ready to use. The distilled Et_2Zn collected in cooling traps was quenched by addition of mixtures of hexanes/acetone and then warmed up to 20 °C.

$(FG\text{-}R)_2Zn$ from FG-RI FG-R	Temperature (°C) for preparation	Reaction time
Oct	75	18
$PivO(CH_2)_4$	55	16
$PivO(CH_2)_5$	55	16
$AcO(CH_2)_5$	50	14

General Procedure 2 for the Protection of Pyridyl-, Quinoyl- and Isoquinoylheteroaromatics with BEt_3
A 10 mL flask with an argon inlet, a magnetic stirring bar and a septum cap was charged with the aldehyde and cooled to 0 °C. Solids, like quinoline- and isoquinoline-4-carbaldehydes, were suspended in ether (1 mL). BEt_3 (1 equiv) was added and the mixture allowed to warm to 20 °C. After stirring for 15 min the resulting complexes were diluted with small amounts of ether (ca. 1 mL) and were ready to use.

General Procedure 3 for the Asymmetric Addition of Functionalized Dialkylzincs to Protected Pyridyl-, Quinoyl- and Isoquinoylcarbaldehyde
A 100 mL two-necked flask with an argon inlet and a septum cap was charged with ether (4 mL), $Ti(Oi\text{-}Pr)_4$ (1.5 mL, 5 mmol, 2.0 equiv) and (*R,R*)-1,2-bis(trifluoromethanesulfonamido)cyclohexane (165 mg, 8 mol %). After cooling to -20 °C, a solution of the functionalized dialkylzinc (1.5-2.7 equiv) was slowly added. The mixture was stirred for 0.5 h and the protected aldehyde **8** (5.0 mmol) was added. The reaction mixture was stirred at -20 °C for 16 h. It was diluted with ether and quenched with a mixture of sat. aq. NH_4Cl and 10 % aq. HCl leading to a clear solution. The aqueous layer was extracted with ether (3 x 30 mL). The combined organic layer was washed with 2N NaOH in order to remove the catalyst and was dried ($MgSO_4$). After filtration and evaporation of the solvents, the residual oil was purified by flash chromatography (hexanes/ether) affording pure heteroaromatic alcohols. The enantiomeric excess was determined with ^{1}H-NMR on the corresponding *O*-acetylmandelic ester prepared using (*S*)-(+)-*O*-acetylmandelic acid and DCC according to Parker's method.[16]

General Procedure 4 for the Asymmetric Addition of Functionalized Dialkylzincs to (3-Oxopropyl)diphenylphosphine-borane complex **5**

A 25 mL three-necked flask equipped with an argon inlet, a thermometer and a septum cap was charged with ether (1.5 mL), $Ti(Oi\text{-}Pr)_4$ (445 mg, 1.6 mmol, 1 equiv), (*R,R*)-1,2-bis(trifluoromethanesulfonamido)-cyclohexane (48 mg, 0.1 mmol, 8 mol%). The reaction mixture was stirred for 30 min at 30 °C and then cooled to -60 °C. A solution of the functionalized dialkylzinc (2.0 - 2.5 equiv) was slowly added and the yellow solution was stirred for 10 min. After warming to - 20 °C, the aldehyde **5** (400 mg, 1.6 mmol) dissolved in ether (1 mL) was rapidly added. The reaction mixture was stirred for 14 h. TLC analysis of a hydrolyzed aliquot indicated the completion of the reaction. The reaction mixture was quenched with sat. aq. NH_4Cl and diluted with ether (50 mL). The aqueous layer was extracted with ether (4 x 50 mL).The combined organic layers were washed with brine and dried ($MgSO_4$). After filtration and evaporation of the solvents, the residual yellowish oil was purified by flash chromatography (hexanes/ether) leading to pure phosphinylalcohols. The enantiomeric excess was determined with ^{1}H-NMR of the corresponding *O*-acetylmandelic ester prepared using (*S*)-(+)-*O*-acetylmandelic acid and DCC according to Parker's method.[16] The absolute configurations of the alcohols were assigned tentatively according to Trost's method.[17]

(S)-1-(3'-Pyridyl)-hexanol **7a**

Pyridyl-3-carbaldehyde (0.5 mL, 5.0 mmol) was first protected with BEt_3 (0.75 mL, 5.0 mmol, 1 equiv) following *procedure 1* and then treated with $Pent_2Zn$ (2.0 equiv) following *procedure 2* yielding alcohol **7a** (0.67 g, 83 %, 88 %ee) after flash chromatographical purification ($EtOAc/CH_2Cl_2$ 2:1; R_f = 0.17); $[\alpha]_D^{20}$ = -34.9 (c = 2.2, $CHCl_3$); IR (neat): 3240 (m), 2918 (s), 2855 (s), 1574 (m), 1460 (m), 1432 (m); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 8.83 (m, 1 H), 8.28 (m, 1 H), 7.64 (m, 1 H), 7.17 (m, 1 H), 4.60 (t, *J* = 6.4 Hz, 1 H), 4.46 (s, 1 H), 1.79 - 1.55 (m, 2 H), 1.40 - 1.21 (m, 6 H), 0.80 (t, *J* = 6.8 Hz, 3 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 148.0, 147.5, 140.9, 133.9, 123.5, 71.7, 39.0, 31.6, 25.3, 22.5, 13.9; MS (EI): m/z 179 (5, M^+), 108 (100), 80 (12), 53 (6); $C_{11}H_{17}NO$ (179.26); calcd C 73.69, H 9.56, N 7.86; found C 73.50, H 9.60, N 7.87.

