DOI: 10.1002/ejic.201000718

Imidazolium-Oxazoline Salts in Ruthenium-Catalyzed Allylic Substitution and Cross Metathesis of Formed Branched Isomers

Hamed Ben Ammar,[a] Bechir Ben Hassine,[b] Cédric Fischmeister,[c] Pierre H. Dixneuf,[c] and Christian Bruneau*[c]

Keywords: Carbene ligands / Allylic substitution / Homogeneous catalysis / Nitrogen heterocycles

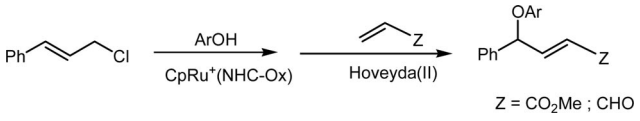
Imidazolium-oxazoline chlorides have been prepared from chloroacetonitrile and used to generate bidentate mixed NHC-oxazoline ligands for ruthenium-catalyzed substitution of cinnamyl chloride by phenols. These ligands associated to $[RuCp^*(MeCN)_3][PF_6]$ promote allylic substitution reactions at room temperature with high regioselectivity in favour of the branched isomers giving terminal alkenes. These allylic ethers have been involved in further ruthenium-catalyzed cross metathesis reactions with electron-deficient olefins to give unsaturated esters and aldehydes.

Introduction

Metal-catalyzed allylic substitution is recognized as a useful method in organic synthesis for C–C and C–heteroatom bond forming reactions.[1] In this context, the control of regioselectivity is of crucial importance as a way to generate functional alkenes. When unsymmetrical allylic derivatives are used, the formation of the branched isomers generates terminal alkenes that are useful not only for access to chiral compounds,[1] but because of the control of catalytic olefin cross metathesis,[2] they now also offer potential for sequential catalysis: allylation/cross metathesis. This sequence has not been explored, whereas the reverse tandem catalytic metathesis/allylation has been described.[3] For the nucleophilic allylic substitution, pentamethylcyclopentadienyl ruthenium catalysts have disclosed promising properties with respect to regioselectivity in favour of the branched isomer.[4] $[RuCp^*(MeCN)_3][PF_6]$ bearing labile acetonitrile ligands was shown to be appropriate for the synthesis of aryl allyl ethers starting from allylic halides and phenols.[5] Other ruthenium catalysts developed by Pregosin,[6a] Lacour[6b] and Onitsuka[6c] have also shown very high regioselectivity in favour of the branched isomers during allylation of phenols. Recently, we have explored the influence of symmetrical bis(imine)s and bipyridines,[7] and unsymmetrical 2-quinolinecarboxylate[8a,8b] and phosphanylsulfonate[8c] chelating ligands, which have led to new Cp*Ru catalysts with diverse catalytic properties in allylation reactions. N-heterocyclic carbenes (NHCs)[9] and oxazoline-containing ligands[10] have also attracted considerable attention for the preparation of transition-metal catalysts.

Bidentate mixed oxazoline-NHC ligands, in which the 2-oxazolyl group is connected to a nitrogen atom of the NHC either directly,[11] or through a methylene[12] or an ethylidene[13] bridge have been prepared and coordinated to metal centres such as palladium, iridium and rhodium to generate catalysts for hydrogenation or hydrosilylation.[13] Monodentate and polydentate NHC ligands associated to a Cp*Ru centre have been shown to favour the formation of the branched isomer to achieve regioselective nucleophilic allylic substitution by phenols.[14] However, unsymmetrical oxazoline-carbene ligands have never been evaluated in the ruthenium-catalyzed nucleophilic allylic substitution.

We now report (1) the preparation from chloroacetonitrile of imidazolium-oxazoline salts, precursors of NHC-oxazoline ligands, (2) their first association to the RuCp* moiety for the catalytic regioselective allylic substitution of allylic chlorides by phenols, leading to the preferential formation of branched isomers and (3) that the latter lead to unsaturated esters and aldehydes by ruthenium-catalyzed cross-metathesis [Equation (1)].



(1)

Results and Discussion

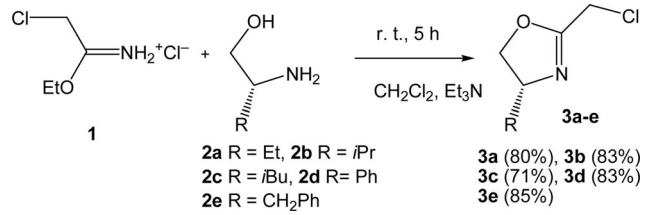
Several routes for the preparation of imidazolium-oxazoline salts have already been reported, either based on the

