Articles

Palladium Complexes with Chiral Oxazoline Ligands. Effect of Chelate Size on Catalytic Allylic Substitutions

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Mono- and bimetallic allylic palladium complexes (**1L**−**5L**) with **L** being chiral bidentate oxazoline ligands (from pyridine (**a**−**d**), quinoline (**e**−**g**), and piperazine (**h**)), containing different kinds of allyl groups (**1**−**5**), were easily obtained, and their structures in solution were elucidated by NMR spectroscopy. Complex **1d** was also characterized by X-ray diffraction. The activity of these complexes in palladium-catalyzed allylic alkylation for acyclic and cyclic substrates was tested. For catalytic systems with ligands **a**−**g**, the activity was very high, although the enantioselectivity was low for pyridine derivatives and moderate for quinolino-oxazoline ligands, showing the beneficial effect of chelate size in the latter case. In contrast, the palladium tetraaza catalytic system (Pd/**h**) exhibited a low activity and a low asymmetric induction. Allylic complexes **1a**, **1d**, and **1e** were also active in the Pd-catalyzed allylic amination, but the activity of these systems was lower than for the alkylations. Under in situ catalytic conditions, the coordination competition of the benzylamine with the bidentate ligand led to different results than using previously isolated precursors.

Introduction

In recent years, chiral nitrogen donor ligands have been applied in multiple catalytic homogeneous processes.[1] The versatility exhibited by oxazoline derivatives as ligands for metal complexes is noteworthy. They have been reported to catalyze a wide variety of organic transformations[2] such as hydrosilylation of ketones,[3] cyclopropanation of olefins,[4] Diels−Alder cycloadditions,[5] Heck reactions,[6] allylic aminations,[7] and allylic alkylations.[8] Among these asymmetric reactions, allylic alkylation is a useful synthetic procedure for C−C bond formation.

Since the development of the first enantioselective catalytic Pd system with phosphines, described by Trost,[9] it was not until the beginning of the present decade that asymmetric allylic alkylation appeared, catalyzed by Pd−oxazoline complexes.[10] Since then, a variety of oxazoline ligands have been tested for the substitution of *rac*-3-acetoxy-1,3-diphenyl-1-propene, which is the model substrate for comparing the activity and selectivity of different catalytic systems.

Besides the use of classical C_2-symmetrical ligands,[11] several recent publications deal with ligands lacking 2-fold rotational axes.[12] With regard to nonsymmetrical

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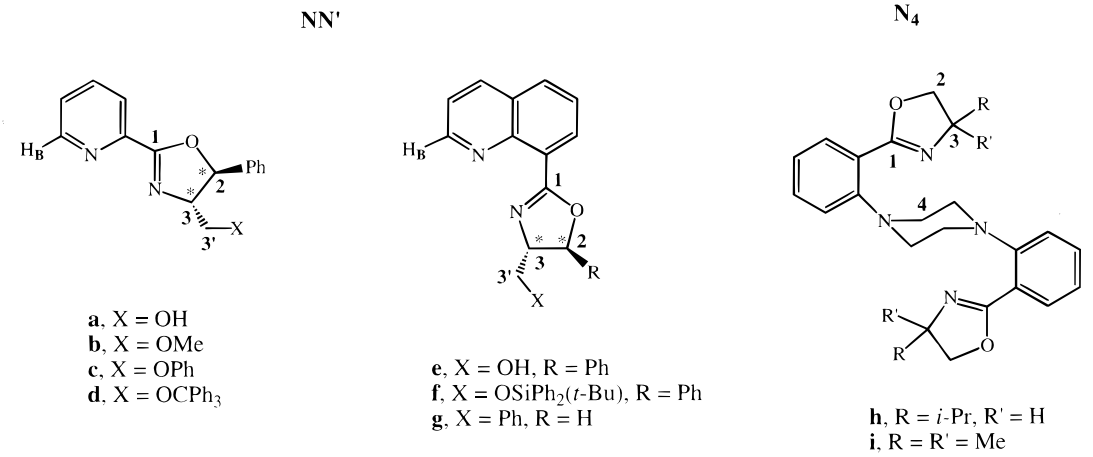

Figure 1. Ligands **NN′** and **N_4**. Hydrogen labels for NMR assignments.

oxazolines, phosphino-oxazolines[13] or thiopheno-oxazolines[14] have demonstrated the effect of the *trans* influence of donor atoms in asymmetric induction, showing that the allyl terminal carbon in the *trans* position to a π-accepting atom is more electrophilic than the carbon atom *trans* to a nitrogen moiety.[15] For pyridino-oxazoline ligands, the lability of a particular bond does not seem to be controlled by an electronic effect; introduction of substituents in positions close to the metal sphere, and therefore close to the allyl fragment, preferentially directs the nucleophilic attack to the terminal position with more steric hindrance.[16] Recently, quinoline ligands with oxazolinyl groups at the 2 and 8 positions have been reported.[17] Although 8-oxazolinylquinolines have electronic properties similar to those of 2-oxazolinylpyridines and 2-oxazolinylquinolines, they enable the influence of the chelate ring size in the enantioselectivity of the catalytic processes to be studied.

Despite the large number of reports dealing with the activity and selectivity of palladium catalytic systems in allylic substitution processes, less work has been done in relation to solution studies of the precursors, [Pd(allyl)(chelate*)]$^+$ (where chelate* is a chiral oxazoline ligand), and intermediate catalytic species such as Pd(0)−olefin and Pd(II)−allyl complexes. Application of NOE-based NMR techniques has been a useful tool for the analyses of these species.[18] Recently, Reggelin et al. have identified Pd(0) species by means of NMR spectroscopy.[19]

To obtain greater insights into the solution structures of π-allyl complexes, we present here our studies on the dynamic behavior of palladium allylic complexes with chiral pyridino-, quinolino-, and piperazino-oxazoline ligands. We also studied their activity in allylic alkylation processes of open-chain acetate substrates such as *rac*-3-acetoxy-1,3-diphenyl-1-propene and (*E*)-3-acetoxy-1-phenyl-1-propene and the cyclic acetate *rac*-3-acetoxy-1-cyclohexene, with dimethyl malonate as nucleophile. The palladium-catalyzed allylic amination of the model acetate, *rac*-3-acetoxy-1,3-diphenyl-1-propene, with benzylamine was also tested.

Results and Discussion

Ligands. Pyridino-oxazolines (**a**−**d**, see Figure 1) were prepared as previously described.[20] Ligand **a** was obtained from commercially available 2-cyanopyridine and (1*S*,2*S*)-(+)-2-amino-1-phenyl-1,3-propanediol, where **a** was the common intermediate for preparing the other pyridine derivatives (**b**, **c**, **d**). Quinolino-oxazoline **e** was conveniently obtained from the 8-cyanoquinoline[21] and the enantiomerically pure aminodiol mentioned before, in a one-step reaction (see Scheme 1), in contrast to the four-step synthetic route from 8-quinolinecarboxylic acid.[17b] The cyclization process takes place under basic conditions in a mixture of glycerol and ethylene glycol.[22] This procedure yielded the expected oxazoline (**e**) and the corresponding amide, which were separated by flash chromatography. The pure amide was further transformed into the oxazoline with an 85% yield through a tosylation/elimination reaction. It is noteworthy that the classical condensation (reflux of chlorobenzene) of the 8-cyanoquinoline with the amino alcohol led to only 7% of **e**. The quinolino-oxazoline **f** was easily obtained by silylation of **e** with $SiClPh_2$(*t*-Bu) in excellent yield. The ligand **g** was obtained by Zn-catalyzed standard condensation between 8-cyanoquinoline and the corresponding amino alcohol. The tetraaza ligand **h** was prepared analogously to **i**.[23]

Allylic Palladium Complexes. According to Scheme 2, the reaction of [Pd(η^3-allyl)(μ-Cl)]$_2$ complexes (**1**, allyl = C_3H_5; **2**, allyl = 2-Me-C_3H_4; **3**, allyl = 1,3-Ph_2−C_3H_3;

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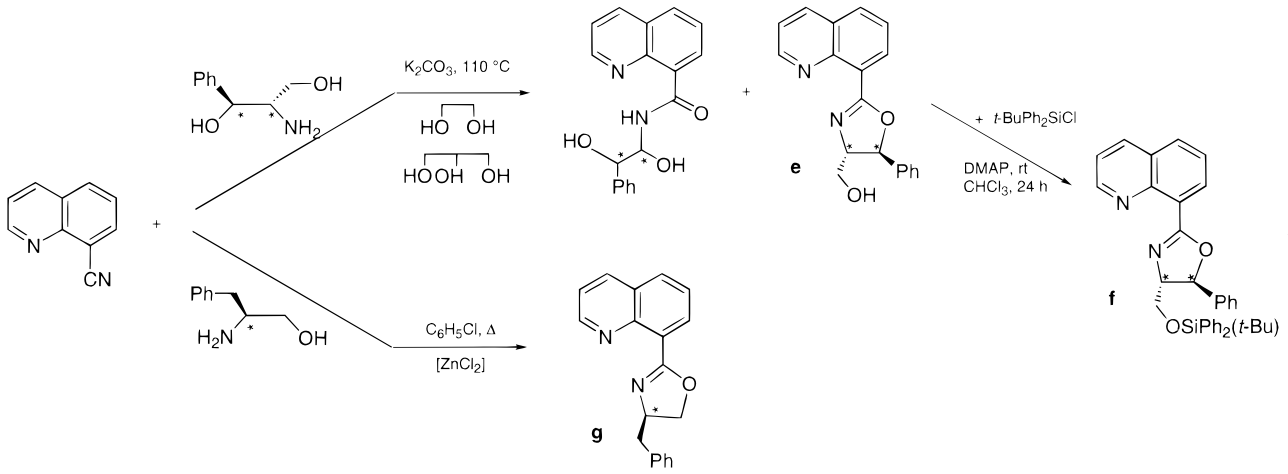
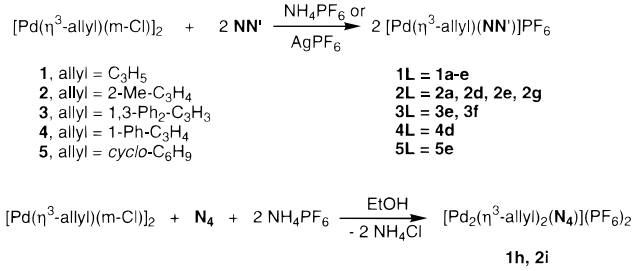
Scheme 1



Scheme 2



4, allyl = 1-Ph−C_3H_4; **5**, allyl = *cyclo*-C_6H_9) with the appropriate **NN′** ligand (**a**−**g**), in the presence of ammonium or silver hexafluorophosphate salts, afforded ionic allylic palladium complexes of general formula [Pd(η^3-allyl)(**NN′**)]PF_6 (**1L**−**5L**).[24]

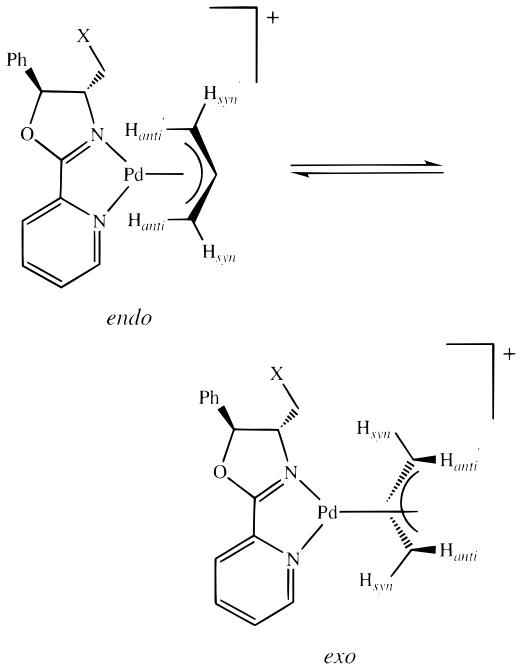
We also prepared allylic complexes with **h** and **i**, in a way similar to that described above for **a**−**g**, but in these cases the reactions yielded bimetallic compounds, **1h** and **2i** (see Scheme 2). In a previous work, we reported the ease for stabilizing π-allylic palladium(II) species with tetraaza ligands.[23]

All these complexes were fully characterized by the usual techniques (see Experimental Section). From IR spectroscopy data, the most interesting absorption was the C═N stretching of the oxazoline moiety; for these complexes, one strong signal was observed in the range 1660−1630 cm^{-1}, slightly shifted to higher frequencies relative to the free ligand, indicating a non π-acceptor behavior of the oxazoline group.