(S)-1-(3'-Pyridyl)-propanol **7b**

Pyridyl-3-carbaldehyde (0.5 mL, 5.0 mmol) was first protected with BEt_3 (0.75 mL, 5.0 mmol, 1 equiv) following *procedure 1* and then treated with Et_2Zn (1.5 equiv) following *procedure 2* yielding alcohol **7b** (0.66 g, 96 %, 92 %ee) after flash chromatographical purification ($EtOAc/CH_2Cl_2$ 2:1; R_f = 0.11); $[\alpha]_D^{20}$ = -43.6 (c 9.1, $CHCl_3$); IR (neat): 3220 (m), 3070 (m), 2970 (s), 2880 (s), 1560 (w), 1460 (m), 1415 (s), 1340 (s), 1220 (m); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 8.31 (m, 1H), 8.25 (m, 1 H), 7.63 (m, 1 H), 7.15 (m, 1 H), 4.90 (s, 1 H), 4.51 (t, *J* = 6.6 Hz, 1 H), 1.68 (m, 2 H), 0.82 (t, 3 H, *J* = 7.41 Hz); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 147.9, 147.4, 140.6, 133.9, 123.3, 72.8, 31.9, 9.8; MS (EI): m/z 137 (9, M^+), 108 (100), 80 (14), 53 (8). The obtained analytical data are identical with the literature.[7]

(S)-1-(3'-Pyridyl)-pentanol **7c**

Pyridyl-3-carbaldehyde (0.5 mL, 5.0 mmol) was first protected with BEt_3 (0.75 mL, 5.0 mmol, 1 equiv) following *procedure 1* and then treated with Bu_2Zn (2.0 equiv) following *procedure 2* yielding alcohol **7c** (0.67 g, 86 %, 84 %ee) after flash chromatographical purification ($EtOAc/CH_2Cl_2$ 2:1; R_f= 0.17); $[\alpha]_D^{20}$ = -35.3 (c 8.8, $CHCl_3$); IR (neat): 3380 (s), 2940 (m), 1640 (m), 1420 (m); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 8.35 (d, 1 H, 1.5Hz), 8.28 (m, 1 H), 7.64 (m, 1 H), 7.17 (m, 1H), 4.60 (t, *J* = 6.1 Hz, 1 H), 4.05 (s, 1 H), 1.79 - 1.56 (m, 2 H), 1.24 (m, 4 H), 0.81 (t, *J* = 7.0 Hz, 3 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 184.1, 147.5, 140.8, 133.8, 132.4, 71.8, 38.8, 27.7, 22.5, 13.9; MS (EI): m/z 163 (3), 118 (11), 108 (100), 80 (38), 36 (48); $C_{10}H_{15}NO$ (165.23): calcd C 72.69, H 9.15, N 8.48; found C 72.39, H 9.38, N 8.51.

(S)-1-(3'-Pyridyl)-nonanol **7d**

Pyridyl-3-carbaldehyde (0.5 mL, 5.0 mmol) was first protected with BEt_3 (0.75 mL, 5.0 mmol, 1 equiv) following *procedure 1* and then treated with Oct_2Zn (2.0 equiv) following *procedure 2* yielding alcohol **7d** (1.0 g, 90 %, 69 %ee) after flash chromatographical purification ($EtOAc/CH_2Cl_2$ 2:1; R_f= 0.34); $[\alpha]_D^{20}$ = -17.6 (c = 8.7, $CHCl_3$); IR (neat): 3248 (m), 2924 (s), 2853 (s), 1740 (w), 1595 (w), 1465 (w), 1430 (w), 1336 (w); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 8.42 (m, 1 H), 8.38 (m, 1 H), 7.68 (m, 1 H), 7.23 (m, 1 H), 4.66 (t, *J* = 6.0 Hz, 1 H), 3.65 (s, 1 H), 1.84 - 1.62 (m, 2 H), 1.21 (m, 12 H), 0.84 (t, *J* = 7.0 Hz, 3 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 148.4, 147.7, 140.6, 123.5, 72.0, 39.2, 31.9, 29.5, 29.2, 25.7, 22.7,

14.1; MS (EI): m/z 221 (6), 108 (100), 80 (11); $C_{14}H_{23}NO$ (221.33); calcd C 75.97, H 10.47, N 6.33; found C 75.85, H 10.41, N 6.30.

