A New Preparation of Optically Active *N*-Acyloxazolidinones via Ruthenium-Catalyzed Enantioselective Hydrogenation

Pierre Le Gendre, Patrice Thominot, Christian Bruneau,* and Pierre H. Dixneuf*

Lab de Chim de Coord et Catalyse, UMR 6509, Campus de Beaulieu, Universite de Rennes I, 35042 Rennes Cedex, France

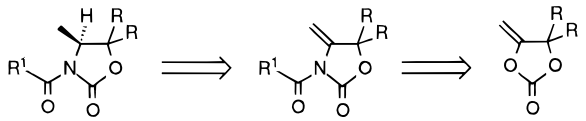
Received July 16, 1997

α-Methylene-*N*-acyloxazolidinones are readily prepared in three steps from propargylic alcohols *via* cyclic carbonates, and the enantioselective hydrogenation of the latter catalyzed by chiral (diphosphine)ruthenium complexes makes possible the obtention of both enantiomers of optically active *N*-acyloxazolidinones with very high enantioselectivities.

Optically active *N*-acyloxazolidinones are powerful chiral auxiliaries with widespread uses for the synthesis of optically active molecules.[1,2] Their efficiency is due to the fact that their deprotonation at the α-carbon of the *N*-acyl group gives a (*Z*)-enolate with high stereoselectivity and that the reaction of the latter with a variety of electrophiles leads to stereoselective C−C bond formation via alkylation,[3] acylation[4] and aldol reaction,[5] or C-heteroatom bond formation via halogenation,[6] sulfenylation,[7] oxygenation,[8] and amination.[9] When the acyl group contains a conjugated double bond, stereoselective Diels−Alder cycloaddition[10] and Michael addition[11] can be performed. The strength of *N*-acyloxazolidones is that their chiral oxazolidinone structure, which carries the stereochemical information, can be easily recovered and reused.

Optically active oxazolidinones are usually prepared from optically active natural compound derivatives or bifunctional substrates. Natural amino acids are substrates of choice for the access to amino alcohols which react with phosgene derivatives to give optically active oxazolidinones.[12,13] Other synthetic processes mainly involve epoxides generated via Sharpless epoxidation of allylic alcohols[14] or *β*-functionalized alcohols such as diols,[15,16] hydroxy azides,[17] and hydroxy esters.[18]

Scheme 1



We report here a novel route to both enantiomers of optically active *N*-acyloxazolidinones with very high optical purity, based on the enantioselective hydrogenation of *N*-acyl-4-methylene-1,3-oxazolidin-2-ones catalyzed by chiral ruthenium complexes (Scheme 1).

Results and Discussion

Preparation of the *N*-Acyl-4-methylene-1,3-oxazolidin-2-ones. The unsaturated cyclic carbonates **1**, **2** can be selectively prepared from prop-2-yn-1-ols by catalytic reaction with carbon dioxide,[19] and it is known that they readily react with primary amines to generate oxazoli-

(1) (a) Evans, D. A.; Bartroli, J.; Shih, T. L. *J. Am. Chem. Soc.* **1981**, *103*, 2127. (b) Evans, D. A.; Takacs, J. M., McGee, L. R.; Ennis, M. D.; Mathre, D. J.; Bartroli, J. *Pure Appl. Chem.* **1981**, *53*, 1109. (c) Evans, D. A. *Aldrichimica Acta* **1982**, *15*, 23. (d) Swern, D.; Dyen, M. E. *Chem. Rev. (Washington, D.C.)* **1967**, *67*, 197.

(2) Ager, D. J.; Prakash, I.; Schaad, D. R. *Chem. Rev. (Washington, D.C.)* **1996**, *96*, 835.

(3) (a) Fadel, A. *Synlett* **1992**, 48. (b) Koch, S. S.; Chamberlin, A. R. *J. Org. Chem.* **1993**, *58*, 2725. (c) Evans, D. A.; Bilodeau, M. T.; Somers, T. C.; Clardy, J.; Cherry, D.; Kato, Y. *J. Org. Chem.* **1991**, *56*, 5750. (d) Kanno, H.; Osamai, K. *Tetrahedron Lett.* **1995**, *36*, 5375.

(4) (a) Evans, D. A.; Urpi, F.; Somers, T. C.; Clark, J. S.; Bilodeau, M. T. *J. Am. Chem. Soc.* **1990**, *112*, 8215. (b) Evans, D. A.; Ennis, M. D.; Le, T.; Mandel, N.; Mandel, G. *J. Am. Chem. Soc.* **1984**, *106*, 1154.

