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Chiral 1,1′-Bi(tetrahydroisoquinoline)-Type Diamines as Efficient Ligands for Nickel-Catalysed Enantioselective Michael Addition to Nitroalkenes

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A chiral C_2-symmetric 1,2-diamine based on a 1,1′-bi(tetrahydroisoquinoline) scaffold was found to be an efficient ligand for the enantioselective Ni^{II}-catalysed Michael addition of malonic esters to conjugated nitroalkenes. The reactions proceed with 92–99 % yield and 91–99 % enantioselectivity even at elevated temperatures. The solid-state structure of the catalyst precursor revealed intramolecular π–π stacking as well as supramolecular halogen···halogen bonding interactions.

Introduction

The development of methods for the efficient construction of chiral compounds constitutes a major goal in modern synthetic chemistry.[1] Great achievements in the field of asymmetric catalysis have led to the establishment of several privileged chiral catalysts and ligand classes.[2] Such ligands typically combine a flexible and economically feasible synthetic route, enhanced thermal stability, strong binding to the metal centre, together with excellent enantioselectivities for a variety of mechanistically diverse reactions. Although an increasing number of highly successful applications of monodentate and C_1-symmetric ligands have been reported, a plethora of ligands showing bidentate binding of the metal and a C_2-symmetric ligand scaffold have proven to be robust and efficient in catalytic processes to achieve excellent stereocontrol for a broad range of substrates.[3,4] Chiral diphosphanes and diols, such as BINAP,[5a] DuPhos,[5b] and BINOL,[5c] or bis-oxazoline ligands[5d] serve as examples in this context. In addition, vicinal diamines represent another versatile stereochemical control element for ligand design, for example, in the highly successful class of salen-type ligands.[6] Most systems that are used in this respect employ readily available *trans*-1,2-diaminocyclohexane (DACH; **1**) or 1,2-diphenylethane-1,2-diamine (DPEN; **2**) derivatives (Figure 1). A further increase of rigidity of DPEN-derived ligands was exemplified by the incorporation of two phenyl groups into a 1,1′-bi(isoindoline) moiety, such as in ligand **4**.[7] However, despite straightforward synthetic access to structurally related, chiral 1,1′-bi(tetrahydroisoquinolines),[8] such diamines have rarely been utilised as chiral ligands.[8c] In recent publications, the potential of 1,1′-biisoquinoline (BIQ) as well as mono-isoquinoline (MIQ) derived N-heterocyclic carbene ligands for asymmetric catalysis has been demonstrated.[9]

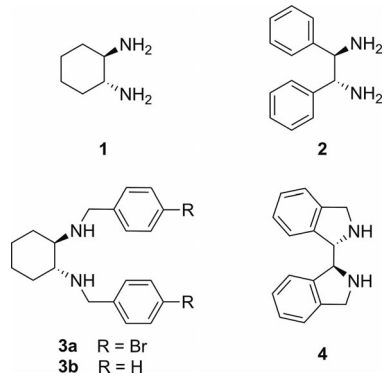

Figure 1. Chiral diamine ligands: *trans*-1,2-diaminocyclohexane (DACH; **1**), 1,2-diphenylethane-1,2-diamine (DPEN; **2**), benzylated diaminocyclohexanes (**3**), and 1,1′-biisoindoline (**4**).

In the course of our earlier studies on the enantioselective gold-catalysed desymmetrisation of 1,4-diynes,[10] we recently reported the preparation of chiral gold carbene complexes **5** based on a 1,1′-bi(tetrahydroisoquinoline) scaffold (Figure 2).[11]

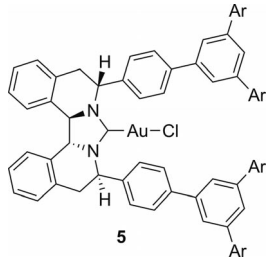

Figure 2. Sterically highly encumbered gold carbene complexes.

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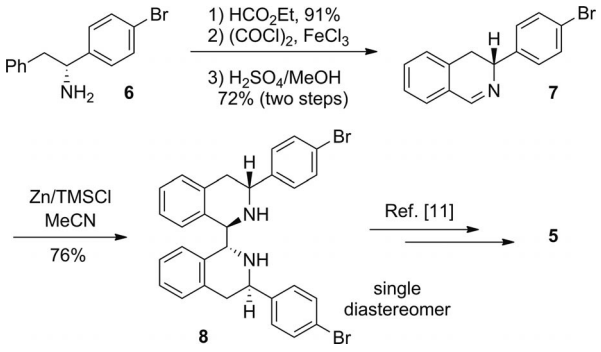
The synthetic sequence used to obtain the core of the sterically encumbered carbene complexes **5** was inspired by a procedure published by Herrmann and co-workers.[9b] By a modification of the reported synthesis, C_2-symmetric diamine **8** was prepared utilising a reductive coupling of 3,4-dihydroisoquinoline **7** with Zn/TMSCl in acetonitrile as a key step (Scheme 1).[8a,12]



Scheme 1. Stereoselective synthesis of 1,1′-bi(tetrahydroisoquinoline) **8**.