[a] Laboratoire de Chimie Organique Appliquée, (99 UR 12-13), Faculté des Sciences de Gabès, 6072 Gabès, Tunisie
[b] Laboratoire de Synthèse Organique Asymétrique et Catalyse Homogène (01 UR 1201), département de chimie, Faculté des Sciences de Monastir, avenue de l'Environnement, 5019 Monastir, Tunisie
[c] UMR 6226: CNRS-Université de Rennes 1, Sciences Chimiques de Rennes, Catalyse et Organométalliques, Campus de Beaulieu, 35042 Rennes, France
E-mail: christian.bruneau@univ-rennes1.fr

View this journal online at wileyonlinelibrary.com

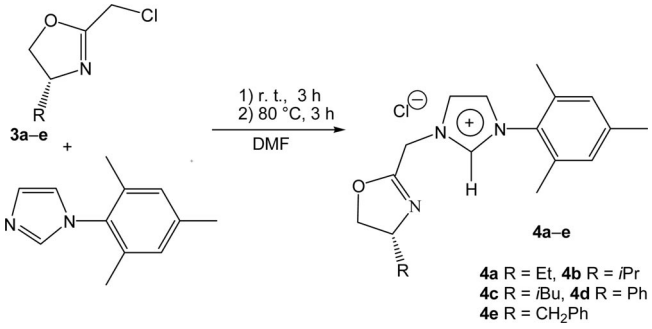
 © 2010 Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim

initial condensation of an imidazole with chloroacetonitrile to give a cyanomethylimidazolium salt, followed by the formation of an imidoester-substituted imidazolium salt and coupling with an α-amino alcohol to form the oxazoline ring,[12a] or the condensation of *N*-chloromethyloxazolines with an imidazole.[12b,12c] We prepared *N*-chloromethyloxazolines[15] according to a straightforward method from chloroacetonitrile by initially synthesizing ethyl chloroacetamidate hydrochloride **1** upon treatment of chloroacetonitrile with ethanol in the presence of gaseous HCl in diethyl ether. The white crystalline solid **1** was obtained in 80% yield. Without further purification, this salt was condensed with an α-amino alcohol **2a**–**e** at room temperature in dichloromethane in the presence of triethylamine to form 2-chloromethyloxazolines **3a**–**e** in good yields around 80% (Scheme 1).[16]



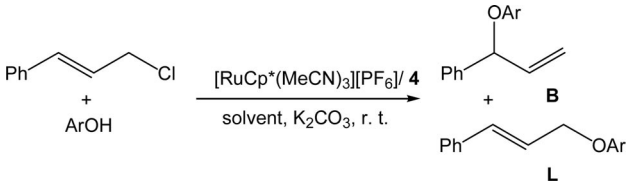
Scheme 1.

Chloromethyloxazolines **3a**–**e** were treated with mesitylimidazole in dimethylformamide (DMF) at room temperature for 3 h and then heated at 80 °C for additional 3 h (Scheme 2). The flexible imidazolium-oxazoline chlorides **4a**–**e** containing a methylene bridge were isolated in an average 85% yield. In NMR spectroscopic analysis, they all show a NCHN proton singlet at δ = 10.4–10.7 ppm and a ^{13}C NMR signal at 161–162 ppm consistent with an imidazolium salt.



Scheme 2.

Whereas oxazoline-imidazolylidene ligands with a methylene bridge have been introduced in catalysis[17] for iridium-catalyzed hydrogenation of olefins[12b] and rhodium-catalyzed hydrosilylation of ketones,[12c] we explored for the first time their efficiency in allylic substitution by their association to a ruthenium catalyst. As 2-imidazolylidene NHCs are formed upon treatment of imidazolium salts in the presence of a base,[18] oxazoline-imidazolium salts **4a**–**e** were directly used to generate new catalysts in association with $[RuCp^*(MeCN)_3][PF_6]$. The following protocol was used to generate in situ bidentate oxazoline-NHC ruthenium species and to evaluate their catalytic activity in the nucleophilic allylic substitution of cinnamyl chloride by phenol (Scheme 3). Imidazolium-oxazoline salt **4a**–**e** was first treated with 1 equiv. of *t*BuOK in 5 mL of THF at 50 °C for 2 h and then 1 equiv. of $[RuCp^*(MeCN)_3][PF_6]$ was added to the solution at 50 °C to generate the catalyst. To the crude ruthenium catalyst in acetonitrile or THF, 1.2 mmol of potassium carbonate, 1.2 mmol of phenol and 1.0 mmol of cinnamyl chloride were successively added. These catalysts appear to be efficient in allylation as in each case, after 16 h reaction time at room temperature, the conversion of cinnamyl chloride was complete, and the **B** isomer was formed as the major product. The results are shown in Table 1 (entries 1–4).



Scheme 3.