1L and **2L** complexes are soluble in coordinating solvents (acetonitrile, acetone, pyridine, DMF), but scarcely soluble in noncoordinating solvents, such as chloroform or dichloromethane. The $CHCl_3$ solubility increases by the addition of some drops of pyridine (5−10%).

The most useful technique for determining isomeric composition is reported as being the NMR spectroscopy.[18] ^1H NMR data were taken in acetonitrile-d_3 or acetone-d_6, at room temperature for **1L** and **2L** complexes (see Experimental Section). Under these conditions, spectra revealed the presence of a single stereoisomer, showing different chemical shifts for the two halves of the symmetric allyl group ($H_{anti} \neq H_{anti}'$; $H_{syn} \neq H_{syn}'$), because of the asymmetry of the **(NN′)** ligand.

But, due to the presence of substituents on the oxazoline moiety, two isomers were able to exist in solution (see eq 1): *exo* and *endo* refer to the relative position of the substituent at the central allylic carbon and the substituent at position 3 of the oxazoline group.



endo

exo

(1)

To distinguish between *exo* and *endo* isomers, variable-temperature ^1H NMR spectra were carried out. Thus, in acetone, below −80 °C, the H_2 proton appeared as two broad signals. So, the exchange between the two isomers is fast even at low temperature in coordinating solvents, as has been postulated in the literature.[25] NMR studies in noncoordinating solvents were therefore tested also. Solutions of complexes **1d** and **1e** in $CDCl_3$ with deuterated pyridine (5%) were investigated. At room temperature, these spectra showed broad signals and the H_2 proton was shifted to lower fields. This is probably due to the partial decoordination of the bidentate ligand in the presence of pyridine. It was only possible to run ^1H NMR spectrum in pure $CDCl_3$ for **2d**

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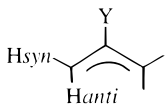
Table 1. Selected ^{1}H NMR Data[a] (δ in ppm, 500 MHz, $CDCl_3$, 298 K) for 2d and 2g Complexes

complex	H_2[b]	H_3	$H_{3'}$	H_{anti}	H_{syn}	Y[c] = Me
2d						
major	6.12 (d, 7.0)	4.34 (m)	3.51−3.60 (m)	2.30 (s) 3.23 (s)	3.55[d] (s) 4.32 (s)	2.11 (s)
minor	5.94 (d, 7.0)	4.41 (m)	3.51−3.60 (m)	2.81 (s) 3.39 (s)	3.47 (bs) 4.30 (bs)	2.01 (s)
2g						
major	4.74 (dd, 17.0, 9.0) 4.51 (m)[e]	4.72 (m)	3.02 (bs) 3.03 (bs)	2.17 (s) 3.13 (s)	3.66 (d, 3) 3.59 (d, 3)	2.03 (s)
minor	4.66 (pt, 9) 4.51 (m)[e]	4.87 (m)	2.86 (dd, 14, 4.5) 3.16 (dd, 14, 8.5)	3.12 (s) 3.45 (s)	3.96 (d, 2.5) 3.81 (d, 2.5)	2.30 (s)

[a] Multiplicity (b, broad; d, doublet; m, multiplet; p, pseudo; s, singlet; t, triplet) and coupling constants (in Hz) in parentheses. [b] See Figure 1 for atom labeling. [c] Hydrogen labels for allyl group:



[d] Overlapped with $H_{3'}$ signal. [e] Overlapped one of the two diastereotopic H_2 protons of the *major* and *minor* isomer.

and **2g** complexes. The presence of two isomers (ratio 3:2 and 3:1, for **2d** and **2g**, respectively), with four different signals for the *syn* as well as for the *anti* protons, could be observed (see Table 1).

Therefore, the exchange between the two *endo* and *exo* stereoisomers is slow on the NMR time scale, in a poor coordinating solvent, at room temperature.

Chelating nitrogen ligands have been useful *reporters* for elucidating solution structure of π-allyl palladium complexes and their dynamic behavior (apparent rotation of the allyl moiety and *syn*/*anti* proton exchange),[26] by means of NMR spectroscopy, specially NOE experiments.[18b] Therefore NOESY experiments were measured to obtain information about nuclear Overhausser effects between different protons in the molecule that are close together, as well as proton exchange processes.

The most interesting NOE interactions are expected to occur between the *syn* or the *anti* protons and the protons close to the nitrogen atoms (H_B close to the pyridine or quinoline nitrogen atom; H_3 close to the oxazoline nitrogen atom). For pyridino-oxazoline complexes with ligands (**a**−**d**), NOESY spectra revealed interaction between the two *syn* protons and H_B, but not with H_3. Weak NOE effects are observed when protons are separated by more than 3.0 Å (for complexes in the range 500−1000 g/mol).[27] From X-ray data for complex **1d** (see below), the estimated distance H_{syn}−H_3 is ca. 3.6 Å. Therefore no NOE interaction betweeen allyl and oxazoline protons was expected.

For complexes with quinolino-oxazoline ligands, **1e** and **2g**, the NOE interaction between H_{syn} and H_3 was observed, according to the bidentate coordination of these ligands in solution. These NOE effects indicate a closer proximity of the oxazoline moiety to the metallic sphere than in the pyridino-oxazoline systems.

NOESY spectrum for complex **2g** in $CDCl_3$ allows one to assign unambiguosly the protons of the allyl, quinoline, and oxazoline groups of each isomer as shown in Scheme 3.

The *major* isomer showed NOE between H_{syn}' and H_3, but this contact was not observed for the *minor* species. Semiempirical calculations for *endo* and *exo* **2g** isomers gave an interatomic H_{syn}'−H_3 distance of 2.81 and 2.95 Å for the *endo* and *exo* complexes, respectively, a trend coherent with the NOE results. Therefore we assigned tentatively the *major* isomer to the *endo* conformation.

NOESY spectra exhibited clear *syn*/*syn* and *anti*/*anti* exchanges, showing the rotation of the π-allyl group with regard to the chelate fragment.[28] This allylic behavior was also shown by the NOE effects observed for both *syn* protons with H_B. In addition, exchange signals between allylic protons of the two isomers of **2d** and **2g** complexes were observed. Variable-temperature NMR experiments did not show any coalescence between *syn* and *anti* protons. To obtain further evidence for this isomerization, 1D NOE spectra were carried out, irradiating selectively *syn* and *anti* allylic protons. These experiments revealed that the irradiation of one of these (*syn*) reverses the resonance of the other (*anti*).[29] Then, $\pi-\sigma-\pi$ exchange is also present, but this process should be slow on the NMR time scale.

We can conclude that for **1L** and **2L** complexes two dynamic processes coexist in solution. The allylic rotation is faster than the $\pi-\sigma-\pi$ movement, in agreement with studies reported in the literature.[30]

Crystals of complex **1d** were obtained by slow diffusion of hexane over an acetone solution of the complex (see Figure 2). Crystallographic data for **1d** are summarized in Table 2. Selected bond lengths and angles are listed in Table 3.

The core "PdC_2N_2" shows a distorted square-planar coordination geometry, with bond distances Pd−C and Pd−N in the expected range for Pd(II) allyl compounds with chelate nitrogen ligands (see Table 3).[31] The difference between the two Pd−C bond distances indicates a major *trans* influence for the pyridinic than for the oxazolinic nitrogen atom. The relative position of the allylic central carbon atom and the trityl group shows an *endo* arrangement in solid state. As usually observed in allylic complexes, *anti* protons are closer (Pd−H_{anti} ca. 2.1 Å) to the metal than those of *syn* ones (Pd−H_{syn} *ca.* 2.9 Å). The interatomic distances H_{syn}−H(8) (ca. 3.6 Å) and H_{syn}−H(1) (ca. 2.8 Å) support structural features observed in solution, from NOE experiments (see above).

Pd-Catalyzed Allylic Alkylations. Open-Chain Acetate Substrates. *rac*-3-Acetoxy-1,3-diphenyl-1-propene. We tested the catalytic activity of our Pd/**NN′** and Pd/$\mathbf{N_4}$ systems in the allylic alkylation of the model substrate, *rac*-3-acetoxy-1,3-diphenyl-1-propene (**I**), using dimethyl malonate as nucleophile, under basic Trost conditions (see eq 2).[32] Catalytic precursors were gener-

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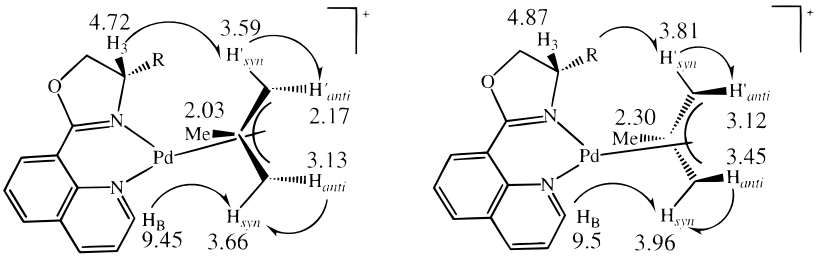
Scheme 3



2g *Major* **2g** *Minor*

= NOE

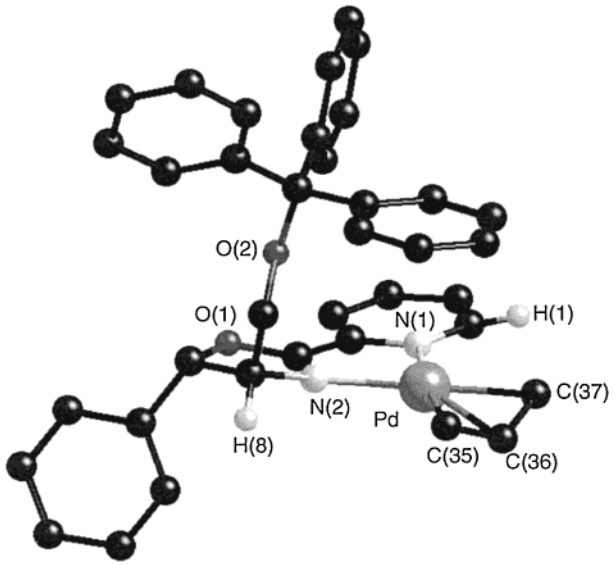


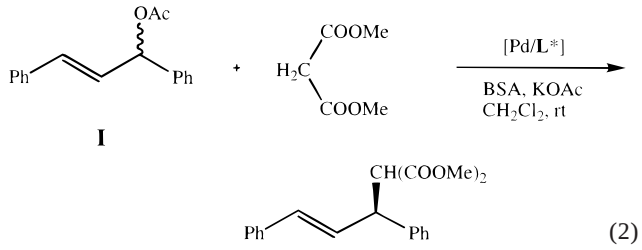
Figure 2. View of the molecular structure of complex **1d**. Hydrogen atoms and the hexafluorophosphate anion have been omitted for clarity.