Remarkably, in this step, **8** is formed as a single diastereoisomer, which is in agreement with observations by Herrmann and co-workers. Overall, **8** was obtained from chiral phenylethylamine precursor **6** in a yield of 50% over three steps. As shown in earlier studies, the *para*-bromo substituent can be readily modified by means of palladium-catalysed Suzuki cross-coupling, employing suitable boronic acid coupling partners.[11] This late-stage derivatization enables easy variation of the steric demand of ligand **8**.

In this publication, we wish to report our initial results using chiral, 3,3′-disubstituted 1,1′-bi(tetrahydroisoquinolines) as efficient ligands for asymmetric catalysis. This approach was exemplified in a nickel-catalysed asymmetric Michael addition of malonates to nitroalkenes.[13]

Results and Discussion

In addition to using diamine **8** as a precursor for the generation of NHC ligands, we became interested in evaluating its performance as a chiral diamine ligand itself in transition-metal-mediated processes. Related structural motifs (i.e., **3**[13c] and **4**[7]) have been reported for asymmetric nickel-catalysed Michael addition reactions (Figure 1). Due to the higher structural rigidity of diamine **8**, we anticipated that, even at elevated temperatures, the corresponding nickel complex might perform well in such transformations. Therefore, we synthesised nickel complexes **9**–**11**, bearing one and two ligands, from the corresponding diamines by reaction with $NiBr_2$ in refluxing acetonitrile following published procedures (Figure 3).[13c]

Evans and co-workers found the bis(diamine) nickel complexes from **3** to perform well as efficient catalysts for the addition of malonates to nitroalkenes.[13c] Therefore, we chose the addition of diethyl malonate (**13a**) to nitrostyrene

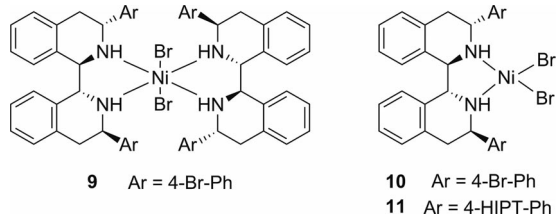
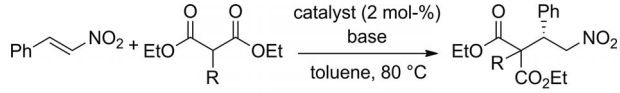


Figure 3. Nickel complexes bearing one and two chiral diamine ligands (HIPT = hexaisopropylterphenyl).

(**12a**) as a benchmark test for our new catalyst (Table 1). In initial studies with complex **9** no conversion, not even at higher temperatures, was observed.[14] This was presumably due to an enhanced stability of **9**, which results in insufficient ligand dissociation and substrate binding (vide infra). However, the addition of an equimolar amount of *N*-methylmorpholine (NMM) as additive allowed the reaction to proceed. After two hours at 80 °C, the addition product was isolated in quantitative yield and with very good enantiopurity (97% *ee*; Table 1, entry 1 vs. 2). 2-Substituted malonates were not suitable substrates, resulting in either low or no conversion (Table 1, entries 3 and 4). The application of catalyst **10** resulted in a very similar outcome, but could be improved by reducing the quantity of the basic additive to catalytic amounts (5 mol-%) of either NMM or triethylamine (TEA; Table 1, entries 7 and 8). This indicates that, under the reaction conditions, complexes **9** and **10** serve as precursors for either the same or a closely related catalytically active species. This assumption is supported by the finding that both transformations proceed with very similar reaction rates irrespective of the type or amount of base used.

Table 1. Nickel-catalysed malonate addition to nitrostyrene; application of complexes **9** and **10**.[a]



12a **13** **14**

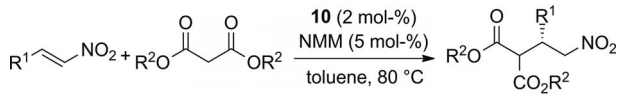
Entry	R	Base	Yield [%]	*ee* [%][e]
1[b]	H (**13a**)	–	–	–
2[b]	H (**13a**)	NMM (1 equiv.)	quant. (*R*-**14a**)	97
3[b]	Ph (**13b**)	NMM (1 equiv.)	–	–
4[b]	Bn (**13c**)	NMM (1 equiv.)	18 (*R*-**14b**)[f]	n.d.
5[c]	H (**13a**)	NMM (1 equiv.)	99 (*R*-**14a**)	93
6[c]	H (**13a**)	TEA (1 equiv.)	99 (*R*-**14a**)	92
7[c]	H (**13a**)	NMM (5 mol-%)	97 (*R*-**14a**)	97
8[c]	H (**13a**)	TEA (5 mol-%)	99 (*R*-**14a**)	97
9[d]	H (**13a**)	NMM (5 mol-%)	93 (*R*-**14a**)	96
10[g]	H (**13a**)	NMM (5 mol-%)	99 (*R*-**14a**)	90

[a] Reagents and conditions: catalyst (2 mol-%), toluene, 80–90 °C, 2 h. [b] Complex **9** was employed as catalyst. [c] Complex **10** was employed as catalyst. [d] Complex **11** was employed as catalyst. [e] The enantiomeric excess was determined by chiral HPLC analysis (ChiralPak IA). [f] Conversion was determined by ^1H NMR analysis of the crude reaction mixture. [g] The reaction was carried out at 120 °C.

