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Syntheses of Novel C_2-Symmetric Chiral Bidentate Bis(*N*-heterocyclic carbene) Ligands and Their Molybdenum Complexes

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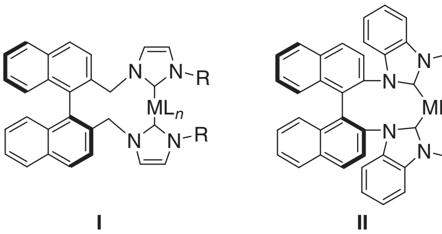
Novel chiral bis(*N*-heterocyclic carbene) was prepared starting from (*S*,*S*)- and (*R*,*R*)-1,2-bis(1-hydroxypropyl)benzene. The chiral bis(*N*-heterocyclic carbene) (NHC) ligand formed C_2-symmetric chiral complex of molybdenum formulated as *cis*-[$\mathrm{Mo(CO)_4}${bis(NHC)}].

Chiral phosphines are widely applicable as ligands in various metal-catalyzed enantioselective organic transformations. In particular, C_2-symmetric bidentate diphosphine ligands are used successfully in many metal-catalyzed enantioselective reactions.[1] *N*-Heterocyclic carbenes (NHCs), first reported by Öfele[2] and Wanzlick[3] and later isolated in the free form by Arduengo,[4] have emerged as an extremely useful class of ligands for transition-metal catalysis.[5] Although the rapid development of so-called chiral "hybrid" ligands including one NHC and one pendant donating group for chelation[6] has been made, only a limited number of chiral C_2-symmetric bidentate bis(NHC) ligands have been reported to date.[7] The first chelated chiral bis(NHC) complexes of Pd and Ni derived from 2,2′-di(bromomethyl)-1,1′-binaphthyl were prepared by RajanBabu and his co-workers, whereas in these complexes the two NHCs are located in *trans*-positions (complex **I** in Figure 1).[8] Recently, a novel family of axially chiral bis(NHC) metal complexes with 1,1′-binaphthyl-2,2′-diamine (BINAM) or H_8-BINAM framework have been developed by Shi and his co-workers (complex **II** in Figure 1).[9] They also reported chiral bis(NHC) with biphenyl framework.[10] In contrast to the complex **I** featuring a chelate ring containing 10 atoms (two NHCs are orientated *trans* to each other), the bis(NHC) ligand in the complex **II** consists of an 8 atom chelating ring and thus two NHCs are *cis*-orientation (Figure 1). These results suggest that in order to construct a C_2-symmetric chiral environment around the metal center, the backbone skeletal structure for constructing bis(NHC) is important.

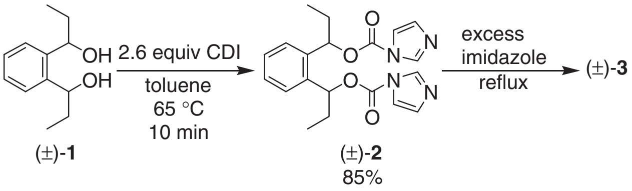
Previously, we reported a convenient method for the preparation of C_2-symmetric chiral 1,4-diol, 1,2-bis-(1-hydroxyalkyl)bezene,[11] and an application of the chiral diol to highly diastereoselective reactions.[12] In this communication, we wish to report the syntheses of novel C_2-symmetric chiral bis(NHC) ligands and their Mo complexes derived from enantiomerically pure 1,4-diol, 1,2-bis(1-hydroxypropyl)benzene (**1**).



I
(*trans* orientation)

II
(*cis* orientation)

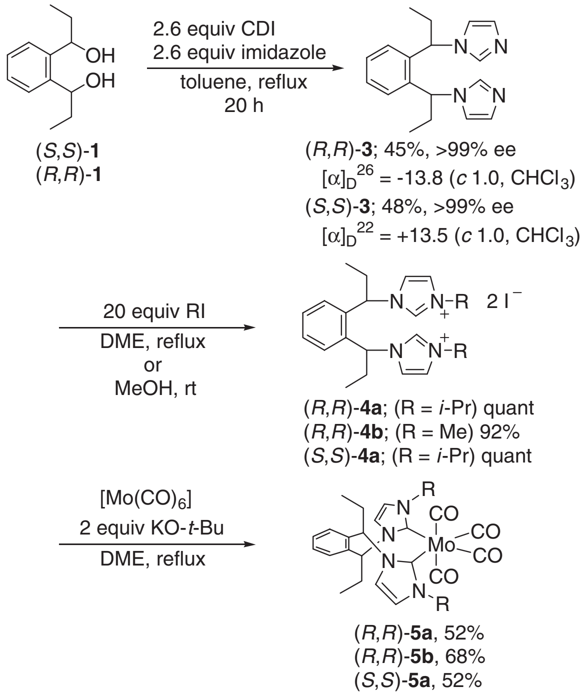
Figure 1. Chiral C_2-symmetric bis(NHC) complexes.



Scheme 1.

First, the conversion of two hydroxy groups in **1** to 1-imidazolyl groups was examined. As such a conversion was reported using carbonyldiimidazole (CDI) under thermal conditions,[13] we examined the reaction of (±)-**1** with 2.6 equivalents of CDI in toluene at 65 °C. The starting material **1** disappeared in 10 min, however not bis(imidazole) (±)-**3** but bis(urethane) (±)-**2** was obtained in 85% yield (Scheme 1). The resulting (±)-**2** was not converted into the corresponding (±)-**3** via decarboxylation, even under higher reaction temperature. Then, the reaction was examined in the presence of excess imidazole and the desired (±)-**3** was obtained. As (±)-**3** was obtained from (±)-**1**, the reaction sequence was applied to the synthesis of (*R*,*R*)-**3**. As a result, the chiral bis(imidazole) compound (*R*,*R*)-**3** was obtained in 45% yield by the reaction of (*S*,*S*)-**1** with CDI (2.6 equivalents) in the presence of 2.6 equivalents of imidazole in refluxing toluene. In the course of the formation of bis(imidazole), two chiral centers in (*S*,*S*)-**1** were inverted without loss of diastereo- and enantiomeric purities. The absolute configuration of the chiral centers were determined by the X-ray analysis (vide infra). Quaternization of the imidazole rings of (*R*,*R*)-**3** with an excess of 2-iodopropane gave the imidazolium salt (*R*,*R*)-**4a** in quantitative yield. In a similar manner, bis(imidazolium) salts (*R*,*R*)-**4b** and (*S*,*S*)-**4a** were prepared (Scheme 2).[14]

As the precursors of the chiral NHC ligands were obtained, formation of molybdenum complex was examined. Treatment of bis(imidazolium) salt (*R*,*R*)-**4a** with [$\mathrm{Mo(CO)_6}$] using two equivalents of KO-*t*-Bu as a base in refluxing 1,2-dimethoxyethane (DME) afforded a carbene complex of molybdenum (*R*,*R*)-**5a** as a yellow solid in 52%. Complexes (*R*,*R*)-**5b** and (*S*,*S*)-**5a** were also obtained as yellow solids in 68% and 52% yields, respectively. The formations of *cis*-[$\mathrm{Mo(CO)_4}${bis(NHC)}] were fully confirmed by elemental analyses, IR, ^{1}H and ^{13}C NMR spectra.[14] In order to obtain further information about stereochemistry of bis(NHC) ligand in the coordination sphere and the chirality of two carbon centers of the benzylic positions, the X-ray analyses of (*R*,*R*)-**5a**, (*R*,*R*)-**5b**, and (*S*,*S*)-**5a**



Scheme 2.

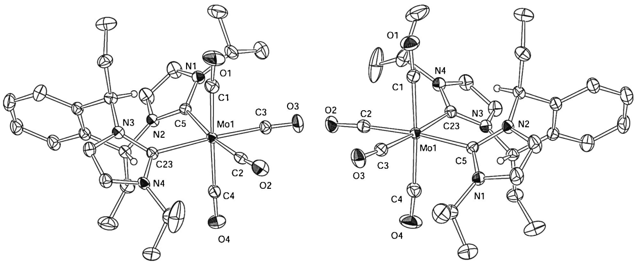


Figure 2. ORTEP drawings of (*R*,*R*)-**5a** (left) and (*S*,*S*)-**5a** (right). All hydrogen atoms except on benzylic carbons are omitted for clarity.

were undertaken.[15] The molecular structures of (*R*,*R*)- and (*S*,*S*)-**5a** are shown in Figure 2. Complex (*R*,*R*)-**5b** showed similar structural features as those of (*R*,*R*)-**5a**. The bis(NHC) ligand coordinated *cis*-position as a bidentate ligand and the complex showed C_2-symmetry. The absolute configurations of the two benzylic carbon atoms were confirmed by the Flack parameter [0.000(18) for (*R*,*R*)-**5a**, 0.016(8) for (*R*,*R*)-**5b**, and 0.001(10) for (*S*,*S*)-**5a**] of the X-ray analyses. It is interesting that two chiral centers of the ligand were completely inverted in the substitution reaction of hydroxy groups by imidazoles in the present work, while the configuration was completely retained in a similar reaction of chiral secondary alcohol in the literature.[13] Although a detailed reaction mechanism is not clear, we assume an $\mathrm{S_N}2$ reaction for diol **1** and $\mathrm{S_N}$i type substitution reaction for the reaction in the literature.[13]

In conclusion, we have synthesized novel chiral bidentate bis(NHC) ligands from enantiomerically pure α,α'-disubstituted *o*-xylylene diol via the bis(imidazolium) salts. As the chiral *o*-xylylene-bridged bis(NHC) are anticipated to be more flexible bidentate ligands in transition-metal complexes[16] compared with rigid binaphthyl and biphenyl bis(NHCs), further investigations on various transition-metal complexes and their applications to enantioselective reactions are now in progress.

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15 CCDC 762814 ((*R*,*R*)-**5a**), 762815 ((*R*,*R*)-**5b**), and 762816 ((*S*,*S*)-**5a**) contains the supplementary crystallographic data for this paper. Copies of the data can be obtained free of charge via http://www.ccdc.cam.ac.uk/cgi-bin/catreq.cgi.

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