Table 2. Crystal Data for Complex 1d

formula	$C_{37}H_{33}N_2F_6O_2PPd$
mol wt	789.044
cryst dimens, mm	0.43 × 0.17 × 0.40
data collect. *T*, K	293
cryst syst	monoclinic
space group	$P12_11$
a, Å	10.953(4)
b, Å	17.385(10)
c, Å	8.980(3)
α, deg	90
β, deg	96.621(3)
γ, deg	90
V, Å^3	1698.5(13)
Z	2
density (calcd), g cm^{-3}	1.543
radiation	Cu Kα (*λ* =1.5418 Å)
F(000)	800
abs coeff, mm^{-1}	0.884
θ range, deg	5.29 < *θ* < 55.6
final *R* indices obsd	0.044
R indices (all data)	0.046

Table 3. Selected Bond Lengths (Å) and Bond Angles (deg) for 1d (with esd's in parentheses)

Pd−N(1)	2.118(7)	N(1)−Pd−N(2)	78.3(2)
Pd−N(2)	2.102(6)	N(1)−Pd−C(37)	104.7(4)
Pd−C(35)	2.134(10)	N(2)−Pd−C(35)	108.0(3)
Pd−C(37)	2.098(13)	N(2)−Pd−C(37)	176.8(4)
		N(1)−Pd−C(35)	173.6(3)
		C(35)−Pd−C(37)	69.0(4)
		C(35)−C(36)−C(37)	128.1(19)



I **II** (2)

methane at room temperature, until the substrate had been completely converted (monitored by TLC). For the tetraaza ligand **h**, DMF was used as the solvent due to the low solubility of the ligand in dichloromethane. The results obtained for these catalytic processes are shown in Table 4.

Palladium complexes with both pyridino- and quinolino-oxazoline type ligands showed considerable high activity in the alkylation of substrate **I** to give the substitution product **II**. At room temperature, the conversion of the substrate was completed in less than 5 h for pyridine derivatives (entries 1−4) and less than 1 h was needed for ligand **e** (entry 5). High yields (75−98%) of isolated product **II** were obtained. In contrast, after 4 days of reaction at 65 °C, the tetraaza ligand **h** gave only 30% of **II** (entry 10). The enantiomeric excesses were in the range 2−69%. The best enantioselectivities were achieved with the quinoline derivatives **e**, **f**, and **g** (entries 5, 8, 9), obtaining an enantiomeric excess up to 69% for ligand **g**.

Although ligands **a**−**g** contain two different donor nitrogen atoms, the electronic effect in the organic transformation is practically negligible. However, Moberg and Chelucci[12,16] published their results in the allylic alkylation process with pyridino-oxazoline ligands, *ortho*

ated in situ from [Pd(η^3-C_3H_5)(μ-Cl)]$_2$ (1 mol %) and the appropriate ligand (2.5 mol % for **a**−**g** and 1.25 mol % for **h**). The reactions were carried out in dichloro-

Table 4. Results of Asymmetric Alkylation of *rac*-3-Acetoxy-1,3-diphenyl-1-propene with Dimethyl Malonate (see eq 2)[a]

entry	ligand	*T* (°C)	time (h)[b]	ee (%)[c]	conf.[d]	yield (%)
1	**a**	rt	2.25	24	S	75
2	**b**	rt	3	2	S	90
3	**c**	rt	5	4.3	R	85
4	**d**	rt	2	25	S	84
5	**e**	rt	0.75	44	S	95
6	**e**	0	9	40	S	90
7	**e**	−10	14	43	S	90
8	**f**	rt	1.5	65	S	85
9	**g**	rt	3	69	R	98
10[e]	**h**	65	96	17	S	30[f]

[a] Results determined from duplicate experiments. [b] Until the conversion of substrate was complete (monitored by TLC). [c] Determined by HPLC on a Chiralcel-OD column. [d] According to the optical rotation in: Leutenegger, U.; Umbricht, G.; Fahrni, C.; Matt, P. V.; Pfaltz, A. *Tetrahedron* **1992**, *48*, 2143. [e] DMF was used as solvent. [f] Conversion of substrate.

substituted on the aromatic ring, achieving enantiomeric excesses greater than 98%.

Another way to improve the asymmetric induction is to modify the size of the chelate, to close the stereocenter to the environment of the metal in the catalytic species. This effect has been recently observed in bidentate **NS** ligands, containing oxazoline moieties.[33]

Our results indicate that in the **NN′** ligand family enantiomeric excesses increased for quinolino-oxazoline systems, relative to those of the analogous pyridino-oxazoline. Thus, ee went from ca. 25% (entries 1 and 4 in Table 4) up to 69% (entry 9). Concerning the enantioselectivity of **a**−**d** ligands, the highest asymmetric inductions (ca. 25%) are achieved for the pyridino-oxazoline ligands with the least (**a**) and the most (**d**) sterically demanding substituents at the stereocenter closer to the palladium atom (entries 1 and 4). But even for the bulky trityl group, the ee is lower than for the 2-(3′,4′-dihydro-4′-phenyl-2′-oxazolyl)pyridine ligand (50%).[12] The relatively high enantiomeric excess for the catalytic system Pd/**a** can be explained by interaction of the hydroxy group with the nucleophile (see below). In fact, the "anomalous" effect of polar substituents at the stereogenic center, close to the oxazoline nitrogen atom, has also been reported for other catalytic systems, containing oxazolino-phosphine ligands.[34]

The catalytic system with ligand **h** showed low activity even at high temperature and low asymmetric induction (entry 10 in Table 4), in contrast to the very good results obtained with other tetraaza ligands, bis-(oxazolinylpyridinyl)dioxolane (yields up to 91% and ee's higher than 98%).[35] With our catalytic system, formation of black palladium was always observed after a few hours of reaction. Therefore, the low activity is probably related to the low stability of Pd(0) species with this ligand, due to the lack of atoms with π-acceptor behavior (neither oxazoline- nor piperazine-nitrogen atoms). The low enantioselectivity is a consequence of the lability Pd(II)−N(piperazine) bond in solution, as we have recently reported.[23]

To get a better understanding of the enantioselectivity, we studied the structures of complexes [Pd(η^3-1,3-Ph_2−C_3H_3)(**NN′**)]PF_6, **3e** and **3f**, in solution. In chloroform at room temperature, ^{1}H NMR spectra showed a mixture of two *syn, syn* isomers (*endo* and *exo*), assigned by the allyl ^3J(H,H) values, in a ratio 2.5:1 and 4:1, respectively (see Table 5). Other minor isomers were also observed, probably issued from *syn, anti* geometries (which also show *endo* and *exo* conformations), as shown in Scheme 4. *Anti, anti* isomers are probably less stable. Therefore the nucleophilic attack can occur at different positions, reducing the final enantiodiscrimination.

NOESY NMR spectra carried out for **3e** and **3f** showed exchange signals between the two *syn, syn* isomers in each case. Also noteworthy are the NOE interactions observed between H_B and H_{anti}' (see Scheme 4 for the atom labeling) corresponding to the major *syn, syn* isomer, but the absence of these signals for the minor *syn, syn* isomer. Moreover, the chemical shift of the H_3 of the oxazoline moiety for the major *syn, syn* isomer occurs at higher frequencies than that of the free ligand (ca. $\Delta\delta = 1.7$ ppm for both complexes **3e** and **3f**), due to the shielding of the close allyl phenyl group. The analogous proton H_3 for the minor *syn, syn* **3e** appears at 5.24 ppm, slightly deshielding relative to the free ligand ($\Delta\delta = 1.7$ ppm). These NMR results suggest an *endo* conformation for the major diastereomer (see Scheme 5). To corroborate these data, some semiempirical calculations (PM3(tm) level) were carried out for the **3f** complex, indicating that the interatomic distances H_B−H_{anti}' for the *endo* and *exo* conformations are 2.56 and 3.21 Å, respectively. We can then propose that the major species has an *endo syn, syn* geometry.

An interesting aspect is the ratio of the more abundant *syn, syn* isomers and the enantiomeric excesses observed for the catalytic systems with ligands **e** and **f**. These values are 44 and 65% respectively (Table 4) and correspond to the same isomeric ratio of the palladium complexes **3e** and **3f**. If we assume that the nucleophilic attack occurs on the terminal allylic carbon always *trans* to the oxazolinic nitrogen, the matching between ee's and the isomeric ratios indicate that the two isomers react at the same rate.

Moreover, it is important to note the effect of the flexible hydroxyl group on the enantioselectivity, also observed with other chiral ligands.[36] The Pd/**e** catalytic system induces a lower asymmetry than the other quinoline systems **f** and **g**, probably due to the capability of the polar "CH_2OH" group to direct the nucleophile[37] and then to favor the attack on the terminal allylic carbon close to the oxazoline moiety.

(*E*)-3-Acetoxy-1-phenyl-1-propene. The palladium-catalyzed allylic alkylation with (*E*)-3-acetoxy-1-phenyl-1-propene (**III**) was investigated to study the regioselectivity of these systems (see eq 3). The catalytic process was carried out under the same conditions as those described for the racemic substrate **I**, but using allylic palladium complexes (**1a**, **1d**, **1e**, **1i**) previously prepared (unless stated otherwise). The results are summarized in Table 6.

The use of an unsymmetrical substrate, such as **III**,

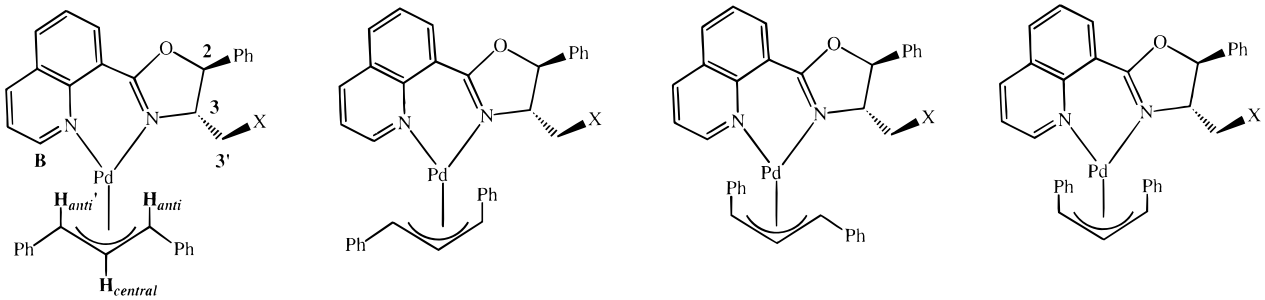
(33) Chesney, A.; Bryce, M. R.; Chubb, R. W. J.; Batsanov, A. S.; Howard, J. A. K. *Tetrahedron: Asymmetry* **1997**, *8*, 2337.
(34) Lloyd-Jones, G. C.; Butts, C. P. *Tetrahedron* **1998**, *54*, 901.
(35) Chelucci, G. *Tetrahedron: Asymmetry* **1997**, *8*, 2667.
(36) Hayashi, T. *Pure Appl. Chem.* **1988**, *60*, 7.
(37) Lloyd-Jones, G. C.; Stephen, S. C. *Chem. Eur. J.* **1998**, *4*, 2539.

Table 5. Selected ^{1}H NMR Data[a] (δ in ppm, 500 MHz, $CDCl_3$, 298 K) for 3e and 3f Complexes

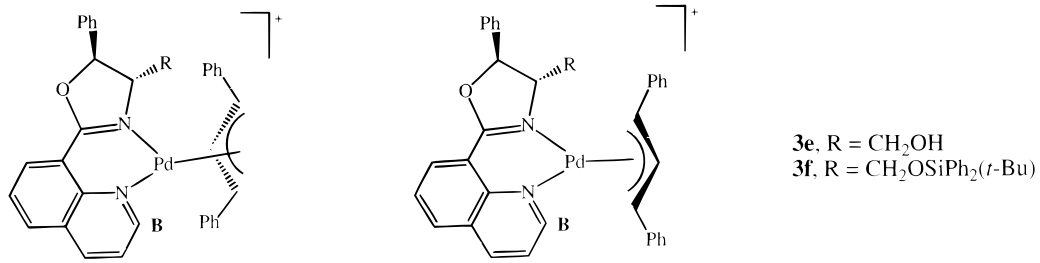
complex	H_2[b]	H_3	$H_{3'}$	H_{anti}[c]	H'_{anti}[c]	Y = H[c]	other
3e							
major	5.43 (d, 8)	2.72 (dt, 8, 2.5)	3.37 (dd, 13, 2.5) 4.39 (dd, 13, 2.5)	5.16 (d, 11)	4.96 (d, 11)	6.21 (t, 11)	O*H* 4.5 (m) H_B 8.74 (dd, 4.8, 1.8)
minor	5.81 (d, 6.5)	5.24 (dt, 6, 3.5)	3.86 (dd, 12, 3) 4.40 (dd, 12.5, 3.5)	5.20 (d, 12)	5.00 (d, 12)	6.14 (t, 12)	O*H* 3.81 (m) H_B 9.89 (dd, 4.8, 1.8)
3f[d]							
major	5.57 (d, 5.5)	2.80 (m)	3.77 (dd, 1, 2.5) 4.00 (dd, 11, 3.5)	4.08 (d, 11.5)	4.51 (d, 11.5)	6.32 (t, 11.5)	C(CH_3)$_3$ 0.86 (s) H_B 8.43 (dd, 5, 2)
minor	5.51 (d, 4.5)	2.97 (m)	3.04 (dd, 15, 2.5) 3.24 (dd, 15, 2.5)	4.85 (d, 11.5)	4.99 (d, 12)	6.49 (t, 12)	C(CH_3)$_3$ 0.70(s) H_B n.o.[e]

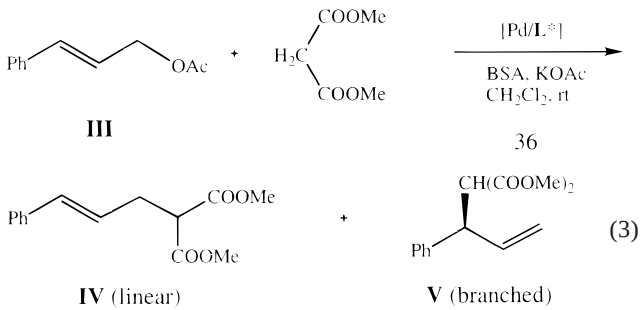
[a] Multiplicity (d, doublet; m, multiplet; s, singlet; t, triplet) and coupling constants (in Hz) in parentheses. [b] See Figure 1 for atom labeling. [c] See *c* footnote Table 1. [d] By NOESY experiments, H_{anti} and H'_{anti} were assigned to protons *trans* to quinoline and oxazoline groups, respectively. [e] Not observed.

Scheme 4



Scheme 5





in allylic alkylation affords a mixture of linear and branched regioisomers **IV** and **V**, depending on the terminal allyl carbon attacked by the nucleophile.[38−40] In our studies, high yields were obtained with **a**, **d**, and **e** ligands (70−87%, entries 11−17), though yields fell for the tetraaza ligand **i** (ca. 53%, entries 18−19). The regioisomeric ratio in all cases was ca. 9:1, **IV**/**V**, respectively (determined by ^{1}H NMR spectroscopy). ^{1}H NMR analysis showed exclusively the formation of the *E* linear isomer. The nucleophilic addition occurred on the unsubstituted terminal carbon of a *syn* complex. It

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Table 6. Results of Allylic Alkylation of (*E*)-3-Acetoxy-1-phenyl-1-propene with Dimethyl Malonate (see eq 3)[a]

entry	precursor	*T* (°C)	time (h)[b]	yield (%)[c]
11	**1a**	reflux	1	87
12	**1a**	rt	22	83
13	**a**[d]	rt	22	81
14	**1d**	rt	22	70
15	**d**[e]	rt	22	72
16	**1e**	rt	2.5	78
17	**e**[e]	−20	65	79
18	**1i**[f]	80	1.5	52
19	**1i**[f]	65	96	55

[a] Results determined from duplicate experiments. [b] Until conversion of substrate was complete (monitored by TLC). [c] Sum of **IV** and **V** isomers. [d] In situ conditions: 1 mol % $[Pd_2(2\text{-}Me\text{-}C_3H_4)_2Cl_2]$ and 2.5 mol % of ligand. [e] In situ conditions: 1 mol % $[Pd_2(C_3H_5)_2Cl_2]$ and 2.5 mol % of ligand. [f] DMF was used as solvent.

Table 7. ^{1}H NMR Data[a] (δ in ppm, 500 MHz, $CDCl_3$, 298 K) for the *anti* and *syn* Protons of *syn*-4d Isomers

	isomer I	isomer II	isomer III	isomer IV
H_{anti}[b]	2.63 (d, 12.0)	3.27 (d, 12.5)	4.97 (d, 11.5)	3.77 (d, 12.0)
	4.61 (d, 12.0)	3.93 (d, 12.5)	n.o.[c]	5.01 (d, 12.0)
H_{syn}[b]	4.04 (d, 6.5)	3.69 (d, 6.5)	n.o.[c]	4.57 (d, 7.0)

[a] Multiplicity (d, doublet; m, multiplet; s, singulet; t, triplet) and coupling constants (in Hz) in parentheses. [b] See footnote of table 1. [c] Not observed signals.

Table 8. Results of Asymmetric Alkylation of *rac*-3-Acetoxy-1-cyclohexene with Dimethyl Malonate (see eq 4)[a]

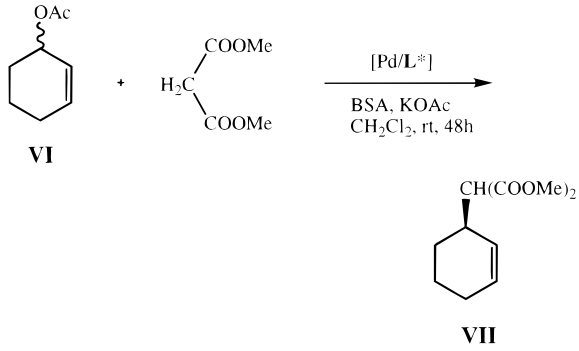
entry	ligand	conv. (%)[b]	ee (%)[c]
20	a	0	
21	b	13	11.0
22	c	13	12.0
23	d	0	
24	e	45	8.1
25	f	60	7.0
26	g	70	0

[a] Results determined from duplicate experiments. [b] Conversion of the substrate determined by ^{1}H NMR spectroscopy. [c] Determined by GC on a β cyclodex chiral column.

is noteworthy that different temperatures did not change the isomeric composition (for **a**, see entries 11, 12; for **e**, see entries 16, 17), indicating no isomerization process between both isomers. Analogously to racemic substrate **I**, the quinolino-oxazoline system (**e**) was the most active catalyst. A complete consumption of substrate was observed at −20 °C, after 65 h (entry 17). No differences were observed between in situ generation of palladium catalyst (entries 13, 15, 17) and precursor complexes, previously isolated (entries 12, 14, 16).

To determine the solution structure of palladium intermediates, complex $[Pd(\eta^3\text{-}1\text{-}Ph\text{-}C_3H_4)(\mathbf{d})]PF_6$, **4d**, was prepared. The ^{1}H NMR spectrum of **4d** shows the existence of four *syn* isomers in a ratio of 2.5:2.0:1.5:1.0. For three of them, two *anti* and one *syn* proton can be distinguished for each (see Table 7), due to the asymmetry of both the ligand and the allyl group. Semiempirical calculations show that *exo* isomers are more stable than *endo* conformations.

Cyclic Acetate Substrate, *rac*-3-Acetoxy-1-cyclohexene. Until now, high enantioselectivities for the asymmetric allylic alkylations with palladium complexes of racemic cyclic acetate substrates were achieved with chiral phosphine ligands, such as diphosphanes,[41] bis(amino)bis(phosphines),[42] and phosphino-oxazolines.[43] For the six-membered substrate, *rac*-3-acetoxy-1-cyclohexene, the enantiomeric excesses are up to 93%. But Pd−diamine systems, such as sparteine and isosparteine precursors, afford lower asymmetric inductions (up to 62%)[44] and are even lower for the C_2-symmetric chiral diamines (up to 16%), reported by Lemaire and co-workers.[45] The lack of symmetry in our **NN′** ligands prompted us to test their selectivity in the alkylation of the racemic cyclic substrate **VI** with dimethyl malonate (see eq 4). This catalytic process was carried out with a method similar to that described for the racemic substrate **I**, but the reactions were stopped after 48 h. The results are summarized in Table 8.



VI **VII** (4)

These systems were not very active, though the quinoline ligands (entries 24−26) were more active than those of pyridine (entries 20−23), achieving up to 70% of substrate conversion for the system Pd/**g** (entry 26). Enantioselectivity was, in any case, very low, achieving only 12% of ee for the pyridino-oxazoline **c** (entry 22). It is noteworthy that the most active catalytic system, Pd/**g**, does not induce asymmetric induction. Among the quinoline ligands (**e**−**g**), the main difference is the nature of the substituent on the stereocenter close to the oxazolinic nitrogen, oxygen (**e** and **f**) or carbon group (**g**).

Analogously to the allyl complexes described above, we prepared the intermediate $[Pd(\eta^3\text{-}cyclo\text{-}C_6H_9)(\mathbf{e})]PF_6$, **5e**. Its ^{1}H NMR spectrum at room temperature shows broad signals. But at lower temperatures, the signals are also broad, but two isomers (*endo* plus *exo*) can be distinguished in a ca. ratio of 3:1 (see Table 9). This behavior points to a similar proportion of both isomers at room temperature, and therefore, low asymmetric induction is expected.

Pd-Catalyzed Allylic Amination. Catalytic palladium systems with chiral bidentate ligands (*PP*[46] or

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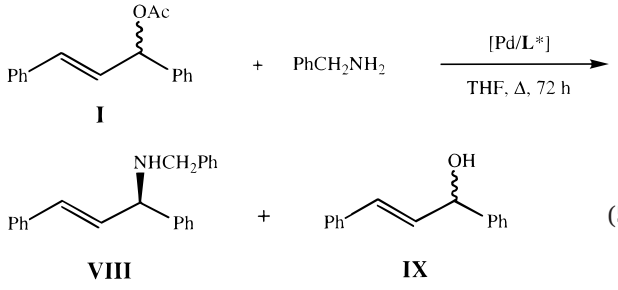
(45) Gamez, P.; Dunjic, B.; Fache, F.; Lemaire, M. *Tetrahedron: Asymmetry* **1995**, *6*, 1109.

Table 9. Selected ^{1}H NMR Data[a] (δ in ppm, 500 MHz, $CDCl_3$, 273 K) for 5e

	H_2[b]	H_3	$H_{3'}$	H_{syn}[c]	H'_{syn}[c]	Y = H[c]	other
major[d]	5.85	4.44	4.03	5.13	5.03	6.13	O*H* 3.07
							CH_2[e] 2.2−0.9
minor[d]	5.85	4.44	4.15	5.19	4.88	5.78	O*H* 3.07
							CH_2[e] 2.2−0.9

[a] All signals appear as multiplets. [b] See Figure 1 for atom labeling. [c] See *c* footnote Table 1. [d] By NOESY experiments, $H_{syn}$and H'_{syn} were assigned to protons *trans* to quinoline and oxazoline groups, respectively. [e] Cyclohexenyl methylenic signals.

NP[47] ligands) induce excellent enantioselectivities in Pd-catalyzed asymmetric aminations, especially with non-symmetric ligands containing nitrogen−phosphorus as donor atoms. We used the most active systems in the alkylations described above, pyridino- and quinolino-oxazolines, in the enantioselective allylic amination of the *rac*-3-acetoxy-1,3-diphenyl-1-propene (**I**) with benzylamine (**bza**) as nucleophile to obtain **VIII** (see eq 5).



(5)

$$[Pd(\eta^3\text{-}C_3H_5)(\mu\text{-}Cl)]_2 + 4\ PhCH_2NH_2 \xrightarrow{NH_4PF_6} 2\ [Pd(\eta^3\text{-}C_3H_5)(bza)_2]PF_6 \quad (6)$$

This process was first tested under in situ catalytic conditions (2 mol % of $[Pd(\eta^3\text{-}C_3H_5)(\mu\text{-}Cl)]_2$ and 2.5 mol % of **e**), but very little conversion of substrate (5%) was observed after 24 h at reflux temperature of THF. But using the catalytic precursor **1e**, 89% conversion of substrate occurred (entry 30, Table 10). Probably under in situ conditions, neutral palladium allylic complexes containing benzylamine are formed, and they are not effective in the catalytic allylic substitutions.[13c] When ammonium hexafluorophosphate was added (entry 32), higher conversion of substrate was produced than without ammonium salt, but lower than with precursor **1e** (entry 30). These results suggest that the basicity of **bza** competes with the bidentate nitrogen ligand, as seen with secondary amines,[48] stabilizing intermediate species containing chloride anion coordinated to the metal (eq 6).

Table 10. Results of the Asymmetric Amination of *rac*-3-Acetoxy-1,3-diphenyl-1-propene with Benzylamine (see eq 5)[a]

entry	precursor	conv. (%)[b]	**VIII/IX**	*T*, t (h)	ee (%)[c]
27	**1a**	99	50/50	reflux, 24	7
28	**1d**	100	60/40	reflux, 72	3
29	**1e**	54	15/85	rt, 72	31
30	**1e**	89	65/35	reflux, 24	28
31	**1e**	100	80/20	reflux, 72	23
32	Pd/**e**[d]	60	57/43	reflux, 24	25

[a] Results determined from duplicate experiments. [b] Conversion of the substrate determined by ^{1}H NMR spectroscopy. [c] Determined by HPLC on a Chiralcel-OD column for **VIII**. [d] Under in situ conditions: 2 mol % of $[Pd_2(C_3H_5)_2Cl_2]$, 2.5 mol % of **e**, and 2 mol % of NH_4PF_6.

As observed for the alkylation processes, the palladium/quinolino-oxazoline catalytic systems are more active than the pyridino derivatives (see Table 10), but low enantioselectivities (up to 31% of ee) have been obtained in any case. Formation of the allylic alcohol **IX** (racemic mixture) was observed in all the catalytic amination tests. The ratio **VIII/IX** depends on the catalytic conditions. At room temperature, a high quantity of alcohol was produced, but at reflux temperature, the main product was **VIII** (entries 29 vs 31). In addition, the stoichiometric noncatalytic process (**I** plus **bza**) afforded only 5% of substrate conversion after 24 h at reflux temperature, being an equimolar mixture of both products. Therefore, under catalytic conditions, the nucleophile can probably attack two different carbon centers, the carbon atom of the acetate group and the terminal allylic carbon atom.

Conclusions

Pyridino- (**a**−**d**) and quinolino-oxazoline (**e**−**g**) ligands were prepared in high yields starting from 2-cyanopyridine or 8-cyanoquinoline with the appropriate chiral amino alcohol, respectively. We studied the dynamic behavior of the allyl palladium complexes $[Pd(\eta^3\text{-allyl})(\mathbf{NN'})]PF_6$, where **NN′** is a chiral pyridino- or quinolino-oxazoline ligand and the allyl group is a C_3H_5 or 2-Me-C_3H_4 moiety (complexes **1L** and **2L**, respectively). By NOE NMR experiments, these compounds showed the two well-known movements, namely, apparent π-allyl rotation and $\pi-\sigma-\pi$ exchange. The determination of the X-ray crystal structure of one complex (**1d**) revealed a higher *trans* influence for the pyridinic nitrogen than for the oxazolinic nitrogen atom. Tetraza ligands **h** and **i** afforded bimetallic complexes (**1h** and **2i**), bridging the piperazinobis(oxazoline) ligand with two palladium−allyl fragments.

Moreover, the study of **3e**, **3f**, **4d**, and **5e** intermediate species in the catalytic substitution reaction by ^{1}H NMR spectroscopy showed the existence of different isomers (*syn, syn* or *syn, anti*). The nature of **3f** isomers was elucidated by NOESY experiments and calculations using semiempirical methods, suggesting an *endo, syn, syn* geometry for the major species.

Complexes **1L** and **2L** with **NN′** ligands were tested as catalytic precursors in allylic alkylation processes with different types of substrate, acyclic acetates (*rac*-3-acetoxy-1,3-diphenyl-1-propene (**I**) and (*E*)-3-acetoxy-1-phenyl-1-propene (**III**)) and *rac*-3-acetoxy-1-cyclohexene (**VI**), with dimethyl malonate as nucleophile. The

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activity of the quinoline derivatives was higher than that of the pyridine catalytic systems, achieving total consumption of substrate at room temperature in less than 1 h for the symmetrical acetate, **I**. However, for this substrate the enantioselectivities were low or moderate, showing the beneficial effect of chelate size for the quinolino-oxazoline catalysts. In other words, the enantioselectivity is better for the quinolino-oxazoline catalytic systems because of the increase in size of the metallic ring, associated with the closer proximity of the stereocenter to the metallic sphere. In addition, high regioselectivity was observed for **III**, favoring the formation of the linear isomer (**IV**) for all tested systems. These systems showed low activity and selectivity for the alkylation process of the cyclic substrate **VI**. Tetraaza palladium complexes were also used as catalytic precursors, but both the activity and the enantioselectivity have been very low, due to the low stability of Pd(0) species and the lability of the Pd(II) complexes with $\mathbf{N_4}$ ligands.

Allylic complexes **1a**, **1d**, and **1e** were also active in the Pd-catalyzed allylic amination of *rac*-3-acetoxy-1,3-diphenyl-1-propene with benzylamine, but the activity of these systems was lower than for the alkylations. In addition, under in situ catalytic conditions, the coordination competition of the benzylamine with the bidentate ligand avoids the substrate conversion.

Experimental Section

General Data. All compounds were prepared under a purified nitrogen atmosphere using standard Schlenk and vacuum-line techniques. The solvents were purified by standard procedures[49] and distilled under nitrogen. $[Pd(\eta^3\text{-}C_3H_5)(\mu\text{-}Cl)]_2$, $[Pd(\eta^3\text{-}2\text{-}Me{-}C_3H_4)(\mu\text{-}Cl)]_2$, $[Pd(\eta^3\text{-}1\text{-}Ph{-}C_3H_4)(\mu\text{-}Cl)]_2$,[50] $[Pd(\eta^3\text{-}1,3\text{-}Ph_2{-}C_3H_3)(\mu\text{-}Cl)]_2$,[51] and $[Pd(\eta^3\text{-}cyclo\text{-}C_6H_9)(\mu\text{-}Cl)]_2$[52] were prepared as previously described. NMR spectra were recorded on Varian XL-500 (^{1}H, standard $SiMe_4$), Varian Gemini (^{13}C, 50 MHz, standard $SiMe_4$), and Bruker DRX 250 spectrometers. Chemical shifts were reported downfield from standards. NOESY experiments were recorded on the Varian XL-500 spectrometer using a 0.6 s mixing time. When longer mixing times were tested (0.9; 1.5 s) no further information was obtained. IR spectra were recorded on a Nicolet 520 FT-IR and FTIR Nicolet Impact 400 spectrometers. FAB mass chromatograms were obtained on a Fisons V6-Quattro instrument. The GC analyses were performed on a Hewlett-Packard 5890 Series II gas chromatograph (50-m Ultra 2 capillary column 5% phenylmethylsilicone and 95% dimethylsilicone) with a FID detector. The GC/MS analyses were performed on a Hewlett-Packard 5890 Series II gas chromatograph (50-m Ultra 2 capillary column) interfaced to a Hewlett-Packard 5971 mass selective detector. Optical rotations were measured on a Perkin-Elmer 241MC spectropolarimeter. Enantiomeric excesses were determined by HPLC on a Hewlett-Packard Series 1050 chromatograph (Chiralcel-OD chiral column) with a UV detector and by GC on a Hewlett-Packard 5890 Series II gas chromatograph (25-m FS-cyclodex-β-I/P column). Conductivities were obtained on a Radiometer CDM3 conductimeter. Elemental analyses were carried out by the Serveis Cientifico-Tècnics de la Universitat de Barcelona in an Eager 1108 microanalyzer. The molecular mechanics calculations were performed using the Spartan program, version 5.0 (Wavefunction Inc., Irvine, CA, 1997).