Table 1. Allylation of phenols with cinnamyl chloride in the presence of $[RuCp^*(MeCN)_3][PF_6]$/**4**.[a]

Entry	Ligand precursor	ArOH	Solvent	**B**/**L** ratio[b]
1	**4a**	phenol	MeCN	82:18
2	**4b**	phenol	MeCN	94:6
3	**4d**	phenol	MeCN	71:29
4	**4e**	phenol	MeCN	83:17
5	**4d**	phenol	CH_2Cl_2	89:11
6	**4d**	phenol	THF	86:14
7	**4a**	*p*-cresol	MeCN	80:20
8	**4b**	*p*-cresol	MeCN	50:50
9	**4d**	*p*-cresol	THF	83:17
10	**4a**	*m*-cresol	MeCN	53:47
11	**4b**	*m*-cresol	MeCN	60:40
12	**4d**	*m*-cresol	THF	78:22
13	**4a**	*o*-cresol	MeCN	54:46
14	**4d**	*o*-cresol	THF	79:21

[a] Conditions: 1.2 mmol of ArOH, 1.2 mmol of K_2CO_3, 1 mmol of cinnamyl chloride, 0.03 mmol based on ruthenium-(**3a**–**d**) catalyst in 5 mL of solvent at room temperature for 16 h. Complete conversion. [b] Branched/Linear (**B**/**L**) ratio determined by ^1H NMR spectroscopic analysis of the crude mixture.

A good selectivity in favour of the branched phenyl ether (**B**) with respect to the linear one (**L**) was obtained in the range 71:29 to 94:6, depending on the imidazolium-oxazoline salt precursor (Scheme 3). We could show that the catalyst arising from **4b** (R = *i*Pr) especially led to an excellent regioselectivity in acetonitrile (entry 2). The study of **4d** revealed that a solvent effect could slightly increase the **B**/**L** selectivity when dichloromethane or THF were used instead of acetonitrile (entries 3, 5, 6).

The scope of the reaction was then studied by investigating the reaction with substituted phenols including *o*, *m*, *p*-cresols. The catalyst arising from ligand **4d** gave the highest **B**/**L** ratio from substituted phenols (entries 9, 12, 14).

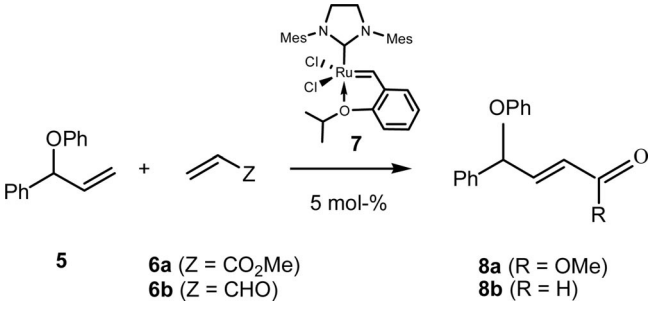
 © 2010 Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim

Thus, not only the catalyst is important in yielding the **B** isomer, but the nature of the nucleophile for a given ruthenium catalyst has a strong influence as well.

The association Cp*Ru/**4b** was the best system to reach the highest **B/L** ratio with phenol (entry 2), but it gave the lowest ratio with *p*-cresol (entry 8). These results indicate that the nature of the phenol has an extremely strong influence on the **B/L** ratio, as shown by a comparison of the results obtained with the **4b**-derived catalyst (entries 2, 8, 11), indicating that for a given nucleophile, several catalysts had to be evaluated, as the regioselectivity was very sensitive to both the nucleophile and the nature of the ligand (e.g. the nature of the R group on the oxazoline).

These results revealed that the catalytic behaviour of the imidazolylidene-oxazoline ligands generated according to the above-described protocol competed with that of simple mono-NHCs in terms of reactivity and regioselectivity.[14] On the other hand, the regioselectivities (**B/L** ratio) were much higher than the ones previously obtained by starting from symmetrical bis(oxazoline) ligands associated to the same precatalyst [RuCp*$(MeCN)_3$][PF_6].[19] Thus, the NHC character of these bidentate ligands is more determining than the oxazoline one for regioselectivity. Apparently, the strong σ-donor ability of the NHC ligand favours the regioselective formation of the branched isomer.

The determination of the enantiomeric excess of the branched ether corresponding to entry 6 gave 40% *ee*, which is in line with that obtained by using bis(oxazoline) ligands with only one substituent at C4.[19] This enantioselectivity does not compete with the excellent results obtained with planar-chiral cyclopentadienyl ruthenium catalysts[6c] and with iridium catalysts.[20] Catalyst **4b** appears to be the most useful catalyst to generate a high yield of the branched isomers **5** (Table 1, entry 2). This terminal olefin **5** was selected to study the initial conditions of catalytic cross metathesis with methyl acrylate, as the second step of sequential catalysis/allylation/cross metathesis (Scheme 4).



Scheme 4.