Given the elevated reaction temperature (80 °C), it is noteworthy that the enantioselectivities are among the highest that have been observed for this transformation. In fact, even at 120 °C, the enantiomeric excess was still 90% (Table 1, entry 10). In comparison, Evans and co-workers reported a significant attenuation of selectivity when the bis(diamine)-nickel complex from **3b** was employed at higher temperature (89% *ee* at 80 °C vs. 95% *ee* at room temp.).[13c] We assume that the findings mentioned above might be traced back to the additional 4-bromophenyl sidechain and to the high rigidity of the ligand scaffold, which leads to improved stereocontrol in the Michael addition. The use of sterically more demanding complex **11** did not result in any improvement in stereoselectivity (Table 1, entry 9).[11]

To evaluate the substrate scope with respect to the Michael acceptor, various substituted arylnitroalkenes were investigated under the same conditions described above (Table 2). For all of the investigated substrates, excellent yields (92–99%) and enantioselectivities (91–99%) were obtained by applying nickel diamine complex **10**.

Table 2. Nickel-catalysed Michael addition of malonates to aromatic nitroalkenes.[a]



12 **13** **14**

Entry	R^1	R^2	Yield [%]	*ee* [%][b]
1	Ph (**12a**)	Et (**13a**)	97 (*R*-**14a**)	97
2	Ph (**12a**)	Me (**13d**)	97 (*R*-**14c**)	97
3	4-MeO-C_6H_4 (**12b**)	Et (**13a**)	94 (*R*-**14d**)	95
4	2,4-$(MeO)_2$-C_6H_3 (**12c**)	Et (**13a**)	95 (*R*-**14e**)	91
5	4-Cl-C_6H_4 (**12d**)	Et (**13a**)	99 (*R*-**14f**)	97
6	2-Cl-C_6H_4 (**12e**)	Et (**13a**)	97 (*R*-**14g**)	99
7	2-furyl (**12f**)	Et (**13a**)	98 (*S*-**14h**)	97
8	2,4-$(Me)_2$-C_6H_3 (**12g**)	Et (**13a**)	96 (*R*-**14i**)	96
9	*trans*-PhCH=CH (**12h**)	Et (**13a**)	98 (*R*-**14j**)	92
10	1-naphthyl (**12i**)	Et (**13a**)	92 (*R*-**14k**)	97

[a] Reagents and conditions: **13** (1.2 equiv.), **10** (2 mol-%), NMM (5 mol-%), toluene (0.25 M), 80 °C, 1.5–7 h. [b] Enantiomeric excess was determined by chiral HPLC analysis (Chiralpak IA or Chiralpak IB).

Huang and Xia reported that the use of sterically hindered *tert*-butyl malonate was necessary to obtain the highest selectivity employing a nickel catalyst incorporating diamine **4**.[7] In contrast, using catalyst **10**, ethyl (**13a**) and methyl malonate (**13d**) also provided the corresponding products in very high selectivity (97% *ee*; Table 2, entries 1 and 2).[15]

It should be pointed out that, in agreement with Evans' findings, complexes of ligand **4** with other metals have proven to be inferior to the nickel catalysts. In test reactions, magnesium bromide, zinc chloride and copper(II) chloride complexes all showed incomplete conversion to product **14a** even after four days at 80 °C (80, 45, and 0% conversion, respectively).

A deeper insight into the catalyst structure was gained by X-ray analysis of the pale-blue single crystals of complex **9**, which were obtained by slow crystallization at –20 °C from a saturated acetonitrile/dichloromethane solution (Figure 4). The geometry of **9** is consistent with those of related known complexes.[7,13] Inspection of the elementary cell reveals a stair-like, octahedral geometry with the two ligating bromine atoms in the apical positions of the central nickel atom. Furthermore, a clear π-stacking interaction between the *para*-bromophenyl rings of the two diamine ligands is evident, because these moieties are orientated in an exactly parallel, staggered conformation, with the closest contacts between the two rings being 3.35 Å. This observation may help to explain the inability of complex **9** to perform adequately as a catalyst for the Michael addition in the absence of additives. This behaviour contrasts with that of the related catalyst incorporating ligand **3**, which is employed as a bis(diamine)-nickel complex.[13c] For complex **9**, diamine ligand dissociation and subsequent substrate binding would only occur at the energetic cost of the π-stacking interaction and may therefore be disfavoured. In the solid state, complex **9** shows a 2D layer motif stabilized by type II halogen bonds with a Ni–Br···Br–C distance of 3.433 Å.

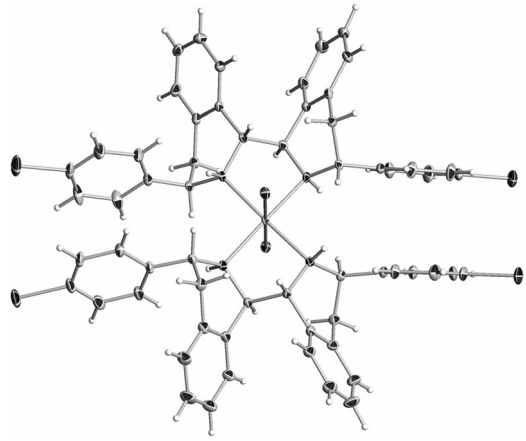


Figure 4. Crystal structure of bis(diamine)-nickel complex **9** (Diamond 3.1[16]).

Conclusions

A chiral diamine ligand incorporating a 3,3′-disubstituted 1,1′-bi(tetrahydroisoquinoline) scaffold was successfully employed in the nickel-catalysed addition of malonic esters to various nitroolefins. The addition reactions proceed with excellent yields (92–99%) and enantioselectivities (91–99% *ee*) even at elevated temperatures. Herein, the choice of the appropriate base (*N*-methylmorpholine) proved to be essential for highest selectivity. Structural analysis of nickel complex **9** permitted insights into the putative catalyst structure and revealed both aromatic π-stacking interactions as well as close bromine–bromine interactions. Further studies aimed at various applications of the new chiral and highly rigid diamine ligand class are underway and will be reported in due course.

Experimental Section

General Remarks: Chemicals were purchased from commercial suppliers and used without further purification unless otherwise noted. All reactions were performed under an argon atmosphere in predried glassware. Flash chromatography was carried out using Merck silica gel 60 (0.040–0.063 mm). ^{1}H and ^{13}C NMR spectra were recorded at room temperature with a Bruker AC 250, JOEL ECX 400, JOEL Eclipse 500, or Bruker Advance 3 (700 MHz) spectrometer. Enantiomeric ratios were determined with a Hitachi LaChrome HPLC System using hexane/2-propanol as eluents with Chiralpak IA or Chiralpak IB columns and UV as well as refractive index (RI) detection. Optical rotation values were measured with a Perkin–Elmer 241 polarimeter, a concentration of $c = 1.0$ represents 10 mg per mL of solvent. Melting points (m.p.) were determined with a Büchi 510 apparatus and are uncorrected. High-resolution mass spectra (HRMS) were determined with an Agilent 6210 ESI-TOF MS instrument; flow rate: 4 μL/min; spray voltage 4 kV, and the desolvation gas set to 15 psi. All other parameters were optimized for maximal abundance of $[M + H]^+$ or $[M + Na]^+$. IR spectra were recorded with a JASCO 6200 FTIR spectrometer.

Synthesis of Diamine-Nickel Complexes

Bis(diamine)-Nickel Complex 9: A mixture of nickel(II) bromide (19.0 mg, 87.1 μmol) and diamine **8** (100 mg, 174 μmol) in acetonitrile (5 mL) was heated for 5 h at reflux. The solvent was removed by distillation and the residue was dissolved in dichloromethane (8 mL). After filtration through a glass frit (porosity 4) the solvent was removed in vacuo and the nickel complex was obtained as a brown solid (211 mg, 154 μmol, 89%).

Diamine-Nickel Complex 10: A mixture of nickel(II) bromide (57.1 mg, 261 μmol) and diamine **8** (150 mg, 261 μmol) in acetonitrile (3 mL) was heated for 3 h at reflux. The solvent was removed by distillation and the residue was dissolved in dichloromethane (5 mL). After filtration through a glass frit (porosity 4), the solvent was removed in vacuo and the nickel complex was obtained as a brown solid (204 mg, 257 μmol, 98%).

Diamine-Nickel Complex 11: A mixture of nickel(II) bromide (15.9 mg, 72.6 μmol) and HIPT-diamine **8-HIPT** (100 mg, 72.6 μmol) in acetonitrile (3 mL) was heated for 3 h at reflux. The solvent was removed by distillation and the residue was dissolved in dichloromethane (3 mL). After filtration through a glass frit (porosity 4) the solvent was removed in vacuo and the nickel complex was obtained as a brown solid (110 mg, 68.6 μmol, 95%).

Asymmetric Ni-Catalysed 1,4-Addition Reactions

General Procedure for the Ni-Catalysed 1,4-Addition of Malonates to Nitroalkenes (GP1): The corresponding nitroalkene in toluene (4 mL/mmol substrate) was treated with the respective malonate (1.2–2.0 equiv.), the nickel catalyst (2 mol-%), and suitable base (0.05–1.0 equiv.). The mixture was stirred for the denoted time at the stated temperature before being directly purified by column chromatography on silica gel (hexane/EtOAc).

(*R*)-Diethyl 2-(2-Nitro-1-phenylethyl)malonate (14a): *trans*-β-Nitrostyrene (**12a**; 74.6 mg, 500 μmol), diethyl malonate (**13a**; 1.2 equiv., 96.1 mg, 600 μmol, 90.7 μL), NMM (0.05 equiv., 2.5 mg, 25.0 μmol, 2.7 μL), and nickel complex **10** (0.02 equiv., 7.9 mg, 10.0 μmol) in toluene (2 mL) were reacted according to GP1 for 2 h at 80 °C. After cooling to room temperature, the reaction mixture was directly purified by column chromatography on silica gel (hexane/EtOAc, 5:1) to obtain the title compound **14a** as a colourless oil (150.4 mg, 486 μmol, 97%). HPLC (column IA, 254 nm; *n*-hexane/*i*PrOH, 80:20; flow: 1.0 mL/min): R_t = 8.7 [(*R*)-**14a**], 18.2 min [(*S*)-**14a**]; *ee* = 97%. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.04 (t, J = 6.8 Hz, 3 H, $CO_2CH_2CH_3$), 1.26 (t, J = 6.8 Hz, 3 H, $CO_2CH_2CH_3$), 3.82 [d, J = 9.5 Hz, 1 H, $(CO_2Et)_2CH$], 4.01 (q, J = 6.9 Hz, 2 H, $CO_2CH_2CH_3$), 4.15–4.31 (m, 3 H, CO_2CH_2CH, $CHCH_2$), 4.79–5.00 (m, 2 H, $CHCH_2$), 6.77–6.99 (m, 5 H, ArH) ppm. $[\alpha]_D^{25}$ = –8.8 (c = 1.0, $CHCl_3$). The absolute configuration was assigned as (*R*) by comparison of the optical rotation with the reported literature value: ref.[13c] $[\alpha]_D^{25}$ = +7.3 (c = 1.07, $CHCl_3$) [95% *ee*, (*S*)-enantiomer]. The spectroscopic data corresponded to those reported in the literature.[17]

(*R*)-Dimethyl 2-(2-Nitro-1-phenylethyl)malonate (14c): *trans*-β-Nitrostyrene (**12a**; 74.6 mg, 500 μmol) dimethyl malonate (**13d**; 1.2 equiv., 79.3 mg, 600 μmol, 69.0 μL), NMM (0.05 equiv., 2.5 mg, 25.0 μmol, 2.7 μL), and nickel complex **10** (0.02 equiv., 7.9 mg, 10.0 μmol) in toluene (2 mL) were reacted according to GP1 for 3 h at 80 °C. After cooling to room temperature, the reaction mixture was directly purified by column chromatography on silica gel (hexane/EtOAc, 5:1) to obtain the title compound **14c** as a colourless oil (136.5 mg, 485 μmol, 97%). HPLC (column IA, 254 nm; *n*-hexane/*i*PrOH, 80:20; flow: 1.0 mL/min): R_t = 9.0 [(*R*)-**14c**], 12.0 min [(*S*)-**14c**]; *ee* = 97%. ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) = 3.56 (s, 3 H, OMe), 3.76 (s, 3 H, OMe), 3.87 [d, J = 9.4 Hz, $(CO_2Me)_2CH$], 4.25 (ddd, J = 9.0, 9.0, 5.2 Hz, $CHCH_2$), 4.99 (dd, J = 13.2, 8.9 Hz, 1 H, $CHCH_{2,b}$), 4.94 (dd, J = 13.1, 5.3 Hz, 1 H, $CHCH_{2,a}$), 7.19–7.37 (m, 5 H, ArH) ppm. $[\alpha]_D^{25}$ = –7.8 (c = 0.77, $CHCl_3$). The absolute configuration was assigned as (*R*) by comparison of the optical rotation with the reported literature value: ref.[13c] $[\alpha]_D^{25}$ = +6.2 (c = 1.38, $CHCl_3$) [94% *ee*, (*S*)-enantiomer]. The spectroscopic data corresponded to those reported in the literature.[13c]

(*R*)-Diethyl 2-[1-(4-Methoxyphenyl)-2-nitroethyl]malonate (14d): Nitrostyrene **12b** (89.6 mg, 500 μmol), diethyl malonate (**13a**; 1.2 equiv., 96.1 mg, 600 μmol, 90.7 μL), NMM (0.05 equiv., 2.5 mg, 25.0 μmol, 2.7 μL), and nickel complex **10** (0.02 equiv., 7.9 mg, 10.0 μmol) in toluene (2 mL) were reacted according to GP1 for 6 h at 80 °C. After cooling to room temperature, the reaction mixture was directly purified by column chromatography on silica gel (hexane/EtOAc, 5:1) to obtain the title compound **14d** as a colourless oil (159.5 mg, 470 μmol, 94%). HPLC (column IA, 254 nm; *n*-hexane/*i*PrOH, 70:30; flow: 0.7 mL/min): R_t = 12.2 [(*R*)-**14d**], 36.4 min [(*S*)-**14d**]; *ee* = 95%. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.07 (t, J = 7.0 Hz, 3 H, $CO_2CH_2CH_3$), 1.27 (t, J = 7.0 Hz, 3 H, $CO_2CH_2CH_3$), 3.72–3.81 [m, 4 H, OMe, $(CO_2Et)_2CH$], 4.02 (q, J = 7.2 Hz, 2 H, $CO_2CH_2CH_3$), 4.14–4.28 (m, 3 H, CO_2CH_2CH, $CHCH_2$), 4.80 (dd, J = 13.6, 9.2 Hz, 1 H, $CHCH_{2,b}$), 4.89 (dd, J = 13.0, 4.8 Hz, 1 H, $CHCH_{2,a}$), 6.82 (d, J = 9.2 Hz, 2 H, ArH), 7.15 (d, J = 9.2 Hz, 2 H, ArH) ppm. $[\alpha]_D^{25}$ = –7.0 (c = 1.0, $CHCl_3$). The absolute configuration was assigned as (*R*) by comparison of the optical rotation with the reported literature value: ref.[13c] $[\alpha]_D^{25}$ = +7.7 (c = 1.01, $CHCl_3$) [95% *ee*, (*S*)-enantiomer]. The spectroscopic data corresponded to those reported in the literature.[13c]

(*R*)-Diethyl 2-[1-(2,4-Dimethoxyphenyl)-2-nitroethyl]malonate (14e): Nitrostyrene **12c** (105 mg, 500 μmol), diethyl malonate (**13a**; 1.2 equiv., 96.1 mg, 600 μmol, 90.7 μL), NMM (0.05 equiv., 2.5 mg, 25.0 μmol, 2.7 μL), and nickel complex **10** (0.02 equiv., 7.9 mg, 10.0 μmol) in toluene (2 mL) were reacted according to GP1 for 24 h at 80 °C. After cooling to room temperature, the reaction mixture was directly purified by column chromatography on silica gel (hexane/EtOAc, 6:1) to obtain the title compound **14e** as a colourless oil (176 mg, 476 μmol, 95%). HPLC (column IA, 215 nm; *n*-hexane/*i*PrOH, 75:25; flow: 0.8 mL/min): R_t = 7.86 [(*R*)-**14e**], 11.7 min [(*S*)-**14e**]; *ee* = 91%. ^{1}H NMR (400 MHz, $CDCl_3$): δ =

1.03 (t, J = 7.1 Hz, 3 H, $CO_2CH_2CH_3$), 1.27 (t, J = 7.1 Hz, 3 H, $CO_2CH_2CH_3$), 3.76 (s, 3 H, OMe), 3.84 (s, 3 H, OMe), 3.69 (q, J = 7.1 Hz, 2 H, $CO_2CH_2CH_3$), 4.11 [d, J = 10.3 Hz, 1 H, $(CO_2Et)_2CH$], 4.17–4.32 (m, 3 H, $CO_2CH_2CH_3$, $CHCH_2$), 4.82 (dd, J = 12.7, 4.5 Hz, 1 H, $CHCH_{2,a}$), 4.98 (dd, J = 12.7, 9.6 Hz, 1 H, $CHCH_{2,b}$), 6.38 (dd, J = 8.3, 2.4 Hz, 1 H, ArH), 6.42 (d, J = 2.4 Hz, 1 H, ArH), 7.04 (d, J = 8.3 Hz, 2 H, ArH) ppm. The absolute configuration was assigned as (*R*) by analogy. The spectroscopic data corresponded to those reported in the literature.[13c]

(*R*)-Diethyl 2-[1-(4-Chlorophenyl)-2-nitroethyl]malonate (14f): Nitrostyrene **12d** (91.8 mg, 500 μmol), diethyl malonate (**13a**; 1.2 equiv., 96.1 mg, 600 μmol, 90.7 μL), NMM (0.05 equiv., 2.5 mg, 25.0 μmol, 2.7 μL), and nickel complex **10** (0.02 equiv., 7.9 mg, 10.0 μmol) in toluene (2 mL) were reacted according to GP1 for 4 h at 80 °C. After cooling to room temperature, the reaction mixture was directly purified by column chromatography on silica gel (hexane/EtOAc, 5:1) to obtain the title compound **14f** as a colourless oil (169.4 mg, 493 μmol, 99%). HPLC (column IA, 254 nm; *n*-hexane/*i*PrOH, 80:20; flow: 1.0 mL/min): R_t = 11.9 [(*R*)-**14f**], 35.9 min [(*S*)-**14f**]; *ee* = 97%. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.08 (t, J = 7.2 Hz, 3 H, $CO_2CH_2CH_3$), 1.26 (t, J = 7.1 Hz, 3 H, $CO_2CH_2CH_3$), 3.79 [d, J = 9.1 Hz, 1 H, $(CO_2Et)_2CH$], 4.03 (q, J = 7.2 Hz, 2 H, $CO_2CH_2CH_3$), 4.23 (m_c, 3 H, CO_2CH_2CH, $CHCH_{2,a}$), 4.83 (dd, J = 13.2, 9.3 Hz, 1 H, $CHCH_{2,b}$), 4.92 (dd, J = 13.2, 4.7 Hz, 1 H, $CHCH_{2,a}$), 7.20 (d, J = 8.4 Hz, 2 H, ArH), 7.30 (d, J = 8.5 Hz, 2 H, ArH) ppm. $[\alpha]_D^{25}$ = –8.7 (c = 1.0, $CHCl_3$). The absolute configuration was assigned as (*R*) by comparison of the optical rotation with the reported literature value: ref.[18] $[\alpha]_D^{25}$ = –8.56 (c = 1.02, $CHCl_3$) [> 99% *ee*, (*R*)-enantiomer]. The spectroscopic data corresponded to those reported in the literature.[13c]