Ligands. (3′*S*,4′*S*)-8-(3′,4′-Dihydro-3′-phenyl-4′-hydroxymethyl-2′-oxazolyl)quinoline, e. In a 250 cm^3, three-necked flask are introduced successively 14.2 g (0.085 mol) of (1*S*,2*S*)-(+)-2-amino-1-phenyl-1,3-propanediol, 7.7 g of 8-cyanoquinoline, and 1.1 g of potassium carbonate, followed by a solution of 10 cm^3 glycerol in 18 cm^3 dry ethylene glycol. The resulting mixture is brought to 105 °C under a flow of argon. The disappearance of the nitrile is followed by thin-layer chromatography (SiO_2; AcOEt/MeOH/NEt_3, 100:5:1). Approximately 12 h are needed for a complete reaction. Two new spots appear on the thin layer, which have been further identified as the amide for the high R_f compound and the oxazoline for the low R_f one. The mixture is cooled to room temperature and then poured over crushed ice. The resulting white solid is filtered, washed with water, and then dried over KOH under vacuum until constant weight. The solid is then purified by flash chromatography (AcOEt/MeOH/NEt_3, 100:2:0.5). The amide is first eluted,[53] followed by the oxazoline. The white solids are then crystallized (AcOEt/hexane). Yield: 10.1 g (66.0%). Mp = 143 °C. $[\alpha]_{20}^{D} = +5.1$ (1.98, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 250 MHz; multiplicity, coupling constants in Hz, and relative integration in parentheses): 8.99 (dd; 1.8, 4.3; 1H); 8.17 (dd; 1.8, 8.3; 1H); 8.07 (dd; 1.5, 7.1; 1H); 7.91 (dd; 1.5, 8.3; 1H); 7.6 to 7.3 (m); 5.7 (d; 5.6; 1H); 4.8 (s; 1H); 4.47 (ddd; 5.6, 2.7, 2.7; 1H); 4.16 (dd; 2.7, 11.6; 1H); 3.80 (dd; 2.7, 11.6; 1H) ppm.

(3′*S*,4′*S*)-8-(3′,4′-Dihydro-3′-phenyl-4′-*tert*-butyldiphenylsilyloxymethyl-2′-oxazolyl)quinoline, f. In a 100 cm^3 three-necked flask dried and flushed with argon are introduced successively 2.14 g (9.46×10^{-3} mol) of the alcohol **e**, 1.36 g (20×10^{-3} mol) of imidazole, 0.05 g (0.4×10^{-3} mol) of DMAP, and 2.5 g (9.24×10^{-3} mol) of *t*-$BuPh_2SiCl$. The solids are dissolved in 50 cm^3 of freshly distilled chloroform, and the resulting mixture is stirred for 24 h at room temperature. The evolution of the reaction is followed by TLC (alumina/EtOAc). When the reaction is over, the organic phase is treated successively with 50 cm^3 saturated aqueous sodium hydrogenocarbonate and 50 cm^3 saturated brine and then dried over magnesium sulfate. After evaportation of the solvent, the resulting oil is purified by chromatography over deactivated alumina (activity III) using a mixture of hexane/ethyl acetate/NEt_3, 80:20:1, as eluent. A light yellow oil is collected. Yield: 4.56 g (91.0%). ^{1}H NMR ($CDCl_3$, 250 MHz; multiplicity, coupling constants in Hz, and relative integration in parentheses): 9.00 (dd; 4.2, 1.8; 1H); 8.10 (m; 2H); 7.80 (dd; 8.2, 1.5; 1H); 7.7 to 7.2 (m; 12H); 5.80 (d; 6.2; 1H); 4.50 (m; 1H); 4.13 (dd; 3.8, 10.4; 1H); 4.01 (dd; 6.6, 10.2; 1H); 1.10 (s; 9H) ppm.

(4′*R*)-8-(3′,4′-Dihydro-4′-benzyl-2′-oxazolyl)quinoline, g. In a 100 cm^3 Schlenk flask, flamed and flushed with argon, 0.03 g of anhydrous zinc chloride was introduced. The salt was fused under high vacuum and then cooled at room temperature. A solution of 3.08 g (0.02 mol) of 8-cyanoquinoline and 3.33 g (0.024 mol) of D-(+)-phenylalaninol in 40 cm^3 of dry chlorobenzene was introduced over the zinc chloride through a cannula. The resulting mixture was refluxed for 48 h, the solvent evaporated under vacuum, and the crude product purified by column chromatography over silica gel (hexane/ethyl acetate/NEt_3, 80:20:1). The isolated solid was crystallyzed from diethyl ether. Yield: 4.10 g (72%). $[\alpha]_{25}^{D} = +0.46$ (1.09, $CHCl_3$). ^{1}H NMR ($CDCl_3$, 250 MHz; multiplicity, coupling constants in Hz, and relative integration in parentheses): 9.10 (bd; 4.0; 1H); 8.82 (m; 1H); 8.3 to 7.3 (m; 9H); 4.80 (m; 1H);

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(53) Analytical data: Yield: 3.5 g (22%). ^{1}H NMR data ($CDCl_3$, 250 MHz; multiplicity, coupling constants in Hz, and relative integration in parentheses): 11.78 (d, 7.3, 1H); 8.90 (dd, 4.3, 1.8, 1H); 8.67 (dd; 7.4, 1.5, 1H); 8.23 (dd, 8.3, 1.8, 1H); 7.90 (dd, 8.1, 1.5, 1H);; 7.62 to 7.2 (m, 7H); 5.23 (d, 4.2, 1H); 4.45 (ddd, 4.2, 4.6, 4.7, 1H); 4.3 (s, 2H); 4.07 (dd, 4.6, 11.2, 1H); 3.92 (dd, 11.2, 4.7, 1H) ppm.

4.52 (t; 8.9; 1H); 4.30 (t; 8.1; 1H); 3.38 (dd; 14.0, 4.7; 1H); 2.87 (dd; 14.0, 9.1; 1H)

(4″*S*)-1,4-Bis(2′-(4″-isopropyl-3″,4″-dihydro-2″-oxazolyl)-phenyl)piperazine, h. In a dry, flushed with argon, three-necked flask (250 cm^3), 0.9 g of anhydrous piperazine was dissolved in 60 cm^3 of dry tetrahydrofuran. The solution was cooled at 0 °C, and 21 cm^3 of a 1.5 N *n*-butyllithium solution in hexane was introduced dropwise in the flask. The mixture was stirred for 1 h at 0 °C before the beginning of a slow addition of 5.36 g (0.02 mol) of (4′*S*)-2-(4′-isopropyl-3′,4′-dihydro-2′-oxazolyl)bromobenzene[54] in 80 cm^3 of anhydrous THF via a cannula. The mixture quickly turned yellow and then to dark red. The solution was stirred for 2 h at 25 °C and two additional hours under reflux. The solvent was evaporated under vacuum, and the crude product was hydrolyzed and extracted with diethyl ether. Following a classical workup, the collected oil was purified by column chromatography (Al_2O_3 activity III; eluent hexane/ether, 90:10). The collected white solid was recrystallyzed from hexane at −20 °C. Yield: 2.7 g (58%). $[\alpha]_{25}^{D} = -0.77$ (1.036, $CHCl_3$). ^1H NMR ($CDCl_3$, 250 MHz; multiplicity, coupling constants in Hz, and relative integration in parentheses): 7.70 (dd; 1.65, 7.61; 2H); 7.39 (td; 1.65, 7.75; 2H); 7.03 (dd; 1.0, 7.3; 2H); 6.99 (td; 1.7, 7.4; 2H); 4.45−4.3 (m; 2H); 4.15−4.0 (m; 4H); 3.20 (s; 8H); 2.01−1.78 (m; 2H); 1.03 (d; 6.75; 6H); 0.95 (d; 6.74; 6H).

Complexes. (η^3-Allyl)-[(3′*S*,4′*S*)-2-(3′,4′-dihydro-3′-phenyl-4′-hydroxymethyl-2′-oxazolyl)pyridine-*N*,*N*]palladium-(II) Hexafluorophosphate, 1a. A 0.121 g sample of [Pd(η^3-C_3H_5)(μ-Cl)]$_2$ (0.33 mmol) and 0.172 g of **a** (0.68 mmol) were dissolved in 40 cm^3 of absolute ethanol. The mixture was stirred at room temperature for 20 min. Then 0.201 g of NH_4PF_6 (1.23 mmol) was added, affording a white solid. The mixture was stirred overnight and then filtered off. The solid was successively washed with distilled water (6 × 10 cm^3), until neutral pH, and diethyl ether. The product was dried under reduced pressure. Yield: 0.127 g (35.2%). IR (KBr): 1662 (st, C═N), 840.8 (st, P−F) cm^{-1}. Anal. Calcd for $C_{18}H_{19}F_6N_2O_2PPd$: C, 39.54; H, 3.50; N, 5.12. Found: C, 39.15; H, 3.65; N, 5.10. Mp: 169.1 °C. Molar conductivity (acetone): 136.1 Ω^{-1} cm^2 mol^{-1}. MS (FAB positive): *m*/*z* 403 ([M^+]). ^1H NMR (CD_3COCD_3, 500 MHz; multiplicity, coupling constants in Hz, Figure 1 for atom labeling): H_2: 6.29 (d, 7.0); H_3, O*H*: 4.55 (m); $H_{3'}$: 4.14 (ddd, 12; 5; 3.5) and 4.01 (ddd, 12; 6.5; 3); H_{anti}: 3.50 (bd, 12.0); H_{syn}: 4.59 (bd, 7.0) and 4.62 (bd, 7.0); $H_{central}$: 5.95 (m).

The following compounds were synthesized in a way similar to that used for the preparation of **1a**.

(η^3-Allyl)[(3′*S*,4′*S*)-2-(3′,4′-dihydro-3′-phenyl-4′-methyloxymethyl-2′-oxazolyl)pyridine-*N*,*N*]palladium(II) Hexafluorophosphate, 1b. Starting materials: 0.146 g (0.4 mmol) of [Pd(η^3-C_3H_5)(μ-Cl)]$_2$, 0.215 g (0.8 mmol) of **b**, and 0.196 g (1.20 mmol) of NH_4PF_6. Yield: 0.395 g (80%). IR (KBr): 1658 (st, C═N), 840 (st, P−F) cm^{-1}. Anal. Calcd for $C_{19}H_{21}F_6N_2O_2$-PPd: C, 40.69; H, 3.75; N, 5.00. Found: C, 40.48; H, 4.20; N, 4.98. Mp: 208 °C. Molar conductivity (acetone): 124 Ω^{-1} cm^2 mol^{-1}. MS (FAB positive) *m*/*z* 415 ([M^+]). ^1H NMR (CD_3CN, 500 MHz; multiplicity, coupling constants in Hz, Figure 1 for atom labeling): H_2: 6.06 (d, 7.5); H_3: 4.45 (m); $H_{3'}$: 3.73 (s) and 3.72 (s); H_{anti}: 3.80 (s) and 3.36 (s); H_{syn}: 4.44 (dd, 7.5; 1.5) and 4.39 (dd, 7.5; 1.5); $H_{central}$: 5.79 (tt, 12.5; 7); OCH_3: 3.4 (s).

(η^3-Allyl)[(3′*S*,4′*S*)-2-(3′,4′-dihydro-3′-phenyl-4′-phenyloxymethyl-2′-oxazolyl)pyridine-*N*,*N*]palladium(II) Hexafluorophosphate, 1c. Starting materials: 0.146 g (0.4 mmol) of [Pd(η^3-C_3H_5)(μ-Cl)]$_2$, 0.246 g (0.8 mmol) of **c**, and 0.196 g (1.20 mmol) of NH_4PF_6. Yield: 0.248 g (50%). IR (KBr): 1651 (st, C═N), 765 (st, P−F) cm^{-1}. Anal. Calcd for $C_{24}H_{23}F_6N_2O_2$-PPd: C, 46.27; H, 3.69; N, 4.49. Found: C, 45.9; H, 3.8; N, 4.5. Mp: 159 °C. Molar conductivity (acetone): 132 Ω^{-1} cm^2 mol^{-1}. MS (FAB positive) *m*/*z* 477 ([M^+]). ^1H NMR (CD_3CN, 500 MHz; multiplicity, coupling constants in Hz, Figure 1 for atom labeling): H_2: 6.11 (d, 7.8); H_3: 4.74 (dt, 7.8; 3.6); $H_{3'}$: 4.34 (m); H_{anti}: 3.38 (s) and 3.31 (s); H_{syn}: 4.41 (s) and 4.37 (s); $H_{central}$ 5.7 (ph, 7; 5.5).

(η^3-Allyl)[(3′*S*,4′*S*)-2-(3′,4′-dihydro-3′-phenyl-4′-tritiloxymethyl-2′-oxazolyl)pyridine-*N*,*N*]palladium(II) Hexafluorophosphate, 1d. Starting materials: 0.150 g (0.41 mmol) of [Pd(η^3-C_3H_5)(μ-Cl)]$_2$, 0.408 g (0.82 mmol) of **d**, and 0.201 g (1.23 mmol) of NH_4PF_6. Yield: 0.591 g (91.3%). IR (KBr): 1657 (st, C═N), 845 (st, P−F) cm^{-1}. Anal. Calcd for $C_{37}H_{33}F_6N_2O_2PPd$: C, 56.32; H, 4.22; N, 3.55. Found: C, 56.42; H, 4.57; N, 3.53. Mp: 229.5.°C Molar conductivity (acetone): 134.6 Ω^{-1} cm^2 mol^{-1}. MS (FAB positive): *m*/*z* 643 ([M^+]). ^1H NMR (CD_3CN, 500 MHz; multiplicity, coupling constants in Hz, Figure 1 for atom labeling): H_2: 6.30 (d, 6.5); H_3: 4.44 (m); $H_{3'}$: 3.59 (dd, 10.0; 2.5) and 3.54 (dd, 10.0; 3.5); H_{anti}: 3.22 (d, 12.5) and 2.89 (d, 11.5); H_{syn}: 4.16 (d, 7.0) and 4.13 (d, 6.5); $H_{central}$: 5.63 (ph, 12.5; 7.0).

(η^3-2-Methylallyl)[(3′*S*,4′*S*)-2-(3′,4′-dihydro-3′-phenyl-4′-tritiloxymethyl-2′-oxazolyl)pyridine-*N*,*N*]palladium(II) Hexafluorophosphate, 2d. Starting materials: 0.150 g (0.38 mmol) of [Pd(η^3-2-Me−C_3H_4)(μ-Cl)]$_2$, 0.379 g (0.76 mmol) of **d**, and 0.196 g (1.20 mmol) of NH_4PF_6. Yield: 0.492 g (80%). IR (KBr): 1650 (st, C═N), 841 (st, P−F) cm^{-1}. Anal. Calcd for $C_{38}H_{35}F_6N_2O_2PPd$: C, 56.83; H, 4.39; N, 3.49. Found: C, 56.48; H, 4.46; N, 3.54. Mp: 236.8 °C. Molar conductivity (acetone): 130.3 Ω^{-1} cm^2 mol^{-1}. MS (FAB positive) *m*/*z* 657 ([M^+]). ^1H NMR (CD_3CN, 500 MHz; multiplicity, coupling constants in Hz, Figure 1 for atom labeling): H_2: 6.25 (d, 6.5); H_3: 4.44 (m); $H_{3'}$: 3.56 (m); H_{anti}: 3.11 (s) and 2.61 (bs); H_{syn}: 4.01 (bs) and 3.87 (bs); $H_{central}$: 2.04 (s).

(η^3-1-Phenylallyl)-[(3′*S*,4′*S*)-2-(3′,4′-dihydro-3′-phenyl-4′-tritiloxymethyl-2′-oxazolyl)pyridine-*N*,*N*]palladium-(II) Hexafluorophosphate, 4d. Starting materials: 0.105 g (0.20 mmol) of [Pd(η^3-1-Ph−C_3H_4)(μ-Cl)]$_2$, 0.200 g (0.40 mmol) of **d**, and 0.100 g (0.61 mmol) of NH_4PF_6. Yield: g (%). IR-(KBr): 1650 (st, C═N), 841 (st, P−F) cm^{-1}. Anal. Calcd for $C_{43}H_{37}F_6N_2O_2PPd$: C, 59.70; H, 4.31; N, 3.24. Found: C, 59.36; H, 4.73; N, 3.23. Mp: 200 °C. Molar conductivity (acetone): 120 Ω^{-1} cm^2 mol^{-1}.

(η^3-Allyl)[(3′*S*,4′*S*)-8-(3′,4′-dihydro-3′-phenyl-4′-hydroxymethyl-2′-oxazolyl)quinoline-*N*,*N*]palladium(II) Hexafluorophosphate, 1e. Starting materials: 0.154 g (0.42 mmol) of [Pd(η^3-C_3H_5)(μ-Cl)]$_2$, 0.256 g (0.84 mmol) of **e**, and 0.219 g (1.35 mmol) of NH_4PF_6. Yield: 0.17 g (34%). IR (KBr): 1646 (st, C═N), 844 (st, P−F) cm^{-1}. Anal. Calcd for $C_{22}H_{21}F_6$-N_2O_2PPd: C, 44.28; H, 3.55; N, 4.69. Found: C, 44.48; H, 3.58; N, 4.63. Mp: 115 °C. Molar conductivity (acetone): 135.6 Ω^{-1} cm^2 mol^{-1}. MS (FAB positive) *m*/*z* 453 ([M^+]). ^1H NMR (CD_3-$COCD_3$, 500 MHz; multiplicity, coupling constants in Hz, Figure 1 for atom labeling): H_2: 6.04 (d, 5.5); H_3: 4.65 (dt, 5.5; 3.0); $H_{3'}$: 4.19 (dt, 12.0; 4.0) and 4.08 (ddd, 12; 6.5; 3); H_{anti}: 3.60 (d, 12.0) and 3.58 (d, 12.0); H_{syn}: 4.26 (m); $H_{central}$: 6.17 (ph, 12.0; 7.0); O*H*: 4.59 (bt, 6.0).

(η^3-2-Methylallyl)[(3′*S*,4′*S*)-8-(3′,4′-dihydro-3′-phenyl-4′-hydroxymethyl-2′-oxazolyl)quinoline-*N*,*N*]palladium-(II) Hexafluorophosphate, 2e. Starting materials: 0.150 g (0.38 mmol) of [Pd(η^3-2-Me−C_3H_4)(μ-Cl)]$_2$, 0.234 g (0.77 mmol) of **e**, and 0.196 g (1.20 mmol) of NH_4PF_6. Yield: 0.32 g (68%). IR (KBr): 1633 (st, C═N), 855 (st, P−F) cm^{-1}. Anal. Calcd for $C_{23}H_{23}F_6N_2O_2PPd$: C, 45.23; H, 3.79; N, 4.59. No reproducible analytical data were obtained. Mp: 220 °C. Molar conductivity (acetone): 102.3 Ω^{-1} cm^2 mol^{-1}. MS (FAB positive): *m*/*z* 465 ([M^+]). ^1H NMR (CD_3COCD_3, 500 MHz; multiplicity, coupling constants in Hz, Figure 1 for atom labeling): H_2: 5.98 (bs); H_3: 4.45 (bs); $H_{3'}$: 3.94 (m); H_{anti}: 3.27 (s) and 3.25 (s); H_{syn}: 3.84 (s) and 3.81 (s); $Me_{central}$: 2.12 (s); O*H*: 4.15 (bs).

(η^3-Cyclohexenylallyl)[(3′*S*,4′*S*)-8-(3′,4′-dihydro-3′-phenyl-4′-hydroxymethyl-2′-oxazolyl)quinoline-*N*,*N*]palladium-(II) Hexafluorophosphate, 5e. Starting materials: 0.100 g

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(0.22 mmol) of $[Pd(\eta^3\text{-}C_6H_9)(\mu\text{-}Cl)]_2$, 0.136 g (0.44 mmol) of **e**, and 0.109 g (0.66 mmol) of NH_4PF_6. Yield: 0.13 g (53%). IR (KBr): 1637 (st, C═N), 843 (st, P−F) cm^{-1}. Anal. Calcd for $C_{25}H_{25}F_6N_2O_2PPd$: C, 47.15; H, 3.96; N, 4.40. Found: C, 46.40; H, 4.16; N, 4.09. Mp (decomposition): 125 °C. Molar conductivity (acetone): 122.8 Ω^{-1} cm^2 mol^{-1}. MS (FAB positive): *m/z* 492 ($[M^+]$).

(η^3-2-Methylallyl)[(4′*R*)-8-(3′,4′-dihydro-4′-benzyl-2′-oxazolyl)quinoline-*N,N*]palladium(II) Hexafluorophosphate, 2g. Starting materials: 0.150 g (0.38 mmol) of $[Pd(\eta^3\text{-}2\text{-}Me{-}C_3H_4)(\mu\text{-}Cl)]_2$, 0.224 g (0.77 mmol) of **g**, and 0.193 g (1.19 mmol) of NH_4PF_6. Yield: 0.218 g (47%). IR (KBr): 1640 (st, C═N), 838 (st, P−F) cm^{-1}. Anal. Calcd for $C_{23}H_{23}F_6N_2OPPd$: C, 46.44; H, 3.90; N, 4.71. Found: C, 46.2; H, 3.9; N, 4.7. Mp: 170 °C. MS (FAB positive): *m/z* 450 ($[M^+]$). ^1H NMR (CD_3COCD_3, 500 MHz; multiplicity, coupling constants in Hz, Figure 1 for atom labeling): H_2: 4.66 (dd, 17; 9) and 4.63 (dd 14, 9); H_3: 4.85 (m); $H_{3'}$: 3.10 (t, 7); H_{anti}: 3.21 (bs); H_{syn}: 3.85 (bs); $Me_{central}$: 2.73 (s).

Bis(η^3-allyl)-[(4"*S*)-1,4-bis(2′-(4"-isopropyl-3",4"-dihydro-2″-oxazolyl)phenyl)piperazine-*N,N*]dipalladium(II) Bishexafluorophosphate, 1h. Starting materials: 0.151 g (0.41 mmol) of $[Pd(\eta^3\text{-}C_3H_5)(\mu\text{-}Cl)]_2$, 0.191 g (0.41 mmol) of **h**, and 0.199 g (1.22 mmol) of NH_4PF_6. Yield: 0.320 g (74.7%). IR (KBr): 1644 (st, C═N), 847 (st, P−F) cm^{-1}. Anal. Calcd for $C_{34}H_{46}F_{12}N_4O_2P_2Pd_2$: C, 39.06; H, 4.43; N, 5.36. Found: C, 40.53; H, 4.64; N, 5.55. Mp: 241.3 °C. Molar conductivity (dichlorometane): 200.4 Ω^{-1} cm^2 mol^{-1}. MS (FAB positive): *m/z* 842 ($[M - PF_6^+] - 2CH_3$). ^1H NMR (CD_3COCD_3, 500 MHz; multiplicity, coupling constants in Hz, Figure 1 for atom labeling): H_2: 4.67 (t, 10.0) and 4.51 (t, 8.0); H_3: 4.34 (bs); $H_{3'}$: 2.20 (bs); H_{anti}: 2.96 (d, 11.0) and 2.74 (bs); H_{syn}: 3.87 (bs) and 3.78 (bs); $H_{central}$: 5.51 (bs); $CH(CH_3)_2$:1.08; 0.98 (d, 7.0); $CH(CH_3)_2$: 2.20 (bs); H_4: 3.78 (m) and 3.43 (m).

Bis(η^3-2-methylallyl)[1,4-bis(2′-(4″,4″-dimethyl-3″,4″-dihydro-2″-oxazolyl)phenyl)piperazine-*N,N*]dipalladium(II) Bishexafluorophosphate, 2i. Starting materials: 0.100 g (0.25 mmol) of $[Pd(\eta^3\text{-}2\text{-}Me{-}C_3H_4)(\mu\text{-}Cl)]_2$, 0.200 g (0.46 mmol) of **i** in 30 cm^3 of absolute ethanol, and 0.131 g (0.80 mmol) of NH_4PF_6. Yield: 0.136 g (51.2%). IR (KBr): 1647 (st, C═N), 842 (st, P−F) cm^{-1}. Anal. Calcd for $C_{34}H_{46}F_{12}N_4O_2P_2Pd_2$: C, 39.06; H, 4.43; N, 5.36. Found: C, 39.29; H, 4.70; N, 5.54. Mp: 237.5 °C. MS (FAB positive): *m/z* 361 ($[M^{2+}]/2$). ^1H NMR (CD_3COCD_3, 500 MHz; multiplicity, coupling constants in Hz, Figure 1 for atom labeling): H_2: 4.42 (s); H_{anti}: 2.91 (s); H_{syn}: 3.90 (s); $Me_{central}$: 2.11(s); R = R′ = Me: 1.43 (s); H_4: 3.4 (s).

(η^3-2-Methylallyl)[(3′*S*,4′*S*)-2-(3′,4′-dihydro-3′-phenyl-4′-hydroxymethyl-2′-oxazolyl)pyridine-*N,N*]palladium(II) Hexafluorophosphate, 2a. A 0.150 g sample of $[Pd(\eta^3\text{-}2\text{-}Me{-}C_3H_4)(\mu\text{-}Cl)]_2$ (0.38 mmol) and 0.194 g of **a** (0.76 mmol) were dissolved in 40 cm^3 of absolute ethanol. The mixture was stirred at room temperature for 20 min. A 0.192 g sample of NH_4PF_6 (1.18 mmol) was added, and the mixture was stirred for 1 day at room temperature. The solvent was removed under reduced pressure, and the residue was dissolved in 15 cm^3 of chloroform. Extractions with distilled water were done until neutral pH. Then, the organic phase was dried over anhydrous Na_2SO_4. After filtration, the solvent was removed under vaccuum, affording a white solid. Yield: 0.287 g (67%). IR (KBr): 1657 (st, C═N), 841 (st, P−F) cm^{-1}. Anal. Calcd for $C_{19}H_{21}F_6N_2O_2PPd$: C, 40.69; H, 3.77; N, 4.99. Found: C, 40.88; H, 3.79; N, 4.87. Mp: 169.1 °C. Molar conductivity (acetonitrile): 137.5 Ω^{-1} cm^2 mol^{-1}. MS (FAB positive): *m/z* 417 ($[M^+]$). ^1H NMR (CD_3COCD_3, 500 MHz; multiplicity, coupling constants in Hz, Figure 1 for atom labeling): H_2: 6.27(d, 7.0); H_3, O*H*: 4.55 (m); $H_{3'}$: 4.13 (dt, 12.4; 4.0) and 4.00 (ddd, 12; 7.5; 3); H_{anti}: 3.32 (s) and 3.31 (s); H_{syn}: 4.38 (s) and 4.36 (s); $Me_{central}$: 2.22 (s). In $CDCl_3$ H_{syn} protons appear as doublets with $J(H_{syn},H_{syn})$ = 2 Hz.

(η^3-1,3-Diphenylallyl)[(3′*S*,4′*S*)-8-(3′,4′-dihydro-3′-phenyl-4′-hydroxymethyl-2′-oxazolyl)quinoline-*N,N*]palladium-(II) Tetrafluoroborate, 3e. A 0.56 g sample of $[Pd(\eta^3\text{-}1,3\text{-}Ph_2{-}C_3H_3)(\mu\text{-}Cl)]_2$ (0.83 mmol) and 0.51 g (1.67 mmol) of **e** were dissolved in CH_2Cl_2/THF/MeOH, 48:40:40 (128 cm^3). The mixture was stirred at 50 °C overnight, cooled at room temperature, and treated with 0.33 g (1.7 mmol) of $AgBF_4$ for 2 h. The white precipitate was filtered. The solution was washed with a NaCl saturated solution (6 × 10 cm^3), and the organic layer dried over Na_2SO_4. The solvent was removed under reduced pressure, and after addition of ether an orange solid was obtained. Yield: 1.06 g (92%). IR (KBr): 1640 (st, C═N), 1096,1022 (st, B−F) cm^{-1}. Anal. Calcd for $C_{34}H_{29}F_4N_2O_2BPd$: C, 59.11; H, 4.23; N, 4.06. Found: C, 58.06; H, 4.82; N, 4.00. Mp: 122 °C. MS (FAB positive): *m/z* 603 ($[M]^+$).

(η^3-1,3-Diphenylallyl)[(3′*S*,4′*S*)-8-(3′,4′-dihydro-3′-phenyl-4′-*tert*-butyldiphenylsilyloxymethyl-2′-oxazolyl)quinoline-*N,N*]palladium(II) Hexafluorophosphate, 3f. A 0.130 g sample of $[Pd(\eta^3\text{-}1,3\text{-}Ph_2{-}C_3H_3)(\mu\text{-}Cl)]_2$ (0.20 mmol) and 0.132 g (0.40 mmol) of **f** were dissolved in CH_2Cl_2/THF/MeOH, 48:40:40 (128 cm^3). The mixture was stirred at 50 °C overnight, cooled at room temperature, and treated with 0.1 g (0.60 mmol) of NH_4PF_6 for 2 h. The solvent was evaporated and 10 cm^3 absolute ethanol added. A pale yellow precipitate was filtered, washed with distilled water (6 × 10 cm^3), and dried under reduced pressure. Yield: 0.09 g (20%). IR (KBr): 1637 (st, C═N), 841 (st, P−F) cm^{-1}. Anal. Calcd for $C_{50}H_{46}F_6N_2O_2PSiPd$: C, 60.88; H, 4.70; N, 2.84. Found: C, 59.8; H, 4.9; N, 2.8. Mp: 147 °C. Molar conductivity (acetone): 158 Ω^{-1} cm^2 mol^{-1}. MS (FAB positive): *m/z* 841 ($[M]^+$).

Crystallography. The crytallographic data for complex **1d** are summarized in Table 3. Crystals were obtained by slow diffusion of hexane over an acetone solution of the complex. A triangular plate crystal of **1d** was selected and mounted on a Philips PW-1100 four-cycle diffractometer. Unit cell parameters were determined from automatic centering of 25 reflections ($2° < \theta < 45°$) and refined by the least-squares method. Intensities were collected with graphite-monochromatized Cu Kα radiation, using the ω-2θ scan technique. A total of 2860 observed reflections were measured in the range $2° < \theta < 65°$ applying the condition $I > 2\sigma(I)$. Lorentz−polarization and absorption corrections were applied. The structure was solved by Patterson synthesis, using the XTAL3.2 computer programs[55] for crystal structure determination and refined by the full-matrix least-squares method. The extinction coefficient was 0.64(5) × 10^4. An individual isotropic model was used for all the H atoms, but six H atoms was kept fixed in the refinement. The absolute structure of the crystal used for the investigation was established as described by H. D. Flack.[56] The final *R* (on *F*) factor was 0.046, the R_w factor was 0.056, and the goodness of fit was 1.320 for all observed reflections. The number of refined parameters was 147. Maximum and minimum peaks in final difference synthesis were 0.92 and −0.68 e Å^3, respectively.

General Procedure for Palladium-Catalyzed Allylic Alkylation. The ligand (2.5 mol % for **a**−**g** and 1.25 mol % for **h**) and $[Pd(\eta^3\text{-}C_3H_5)(\mu\text{-}Cl)]_2$ (1 mol %) were dissolved in 2 cm^3 of CH_2Cl_2. *rac*-3-Acetoxy-1,3-diphenyl-1-propene (**I**) or (*E*)-3-acetoxy-1-phenyl-1-propene (**III**) (1 equiv), dissolved in 2 cm^3 of CH_2Cl_2, was added followed by dimethyl malonate (3 equiv), BSA (3 equiv), and a catalytic amount of KOAc. The mixture was stirred at room temperature until total comsumption of substrate (monitored by TLC; eluent hexane/ethyl acetate, 3:1). Then, the solution was diluted with diethyl ether (10 cm^3), filtered over Celite, and washed with water (4 × 10 cm^3). The organic phase was dried over anhydrous Na_2SO_4 and filtered off, and solvent was removed under reduced pressure. Puri-

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fication of the product was done by column chromatography (SiO_2; ethyl acetate), followed by heating treatment at 130 °C under vacuum. Yields: 75−95%. The enantiomeric excesses for **II** were determined by HPLC on a Chiralcel OD column, using hexane/*i*-PrOH, 99:1, as eluent, in a flow of 0.5 mL/min and a pressure of 14 bar.

Allylic alkylations with *rac*-3-acetoxy-1-cyclohexene followed the same procedure. The reactions were monitored by TLC, being the eluent hexane/ethyl acetate, 4:1. The enantiomeric excesses for **VII** were determined by GC on a Hewlett-Packard 5890 Series II gas chromatograph (25-m FS-cyclodex-*β*-I/P column, at 100 °C) with a flame ionization detector.

General Procedure for Palladium-Catalyzed Allylic Amination. The precursor (3 mol % of **1a**, **1d**, or **1e**) was dissolved in 2 cm^3 of THF, and then, *rac*-3-acetoxy-1,3-diphenyl-1-propene (**I**) (1 equiv), dissolved in 2 cm^3 of THF, was added, followed by benzylamine (3 equiv). The mixture was stirred at reflux for 72 h. Then, the solution was diluted with diethyl ether (10 cm^3), filtered over Celite, and washed with water (3 × 10 cm^3). The organic phase was dried over anhydrous Na_2SO_4 and filtered off, and solvent was removed under reduced pressure. Purification of the product was done by column chromatography (SiO_2; ethyl acetate). The enantiomeric excesses for **VIII** were determined by HPLC on a Chiracel OD column, using hexane/*i*-PrOH, 99:1, as eluent, in a flow of 1 mL/min and a pressure of 24 bar.

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Supporting Information Available: Crystallographic data for **1d**. This material is available free of charge via the Internet at http://pubs.acs.org.

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