

Modular Assembly of a Chiral Bis(oxazoliny)carbene: A New Meridionally Coordinating Tridentate Spectator Ligand

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Summary: A highly modular assembly of meridionally coordinating tridentate bis(oxazoline)carbene ligands ("BoxCarb") is reported, in which the coupling of the oxazoline units with the central imidazolidene ring occurs by means of chemically orthogonal reaction steps. Reaction of the imidazolium salt (*i*Pr)₂-BoxCarbH⁺Br⁻ **4** with [Rh(OtBu)(nbd)]₂ at temperatures below -30 °C gave a thermally unstable rhodium(I) species, which was directly reacted at -78 °C with 1 molar equiv of bromine, giving the rhodium(III) compound [RhBr₃((iPr)₂-BoxCarb)] (**5**). An X-ray diffraction study established the meridional tricoordination of the ligand. Reacting **4** with 0.5 molar equiv of Ag₂O gave the silver(I) complex **6**, which was converted with [PdCl₂(COD)] in CH₂Cl₂ to give the cationic square planar palladium(II) complex [PdCl((iPr)₂-BoxCarb)]Cl (**7**).

Ligand design in asymmetric catalysis is guided by several simple concepts and principles, such as molecular symmetry,¹ orientation of the stereodirecting units,² and modularity in the assembly of polydentate ligands.³ The latter allows for convenient search strategies⁴ for the optimal system for a given reaction and type of substrates. The basic structural motifs of such modular catalyst systems are derived from the available mechanistic insight into the catalytic process combined with the known ligand properties of its components.

N-Heterocyclic carbenes⁵ are excellent "anchor" units for late transition metals which form strong metal-carbon bonds and have thus been widely used in homogeneous catalysis.⁶ They may be readily combined with other ligating units, in particular, by the appropriate functionalization of the N atoms in their heterocyclic

structures.^{7,8} One early example was provided by Herrmann et al., who reported the bidentate ligand **A**, comprising a combination of an *N*-heterocyclic carbene with an oxazoline unit, which are linked by a methylene bridge (Chart 1).⁹ We subsequently described the direct coupling of oxazolines and *N*-heterocyclic carbenes generating highly rigid type **B** chelate ligands.¹⁰ These provide the key to a highly efficient class of catalysts for the asymmetric hydrosilylation of prochiral ketones.¹¹

The coupling strategies of the two heterocycles in both **A** and **B** may be combined in a highly modular assembly of meridionally coordinating tridentate bis(oxazoline)carbene ligands of type **C**, in which the coupling of the oxazoline units with the central imidazolidene ring occurs by means of chemically orthogonal reaction steps. This in principle allows the free combination of oxazoline substituents in a ligand system that is topologically related to (but of lower symmetry than) the ubiquitous bis(oxazoline)pyridine ("pybox").¹² The bridging methylene group in ligand **A** was replaced by a (CH₃)₂C unit in **C** in order to suppress the lability of the CH₂ bridge under the conditions of molecular catalysis. In this work we report the modular synthesis of this new ancillary ligand system as well as first results of its coordination chemistry.

The synthesis of the imidazolium precursor **4** of the tridentate BoxCarb ligand is summarized in Scheme 1, the key step being the final coupling of (4*S*)-2-bromo-4-isopropylloxazoline with the imidazole **3**. The first step

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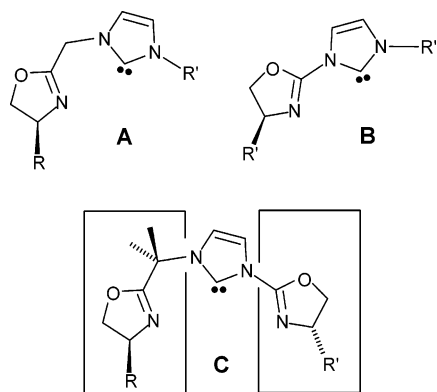
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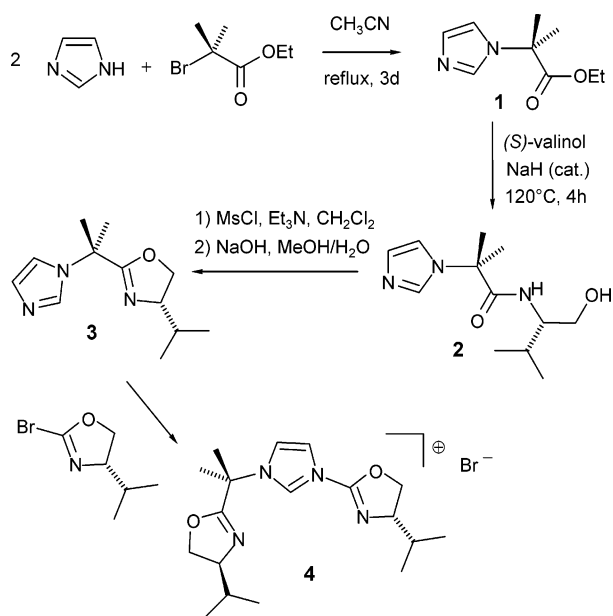
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Chart 1



Scheme 1. Synthesis of the Imidazolium Precursor 4 of the Novel Bis(oxazoline)carbene Ligand



in the synthesis of the latter is the generation of the α -(*N*-imidazolyl)ester **1** by nucleophilic substitution of the commercially available bromoester using 1 equiv of imidazole.¹³ The 2:1 stoichiometry was chosen to remove the HBr formed during the course of the substitution. Ester **1** is subsequently condensed with (*S*)-valinol in the presence of a catalytic amount of NaH, giving the corresponding amide **2** in quantitative yield. In situ mesylation of the alcohol and subsequent cyclization in the presence of base gave the imidazole derivative **3** in good yield. The final coupling step of the substituted imidazole **3** and (*4S*)-2-bromo-4-isopropylloxazoline was carried out under conditions similar to those previously reported for the bidentate CarbOx ligands.^{10,11} The ¹H and ¹³C NMR spectra of **4** are consistent with the proposed structure of the molecule. The signal of the C-2-bound proton of the imidazolium ring is observed at δ 10.13 ppm, while the resonances of the C(Me)₂ protons in the bridge are shifted to lower field (δ = 2.18 and 2.15 ppm) in comparison to **3**, reflecting the electron

acceptor properties of the cationic imidazolium ring. Finally, the two IR vibrational bands ν (C=N) of the two oxazoline units are observed at 1698 cm⁻¹ for the oxazoline directly linked to the imidazolium ring and at 1669 cm⁻¹ for the oxazoline unit linked through the -C(Me)₂ bridge.

First examples for the coordination of the *N*-heterocyclic carbene ligand derived from **4** to transition metal centers are summarized in Scheme 2. Reaction of the imidazolium salt **4** with [Rh(*O*tBu)(nbd)]₂ at temperatures below -30 °C gave a thermally unstable rhodium(I) species, for which the ¹H NMR data were consistent with its formulation as [RhBr(nbd)((*i*Pr)₂-BoxCarb)].¹⁴ The in situ generated complex was then directly reacted at -78 °C with 1 molar equiv of bromine, giving the rhodium(III) compound [RhBr₃((*i*Pr)₂-BoxCarb)] (**5**) in good yield. This deep red complex was found to be stable in the air and could be readily purified by column chromatography on silica.

The formulation of complex **5** was supported by its analytical data and the observation of its molecular ion in the ESI mass spectrum. The generation of an *N*-heterocyclic carbene complex was confirmed by the disappearance of the low-field-shifted C2-bound proton of the imidazolium precursor and the detection of the ¹³C NMR resonance of the carbene nucleus at δ = 177.5 ppm [J (Rh-C) = 35 Hz]. Moreover, the shift of the ν (C=N) bands in the IR spectrum to lower wavenumbers indicated the coordination of both oxazoline rings to the metal center [ν (C=N) = 1662 and 1636 cm⁻¹ in **5** in comparison to 1698 and 1669 cm⁻¹ in **4**].

An X-ray diffraction study of compound **5** established its structural details and the tridentate nature of the new bis(oxazoline)carbene ligand. Its molecular structure is displayed in Figure 1 along with the principal bond lengths and angles. The three heterocycles in (*i*Pr)₂-BoxCarb are meridionally coordinated to the metal center, which adopts a slightly distorted octahedral coordination geometry. The ligand skeleton is quasi-planar with the directly linked imidazolidene and oxazoline rings slightly twisted with respect to each other [C(9)-N(2)-C(6)-N(1) = 3.0°], while the six-membered metallacycle at the other side is also virtually planar. The Rh-C(9) distance of 1.900(4) Å is somewhat shorter than the M-C_{carbene} bond lengths found in other *NHC*-transition metal complexes, which normally lie in the range of 1.95 and 2.1 Å.^{9,15} This may be a consequence of the chelating coordination and thus the structural requirements of tridentate ligand. The oxazolinylcarbene bite angle of C(9)-Rh-N(1) 78.8(2)° is identical to that of the previously characterized bidentate CarbOx ligands,^{10,11} whereas the second chelate angle of C(9)-Rh-N(4) 87.4(2)° is somewhat greater than that reported by Herrmann et al. for their (oxazolinylmethyl)carbenerhodium(I) complex [N_{oxa}-Rh-C_{carb} = 83.7(2)°].⁹ It appears that the oxazolinyl-C(Me)₂-imidazolylidene unit is fairly flexible and may adapt itself to allow for the tricoordination to the metal center.