(S)-5-Pivaloxy-1-(3´-pyridyl)-pentanol **7e**
Pyridyl-3-carbaldehyde (0.25 mL, 2.5 mmol) was first protected with BEt_3 (0.38 mL, 2.5 mmol, 1 equiv) following *procedure 1* and then treated with di(4-pivaloxybutyl)zinc (1.6 equiv) following *procedure 2* yielding alcohol **7e** (1.0 g, 61 %, 91 %ee) after flash chromatographical purification (EtOAc/CH_2Cl_2 2:1; R_f = 0.16); $[\alpha]_D^{20}$ = -21.3 (c = 6.7, $CHCl_3$); IR (neat): 3245 (m), 2954 (s), 2870 (m), 1723 (s), 1580 (w), 1480 (m), 1430 (w), 1285(m), 1160 (s); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 8.34 (s, 1 H), 8.27 (m, 1 H), 7.63 (m, 1 H), 7.17 (m, 1 H), 4.72 (s, 1 H), 4.61 (t, *J* = 5.8 Hz, 2 H), 3.94 (t, *J* = 6.5 Hz, 2 H), 1.76 - 1.26 (m, 6 H), 1.07 (s, 9 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 178.4, 147.9, 147.2, 140.6, 133.7, 123.4, 71.3, 63.9, 38.5, 38.4, 28.2, 26.9, 21.8; MS (EI): m/z 265 (4, M^+), 122 (18), 108 (100), 103 (16), 101 (20), 57 (39); $C_{15}H_{23}NO_3$ (265.34); calcd C 67.89, H 8.74, N 5.28; found C 67.71, H 8.65, N 5.48.

(S)-5-Pivaloxy-1-(3´-pyridyl)-hexanol **7f**
Pyridyl-3-carbaldehyde (0.5 mL, 5 mmol) was first protected with BEt_3 (0.75 mL, 5.0 mmol, 1 equiv) following *procedure 1* and then treated with di(5-pivaloxypentyl)zinc (3.2 equiv) following *procedure 2* yielding alcohol **7f** (0.76 g, 54 %, 93 %ee) after flash chromatographical purification (EtOAc/CH_2Cl_2 2:1; R_f = 0.15); $[\alpha]_D^{20}$ = -13.0 (c = 4.7, $CHCl_3$); IR (neat): 3220 (m), 2970 (s), 1723 (s), 1600 (m), 1410 (m), 1280 (m), 1150 (s); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 8.44 (s, 1 H), 8.39 (m, 1 H), 7.66 (m, 1 H), 7.22 (m, 1 H), 4.66 (t, *J* = 6.7 Hz, 1 H), 3.98 (t, *J* = 6.6 Hz, 2 H), 3.51 (s, 1 H), 1.81 - 1.25 (m, 6 H), 1.14 (s, 9 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 178.4, 147.9, 147.2, 140.6, 133.7, 123.4, 71.3, 63.9, 38.5, 38.4, 28.2, 26.9, 21.8; MS (EI): m/z 279 (3, M^+), 122 (8), 108 (100), 103 (30), 57 (27); $C_{16}H_{25}NO_3$ (279.37); calcd C 68.78, H 9.02, N 5.01; found C 68.75, H 9.06, N 4.94.

(S)-1-(4´-Pyridyl)-propanol **7g**
Pyridyl-4-carbaldehyde (0.5 mL, 5 mmol) was first protected with BEt_3 (0.75 mL, 5.0 mmol, 1 equiv) following *procedure 1* and then treated with Et_2Zn (2.0 equiv) following *procedure 2* yielding alcohol **7g** (0.42 g, 61 %, 91 %ee) after flash chromatographical purification (EtOAc/CH_2Cl_2 2:1; R_f = 0.10); $[\alpha]_D^{20}$ = -45.3 (c = 6.2, $CHCl_3$); IR (neat): 3220 (s), 3000 (s), 2880 (s), 1690 (s), 1600 (s), 1560 (m), 1410 (s), 1220 (m); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 8.44 (d, *J* = 4.7 Hz, 2 H), 7.24 (d, *J* = 4.8, 2 H), 4.59 (t, *J* = 6.3 Hz), 3.41 (s, 1 H), 1.73 (q, *J* = 7.5 Hz, 2 H), 0.91 (t, *J* = 7.4 Hz); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 153.6, 149.5, 121.0, 74.0, 31.7, 9.7; MS (EI): m/z 137 (24, M^+), 108 (100), 80 (30), 53 (11), 51 (11); $C_8H_{11}NO$ (137.18); calcd C 70.04, H 8.08, N 10.21; found C 70.09, H 7.83, N 10.36.

(S)-1-(4´-Pyridyl)-hexanol **7h**
Pyridyl-4-carbaldehyde (0.5 mL, 5 mmol) was first protected with BEt_3 (0.75 mL, 5.0 mmol, 1 equiv) following *procedure 1* and then treated with $Pent_2Zn$ (2.0 equiv) following *procedure 2* yielding alcohol **7h** (0.42 g, 61 %, 91 %ee) after flash chromatographical purification (EtOAc/CH_2Cl_2 2:1; R_f = 0.14); $[\alpha]_D^{20}$ = -31.2 (c = 3.4, $CHCl_3$); IR (neat): 3215 (m), 3030 (m), 2950 (s), 2930 (s), 2860 (s), 1600 (s), 1410 (m); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 8.34 (s, 2H), 7.23 (d, *J* = 5.9 Hz, 2 H), 4.63 (t, *J* = 6.0 Hz, 1 + 1 H), 1.66 (m, 2 H), 1.26 (m, 6 H), 0.83 (t, *J* = 6.1 Hz, 3 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ 154.8, 149.3, 121.1, 72.7, 38.9, 31.7, 25.2, 22.5, 13.9; MS (EI): m/z 179 (11, M^+), 108 (100), 80 (21), 43 (6); $C_{11}H_{17}NO$ (179.26); calcd C 73.69, H 9.56, N 7.82; found C 73.18, H 9.57, N 8.16.

(S)-1-(4´-Pyridyl)-nonanol **7i**
Pyridyl-4-carbaldehyde (0.5 mL, 5 mmol) was first protected with BEt_3 (0.75 mL, 5.0 mmol, 1 equiv) following *procedure 1* and then treated with Oct_2Zn (2.0 equiv) following *procedure 2* yielding alcohol **7i** (0.39 g, 35 %, 66 %ee) after flash chromatographical purification (EtOAc/CH_2Cl_2 2:1; R_f = 0.29); $[\alpha]_D^{20}$ = -14.9 (c = 2.7, $CHCl_3$); IR (neat): 3260 (m), 2915 (s), 2850 (s), 1740 (w), 1600 (w), 1455 (w), 1425 (w), 1340 (w); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 8.41 (s, 2H), 7.23 (d, *J* = 5.9 Hz, 2 H), 5.19 (t, *J* = 6.0 Hz, 1 H), 4.33 (s, 1 H), 1.63 - 1.61 (m, 2 H), 1.17 (m, 12 H), 0.72 (t, *J* = 7.0 Hz, 3 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 153.7, 148.6, 121.2, 72.6, 38.9, 31.8, 29.4, 29.1, 25.2, 22.6, 14.0; MS (EI): m/z 221 (2, M^+), 108 (100), 80 (11); $C_{14}H_{23}NO$ (221.33); calcd C 75.97, H 10.47, N 6.33; found C 75.92, H 10.36, N 6.19.

(S)-5-Pivaloxy-1-(4´-pyridyl)-pentanol **7j**
Pyridyl-4-carbaldehyde (0.5 mL, 5 mmol) was first protected with BEt_3 (0.75 mL, 5.0 mmol, 1 equiv) following *procedure 1* and then treated with di(4-pivaloxybutyl)zinc (1.6 equiv) following *procedure 2* yielding alcohol **7j** (0.42 g, 61 %, 91 %ee) after flash chromatographical purification (EtOAc/CH_2Cl_2 2:1; R_f = 0.12); $[\alpha]_D^{20}$ = -20.0 (c = 5.1, $CHCl_3$); IR (neat) 3230 (s), 2940 (s), 1720 (s), 1600 (s), 1480 (s), 1280 (s), 1150 (s); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 8.39 (m, 2 H), 7.19 (m, 2 H), 4.61 (t, *J* = 5.9 Hz, 1 H), 3.95 (t, *J* = 6.6 Hz, 2 H), 3.57 (s, 1 H), 1-68 - 1.29 (m, 6 H), 1.10 (s, 9 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 178.7, 154.2, 149.5, 120.9, 72.6, 64.2, 38.8, 28.5, 27.2, 25.8, 25.1; MS (EI): m/z 165 (2), 250 (3), 122 (19), 108 (100), 101 (62), 80 (21), 57 (99); $C_{15}H_{23}NO_3$ (265.34); calcd C 73.69, H 9.56, N 7.82; found C 73.18, H 9.57, N 8.16.

(S)-6-Pivaloxy-1-(4´-pyridyl)-hexanol **7k**
Pyridyl-4-carbaldehyde (0.5 mL, 5 mmol) was first protected with BEt_3 (0.75 mL, 5.0 mmol, 1 equiv) following *procedure 1* and then treated with di(5-pivaloxypentyl)zinc (1.6 equiv) following *procedure 2* yielding alcohol **7k** (0.59 g, 42 %, 88 %ee) after flash chromatographical purification (EtOAc/CH_2Cl_2 2:1; R_f = 0.15); $[\alpha]_D^{20}$ = -17.5 (c = 3.7, $CHCl_3$); IR (neat): 3200 (m), 29970 (s), 1720 (s), 1600 (m), 1290 (s), 1160 (s); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 8.32 (m, 2 H), 7.19 (m, 2 H), 4.60 (t, *J* = 6.7 Hz, 1 + 1 H), 3.94 (t, *J* = 6.6 Hz, 2 H), 1.66 - 1.28 (m, 8 H), 1.09 (s, 9 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ =178.7, 154.7, 149.2, 121.0, 72.4, 64.2, 38.8, 38.7, 31.6, 28.5, 27.3, 25.8, 25.1; MS (EI): m/z 250 (3), 180 (9), 163 (4), 122 (23), 108 (81), 101 (61), 80 (25), 57 (100); $C_{16}H_{25}NO_3$ (279.37); calcd C 73.69, H 9.56, N 7.82; found C 73.18, H 9.57, N 8.16.

(S)-1-(4´-Quinolyl)-propanol **14a**
Quinolyl-4-carbaldehyde (0.40 g, 2.5 mmol) was treated with Et_2Zn (2.0 equiv) following *procedure 2* yielding alcohol **14a** (0.33 g, 71 %, 72 %ee) after flash chromatographical purification (EtOAc/CH_2Cl_2 2:1; R_f= 0.25); $[\alpha]_D^{20}$ = +38.4 (c = 12.5, $CHCl_3$); IR (neat): 3210 (s), 3075 (s), 2968 (s), 1588 (s), 1509, (s), 1460 (m), 1120 (m), 1090 (m); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 8.57 (m, 1 H), 7.93 (m, 2 H), 7.54 (m, 1 H), 7.42 (m, 2 H), 5.30 (m, 1 H), 4.34 (s, 1 H), 1.83 (m, 2 H), 0.94 (t, *J* = 7.3 Hz, 1 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 151.1, 149.9, 147.8, 129.8, 128.8, 126.2, 125.4, 122.9, 117.3, 69.7, 31.5, 25.6, 22.4, 13.8; MS (EI): m/z 187 (55, M^+), 158 (100), 130 (97), 103 (11), 77 (12), 75 (7), 51 (5); $C_{12}H_{13}NO$ (187.23); calcd C 76.97, H 6.99, N 7.48; found C 76.72, H 7.11, N 7.48.

(S)-1-(4´-Quinolyl)-hexanol **14b**
Quinolyl-4-carbaldehyde (0.40 g, 2.5 mmol) was treated with $Pent_2Zn$ (2.0 equiv) following *procedure 2* yielding alcohol **14b** (0.37 g, 64 %, 81 %ee) after flash chromatographical purification (EtOAc/CH_2Cl_2 2:1; R_f = 0.34); $[\alpha]_D^{20}$ = +50.9 (c = 3.7, $CHCl_3$); IR (neat): 3225 (s), 2930 (s), 1590 (m), 1510 (m), 1380 (s), 1190 (s); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 8.57 (m, 1 H), 7.93 (m, 2 H), 7.54 (m, 1 H), 7.42 (m, 2 H), 5.30 (m, 1 H), 4.34 (s, 1 H), 1.83 (m, 2 H), 0.94 (t, *J* = 7.3 Hz, 1 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 151.1, 149.9, 147.8, 129.8, 128.8, 126.2, 125.4, 122.9, 117.3, 69.7, 38.3, 31.5, 25.6, 22.4, 13.8; MS (EI): m/z 229 (30, M^+), 158 (100), 130 (35), 103 (5); $C_{15}H_{19}NO$ (229.91); calcd C 78.56, H 8.35, N 6.11; found C 78.45, H 8.30, N 6.06.

(S)-1-(4´-Isoquinolyl)-propanol **14c**
Isoquinolyl-4-carbaldehyde (0.47 g, 3.0 mmol) was first protected with BEt_3 (0.45, 3.0 mmol, 1 equiv) following *procedure 1* and then treated with Et_2Zn (2.0 equiv) following *procedure 2* yielding alcohol **14c** (0.28 g, 50 %, 93 %ee) after flash chromatographical purification (EtOAc/CH_2Cl_2 2:1; R_f= 0.06); $[\alpha]_D^{20}$ = +42.7 (c = 1.9, $CHCl_3$); IR (neat): 3250 (s), 2960 (s), 1620 (s), 1240 (m), 980 (m); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 8.62 (s, 1 H), 8.17 (s, 1 H), 7.90 (d, *J* = 8.6 Hz), 7.58 (d, *J* = 8.2 Hz, 1 H), 7.32 (m, 2 H), 5.14 (s, 1 H), 4.94 (t, *J* = 8.7 Hz, 1 H), 1.72 (q, *J* = 10.8 Hz, 2 H), 0.73 (t, *J* = 11.1 Hz, 3 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 151.5, 139.9, 133.7, 133.3, 130.1, 128.1, 128.0, 126.6, 123.0, 71.4, 30.8, 10.4; MS (EI): m/z 187 (16), 158 (100), 130 (47), 77 (10); $C_{12}H_{13}NO$ (187.23); calcd C 76.98, H 6.99, N 7.48; found C 76.72, H 6.50, N 7.36.