It was found that the reaction of allylic ether **5** (0.5 mmol) with 2 equiv. of methyl acrylate (**6a**) in toluene was better performed with the Hoveyda(II) catalyst **7** (5 mol-%). After 16 h at 80 °C, the conversion of **5** was completed, and only the unsaturated *trans*-ester **8a** was formed, which was isolated in 65% yield. Analogously, treating unsaturated ether **5** with 2 equiv. of acrolein (**6b**) in the presence of Hoveyda(II) catalyst **7** (5 mol-%) at 80 °C in toluene, but for only 6 h, led to complete reaction and the isolation of aldehyde **8b** in 63% yield.

Conclusion

We prepared imidazolium-oxazoline chloride salts and showed that their coordination as NHC-oxazoline to a RuCp* moiety led to efficient catalysts for the nucleophilic allylic substitution of cinnamyl chloride by phenols leading to high selectivity for the branched isomer. These easy-to-prepare new mixed oxazoline-NHC-ruthenium catalytic systems, especially **4b**, lead to a high yield of the branched allylic ether with phenol. The latter can be used to generate unsaturated esters and aldehydes by cross metathesis with Hoveyda(II) catalysis. These initial separate efficient catalytic transformations show that sequential catalysis, allylation and cross metathesis, are possible and these are under current investigation.

Experimental Section

^1H and ^{13}C NMR spectra were recorded with an AC 200 FT Bruker instrument (^1H: 200 MHz, ^{13}C: 50 MHz) and referenced internally to tetramethylsilane. Mass spectra were measured with a Micromass ZAB Spec-TOF spectrometer. All solvents were distilled according to usual methods, dichloromethane over CaH_2, ether and THF over sodium in the presence of benzophenone. Amino alcohols **2a**–**e** were prepared from the optically pure (*R*)-amino acids supplied by Acros Organics.

General Procedure for the Synthesis of 2-Chloromethyl-4,5-dihydrooxazole (3a–e): Into a Schlenk type flask equipped with a magnetic stirrer were successively added under a nitrogen atmosphere ethyl 2-chloroethanimidoate hydrochloride **1** (15.8 mmol), α-amino alcohol **2** (16 mmol) and triethylamine (20.54 mmol) in anhydrous dichloromethane (20 mL). The reaction mixture was stirred at room temperature for 5 h until complete conversion. The solid (NH_4Cl) was filtered off, and the organic phase was concentrated under vacuum to give a yellowish oil. The product was purified by chromatography over silica pretreated with triethylamine in heptane and eluted with a EtOAc/heptane (2.5:7.5) mixture.

2-Chloromethyl-(4*R*)-ethyl-4,5-dihydrooxazole (3a): Yield: 83%. ^1H NMR ($CDCl_3$, 200.13 MHz): δ = 0.98 (t, J = 7.4 Hz, 3 H, CH_3CH_2); 1.64 (m, 2 H, CH_2CH_3); 4.00 (dd, 1 H) and 4.45 (dd, 1 H) [$J = J'$ = 7.7 Hz, CH_2O]; 4.13 (s, 2 H, CH_2Cl); 4.13 (masked m, 1 H, CH-N) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 9.9, 28.4, 36.6, 67.9, 73.2, 162.5 ppm.

2-Chloromethyl-(4*R*)-isopropyl-4,5-dihydrooxazole (3b): Yield: 80%. ^1H NMR ($CDCl_3$, 200.13 MHz): δ = 0.83 (d, J = 6.7 Hz, 3 H, CH_3CH); 0.90 (d, J = 6.7 Hz, 3 H, CH_3CH); 1.69 (m, 1 H, $CHMe_2$); 3.88–4.00 (m, 2 H, CH-N, CH-O); 4.05 (s, 2 H, CH_2Cl); 4.29 (dd, J = 8.1, J' = 9.1 Hz, 1 H, CH-O) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 18.4, 18.9, 32.7, 36.7, 71.4, 72.7, 162.6 ppm.

2-Chloromethyl-(4*R*)-isobutyl-4,5-dihydrooxazole (3c): Yield: 71%. ^1H NMR ($CDCl_3$, 200.13 MHz): δ = 0.85 (d, J = 6.5 Hz, 3 H, CH_3CH); 0.88 (d, J = 6.5 Hz, 3 H, CH_3CH); 1.17–1.30 (m, 1 H, CH_2CHMe_2); 1.47–1.61 (m, 1 H, CH_2CHMe_2); 1.71 (m, 1 H, $CHMe_2$); 3.84 (dd, $J = J'$ = 7.9 Hz, 1 H, CH-O); 4.03 (s, 2 H, CH_2Cl); 4.13 (m, 1 H, CH-N); 4.38 (dd, $J = J'$ = 8.3 Hz, 1 H, CH-

 © 2010 Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim

O) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 22.9, 23.1, 25.7, 36.8, 45.5, 65.3, 74.4, 162.5 ppm.