(*R*)-Diethyl 2-[1-(2-Chlorophenyl)-2-nitroethyl]malonate (14g): Nitrostyrene **12e** (91.8 mg, 500 μmol), diethyl malonate (**13a**; 1.2 equiv., 96.1 mg, 600 μmol, 90.7 μL), NMM (0.05 equiv., 2.5 mg, 25.0 μmol, 2.7 μL), and nickel complex **10** (0.02 equiv., 7.9 mg, 10.0 μmol) in toluene (2 mL) were reacted according to GP1 for 6 h at 80 °C. After cooling to room temperature, the reaction mixture was directly purified by column chromatography on silica gel (hexane/EtOAc, 6:1) to obtain the title compound **14g** as a colourless oil (168.4 mg, 490 μmol, 97%). HPLC (column IA, 215 nm; *n*-hexane/*i*PrOH, 75:25; flow: 0.8 mL/min): R_t = 6.75 [(*R*)-**14g**], 21.6 min [(*S*)-**14g**]; *ee* = 99%. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.10 (t, J = 7.1 Hz, 3 H, $CO_2CH_2CH_3$), 1.23 (t, J = 7.1 Hz, 3 H, $CO_2CH_2CH_3$), 4.03–4.09 [m, 3 H, $CO_2CH_2CH_3$, $(CO_2)_2CH$], 4.15–4.24 (m, 2 H, CO_2CH_2CH), 4.74 (m_c, 1 H, $CHCH_2$), 4.94 (dd, J = 13.5, 4.4 Hz, 1 H, $CHCH_{2,b}$), 5.09 (dd, J = 13.5, 8.5 Hz, 1 H, $CHCH_{2,a}$), 7.20–7.27 (m, 3 H, ArH), 7.37–7.42 (m, 1 H, ArH) ppm. The absolute configuration was assigned as (*R*) by analogy. The spectroscopic data corresponded to those reported in the literature.[13c]

(*S*)-Diethyl 2-[1-(2-Furyl)-2-nitroethyl]malonate (14h): Nitroalkene **12f** (69.6 mg, 500 μmol), diethyl malonate (**13a**; 1.2 equiv., 96.1 mg, 600 μmol, 90.7 μL), NMM (0.05 equiv., 2.5 mg, 25.0 μmol, 2.7 μL), and nickel complex **10** (0.02 equiv., 7.9 mg, 10.0 μmol) in toluene (2 mL) were reacted according to GP1 for 6 h at 80 °C. After cooling to room temperature, the reaction mixture was directly purified by column chromatography on silica gel (hexane/EtOAc, 6:1) to obtain the title compound **14h** as a colourless oil (148.0 mg, 495 μmol, 98%). HPLC (column IA, 215 nm; *n*-hexane/*i*PrOH, 75:25; flow: 0.8 mL/min): R_t = 7.42 [(*S*)-**14h**], 8.57 min [(*R*)-**14h**]; *ee* = 97%. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.19 (t, J = 7.1 Hz, 3 H, $CO_2CH_2CH_3$), 1.25 (t, J = 7.1 Hz, 3 H, $CO_2CH_2CH_3$), 3.89 [d, J = 7.9 Hz, 1 H, $(CO_2)_2CH$], 4.13 (q, J = 7.1 Hz, 2 H, $CO_2CH_2CH_3$), 4.21 (q, J = 7.1 Hz, 2 H, $CO_2CH_2CH_3$), 4.34–4.40 (m, 1 H, $CHCH_2$), 4.87 (dd, J = 11.5, 3.3 Hz, 1 H, $CHCH_{2,b}$), 4.91 (dd, J = 11.5, 6.2 Hz, 1 H, $CHCH_{2,a}$), 6.21 (d, J = 3.3 Hz, 1 H, ArH), 6.28 (dd, J = 1.9, 3.3 Hz, 1 H, ArH), 7.33 (dd, J = 0.8, 1.9 Hz, 1 H, ArH) ppm. The absolute configuration was assigned as (*S*) by analogy. The spectroscopic data corresponded to those reported in the literature.[13c]

(*R*)-Diethyl 2-[1-(2,4-Dimethylphenyl)-2-nitroethyl]malonate (14i): Nitrostyrene **12g** (88.6 mg, 500 μmol), diethyl malonate (**13a**; 1.2 equiv., 96.1 mg, 600 μmol, 90.7 μL), NMM (0.05 equiv., 2.5 mg, 25.0 μmol, 2.7 μL), and nickel complex **10** (0.02 equiv., 7.9 mg, 10.0 μmol) in toluene (2 mL) were reacted according to GP1 for 4 h at 80 °C. After cooling to room temperature, the reaction mixture was directly purified by column chromatography on silica gel (hexane/EtOAc, 5:1) to obtain the title compound **14i** as a colourless oil (161.6 mg, 493 μmol, 99%). HPLC (column IA, 254 nm; *n*-hexane/*i*PrOH, 80:20; flow: 1.0 mL/min): R_t = 5.4 [(*R*)-**14i**], 13.1 min [(*S*)-**14i**]; *ee* = 96%. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.02 (t, J = 7.2 Hz, 3 H, $CO_2CH_2CH_3$), 1.26 (t, J = 7.2 Hz, 3 H, $CO_2CH_2CH_3$), 2.24 (s, 3 H, Ar-CH_3), 2.38 (s, 3 H, Ar-CH_3), 3.77 [d, J = 9.6 Hz, 1 H, $(CO_2Et)_2CH$], 3.98 (m_c, 2 H, $CO_2CH_2CH_3$), 4.22 (m_c, 2 H, $CO_2CH_2CH_3$), 4.51 (ddd, J = 9.2, 9.2, 5.0 Hz, 1 H, $CHCH_2$), 4.80 (dd, J = 12.7, 8.8 Hz, 2 H, $CHCH_{2,b}$), 6.92–7.04 (m, 3 H, ArH) ppm. ^{13}C NMR (100.5 MHz, $CDCl_3$): δ = 13.75, 14.05 ($CO_2CH_2CH_3$), 19.49, 21.01 (2 × Ar-CH_3), 37.61 ($CHCH_2$), 54.90 [$(CO_2Et)_2CH$], 61.87, 62.18 ($CO_2CH_2CH_3$), 77.79 ($CHCH_2$), 126.0, 127.2, 131.6, 132.0, 136.8, 137.7 (C-Ar), 167.1, 167.8 (2 × C=O) ppm. HRMS (ESI): calcd. for $C_{17}H_{23}NNaO_6^+$ 360.1418; found 360.1427. $[\alpha]_D^{25}$ = –2.9 (c = 1.0, $CHCl_3$). The absolute configuration was assigned as (*R*) by analogy.