(S)-1-(4´-Isoquinolyl)-hexanol **14d**
Isoquinolyl-4-carbaldehyde (0.47 g, 3.0 mmol) was first protected with BEt_3 (0.45, 3.0 mmol, 1 equiv) following *procedure 1* and then treated with $Pent_2Zn$ (2.0 equiv) following *procedure 2* yielding alcohol **14d**

(0.28 g, 86 %, 92 %ee) after flash chromatographical purification (EtOAc/CH_2Cl_2 2:1; R_f = 0.06); $[\alpha]_D^{20}$ = +57.1 (c = 0.8, $CHCl_3$); IR (neat): 3300 (s), 3010 (m), 1940 (m), 1480 (m), 1440 (s), 1180 (m), 1000(s); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 8.88 (s, 1 H), 8.38 (s, 1 H), 8.11 (d, *J* = 8.4 Hz, 1 H), 7.80 (d, *J* = 7.9 Hz, 1 H), 7.61 (m, 1 H), 7.48 (m, 1 H), 5.21 (t, *J* = 7.3 Hz, 1 H), 4.52 (s, 1 H), 1.86 (m, 2 H), 1.52 - 1.21 (m, 6 H), 0.80 (t, *J* = 7.2 Hz, 3 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 152.0, 140.1, 134.0, 133.5, 130.4, 128.4, 126.9, 123.3, 70.7, 38.3, 31.8, 26.1, 22.7, 14.1; MS (EI): m/z 229 (11, M^+), 158 (100), 130 (30), 128 (14), 77 (10); $C_{15}H_{19}NO$ (229.31); calcd C 78.56, H 8.35, N 6.11; found C 78.36, H 8.71, N 5.95.

[(S)-3-Hydroxypentyl]-diphenylphosphine-borane complex **15a**
Prepared using Et_2Zn (0.35 mL, 3.4 mmol) and **5** (400 mg, 1.6 mmol) following *procedure 4* (reaction conditions: -35 °C, 14 h, toluene) yielding alcohol **15a** (370 mg, 83 %, 90 %ee) after flash chromatographical purification (hexane/ether 1:1); $[\alpha]_D^{20}$ = +15.5 (c = 1.3, $CHCl_3$); IR (neat): 3400 (br), 2940 (m), 2380 (s), 1440 (s), 1110 (s), 1060 (s), 740 (s), 690 (s); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 7.73-7.41 (m, 10 H), 3.55 (m, 1 H), 2.58-2.44 (m, 1 H), 2.30-2.16 (m, 1 H), 1.82-1.68 (m, 2 H), 1.63-1.35 (m, 3 H), 0.9 (t, *J* = 7.4 Hz, 3H), 1.96 - 0.38 (m, 3 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 132.1 (d, *J* = 9.2 Hz), 132.0 (d, *J* = 9.1 Hz), 131.1 (m), 129.7 (d, *J* = 55.1 Hz), 129.1 (d, *J* = 55.1 Hz), 128.7 (d, *J* = 9.8 Hz), 73.2 (d, *J* = 13.4 Hz), 29.9 , 21.6 (d, *J* = 38.4 Hz), 9.8; MS (EI): m/z 285 (5), 272 (52), 200 (100), 199 (92), 183 (23); $C_{17}H_{24}BOP$ (286.14); calcd C 71.36; H 8.45; found C 71.56; H 8.75.

[(S)-3-Hydroxyoctyl]-diphenylphosphine-borane complex **15b**
Prepared using $Pent_2Zn$ (810 mg, 3.9 mmol) and **5** (400 mg, 1.6 mmol) following *procedure 4* (reaction conditions: -25 °C, 14 h, toluene) yielding alcohol **15b** (370 mg, 72 %, 93 %ee) after flash chromatographical purification (hexane/ether 2:1); $[\alpha]_D^{20}$ = +10.9 (c = 1.2, $CHCl_3$); IR (neat): 3420 (br), 2940 (s), 2380 (s), 1440 (s), 1110 (m), 1060 (s), 740 (s), 690 (s); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 7.70 - 7.37 (m, 10 H), 3.60 (m, 1 H), 2.60 - 2.40 (m, 1 H), 2.32-2.16 (m, 1 H), 1.97 (br, 1 H), 1.82-1.66 (m, 1 H), 1.66 - 1.48 (m, 1 H), 1.48 - 1.16 (m, 8 H), 0.87 (t, *J* = 6.8 Hz, 3 H), 1.90 - 0.41 (m, 3 H); ^{13}C-NMR ($CDCl_3$, 75 Hz): δ = 132.0 (d, *J* = 9.4 Hz), 131.9 (d, *J* = 9.4 Hz), 131.0 (m), 129.6 (d, *J* = 55.0 Hz), 129.2 (d, *J* = 55.0 Hz), 128.7 (d, *J* = 10.0 Hz), 128.6 (d, *J* = 9.8 Hz), 71.8 (d, *J* = 13.4 Hz), 37.0, 31.6, 30.3, 25.1, 22.4, 21.4 (d, *J* = 38.4 Hz), 13.8; MS (EI): m/z 327 (5), 314 (46), 200 (100), 183 (26), 108 (23). Exact mass. calcd for $C_{20}H_{29}BOP$: 327.2049; observed: 327.2048.

[(S)-3-Hydroxy-7-pivaloxyheptyl]-diphenylphosphine-borane complex **15c**
Prepared using di(4-pivaloxybutyl)zinc (3.9 mmol) and **5** (400 mg, 1.6 mmol) following *procedure 4* (reaction conditions: -20 °C, 14 h, ether) yielding alcohol **15c** (393 mg, 61 %, 95 %ee) after flash chromatographical purification (hexane/ether 1:1, 1% NEt_3 added); $[\alpha]_D^{20}$ = +9.2 (c = 0.6, $CHCl_3$); IR (neat): 3460 (br), 2950 (s), 2370 (s), 1740 (s), 1290 (s), 1160 (s), 1060 (s), 740 (s), 690 (s); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 7.73 - 7.61 (m, 4 H), 7.42 - 7.36 (m, 6 H), 4.02 (t, *J* = 6.5 Hz, 2 H), 3.68 - 3.56 (m, 1 H), 2.56 - 2.40 (m, 1 H), 2.29 - 2.15 (m, 1 H), 1.98 (br, 1 H), 1.17 (s, 9 H), 1.79 - 0.50 (m, 11 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 178.5, 132.0 (m), 131.0 (m), 129.6 (d, *J* = 55.0 Hz), 129.2 (d, *J* = 55.0 Hz), 128.7 (d, *J* = 9.8 Hz), 128.6 (d, *J* = 9.9 Hz), 71.5 (d, *J* = 13.3 Hz), 64.0, 38.6, 36.6, 30.4, 28.4, 27.1, 21.9, 21.5 (d, *J* = 38.3 Hz). MS (EI): m/z 400 (10), 299 (8), 200 (100), 183 (22), 108 (20), 57 (27); $C_{24}H_{36}BO_3P$ (414.31); calcd C 69.57; H 8.76; found: C 69.57; H 9.02.

[(S)-8-Acetoxy-3-hydroxyoctyl]-diphenylphosphine-borane complex **15d**
Prepared using di(5-acetoxypentyl)zinc (5.1 mmol) and **5** (500 mg, 2.0 mmol) following *procedure 4* (reaction conditions: -20 °C, 14 h, toluene) yielding alcohol **15d** (424 mg, 56 %, 94 %ee) after flash chromatographical purification (toluene/EtOAc 4:1, 1% NEt_3 added); $[\alpha]_D^{20}$ = +7.6 (c = 1.6, $CHCl_3$); IR (neat): 3400 (br), 2930 (s), 2370 (s), 1720 (s), 1240 (s), 1060 (s), 740 (s), 690 (s); ^{1}H-NMR ($CDCl_3$, 300 MHz): δ = 7.71 - 7.58 (m, 4 H), 7.48 - 7.34 (m, 6 H), 3.99 (t, *J* = 6.7 Hz, 2 H), 3.62 - 3.52 (m, 1 H), 2.58 - 2.38 (m, 1 H), 2.28 - 2.10 (m, 1 H), 1.99 (bs, 4 H), 1.80-0.30 (m, 13 H); ^{13}C-NMR ($CDCl_3$, 75 MHz): δ = 171.1, 132.1 (d, *J* = 9.1 Hz), 131.9 (d, *J* = 9.1 Hz), 131.0 (m), 129.6 (d, *J* = 55.2 Hz), 128.7 (d, *J* = 9.8 Hz), 128.6 (d, *J* = 9.8 Hz), 71.6 (d, *J* = 13.4 Hz), 64.3, 36.9, 30.4, 28.4, 25.7, 25.1, 21.5 (d, *J* = 38.4 Hz), 20.8; MS (EI): m/z 372 (20), 200 (100), 183 (24), 108 (24), 43 (29); $C_{22}H_{32}BO_3P$ (386.28); calcd C 68.41; H 8.35; found: C 68.45; H 8.67.