(5) (a) Shirodkar, S.; Nerz-Stormes, M.; Thornton, E. R. *Tetrahedron Lett.* **1990**, *31*, 4699. (b) Evans, D. A.; Bartroli, J. *Tetrahedron Lett.* **1982**, *23*, 807.

(6) Evans, D. A.; Britton, T. C.; Ellman, J. A.; Dorow, R. L. *J. Am. Chem. Soc.* **1990**, *112*, 4011.

(7) Chibale, K.; Warren, S. *Tetrahedron Lett.* **1994**, *35*, 3991.

(8) (a) Evans, D. A.; Gage, J. R. *J. Org. Chem.* **1992**, *57*, 1958.

(9) (a) Evans, D. A.; Britton, T. C.; Dorow, R. L.; Dellaria, J. F. *J. Am. Chem. Soc.* **1986**, *108*, 6395. (b) Trimble, L. A.; Vederas, C. J. *J. Am. Chem. Soc.* **1986**, *108*, 6397. (c) Evans, D. A.; Britton, T. C. *J. Am. Chem. Soc.* **1987**, *109*, 6881. (d) Harris, J. M.; Bolessa, A. E.; Mendonca, A. J.; Feng, S. C.; Verderas, J. C. *J. Chem. Soc., Perkin Trans. 1* **1995**, 1945.

(10) (a) Evans, D. A.; Chapman, K. T.; Bisaha, J. *J. Am. Chem. Soc.* **1988**, *110*, 1238. (b) Sugahara, T.; Iwata, T.; Yamaoka, M.; Takano, S. *Tetrahedron Lett.* **1989**, *30*, 1821.

(11) (a) Kakamura, T.; Hashimoto, N.; Ishizuka, T.; Kunieda, T. *Tetrahedron Lett.* **1997**, *38*, 559. (b) Wu, M. J.; Yeh, J. Y. *Tetrahedron Lett.* **1994**, *50*, 1073.

(12) Davies, S. G.; Polywka, M. E. C.; Sanganee, H. J. *Int. Appl.* WO 95/18112, 1995.

(13) (a) Nicolas, E.; Russel, K. C.; Hruby, V. J. *J. Org. Chem.* **1993**, *58*, 766. (b) Wuts, P. G. M.; Pruitt, L. E. *Synthesis* **1989**, 622. (c) Yan, T. H.; Chu, V. V.; Lin, T. C.; Wu, C. H.; Liu, L. H. *Tetrahedron Lett.* **1991**, *32*, 4959. (d) Kubota, Y.; Kodaka, M.; Tomohiro, T.; Okuno, H. *J. Chem. Soc., Perkin Trans. 1* **1993**, 5. (e) Imada, Y.; Mitsue, Y.; Ike, K.; Washizuka, K. I.; Murahashi, S. I. *Bull. Chem. Soc. Jpn.* **1996**, *69*, 2079. (f) Sakaitani, M.; Ohfune, Y. *J. Am. Chem. Soc.* **1990**, *112*, 1150.

(14) (a) Juliana, R.; Herzig, T.; Bernet, B.; Vasella, A. *Helv. Chim. Acta* **1986**, *69*, 368. (b) Rama Rao, A. V.; Dhar, T. G. H.; Chakraborty, T. K.; Guyar, M. K. *Tetrahedron Lett.* **1988**, *29*, 2069. (c) Katsumura, S.; Kondo, A.; Han, Q. *Chem. Lett.* **1991**, 1245. (d) Jung, M. E.; Jung, Y. H. *Synlett* **1995**, 563. (e) Trost, B. M.; Sudhakar, A. R. *J. Am. Chem. Soc.* **1987**, *109*, 3792. (f) Iwawa, S.; Katsumura, S. *Bull. Chem. Soc. Jpn.* **1994**, *67*, 3363.

(15) (a) Georges, M.; Mackay, D. *J. Am. Chem. Soc.* **1982**, *104*, 1101. (b) Banks, M. R.; Blake, A. J.; Cadogan, J. I. G.; Dawson, I. M.; Gaur, S.; Gosney, I.; Gould, R. O.; Grant, K. J.; Hodgson, P. K. G. *J. Chem. Soc., Chem. Commun.* **1993**, 1146.

(16) (a) Xu, D.; Sharpless, K. B. *Tetrahedron Lett.* **1993**, *34*, 5545. (b) Trost, B. M.; Van Vraiken, D. L.; Bingel, C. *J. Am. Chem. Soc.* **1992**, *114*, 9327.