2-Chloromethyl-(4*R*)-phenyl-4,5-dihydrooxazole (3d): Yield: 83%. ^1H NMR ($CDCl_3$, 200.13 MHz): δ = 4.25 (s, 2 H, CH_2-Cl masking CH-N, m); 4.76 and 5.29 (apparent triplet, J = 9.0 Hz, 1 H each, CH_a-O); 7.29–7.39 (m, 5 H, CH_{arom}) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 36.8, 70.2, 76.1, 127.0, 128.3, 129.3, 141.7, 164.2 ppm.

2-Chloromethyl-(4*R*)-benzyl-4,5-dihydrooxazole: (3e): Yield: 85%. ^1H NMR ($CDCl_3$, 200.13 MHz): δ = 2.73 and 3.14 (dd, J = 14.7, J' = 6.7 Hz, 1 H each, CH_2-Ph); 4.14 (s, 2 H, CH_2-Cl, masking 1 H of CH_2-0); 4.34 (apparent triplet, J = 9.3 Hz, 1 H, 1 H of CH_a-O); 4.49 (m, 1 H, C*H*-*N*); 7.24–7.37 (m, 5 H, CH_{arom}) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 36.8, 41.7, 67.9, 73.2, 127.1, 129.0, 129.7, 137.7, 163.5 ppm.

General Procedure for the Synthesis of Imidazolium Chlorides 4a–e: To a Schlenk flask equipped with a magnetic stirrer were successively added under a nitrogen atmosphere, 2,4,6-trimethylphenylimidazole (2.58 mmol), anhydrous DMF (3 mL) and 2-chloromethyl-4,5-dihydrooxazole (2.58 mmol). The reaction mixture was stirred at room temperature for 3 h and was heated at 80 °C for 3 h. After cooling at room temperature, dry Et_2O was added, and a white solid precipitated. The solid was washed with dry Et_2O and filtered, and the residue was dissolved in CH_2Cl_2 (3 mL). Dry Et_2O was added to the solution, and the solid immediately began to precipitate. The product was filtered and dried under vacuum.

1-{[(4*R*)-Ethyl-4,5-dihydro-1,3-oxazol-2-yl]methyl}-3-mesityl-1*H*-imidazol-3-ium Chloride (4a): Yield: 72%. ^1H NMR ($CDCl_3$, 200.13 MHz): δ = 0.92 (t, J = 7.1 Hz, 3 H, CH_3CH$_2$); 1.56 (m, 2 H, CH_2CH$_3$); 2.11 (s, 6 H, CH$_3$Mes); 2.36 (s, 3 H, CH$_3$Mes); 4.02 (m, 2 H, CH-N, CH-O); 4.45 (m, 1 H, CH-O); 5.84 (s, 2 H, NCH_2); 7.02 (s, 2 H, CH,Mes); 7.16 (s, 1 H, MesN-CH=CH-N); 7.83 (s, 1 H, MesN-CH=CH-N); 10.59 (s, 1 H, NCHN) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 10.5, 17.9, 21.5, 28.9, 46.9, 68.1, 74.2, 122.7, 124.1, 134.8, 140.5, 141.8, 130.2, 161.1 ppm. HRMS (ESI) calcd. for $C_{18}H_{24}N_3O^+$ [M]$^+$ 298.1919; found 298.1921.

1-{[(4*R*)-Isopropyl-4,5-dihydro-1,3-oxazol-2-yl]methyl}-3-mesityl-1*H*-imidazol-3-ium Chloride (4b): Yield: 78%. ^1H NMR ($CDCl_3$, 200.13 MHz): δ = 0.86 (t, J = 7.7 Hz, 3 H, CH_3CH); 0.90 (t, J = 7.7 Hz, 3 H, CH_3CH); 1.69 (m, 2 H, CHMe$_2$); 2.10 (s, 6 H, CH$_3$Mes); 2.36 (s, 3 H, CH$_3$Mes); 3.90 (m, 1 H, CH-N); 4.09 (apparent triplet, J = 8.4 Hz, 1 H, CH-O); 4.42 (apparent triplet, J = 9.4 Hz, 1 H, CH-O); 5.83 (s, 2 H, CH$_2$-N); 7.01 (s, 2 H, CHMes); 7.16 (s, 1 H) and 7.89 (s, 1 H) [MesN-CH=CH-N], 10.45 (s, 1 H, NCHN) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 17.9, 18.9, 19.2, 21.5, 33.2, 46.9, 72.6, 72.7, 122.7, 124.2, 131.1, 134.8, 140.4, 141.8, 130.2, 161.1 ppm. HRMS (ESI) calcd. for $C_{19}H_{26}N_3O^+$ [M]$^+$ 312.2076; found 312.2073.