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References and Notes

1. (a) P. Knochel, R. D. Singer, *Chem. Rev.* **1993**, *93*, 2117; (b) P. Knochel, *Synlett* **1995**, 393.
2. (a) H. Takahashi, T. Kawakita, M. Ohno, M. Yoshioka, S. Kobayashi, *Tetrahedron* **1992**, *48*, 5691; (b) J. F. Larrow, E. N. Jacobsen, Y. Gao, Y. Hong, X. Nie, C. M. Zepp, *J. Org. Chem.* **1994**, *59*, 1939.
3. (a) P. Knochel, S. Vettel, C. Eisenberg, *Applied Organomet. Chem.* **1995**, *9*, 175. (b) S. Vettel, C. Lutz, P. Knochel, *Synlett* **1996**, 731; (c) F. Langer, L. Schwink, A. Devasagayaraj, P.-Y. Chavant, P. Knochel, *J. Org. Chem.* **1996**, *61*, 8229; (d) C. Lutz, P. Knochel, *J. Org. Chem.* **1997**, 62, 7895.
4. D. J. Brooks, D. S. Dowell, D. E. Minter, M. C. Villarreal, *J. Org. Chem.* **1984**, *49*, 130.
5. S. V. Kessar, P. Singh, K. N. Singh, M. Dutt, *J. Chem. Soc., Chem. Commun.* **1991**, 570.
6. (a) H. Schmidbaur, *J. Organomet. Chem.* **1980**, *200*, 287; (b) T. Imamoto, T. Oshiki, T. Onozawa, T. Kusumoto, K. Sato, *J. Am. Chem. Soc.* **1990**, *112*, 5244; (c) Y. Gourdel, P. Pellon, L. Toupet, M. Le Corre, *Tetrahedron Lett.* **1994**, *35*, 1197; (d) A. Longeau, F. Langer, P. Knochel, *Tetrahedron Lett.* **1996**, *37*, 2209.
7. (a) C. Bolm, M. Zehnder, D. Bur, *Angew. Chem.* **1990**, *102*, 206; *Angew. Chem. Int. Ed. Engl.* **1990**, *102*, 205; (b) G. Chelucci, S. Conti, M. Falorni, G. Ciacomelli, *Tetrahedron* **1991**, *47*, 8251; (c) C. Bolm, M. Ewald, M. Felder, G. Schlingloff, *Chem. Ber.* **1992**, *125*, 1169; (d) M. Ishizaki, K. Fujita, M. Shimamoto, O. Hoshino, *Tetrahedron : Asymmetry* **1994**, *5*, 411.
8. (a) K. Soai, S. Niwa, T. Kobayashi, *J. Chem. Soc., Chem. Commun.* **1987**, 801; (b) M. M. Midland, J. I. Mc Loughlin, J. Gabriel, *J. Org. Chem.* **1989**, *54*, 159; (c) H. C. Brown, S. A. Weismann, S. Swaminathan, P. V. Ramachandran, *J. Org. Chem.* **1990**, *55*, 6328; (d) U. S. Racherla, H. C. Brown, *J. Org. Chem.* **1991**, *56*, 401; (e) U. S. Racherla, Y. Liao, H. C. Brown, *J. Org. Chem.* **1992**, *57*, 6614.
9. (a) R. Seemayer, M. P. Schneider, *Tetrahedron : Asymmetry* **1992**, *3*, 827; (b) B. D. Simone, D. Savoia, E. Tagliavini, A. Umani-Ronchi, *Tetrahedron : Asymmetry* **1995**, *6*, 301.
10. (a) K. Soai, S. Niwa, H. Hori, *J. Chem. Soc., Chem. Commun.* **1990**, 982; (b) K. Soai, T. Hayase, C. Shimada, K. Isobe, *Tetrahedron : Asymmetry* **1995**, *5*, 789; (c) K. Soai, T. Hayase, K. Takai, *Tetrahedron : Asymmetry* **1996**, *6*, 637; (d) T. Shibata, H. Morioka, T. Hayase, K. Choji, K.Soai, *J. Am. Chem. Soc.* **1996**, *118*, 471; (e) T. Shibata, K. Choji, H. Morioka, T. Hayase, K. Soai, *J. Chem. Soc., Chem. Commun.* **1996**, 751; (f) T. Shibata, H. Morioka, S. Tanji, T. Hayase, Y. Kodaka, K. Soai, *Tetrahedron Lett.* **1996**, *37*, 8783.
11. K. Nützel in *Houben-Weyl, Methoden der Organischen Chemie*, Vol. 13/2a, p. 552; Thieme, Stuttgart, **1973**.
12. A. Oku, T. Harada, K. Kita, *Tetrahedron Lett.* **1982**, *23*, 681.
13. P. Pellon, *Tetrahedron Lett.* **1992**, *33*, 4451.
14. H. Brisset, Y. Gourdel, P. Pellon, M. LeCorre, *Tetrahedron Lett.* **1993**, *34*, 4523.
15. M. J. Rozema, S. AchyuthaRao, P. Knochel, *J. Org. Chem.* **1992**, *57*, 1956.
16. D. Parker, *J. Chem. Soc., Perkin Trans. 2* **1983**, 83.
17. B. M. Trost, J. L. Belletire, S. Godleski, P. G. McDougal, J. M. Balkovec, J. J. Baldwin, M. E. Christy, G. S. Ponticello, S. L. Varga, J. P. Springer, *J. Org. Chem.* **1986**, *51*, 2370.