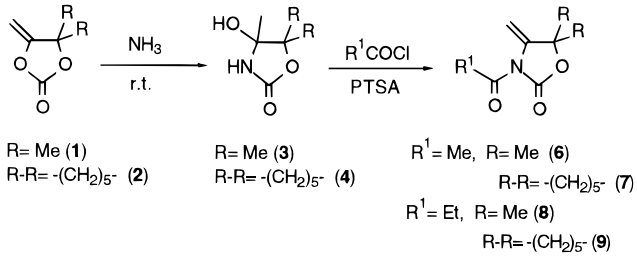
(17) Sato, T.; Mizutani, T.; Okumura, Y.; Fujisawa, F. *Tetrahedron Lett.* **1989**, *30*, 3701.

(18) Ghosh, A. K.; Cho, H.; Onishi, M. *Tetrahedron: Asymmetry* **1997**, *8*, 821.

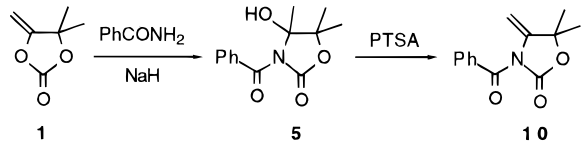
(19) (a) Fournier, J.; Bruneau, C.; Dixneuf, P. H. *Tetrahedron Lett.* **1989**, *30*, 3981. (b) Joumier, J. M.; Fournier, J.; Bruneau, C.; Dixneuf, P. H. *J. Chem. Soc., Perkin Trans. 1* **1991**, 3271.

S0022-3263(97)01733-7 CCC: $15.00
Published on Web 02/20/1998

Scheme 2



Scheme 3



dinones.[20] Advantage can thus be taken of these carbonates to produce the desired precursors *N*-acyloxazolidinones according to Scheme 2.

Treatment of carbonates **1**, **2** with ammonia at room temperature led to the hydroxylated oxazolidinones **3** and **4** in 95% isolated yield. Subsequent treatment with an excess of acyl chloride in refluxing dichloromethane in the presence of a catalytic amount of *p*-toluenesulfonic acid (PTSA) led to the *N*-acyloxazolidinones **6**−**9** in 86, 80, 80, and 65% yield, respectively, resulting from both acylation of the N−H functionality and dehydration. *N*-Acyloxazolidinones are commonly prepared by deprotonation of the parent oxazolidinones in the presence of BuLi[1a,3b,8a] or Et_3N[21] followed by acylation with anhydrides or acid chlorides. Furthermore, acylation with an optically pure acyl chloride has been used to resolve 4-methyloxazolidinone.[22] By using a catalytic amount of PTSA instead of a base, the α-methylene-*N*-acyloxazolidinones **6**−**9** could be prepared in three steps from tertiary propargylic alcohol, CO_2, ammonia, and an acyl chloride.

The *N*-acyloxazolidinone **10** was obtained with an alternative synthesis involving initial introduction of the benzoyl group by treatment of the cyclic carbonate **1** with deprotonated benzamide to give **5** (72%), and subsequent dehydration in the presence of PTSA (Scheme 3).

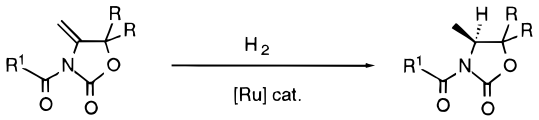
Enantioselective Hydrogenation of *N*-Acyl-4-methylene-1,3-oxazolidin-2-ones. The *N*-acyloxazolidinones **6**−**10** contain an enamide C=C, which is expected to be enantioselectively hydrogenated in the presence of a chiral ruthenium(II) catalyst,[23] and an oxazolidinone ring that can also act as a chelating ligand. This consideration led us to attempt the hydrogenation of the *N*-acyloxazolidinones **6**−**10** with chiral ruthenium complexes containing the Binap and Biphemp optically active diphosphine ligands.[24] A typical hydrogenation was performed from 0.2 g of unsaturated oxazolidinone,