1-{[(4*R*)-Isobutyl-4,5-dihydro-1,3-oxazol-2-yl]methyl}-3-mesityl-1*H*-imidazol-3-ium Chloride:(4c): Yield: 76%. ^1H NMR ($CDCl_3$, 200.13 MHz): δ = 0.93 (d, J = 6.5 Hz, 3 H); 0.94 (d, J = 6.5 Hz, 3 H); 1.30–1.80 (m, 3 H); 2.11 (s, 6 H); 2.37 (s, 3 H); 3.95 (m, 1 H); 4.16 (m, 1 H); 4.48 (apparent triplet, J = 8.0 Hz, 1 H); 5.84 (s, 2 H); 7.03 (s, 2 H); 7.13 (s, 1 H); 7.73 (s, 1 H); 10.69 (s, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 17.9, 21.51, 22.9, 23.2, 25.8, 45.5, 46.9, 65. 1, 74.9, 122.8, 124.5, 124.8, 130.2, 130.9, 131.1, 134.8, 140.2, 141.7, 143.9, 160.9 ppm.

1-{[(4*R*)-Phenyl-4,5-dihydro-1,3-oxazol-2-yl]methyl}-3-mesityl-1*H*-imidazol-3-ium Chloride (4d): Yield: 85%. ^1H NMR ($CDCl_3$, 200.13 MHz): δ = 2.07 (s, 6 H); 2.35 (s, 3 H); 4.22 (apparent triplet, J = 8.2 Hz, 1 H); 4.79 (dd, J = 9.3, J = 8.4 Hz, 1 H); 5.22 (t, J = 9.2 Hz, 1 H); 6.03 (s, 2 H); 7.00 (s, 2 H); 7.14 (s, 1 H); 7.22–7.40 (m, 5 H); 7.95 (s, 1 H); 10.64 (s, 1 H) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 17.8, 21.5, 46.8, 69.8, 76.5, 122.9, 124.9, 126.9, 129.1, 130.1, 128.1, 131.1, 134.7, 139.9, 141.4, 162.8 ppm. HRMS (ESI) calcd. for $C_{22}H_{24}N_3O^+$ [M]$^+$ 346.1919; found 346.1915.

1-{[(4*R*)-Benzyl-4,5-dihydro-1,3-oxazol-2-yl]methyl}-3-mesityl-1*H*-imidazol-3-ium Chloride (4e): Yield: 87%. ^1H NMR ($CDCl_3$, 200.13 MHz): δ = 2.08 (s, 6 H, CH_3Mes); 2.37 (s, 3 H, CH_3Mes); 2.72 (dd, J = 13.7, J = 6.0 Hz, 1 H, CH$_2$Ph); 2.96 (dd, J = 13.7, J = 5.4 Hz, 1 H, CH$_2$Ph); 4.12 (m, 1 H, C*H*-N); 4.38 (m, 2 H, CH_2-O); 5.81 and 5.89 (AB, J = 14.5 Hz, 2 H, CH_2-N); 7.03 (s, 2 H, C*H*-*Mes*); 7.13–7.29 (m, 6 H, Ph, N-CH=); 7.75 (s, 1 H, =C*H*-N); 10.52 (s, 1 H, NCHN) ppm. ^{13}C NMR ($CDCl_3$, 50 MHz): δ = 17.9, 21.5, 41.7, 46.7, 67.6, 73.8, 122.9, 124.8, 126.9, 129.6, 130.1, 128.8, 131.1, 134.7, 139.8, 141.6, 161.6 ppm. HRMS (ESI) calcd. for $C_{23}H_{26}N_3O^+$ [M]$^+$ 360.2076; found 360.2070.

General Procedure for the Catalytic Allylation Reaction: Into a Schlenk tube equipped with a magnetic stirring bar and under argon were introduced oxazoline–imidazolium salt (0.03 mmol) and *t*BuOK (0.03 mmol). The mixture was kept under vacuum for a few minutes and then under argon. Dry THF (5 mL) was added, and the mixture was stirred at 50 °C for 2 h. [Cp*Ru(MeCN)$_3$][PF_6] (0.03 mmol) was then introduced, and the reaction was run for 2 h under the same conditions. Then the solvent was removed under vacuum, CH_3CN (5 mL) was added, and then were added K_2CO_3 (1.2 mmol), cinnamyl chloride (1 mmol) and phenol (1.2 mmol). The reaction mixture was stirred at room temperature for 16 h. The solvent was evaporated, dichloromethane (10 mL) was added, and the resulting solution was filtered under argon. The solution was concentrated for fast chromatography on a column of silica (eluent: Et_2O/hexane = 1:9). The conversion and the **B**/**L** ratio of the products were determined by ^1H NMR spectroscopy.

General Procedure for Cross Metathesis of Allylic Ether 5: In a Schlenk tube were introduced **5** (105 mg, 0.5 mmol), acrylic derivatives **6a** and **6b** (2 equiv., 1 mmol), distilled toluene (5 mL) and then Hoveyda II catalyst **7** (15.5 mg, 5 mol-%). The mixture was heated at 80 °C for 16 h (**8a**) or 6 h (**8b**). The solution was quickly filtered on silica (in a Pasteur pipette). The solvent was removed under vacuum, and the product was chromatographed on silica gel, eluent: petroleum ether/diethyl ether (9:1). The solvent was evaporated to give a white solid for **8a** (66.5 mg, 65%) and a transparent oil for **8b** (56 mg, 63%).