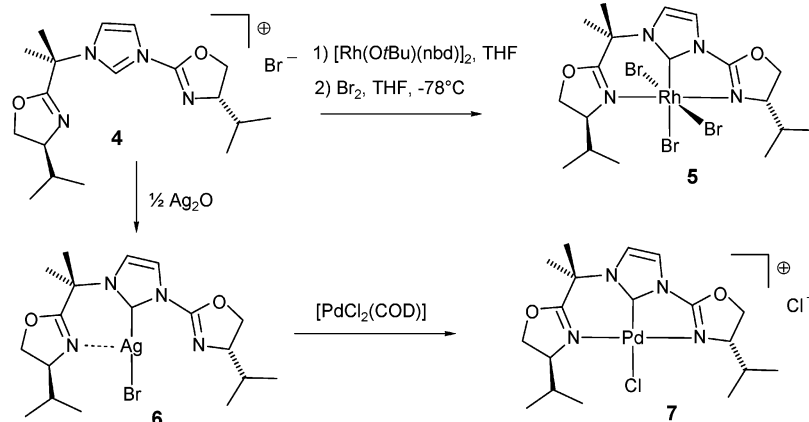
The view along the Br(1)-Rh bond, which is displayed in Figure 1b, illustrates the pseudo-C₂-symmetrical

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Scheme 2. Synthesis of Complexes 5–7



arrangement of molecule. The Rh–Br(2) and Rh–Br(3) vectors deviate from an orthogonal orientation with respect to the plane spanned by the BoxCarb ligand as well as Br(1) [$\text{N}(1)\text{--Rh--Br}(2) = 86.1(4)^\circ$ in comparison to $\text{N}(1)\text{--Rh--Br}(3) = 92.2(1)^\circ$] due to intramolecular

repulsion of the axial bromo ligands and the adjacent isopropyl groups.

Reaction of the imidazolium salt **4** with 0.5 molar equiv of Ag_2O gave the silver(I) complex **6** (Scheme 2). The ^1H and ^{13}C NMR as well as IR spectroscopic data are consistent with a linear structure of the (carbene)–Ag–Br complex in which the oxazoline units are not bound to the metal center. Upon stirring **6** with $[\text{PdCl}_2(\text{COD})]$ in CH_2Cl_2 , the cationic square planar palladium(II) complex **7** was obtained and isolated in good yield. The NMR and IR spectroscopic data are consistent with the structure depicted in Scheme 2. The proton resonances of the oxazoline rings are strongly shifted with respect to those in precursors **4** and **6**, and the shift of the $\nu(\text{C}=\text{N})$ bands to lower wavenumbers is also consistent with the coordination of both oxazoline rings. It proved particularly difficult to crystallize complex **7**, and the preliminary X-ray data obtained were of insufficient quality for a refinement of the structure. However the basic connectivities were verified.

In conclusion, we have devised a modular strategy for the synthesis of chiral meridionally coordinating BoxCarb ligands, which display coordination behavior not unlike the Pybox ligands. The two independent linkage reactions coupling the heterocyclic ligating units in principle allow the combination of different stereodirecting substituents.

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Supporting Information Available: Details of the synthetic procedures (+ analytical and spectroscopic data) for compounds 1–7 as well as the X-ray crystallographic data in CIF format for the structure determination of **5**. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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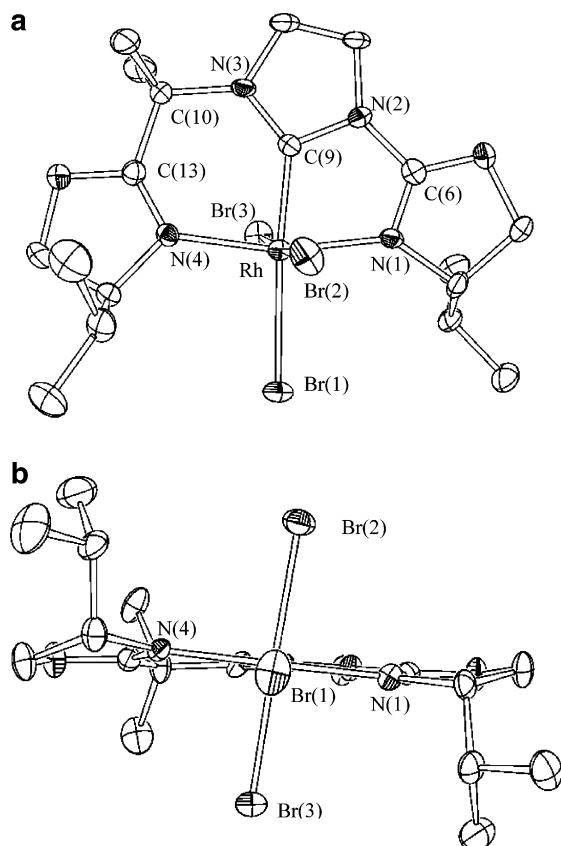


Figure 1. (a) Molecular structure of complex **5**. Selected bond lengths (Å) and angles (deg): Rh–C(9) 1.900(4), Rh–N(1) 2.045(3), Rh–N(4) 2.027(3), Rh–Br(1) 2.5758(5), Rh–Br(2) 2.4747(5), Rh–Br(3) 2.4752(5), C(9)–Rh–N(1) 78.8(2), C(9)–Rh–N(4) 87.4(2), N(1)–Rh–Br(1) 96.1(1), N(4)–Rh–Br(1) 97.7(1), N(1)–Rh–Br(2) 86.4(1), N(1)–Rh–Br(3) 92.2(1), C(9)–N(2)–C(6)–N(1) 3.0, Rh–C(9)–N(3)–C(10) -0.3 , Rh–N(4)–C(13)–C(10) -13.0 . (b) View along the pseudo- C_2 -axis.