Table 1. Hydrogenation of *N*-Acyloxazolidinones 6−10 Catalyzed by (diphosphine)Ru(II) Complexes[a]

run	substrate	catalyst	compound[b]	ee[c]
1	**6**	((*R*)-Binap)Ru(O_2CCF_3)$_2$	R-(−)-**11**	>99
2	**6**	((*S*)-Biphemp)Ru(O_2CCF_3)$_2$	S-(+)-**11**	99
3	**6**	[((*R*)-Binap)$RuCl_2$]$_2$$NEt_3$	R-(−)-**11**	99
4	**7**	((*R*)-Binap)Ru(O_2CCF_3)$_2$	R-(−)-**12**	>99
5	**8**	((*R*)-Binap)Ru(O_2CCF_3)$_2$	R-(−)-**13**	98
6	**9**	((*R*)-Binap)Ru((O_2CCF_3)$_2$	R-(−)-**14**	98
7	**10**	[((*R*)-Binap)$RuCl_2$]$_2$$NEt_3$	R-(−)-**15**	98

[a] Reactions carried out in dry methanol with a substrate/catalyst ratio = 100 at 50 °C under 10 MPa hydrogen pressure. [b] Absolute configurations were deduced from literature data. [c] ee were determined by high pressure liquid chromatography with a chiral (*S*,*S*-WHELK 0-1 column eluted with a hexane−2-propanol mixture.

Scheme 4



1 mol % of ruthenium catalyst (Table 1), and 10 mL of distilled methanol, which were introduced under inert atmosphere into a 125 mL autoclave. The hydrogenation was then carried out at 50 °C under 10 MPa initial pressure of hydrogen, and the conversion was determined by gas chromatography (Scheme 4).

Under these conditions, complete conversion of the starting *N*-acyl-4-methylene oxazolidinones was obtained after 20 h of reaction and the ^1H and ^{13}C NMR of the reaction product showed the hydrogenated *N*-acyloxazolidinones as the sole products, indicating that the reaction was very selective and no cleavage of the acyl group or ring opening took place. The pure compounds were isolated by distillation under reduced pressure in more than 85% yield. The enantiomeric excesses of the *N*-acyloxazolidinones **6**−**10** were determined by high-pressure liquid chromatography with a chiral (*S*,*S*)-WHELK 0-1 column eluted with a hexane−2-propanol (95/5) mixture.

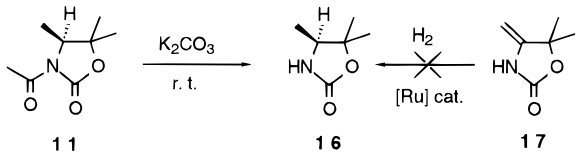
The various ruthenium catalyst precursors tested were very efficient in terms of activity and enantioselectivity as the amount of the minor enantiomer was always at the limit of detection of the HPLC analysis (Table 1). The nature of the acylating groups (acetyl, propionyl, or benzoyl) and the nature of the substituents at C(5) had no effect on the enantioselectivity of the hydrogenation.

The hydrogenation of the *N*-cyclohexyl-4-methylene-1,3-oxazolidin-2-one, which contains no acyl group, was not possible under our experimental conditions. The excellent enantioselectivities obtained from acyloxazolidinones might be due to the coordination of both the exocyclic C=C double bond and the acyl NCO group to the chiral ruthenium center. In this process, the carbonyl group of the cyclic carbamate is probably not involved

(20) Bruneau, C.; Dixneuf, P. H. *J. Mol. Catal.* **1992**, *74*, 97.
(21) (a) Ager, D. T.; Allen, D. R.; Schaad, D. R. *Synthesis* **1996**, 1283. (b) Ho, G.-J.; Mathre, D. J. *J. Org. Chem.* **1995**, *60*, 2271.
(22) Ishizuka, T.; Kimura, K.; Ishibushi, S.; Kunieda, T. *Chem. Lett.* **1992**, 991.
(23) (a) Heiser, B.; Broger, A.; Crameri, Y. *Tetrahedron: Asymmetry* **1991**, *2*, 51. (b) Kitamura, M.; Hsiao, Y., Noyori, R. *Tetrahedron Lett.* **1987**, *28*, 4829. (c) Noyori, R.; Ohta, M.; Hsiao, Y.; Kitamura, M.; Ohta, T.; Takaya, H. *J. Am. Chem. Soc.* **1986**, *108*, 7117. (d) Kitamura, M.; Hsiao, Y.; Ohta, M.; Tsukamoto, M.; Ohta, T.; Takaya, H.; Noyori, R. *J. Org. Chem.* **1994**, *59*, 297. (e) Tschaen, D. M.; Abramson, L.; Cai, D.; Desmond, R.; Dolling, U. H.; Frey, L.; Karady, S.; Shi, Y. J.; Verhoeven, T. R. *J. Org. Chem.* **1995**, *60*, 4324.

(24) Binap: (1,1′-binaphthyl-2,2′-diyl)bis(diphenylphosphine); Biphemp: (6,6′-dimethylbiphenyl-2,2′-diyl)bis(diphenylphosphine).

Scheme 5



11 **16** **17**

as already suggested in the enantioselective hydrogenation of the similar cyclic carbonate[25] and lactone structures.[26]

It has been shown that the use as chiral auxiliary of a 5,5-symmetrically disubstituted oxazolidinone ring rather than the corresponding unsubstituted ring was preferable as it gave less undesirable degradation byproducts.[12] It is also noteworthy that using compound **13**, containing an alkyl group as small as a methyl attached to the asymmetrical C(4) carbon atom, good diastereoselectivity was observed upon alkylation with $PhCH_2Br$/LDA.[12]

Cleavage of the Acyl Group: Synthesis of Optically Active Oxazolidinones. The presence of the acyl group is required to obtain a high enantioselectivity during the hydrogenation of the exocyclic olefinic double bond. Subsequent deacylation is achieved by treatment with potassium carbonate in methanol at room temperature (Scheme 5). Thus, treatment of 0.16 g (0.9 mmol) of **11** with 0.2 g (1.4 mmol) of potassium carbonate in 10 mL of anhydrous methanol at room temperature for 24 h led to the quantitative conversion to the oxazolidinone **16**. After usual workup, the optically active R-(−)-4,5,5-trimethyloxazolidin-2-one **16** was obtained in 90% yield. ($[\alpha_D] = -2.6$ (*c* 4, $CHCl_3$)).[12]

Compound **16** could have arisen from the 4-methyleneoxazolidin-2-one **17** via hydrogenation; however, **17** was not accessible by direct dehydration of **3**. The three-step process involving acylation of **3**, catalytic enantioselective hydrogenation of **6** followed by the deacylation of **11**, produced **16** in more than 70% yield and with high enantiomeric purity.

In summary, the enantioselective hydrogenation of *N*-acyl-4-methylene-1,3- oxazolidin-2-ones in the presence of ruthenium catalysts containing an optically pure diphosphine ligand provides a novel method for direct access to optically active *N*-acyloxazolidinones of high optical purity. This method also allows the preparation of both enantiomers of new chiral auxiliaries symmetrically disubstituted at C(5) with introduction of the chirality at the last step of the synthesis and competes with the methods starting from natural compounds such as L-amino acids. It also offers an efficient access to optically active 4-methyloxazolidinones via cleavage of the acyl group under mild conditions.

Experimental Section

General. NMR spectra were recorded on a Bruker AC 300P (300.13 MHz for ^1H; 75.49 for ^{13}C) spectrometer. Infrared spectra were obtained on a Nicolet 205 FT-IR and mass spectra were provided by Le Centre de Mesures Physiques de l'Ouest (Rennes) on a Varian Mat 311 machine. $[\alpha]_D$ were measured on a Perkin-Elmer 241 MC polarimeter, and the enantiomeric excesses were determined after separation of the enantiomers by HPLC on a Perkin-Elmer chromatograph equipped with a chiral (*S,S*)-WELK 0-1 column (250 × 4.6 mm) eluted with a hexane−2-propanol (95/5) mixture. Elemental analyses were carried out by Le Service d'Analyses du CNRS at Vernaison (France). All solvents were distilled and dried before use.

4-Hydroxy-4,5,5-trimethyl-1,3-oxazolidin-2-one (3). Ammonia was bubbled overnight through a solution containing 9 mmol of carbonate **1** in 50 mL of ethyl acetate. After evaporation of the solvent and washing with diethyl ether, the cyclic carbamate **3** was isolated by filtration as a white solid (95%): mp = 136 °C; IR (KBr) ν 3250, 1750 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 6.86 (s, 1H), 4.65 (s, 1H), 1.42 (s, 3H), 1.40 (s, 3H), 1.37 (s, 3H); ^{13}C {^1H} NMR (75 MHz, $CDCl_3$) δ 160.20, 88.80, 88.70, 25.20, 22.80, 20.90. Anal. Calcd for $C_6H_{11}NO_3$: C, 49.64; H, 7.64; N, 9.65. Found: C, 49.51; H, 7.56; N, 9.75.

5′-Cyclohexanespiro-4′-hydroxy-4′-methyl-1′,3′-oxazolidin-2′-one (4). Under the above experimental conditions, 95% of **4** was isolated as a white solid: mp = 174 °C; IR (KBr) ν 3402, 1764 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 6.66 (s, 1H), 4.31 (s, 1H), 1.41 (s, 3H), 2.20−1.00 (m, 10H). Anal. Calcd for $C_9H_{15}NO_3$: C, 58.36; H, 8.16; N, 7.56. Found: C, 58.52; H, 8.12; N, 7.88.

General Procedure for the Acylation of the Oxazolidinones 3 and 4. A 7 mmol amount of **3** or **4** and 30 mmol of acyl chloride were heated in the presence of 0.5 mmol of *p*-toluenesulfonic acid in 50 mL of refluxing dichloromethane (18 h with acetyl chloride, 48 h with propionyl chloride). The water was removed thanks to a cartridge of calcium chloride placed in a Soxhlet apparatus. After evaporation of the solvent, the acyloxazolidinones were isolated by distillation under reduced pressure or chromatography over silica gel.

***N*-Acetyl-5,5-dimethyl-4-methylene-1,3-oxazolidin-2-one (6).** Isolated by distillation as a white solid (86%): mp = 56 °C; IR (KBr) ν 1789, 1722, 1657 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.84 (d, 1H, J = 2.0 Hz), 4.52 (d, 1H, J = 2.0 Hz), 2.54 (s, 3H), 1.47 (s, 6H); ^{13}C {^1H} NMR (75 MHz, $CDCl_3$) δ 170.59, 152.63, 145.51, 93.71, 82.27, 28.08, 25.86. Anal. Calcd for $C_8H_{11}NO_3$: C, 56.79; H, 6.56; N, 8.27. Found: C, 56.79; H, 6.70; N, 8.18.

***N*-Acetyl-5′-cyclohexanespiro-4′-methylene-1′,3′-oxazolidin-2′-one (7).** Isolated as a white solid after chromatography over silica gel with a ether−pentane (3/1) mixture as eluent (80%): mp = 90 °C; IR (KBr) ν 1787, 1721, 1660 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.85 (d, 1H, J = 1.9 Hz), 4.49 (d, 1H, J = 1.9 Hz), 2.55 (s, 3H), 2.00−1.00 (m, 10H); ^{13}C {^1H} NMR (75 MHz, $CDCl_3$) δ 170.76, 152.86, 145.63, 93.85, 83.94, 37.06, 26.01, 24.50, 21.59. Anal. Calcd for $C_{11}H_{15}NO_3$: C, 63.14; H, 7.23; N, 6.69. Found: C, 63.02; H, 7.38; N, 6.54.

***N*-Propionyl-5,5-dimethyl-4-methylene-1,3-oxazolidin-2-one (8).** Isolated as a colorless liquid by chromatogaphy over silica gel with diethyl ether as eluent (80%): IR (neat) ν 1794, 1723, 1652 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.89 (d, 1H, J = 2.5 Hz), 4.56 (d, 1H, J = 2.5 Hz), 3.12 (q, 2H, J = 6.9 Hz), 1.54 (s, 6H), 1.17 (t, 3H, J = 6.9 Hz). Anal. Calcd for $C_9H_{13}NO_3$: C, 59.00; H, 7.15; N, 7.65. Found: C, 59.28; H, 7.34; N, 7.61.

***N*-Propionyl-5′-cyclohexanespiro-4′-methylene-1′,3′-oxazolidin-2′-one (9).** Isolated as a white solid after chromatography over silica gel with diethyl ether as eluent (65%): mp = 98 °C; IR (KBr) ν 1787, 1719, 1655 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.86 (d, 1H, J = 1.9 Hz), 4.48 (d, 1H, J = 1.9 Hz), 2.96 (q, 2H, J = 7.3 Hz), 2.00−1.30 (m, 10H), 1.17 (t, 3H, J = 7.3 Hz); ^{13}C {^1H} NMR (75 MHz, $CDCl_3$) δ 174.7, 152.81, 145.89, 93.67, 83.96, 37.16, 31.08, 24.55, 21.61, 8.33. Anal. Calcd for $C_{12}H_{17}NO_3$: C, 64.55; H, 7.67; N, 6.27. Found: C, 64.50; H, 7.76; N, 6.11.

***N*-Benzoyl-4-hydroxy-4,5,5-trimethyl-1,3-oxazolidin-2-one (5).** A 1.23 g (41 mmol) amount of NaH (80% in mineral oil) was cooled to 0 °C in 40 mL of tetrahydrofuran. A 3 g (25 mmol) amount of benzamide diluted in 20 mL of dichloromethane and 3 mL (25 mmol) of carbonate **1** were added, and the solution was stirred at room temperature for 4 h. After treatment with a saturated NH_4Cl solution, extraction with diethyl ether, drying over $MgSO_4$, and evaporation of the solvent, **5** was recrystallized from diethyl ether as a white solid

(25) Le Gendre, P.; Braun, T.; Bruneau, C.; Dixneuf, P. H. *J. Org. Chem.* **1996**, *61*, 8453.
(26) Ohta, T.; Miyake, T.; Seido, N.; Kuniobayashi, H.; Takaya, H. *J. Org. Chem.* **1995**, *60*, 357.

(72%): mp = 118 °C; IR (KBr) ν 3462, 1778, 1680 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.82−7.42 (m, 5H), 4.50 (s, 1H), 1.76 (s, 3H), 1.54 (s, 3H), 1.52 (s, 3H). MS m/z = 249 (M^+).

***N*-Benzoyl-5,5-dimethyl-4-methylene-1,3-oxazolidin-2-one (10).** A 0.5 g (2 mmol) amount of **5** and 17 mg (5 mol %) of *p*-toluenesulfonic acid were heated in refluxing toluene for 12 h in a Dean−Stark apparatus. After evaporation of toluene, the reaction mixture was treated with a saturated $NaHCO_3$ solution, extracted with dichloromethane, and dried over $MgSO_4$. The resulting solid was recrystallized from diethyl ether (26%): mp = 132 °C; IR (KBr) ν 1778, 1764, 1662 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.69−7.42 (m, 5H), 5.55 (d, 1H, J = 2.6 Hz), 4.60 (d, 1H, J = 2.6 Hz), 1.64 (s, 6H). Anal. Calcd for $C_{13}H_{13}NO_3$: C, 67.52; H, 5.67. Found: C, 67.77; H, 5.74.

General Procedure for the Hydrogenation of *N*-Acyloxazolidinones (6−10). *N*-Acyloxazolidinone (0.2 g) and the ruthenium catalyst (1 mol %) were placed in a 125 mL stainless steel autoclave. After addition of 10 mL of distilled methanol under nitrogen, the autoclave was pressurized with hydrogen (10 MPa) and heated at 50 °C for 18 h. The solvent was evaporated and the hydrogenated *N*-acyloxazolidinone was recovered by distillation under reduced pressure. The conversion was determined by GC of the crude on a capillary column coated with FFAP (30 m × 0.53 mm) and the enantiomeric excess by HPLC of the isolated compound on a (*S*,*S*)-WHELK 0-1 column (25 cm × 4.5 mm) eluted with a hexane−2-propanol (95/5) mixture. The optical rotation was measured with a Perkin-Elmer 241 polarimeter.

(*R*)-*N*-Acetyl-4,5,5-trimethyl-1,3-oxazolidin-2-one (11): white solid (87%); mp = 42 °C; IR (KBr) ν 1764, 1703 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 4.10 (q, 1H, J = 6.5 Hz), 2.44 (s, 3H), 1.36 (s, 3H), 1.34 (s, 3H), 1.21 (d, 3H, J = 6.5 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 170.57 (s), 152.88(s), 81.39 (s), 58.78 (d, J = 146 Hz), 27.81 (q, J = 125 Hz), 23.98 (q, J = 146 Hz), 21.53 (q, J = 124 Hz), 14.63 (q, J = 128 Hz). Anal. Calcd for $C_8H_{13}NO_3$: C, 56.12; H, 7.65; N, 8.18. Found: C, 55.76; H, 7.62; N, 8.07. $[\alpha]_D$ −20 (c = 0.5, EtOH) (ee = 99%).

(*R*)-*N*-Acetyl-5′-cyclohexanespiro-4′-methyl-1′,3′-oxazolidin-2′-one (12): white solid (87%); mp = 59 °C; IR (KBr) ν 1777, 1702 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 4.16 (q, 1H, J = 6.5 Hz), 2.49 (s, 3H), 2.00−1.30 (m, 10H), 1.24 (d, 3H, J = 6.5 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 170.67 (s), 152.95 (s), 82.75 (s), 57.98 (d, J = 143 Hz), 24.02 (q, J = 129 Hz), 36.47 (t, J = 129 Hz), 30.49 (q, J = 129 Hz), 24.85 (t, J = 129 Hz), 22.30 (t, J = 129 Hz), 22.03 (t, J = 129 Hz), 13.77 (q, J = 128 Hz). Anal. Calcd for $C_{11}H_{17}NO_3$: C, 62.54; H, 8;11; N, 6.63. Found: C, 62.65; H, 8.20; N, 6.59. $[\alpha]_D$ −21 (c = 0.45, $CHCl_3$) (ee = 99%).

(*R*)-*N*-Propionyl-4,5,5-trimethyl-1,3-oxazolidin-2-one (13):[12] white solid (95%); mp = 82 °C; IR (KBr) ν 1777, 1704 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 4.16 (q, 1H, J = 6.6 Hz), 2.90−2.88 (m, 2H, J = 16.0 and 7.3 Hz), 1.41 (s, 3H), 1.39 (s, 3H), 1.26 (d, 3H, J = 6.6 Hz) 1.14 (t, 3H, J = 7.3 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 174.34 (s), 152.79 (s), 81.41 (s), 58.88 (d, J = 147 Hz), 29.33 (t, J = 128 Hz), 27.83 (q, J = 128 Hz), 21.55 (q, J = 127 Hz), 14.69 (q, J = 128 Hz), 8.35 (q, J = 128 Hz). Anal. Calcd for $C_9H_{15}NO_3$: C, 58.36; H, 8.16; N, 7.56. Found: C, 58.07; H, 8.45; N, 7.60. $[\alpha]_D$ −51 (c = 0.9, $CHCl_3$) (ee = 98%).

***N*-Propionyl-5′-cyclohexanespiro-4′-methyl-1′,3′-oxazolidin-2′-one (14):** white solid (93%): mp = 78 °C; IR (KBr) ν 1775, 1701 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 4.18 (q, 1H, J = 6.5 Hz), 2.90 (m, 2H), 1.90−1.30 (m, 10H), 1.25 (d, 3H, J = 6.5 Hz), 1.14 (t, 3H, J = 7.3 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 174.44 (s), 152.85 (s), 82.69 (s), 58.00 (d, J = 146 Hz), 36.49 (t, J = 127 Hz), 30.52 (t, J = 128 Hz), 29.36 (t, J = 129 Hz), 24.91 (t, J = 127 Hz), 22.32 (t, J = 129 Hz), 22.00 (t, J = 129 Hz), 13.80 (q, J = 128 Hz), 8.40 (q, J = 128 Hz). Anal. Calcd for $C_{12}H_{19}NO_3$: C, 63.98; H, 8.50; N, 6.22. Found: C, 63.80; H, 8.54; N, 5.93. $[\alpha]_D$ −53 (c = 0.9, $CHCl_3$) (ee = 98%).

***N*-Benzoyl-4,5,5-trimethyl-4-methylene-1,3-oxazolidin-2-one (15):** white solid (85%); mp = 88 °C; IR (KBr) ν 1781, 1684 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.59−7.30 (m, 5H), 4.20 (q, 1H, J = 6.5 Hz), 1.43 (s, 3H), 1.36 (s, 3H), 1.32 (d, 3H, J = 6.5 Hz); ^{13}C {^1H} NMR (75 MHz, $CDCl_3$) δ 170.32, 152.87, 133.64, 132.46, 129.04, 127.99, 81.92, 60.07, 27.07, 21.95, 13.99. Anal. Calcd for $C_{13}H_{15}NO_3$: C, 66.94; H, 6.48; N, 6.01. Found: C, 66.73; H, 6;72; N, 5.98. $[\alpha]_D$ −143 (c = 2, EtOH) (ee = 98%).

(*R*)-4,5,5-Trimethyl-4-methylene-1,3-oxazolidin-2-one (16):[12] white solid (90%); mp = 61 °C; IR (KBr) ν 3273, 1741 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.94 (s, 1H), 3.62 (q, 1H, J = 6.5 Hz), 1.42 (s, 3H), 1.30 (s, 3H), 1.15 (d, 3H, J = 6.5 Hz); ^{13}C {^1H} NMR (75 MHz, $CDCl_3$) δ 159.22 (s), 83.59 (s), 57.17 (d, J = 142 Hz), 27.22 (q, J = 127 Hz), 21.55 (q, J = 127 Hz), 16.16 (q, J = 127 Hz). $[\alpha]_D$ −2.6 (c = 4, $CHCl_3$) (from **11**, ee = 99%).

Acknowledgment. The authors thank Dr. R. Schmid from F. Hoffmann-La Roche Ltd (Basel) for helpful discussions and a generous gift of Biphemp ligand.

JO971733D