Compound 8a: ^{1}HNMR (500.13 MHz. $CDCl_3$): δ = 3.68 (s, 3 H, OMe); 4.85 [dd, 1 H, J = 1.5 and 4.8 Hz, *CH*(OPh)]; 7.08 (dd, 1 H, J = 4.8 and 15.7 Hz, *CH*=CHCO$_2$Me); 6.89 (dd, 1 H, J = 1.5 and 15.7 Hz, =*CH*CO$_2$Me); 7.19 (m, 2 Harom); 7.27 (m, 1 Harom); 7.34 (m, 4 H) ppm. MS: *m*/*z* = 268.

Compound 8b: ^1H NMR (500.13 MHz. $CDCl_3$): δ = 5.86 [dd, J = 1.5 and 7.7 Hz, 1 H, *CH*(OPh)]; 6.42 (ddd, J = 1.5, 7.7, 15.5 Hz, 1 H, =CH); 6.88–6.96 (m, 4 H, =*CH*CHO, Harom); 7.20–7.24 (m, 2 H); 7.30–7.33 (m, 1 H): 7.36–7.40 (m, 4 H) ppm. ^{13}C NMR (75.46 MHz,$CDCl_3$): δ = 193.18 (CHO); 157.2 (*CH*=CHCHO); 154.5 (OCarom); 137.9 (=*CH*CHO); 131.2; 129.6; 129.1; 128.7; 126.7; 116.0; 78.8 (CHOPh) ppm. MS: *m*/*z* = 238.

Acknowledgments

The authors acknowledge Centre National de la Recherche Scientifique (CNRS) and DGRSRT (project SC17802) for financial support.

 © 2010 Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim

[1] a) J. Tsuji in *Transition Metal Reagents and Catalysts. Innovations in Organic Synthesis*, Wiley, Chichester, **2000**, p 109; b) Z. Lu, S. Ma, *Angew. Chem. Int. Ed.* **2008**, *47*, 258–297; c) B. M. Trost, D. L. van Vranken, *Chem. Rev.* **1996**, *96*, 395–422; d) G. Helmchen, A. Pfaltz, *Acc. Chem. Res.* **2000**, *33*, 336–345.

[2] a) A. K. Chatterjee, "Olefin Cross-Metathesis" in *Handbook of Metathesis* (Ed.: R. H. Grubbs), Wiley, Weinheim, **2003**, pp. 246–295; b) A. K. Chatterjee, T.-L. Choi, D. P. Sanders, R. H. Grubbs, *J. Am. Chem. Soc.* **2003**, *125*, 11360–11370; c) L. Ferrié, S. Bouzbouz, J. Cossy, *Org. Lett.* **2009**, *11*, 5446–5448.

[3] a) M. Achard, N. Derrien, H.-J. Zhang, B. Demerseman, C. Bruneau, *Org. Lett.* **2009**, *11*, 185–188; b) S. C. Schürer, S. Blechert, *Synlett* **1998**, 1666–168.

[4] For recent reviews see: a) T. Kondo, T. Mitsudo, *Curr. Org. Chem.* **2002**, *6*, 1163–1179; b) J.-L. Renaud, C. Bruneau, B. Demerseman, M. D. Mbaye, *Curr. Org. Chem.* **2006**, *10*, 115–133; c) C. Bruneau, J.-L. Renaud, B. Demerseman, *Chem. Eur. J.* **2006**, *12*, 5178–5187; d) M. Austeri, F. Buron, S. Constant, J. Lacour, D. Linder, J. Müller, S. Tortoioli, *Pure Appl. Chem.* **2008**, *80*, 967–977.

[5] a) B. M. Trost, P. L. Fraisse, Z. T. Ball, *Angew. Chem. Int. Ed.* **2002**, *41*, 1059–1061; b) M. D. Mbaye, B. Demerseman, J.-L. Renaud, L. Toupet, C. Bruneau, *Adv. Synth. Catal.* **2004**, *346*, 835–841.

[6] a) R. Hermatschweiler, I. Fernandez, P. Pregosin, F. Breher, *Organometallics* **2006**, *25*, 1440–1447; b) M. Austeri, D. Linder, J. Lacour, *Chem. Eur. J.* **2008**, *14*, 5737–5741; c) K. Onitsuka, H. Okuda, H. Sasai, *Angew. Chem. Int. Ed.* **2008**, *47*, 1454–1457.

[7] a) M. D. Mbaye, B. Demerseman, J.-L. Renaud, C. Bruneau, *J. Organomet. Chem.* **2005**, *690*, 2149–2158; b) M. D. Mbaye, B. Demerseman, J.-L. Renaud, L. Toupet, C. Bruneau, *Angew. Chem. Int. Ed.* **2003**, *42*, 5066–5068.