(*R*)-Diethyl 2-[2-Nitro-1-(1-styryl)ethyl]malonate (14j): Nitroalkene **12h** (87.6 mg, 500 μmol), diethyl malonate (**13a**; 1.2 equiv., 96.1 mg, 600 μmol, 90.7 μL), NMM (0.05 equiv., 2.5 mg, 25.0 μmol, 2.7 μL), and nickel complex **10** (0.02 equiv., 7.9 mg, 10.0 μmol) in toluene (2 mL) were reacted according to GP1 for 6 h at 80 °C. After cooling to room temperature, the reaction mixture was directly purified by column chromatography on silica gel (hexane/EtOAc, 6:1) to obtain the title compound **14j** as a colourless oil (165.0 mg, 495 μmol, 98%). HPLC (column IB, 215 nm; *n*-hexane/*i*PrOH, 98:2; flow: 1.0 mL/min): R_t = 7.86 [(*R*)-**14j**], 11.7 min [(*S*)-**14j**]; *ee* = 92%. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.23 (t, J = 7.1 Hz, 3 H, $CO_2CH_2CH_3$), 1.27 (t, J = 7.1 Hz, 3 H, $CO_2CH_2CH_3$), 3.66 [d, J = 7.3 Hz, 1 H, $(CO_2)_2CH$], 3.70–3.78 (m, 1 H, $CHCH_2$), 4.15–4.27 (m, 4 H, $CO_2CH_2CH_3$), 4.69 (dd, J = 8.14, 12.6 Hz, 1 H, $CHCH_{2,b}$), 4.76 (dd, J = 12.7, 5.0 Hz, 1 H, $CHCH_{2,a}$), 6.21 (dd, J = 15.8, 9.2 Hz, 1 H, Ar-CH=CH), 6.58 (d, J = 15.8 Hz, 1 H, Ar-CH), 7.22–7.34 (m, 5 H, ArH) ppm. The absolute configuration was assigned as (*R*) by analogy. The spectroscopic data corresponded to those reported in the literature.[13c]

(*R*)-Diethyl 2-[1-(Naphth-1-yl)-2-nitroethyl]malonate (14k): Nitroalkene **12i** (99.6 mg, 500 μmol), diethyl malonate (**13a**) (1.2 equiv., 96.1 mg, 600 μmol, 90.7 μL), NMM (0.05 equiv., 2.5 mg, 25.0 μmol, 2.7 μL), and nickel complex **10** (0.02 equiv., 7.9 mg, 10.0 μmol) in toluene (2 mL) were reacted according to GP1 for 4 h at 80 °C. After cooling to room temperature, the reaction mixture was directly purified by column chromatography on silica gel (hexane/EtOAc, 5:1) to obtain the title compound **14k** as a colourless oil (165.3 mg, 460 μmol, 92%). HPLC (column IA, RI; *n*-hexane/*i*PrOH, 80:20; flow: 1.0 mL/min): R_t = 8.3 [(*R*)-**14k**], 20.0 min [(*S*)-**14k**]; *ee* = 97%. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.07 (t, J = 7.1 Hz, 3 H, $CO_2CH_2CH_3$), 1.22 (t, J = 7.0 Hz, 3 H, $CO_2CH_2CH_3$), 3.96 (m_c, 2 H, $CO_2CH_2CH_3$), 4.08 [d, J = 8.6 Hz, 1 H, $(CO_2Et)_2$-

C*H*], 4.20 (m_c, 2 H, $CO_2CH_2CH_3$), 5.06 (dd, J = 13.3, 4.9 Hz, 1 H, $CHCH_{2,b}$), 5.11–5.28 (m, 2 H, $CHCH_{2,b}$, $CHCH_2$), 7.37–7.45 (m, 2 H, ArH), 7.49–7.55 (m, 1 H, ArH), 7.57–7.64 (m, 1 H, ArH), 7.75–7.89 (m, 2 H, ArH), 8.20 (d, J = 8.6 Hz, 1 H, ArH) ppm. $[\alpha]_D^{25}$ = +1.3 (c = 1.0, $CHCl_3$). The absolute configuration was assigned as (*R*) by analogy. The spectroscopic data corresponded to those reported in the literature.[18]

Supporting Information (see footnote on the first page of this article): X-ray crystal structure data, HPLC traces of chiral products, and ^{1}H NMR spectra.

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[14] A similar observation was made by Xia et al. with the bis(diamine) complex obtained from **6**, see ref. [7].

[15] For some substrates, lower *ee* values were observed when triethylamine was used as base. For example, product **14k** was isolated with 85% *ee*.

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