[8] a) H.-J. Zhang, B. Demerseman, L. Toupet, Z. Xi, C. Bruneau, *Adv. Synth. Catal.* **2008**, *350*, 1601–1609; b) H.-J. Zhang, B. Demerseman, L. Toupet, Z. Xi, C. Bruneau, *Organometallics* **2009**, *28*, 5173–5182; c) B. Sundararaju, M. Achard, B. Demerseman, L. Toupet, G. V. M. Sharma, C. Bruneau, *Angew. Chem. Int. Ed.* **2010**, *49*, 2782–2785.

[9] Reviews on NHC-metal catalysts: a) *Top. Organomet. Chem.: N-Heterocyclic Carbenes in Transition Metal Catalysis* (Ed.: F. Glorius), Springer, Heidelberg, **2007**, vol. 21; b) S. P. Nolan (Ed.), *N-Heterocyclic Carbenes in Synthesis*, Wiley, Weinheim, **2006**.

[10] For reviews on oxazolines in catalysis see: a) H. A. McManus, P. J. Guiry, *Chem. Rev.* **2004**, *104*, 4151–4202; b) **G. C**. Hargaden, P. J. Guiry, *Chem. Rev.* **2009**, *109*, 2505–2550.

[11] a) V. César, S. Bellemin-Laponnaz, L. H. Gade, *Organometallics* **2002**, *21*, 5204–5208; b) V. César, S. Bellemin-Laponnaz, L. H. Gade, *Angew. Chem. Int. Ed.* **2004**, *43*, 1014–1017; c) V. César, S. Bellemin-Laponnaz, H. Wadepohl, L. H. Gade, *Chem. Eur. J.* **2005**, *11*, 2862–2873.

[12] a) W. A. Herrmann, L. J. Goossen, M. Spiegel, *Organometallics* **1998**, *17*, 2162–2168; b) S. Nanchen, A. Pfaltz, *Chem. Eur. J.* **2006**, *12*, 4550–4558; c) N. Schneider, M. Kruck, S. Bellemin-Laponnaz, H. Wadepohl, L. H. Gade, *Eur. J. Inorg. Chem.* **2009**, 493–500.

[13] a) Y. Fan, X. Cui, K. Burgess, M. B. Hall, *J. Am. Chem. Soc.* **2004**, *126*, 16688–16689; b) X. Cui, J. W. Ogle, K. Burgess, *Chem. Commun.* **2005**, 672–674.

[14] a) N. Gürbüz, I. Özdemir, B. Cetinkaya, J.-L. Renaud, B. Demerseman, C. Bruneau, *Tetrahedron Lett.* **2006**, *47*, 535–538; b) S. Yasar, I. Özdemir, B. Cetinkaya, J.-L. Renaud, C. Bruneau, *Eur. J. Org. Chem.* **2008**, 2142–2149; c) N. Gürbüz, S. Demir, I. Özdemir, B. Cetinkaya, C. Bruneau, *Tetrahedron* **2010**, *66*, 1346–1351.

[15] a) G. Guillemot, M. Neuburger, A. Pfaltz, *Chem. Eur. J.* **2007**, *13*, 8960–8970; b) M. R. Stilling, A. P. Welbourn, D. S. Walter, *J. Med. Chem.* **1986**, *29*, 2280–2284; c) K. Kamata, H. Sato, E. Yakagi, I. Agata, A. I. Meyers, *Heterocycles* **1999**, *51*, 373–378; d) Z.-L. Shang, Z.-C. Shang, Q.-S. Yu, *Synth. Commun.* **2002**, *32*, 3461–3464.

[16] Compounds **3b** and **3d** have already been reported, but using orthochloroacetate[15d] or chloroacetyl chloride[15a] instead of chloroacetonitrile as precursor.

[17] L. H. Gade, S. Bellemin-Laponnaz, *Coord. Chem. Rev.* **2007**, *251*, 718–725.

[18] E. Peris, *Top. Organomet. Chem.* **2007**, *21*, 83–116.

[19] The **B/L** ratio observed for the substitution of cinnamyl chloride by phenol in acetonitrile with a RuCp*{bis(oxazoline)} catalyst was about 2–3:1. See M. D. Mbaye, J.-L. Renaud, B. Demerseman, C. Bruneau, *Chem. Commun.* **2004**, 1870–1871.

[20] a) G. Helmchen, A. Dahnz, P. Dübon, M. Schelwies, R. Weihofen, *Chem. Commun.* **2007**, 675–691; b) S. Ueno, J. F. Hartwig, *Angew. Chem. Int. Ed.* **2008**, *47*, 1928–1931.

Received: June 30, 2010
Published Online: September 20, 2010

 © 2010 Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim