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Bis-Lewis acids-catalyzed highly diastereoselective one-pot reductive dehydroxylation of chiral *N*,*O*-acetals

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ABSTRACT

A one-pot and highly diastereoselective method for the reductive dehydroxylation of three classes of heterocyclic *N*,*O*-acetals with general structure **4** is reported. The method features a 'two in one' concept, namely, by synergetic action of two complementary Lewis acids ($BF{\cdot}OEt_2$ and $TiCl_4$), the bicyclic or tricyclic oxazololactams **5** were formed in situ and reductively cleaved to give the corresponding lactams **6** in a high-yielding and highly diastereoselective manner.

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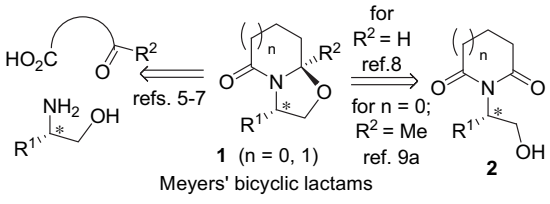
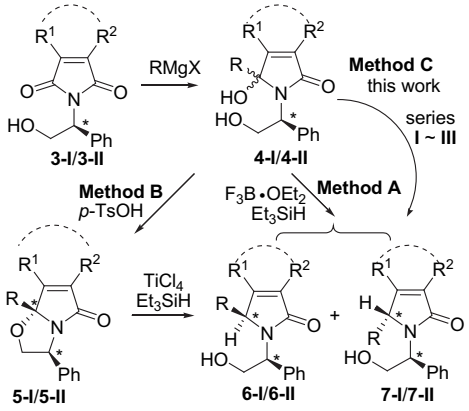
1. Introduction

The concept of cooperative Lewis acid/base/transition metal catalysis and multi-catalyst systems has been developed to achieve some challenging transformations such as asymmetric synthesis[1] and one-pot reactions.[2–4] In the context of stereocontrolled synthesis of *N*-containing heterocycles, Meyers' chiral bicyclic lactam (**1**)-based synthetic methodology is gaining popular.[5–8] In this methodology, the cyclocondensation between δ-oxo acids and enantiomeric pure β-aminoalcohols[5–7] (Scheme 1) has been employed almost as the sole entry to the chiral bicyclic/tricyclic oxazololactams (**1**).[8,9] An alternative and more flexible method to access the chiral bicyclic/tricyclic oxazololactams resides in the Grignard addition to cyclic imides **2**.[9a,10] To the best of our knowledge, this advantageous approach was not pursuit until the works reported from these laboratories.[11,12]



Scheme 1. Two approaches for the synthesis of chiral non-racemic bicyclic lactams.

In our previous work on the stereoselective synthesis of 3-alkylindolidin-3-ones[13] **6-I** from *N*,*O*-acetals **4-I**,[11] it was found that the stepwise bicyclic oxazololactams (**5-I**) formation-reductive ring-opening reaction (**Method B**, Scheme 2) afforded a better diastereoselectivity than the direct reductive dehydroxylation of **4-I** did (**Method A**). Similar results were obtained in the synthesis of methyl 5-alkyltetramate derivatives **6-II**.[12] *The modest diastereoselectivity of **method A** and the overall inefficiency of the two-step procedure (**Method B**) made it worthwhile to develop an improved method to achieve both high efficiency and high diastereoselectivity.*



Scheme 2.

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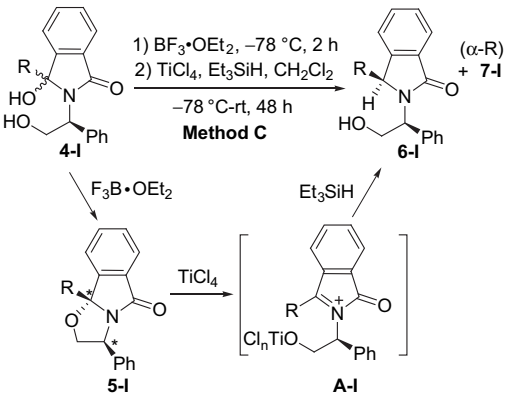
With this aim in mind, we set to explore a bis-Lewis acids-catalyzed one-pot cyclization-reductive ring-opening reaction variant on three ring systems **I**–**III** (Scheme 2, **Method C**), and the results are reported herein.

2. Results and discussion

Our basic consideration was to take advantages of both the brevity of **method A** and the high diastereoselectivity offered by **method B**, and develop an efficient and highly diastereoselective one-pot reductive dehydroxylation method. In view of the excellent capacity of boron trifluoride etherate in the dehydroxylation,[10c,f,11] and that of titanium tetrachloride in the cleavage of oxazolidine rings,[11] they were selected as complementary Lewis acids[4] for the one-pot reductive dehydroxylation of three classes of heterocyclic *N*,*O*-acetals **4**.

The synthesis of the series of 3-alkylindolin-1-one derivatives[13] **6-I** was first investigated (Scheme 3). Thus the known *N*,*O*-acetal **4-Ia**[11] was treated with 1.0 molar equiv of $BF_3{\cdot}OEt_2$ at −78 °C, and stirred for 2 h, which was followed by successive addition of $TiCl_4$ and triethylsilane.[14] From this one-pot reaction, 3-methylisoindolin-1-ones **6-Ia** and **7-Ia** were obtained in 94:6 diastereoselectivity with 96% combined yield (Table 1, entry 1). The reaction was presumed to proceed via the *N*-acyliminium intermediate **A**.[15] The one-pot reaction of other *N*,*O*-acetals **4-Ib**–**e**[11] afforded the corresponding (*S*)-3-alkylisoindolin-1-ones **6-Ib**–**e**[11] with similar high efficiency and excellent diastereoselectivities (Table 1, entries 2–5).



Scheme 3.

Table 1
Comparison of **method B** and **method C** for the synthesis of 3-substituted isoindolin-1-ones **6-I** from *N*,*O*-acetals **4-I**

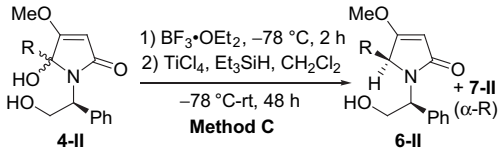
Entry	Starting compound (R)	**Method B**[11b] **6-I**:**7-I**[a] (% overall yield)[b]	**Method C 6-I**:**7-I**[a] (% yield)[c]
1	**4-Ia** (Me)	95:5 (83)	94:6 (96)
2	**4-Ib** (*i*-Bu)	100:0 (33)	97:3 (91)
3	**4-Ic** (n-C_7H_{15})	91:9 (60)	93:7 (83)
4	**4-Id** (Ph)	96:4 (75)	95:5 (96)
5	**4-Ie** (Bn)	92:8 (39)	90:10 (75)

[a] Ratio determined by column chromatographic separation.
[b] Overall yield from **4-I**.
[c] Isolated yield.

It is worth notice that the low overall yields (33%; 39%) in the synthesis of 3-*iso*-butyl and benzyl (3*S*)-isoindolin-1-one derivatives **6-Ib**,**e** by **method B** (Table 1, col. 3, entries 2, 5)[11] were greatly improved (91%; 75%), which indicated that the reaction conditions used in **method C** are quite mild, and the dehydration side reaction was efficiently avoided.

The success in the bis-Lewis acids-mediated highly diastereoselective one-pot reductive dehydroxylation of (*S*)-3-hydroxy-3-alkylisoindolin-1-one derivatives (**4-I**) led us to consider an extension of this concept to the tetramate series **4-II**.[11] 5-Alkyltetramates and 5-alkyltetramic acids are frameworks found in a number of bioactive natural products.[16,17] Treatment of the *N*,*O*-acetal **4-IIa**[12] with 1.0 molar equiv of $BF_3{\cdot}OEt_2$ at −78 °C for 2 h, followed by $TiCl_4$-mediated reduction with triethylsilane led to 5-methyltetramate **6-IIa** in a 91:9 diastereoselectivity and 88% combined yield (Table 2, entry 1). Extension of this method to other *N*,*O*-acetals **4-IIb**–**g** yielded the corresponding 5-alkyltetramates **6-IIb**–**g** and the results are displayed in Table 2. As can be seen from Table 2, comparing with **method B**, the one-pot reaction (**Method C**) gave, in all cases, significantly improved chemical yields while remaining about the same diastereoselectivities.

Table 2
Comparison of the two methods for the synthesis of methyl 5-alkyltetramates **6-II** from *N*,*O*-acetals **4-II**

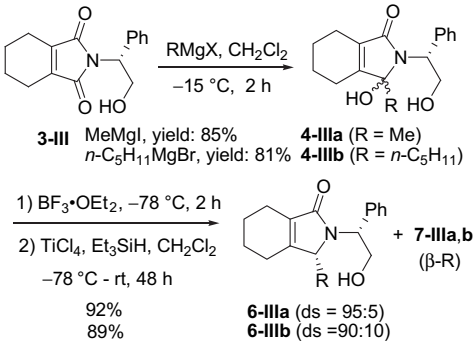


Entry	Starting compound (R)	**Method B**[12] **6-II**:**7-II** (% overall yield)[a]	**Method C 6-II**:**7-II** (% yield)[a]
1	**4-IIa** (Me)	91:9 (71)	91:9 (88)[b]
2	**4-IIb** (Et)	91:9 (65)	91:9 (95)[c]
3	**4-IIc** (n-C_5H_{11})	93:7 (66)	92:8 (85)[b]
4	**4-IId** (n-C_6H_{13})	92:8 (69)	90:10 (83)[b]
5	**4-IIe** (n-C_7H_{15})	88:12 (60)	90:10 (93)[b]
6	**4-IIf** (*i*-Bu)	99:1 (66)	96:4 (72)[c]
7	**4-IIg** (Bn)	88:12 (41)	90:10 (56)[b]

[a] Isolated yield.
[b] Ratio determined by ^1H NMR.
[c] Ratio determined by column chromatographic separation.

To probe the intermediate of the reaction, the *N*,*O*-acetal **4-IIa** was treated with 1.0 molar equiv of $BF_3{\cdot}OEt_2$ at −78 °C for 2 h. The isolated product turned out to be the bicyclic oxazololactam **5-IIa**. The stereochemistry of **5-IIa** was determined to be (*R*,*S*) by NOESY experiments.[12]

The method was further extended to another ring system. Thus, the one-pot cyclization–reduction of the *N*,*O*-acetals **4-IIIa**[8c,18] and **4-IIIb**, derived from (*R*)-imide **3-III**[18] by Grignard addition, afforded the diastereomeric lactams **6-IIIa** and **6-IIIb** in 95:5 and 90:10 ratio, respectively (Scheme 4).



Scheme 4.

The oily property of both diastereomers **6-IIIa** and **6-IIIb** prevented a determination of the stereochemistry of the newly formed chiral center by single crystal X-ray diffraction analysis, which was deduced as follows. The lactams **6-IIIa** and **6-IIIb** were presumed to be formed via the corresponding cyclic intermediates **5-IIIa**/**b**.

Indeed when *N*,*O*-acetal **4-IIIa** was treated with $BF_3 \cdot OEt_2$, tricyclic lactam **5-IIIa** was formed in 70% yield as a sole diastereomer. The NOESY experiments showed that the methyl and phenyl groups are in the same face (Fig. 1). In light of the well documented fact that the reductive ring-opening reaction of the similar cyclic lactams with Lewis acid/Et_3SiH system generally undergoes with retention of configuration,[5–9,11] the *C*-3 stereochemistry of **6-IIIa** and **6-IIIb** was assigned as *R*.

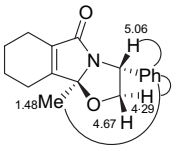


Figure 1. The observed NOEs for **5-IIIa** (in part).

3. Conclusion

In summary, by the synergetic action of two different Lewis acids we were able to achieve both the efficiency and high diastereoselectivity in the one-pot transformation of three classes of *N*,*O*-acetals (**4-I–III**) into the corresponding lactams (**6-I–III**). Thus, in combination with our previous results,[11,12] a versatile two-step entrance to three classes of cyclic lactams (**6-I–III**) from imide **3-I–III** was established. The lactams obtained are useful synthetic intermediates for *N*-containing bioactive compounds and natural products, and may serve as valuable chiral ligands. It was believed that the 'two in one' concept will find application in organic synthesis.

4. Experimental section

4.1. General procedure for the one-pot cyclization-reductive ring-opening of compounds 4

To a cooled (−78 °C) dichloromethane (9 mL) solution of a diastereomeric mixture of *N*,*O*-acetal (0.324 mmol) **4** was added dropwise boron trifluoride etherate (0.324 mmol) under nitrogen atmosphere. After stirring at −78 °C for 2 h, $TiCl_4$ (0.486 mmol) and triethylsilane (3.24 mmol) were added successively. After stirring at −78 °C for an additional 2 h, the mixture was allowed to warm up and was stirred for about 48 h. The reaction was quenched with a saturated $NaHCO_3$ solution. The organic layer was separated and the aqueous phase was extracted with CH_2Cl_2 (3×15 mL). The combined organic layers were washed with brine, dried over anhydrous Na_2SO_4, filtered, and concentrated under reduced pressure. The residue was purified by flash chromatography eluting with (EtOAc/PE, v/v) to give lactam **6** and its diastereomer **7**.

*4.1.1. (3S,1′S)-2-(2-Hydroxyl-1-phenylethyl)-3-methylisoindolin-1-one (3S,1′S)-**6-Ia**.* dr=94:6, combined yield 96%. Colorless oil. $[\alpha]_D^{20}$ −88.2 (*c* 1.3, $CHCl_3$) {lit.[11b] $[\alpha]_D^{20}$+87.9 (*c* 0.99, $CHCl_3$) for the antipode}.

*4.1.2. (3S,1′S)-2-(2-Hydroxyl-1-phenylethyl)-3-isobutylisoindolin-1-one (3S,1′S)-**6-Ib**.* dr=97:3, combined yield 91%. White solid, mp 54.5–56.5 °C (EtOAc/PE); $[\alpha]_D^{20}$ −53.1 (*c* 1.04, $CHCl_3$) {lit.[11b] mp 54–56 °C; $[\alpha]_D^{20}$ +44.7 (*c* 0.95, $CHCl_3$) for the antipode}.

*4.1.3. (3S,1′S)-3-n-Heptyl-2-(2-hydroxyl-1-phenylethyl) isoindolin-1-one (3S,1′S)-**6-Ic**.* dr=93:7, combined yield 83%. Colorless oil. $[\alpha]_D^{20}$ −41.0 (*c* 0.95, $CHCl_3$) {lit.[11b] $[\alpha]_D^{20}$ +41.1 (*c* 0.68, $CHCl_3$)}.

*4.1.4. (3S,1′S)-2-(2-Hydroxyl-1-phenylethyl)-3-phenylisoindolin-1-one (3S,1′S)-**6-Id**.* dr=95:5, combined yield 96%. White solid, mp 149–150.5 °C (EtOAc/PE); $[\alpha]_D^{20}$ +67.3 (*c* 1.00, $CHCl_3$) {lit.[11b] mp 134–135 °C; $[\alpha]_D^{20}$ −56.6 (*c* 1.07, $CHCl_3$) for the antipode}.

*4.1.5. (3S,1′S)-3-Benzyl-2-(2-hydroxyl-1-phenylethyl)isoindolin-1-one (3S,1′S)-**6-Ie**.* dr=90:10, combined yield 75%. White solid, mp 149–150.5 °C (EtOAc/PE); $[\alpha]_D^{20}$ +67.3 (*c* 1.0, $CHCl_3$) {lit.[11b] mp 134–135 °C}; $[\alpha]_D^{20}$ −56.6 (*c* 1.07, $CHCl_3$) for the antipode}.

4.2. (5*S*,1′*S*)-2-Hydroxyl-1-phenylethyl-4-methoxy-5-alkyl-1*H*-pyrrol-2(5*H*)-ones

(5*S*,1′*S*)-**6-IIa–g** were prepared according to the general procedure. The yields and diastereomeric ratios are indicated in Table 2, and the physical and spectroscopic data are in agreement with those reported in Ref. 12.

*4.2.1. 3-Methyl-2-[(1′R)-1′-phenyl-2′-hydroxyethyl]-hexahydroisoindolin-1-one (**6-IIIa**).* dr=95:5, combined yield 92%. Major diastereomer (**6-IIIa**): colorless oil. $[\alpha]_D^{20}$ +45.7 (*c* 3.3, $CHCl_3$). IR (film): 3357, 2921, 2847, 1640, 1424, 1347, 1253, 1205, 1088 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 1.19 (d, *J*=6.87 Hz, 3H, CH_3), 1.62–1.82 (m, 4H), 2.04–2.27 (m, 4H), 3.66 (m, 1H), 4.01 (ddd, *J*=12.32, 6.65, 3.26 Hz, 1H), 4.31 (td, *J*=12.34, 7.71 Hz, 1H), 4.61 (dd, *J*=7.69, 3.20 Hz, 1H), 5.20 (dd, *J*=7.37, 3.82 Hz, 1H), 7.25–7.40 (m, 5H, Ar-*H*) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ 16.1, 20.0, 21.8, 22.0, 22.9, 59.2, 61.9, 64.8, 127.1, 127.7, 128.7, 130.8, 138.6, 156.1, 172.6 ppm; MS (ESI, *m*/*z*): 272 ($M+H^+$, 100). Anal. Calcd for $C_{17}H_{21}NO_2$: C, 75.25; H, 7.80; N, 5.16. Found: C, 75.04; H, 7.48; N, 4.81.

*4.2.2. 3-Ethyl-2-[(1′R)-1′-phenyl-2′-hydroxyethyl]-hexahydroisoindolin-1-one (**6-IIIb**).* dr=90:10, combined yield 89%. Major diastereomer (**6-IIIb**): colorless oil. $[\alpha]_D^{20}$ −63.5 (*c* 0.3, $CHCl_3$). IR (film): 3377, 2925, 2853, 1656, 1420, 1068 cm^{-1}. ^1H NMR (400 MHz, $CDCl_3$) δ 0.87 (t, *J*=7.01 Hz, 3H), 0.87(m, 1H), 1.09 (m, 1H), 1.15–1.24 (m, 4H), 1.56 (m, 1H), 1.66–1.80 (m, 5H), 2.10 (m, 2H), 2.18–2.34 (m, 2H), 3.73 (dd, *J*=4.62, 2.16 Hz, 1H), 4.01 (ddd, *J*=12.34, 6.71, 3.21 Hz, 1H), 4.30 (td, *J*=12.34, 7.70 Hz, 1H), 4.49 (dd, *J*=7.64, 3.22 Hz, 1H), 5.24 (dd, *J*=7.73, 6.75 Hz, 1H), 7.17–7.36 (m, 5H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.0, 20.1, 20.9, 21.9, 22.1, 22.5, 23.3, 27.7, 31.7, 62.2, 62.7, 64.8, 127.1, 127.7, 128.7, 132.1, 138.7, 154.3, 173.3 ppm; MS (ESI, *m*/*z*): 328 ($M+H^+$, 100). HRESIMS Calcd for $[C_{21}H_{27}NO_3+H]^+$: 328.2277; found: 328.2288.

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References and notes

1. For selected reviews on bifunctional/cooperative asymmetric catalysis, see: (a) Shibasaki, M.; Yoshikawa, N. *Chem. Rev.* **2002**, *102*, 2187–2209; (b) Kanai, M.; Kato, N.; Ichikawa, E.; Shibasaki, M. *Synlett* **2005**, 1491–1508; (c) Yamamoto, H.; Futatsug, K. *Angew. Chem., Int. Ed.* **2005**, *44*, 1924–1942; (d) Paull, D. H.; Abraham, C. J.; Scerba, M. T.; Alden-Danforth, E.; Lectka, T. *Acc. Chem. Res.* **2008**, *41*, 655–663.
2. For selected reviews on multicomponent reactions and one-pot reactions, see: (a) *Multicomponent Reactions*; Zhu, J.-P., Bienaymé, H., Eds.; Wiley-VCH: Weinheim, 2005; (b) Bunce, R. A. *Tetrahedron* **1995**, *51*, 13103–13159; (c) Bienaymé, H.; Hulme, C.; Oddon, G.; Schmitt, P. *Chem.—Eur. J.* **2000**, *6*, 3321–3329; (d) Nicolaou, K. C.; Edmonds, D. J.; Bulger, P. G. *Angew. Chem., Int. Ed.* **2006**, *45*, 7134–7186; (e) Dömling, A. *Chem. Rev.* **2006**, *106*, 17–89; (f) Ganem, B. *Acc. Chem. Res.* **2009**, *42*, 463–472.
3. For selected reviews on cooperative Lewis acid/base/transition metals systems and multi-catalyst systems for one-pot organic transformations, see: (a) Lee, J. M.; Na, Y.; Han, H.; Chang, S. *Chem. Soc. Rev.* **2004**, *33*, 302–312; (b) Wang, C. Y.; Xi, Z. F. *Chem. Soc. Rev.* **2007**, *36*, 1395–1406; (c) Park, Y. J.; Park, J.-W.; Jun, C.-H. *Acc. Chem. Res.* **2008**, *41*, 222–234; (d) Shao, Z. H.; Zhang, H.-B. *Chem. Soc. Rev.* **2009**, *38*, 2745–2755.

4. For reviews on the use of Lewis acids in organic synthesis, see: (a) *Acid Catalysis in Modern Organic Synthesis*; Yamamoto, H., Ishihara, K., Eds.; Wiley-VCH: Weinheim, 2008; Vols.1 and 2; For examples of synergistic combination of Lewis acids, see: (b) Nicolaou, K. C.; Hwang, C. K.; Duggan, M. E. *J. Am. Chem. Soc.* **1989**, *111*, 6682–6690; (c) Hong, C. Y.; Kishi, Y. *J. Am. Chem. Soc.* **1991**, *113*, 9693–9694; (d) Myers, E. L.; Butts, C. P.; Aggarwal, V. K. *Chem. Commun.* **2006**, 4434–4436; (e) Myers, E. L.; de Vries, J. G.; Aggarwal, V. K. *Angew. Chem., Int. Ed.* **2007**, *46*, 1893–1896.
5. For reviews on the chemistry of chiral bicyclic lactams, see: (a) Romo, D.; Meyers, A. I. *Tetrahedron* **1991**, *47*, 9503–9569; (b) Meyers, A. I.; Brengel, G. P. *Chem. Commun.* **1997**, 1–8; (c) Groaning, M. D.; Meyers, A. I. *Tetrahedron* **2000**, *56*, 9843–9873; (d) Escolano, C.; Amat, M.; Bosch, J. *Chem.—Eur. J.* **2006**, *12*, 8198–8207; (e) Bouet, A.; Oudeyer, S.; Dupas, G.; Marsais, F.; Levacher, V. *Tetrahedron: Asymmetry* **2008**, *19*, 2396–2401.
6. For selected examples, see: (a) Burgess, L. E.; Meyers, A. I. *J. Am. Chem. Soc.* **1991**, *113*, 9858–9859; (b) Meyers, A. I.; Burgess, L. E. *J. Org. Chem.* **1991**, *56*, 2294–2296; (c) Burgess, L. E.; Meyers, A. I. *J. Org. Chem.* **1992**, *57*, 1656–1662; (d) Freville, S.; Célérier, J. P.; Thuy, V. M.; Lhommet, G. *Tetrahedron: Asymmetry* **1995**, *6*, 2651–2654; (e) Jossang, A.; Melhaoui, A.; Bodo, B. *Heterocycles* **1996**, *43*, 755–766; (f) Yamazaki, N.; Ito, T.; Kibayashi, C. *Tetrahedron Lett.* **1999**, *40*, 739–742; (g) Meyers, A. I.; Andres, C. J.; Resek, J. E.; Woodall, C. C.; McLaughlin, M. A.; Lee, P. H.; Price, D. A. *Tetrahedron* **1999**, *55*, 8931–8952; (h) Jiang, J. L.; DeVita, R. J.; Doss, G. A.; Goulet, M. T.; Wyvratt, M. J. *J. Am. Chem. Soc.* **1999**, *121*, 593–594.
7. For recent examples, see: (a) Itoh, T.; Yamazaki, N.; Kibayashi, C. *Org. Lett.* **2002**, *4*, 2469–2472; (b) Penhoat, M.; Levacher, V.; Dupas, G. *J. Org. Chem.* **2003**, *68*, 9517–9520; (c) Bouet, A.; Heller, B.; Papamicaël, C.; Dupas, G.; Oudeyer, S.; Marsais, F.; Levacher, V. *Org. Biomol. Chem.* **2007**, *5*, 1397–1404; (d) Edwards, D. J.; House, D.; Sheldrake, H. M.; Stone, S. J.; Wallace, T. W. *Org. Biomol. Chem.* **2007**, *5*, 2658–2669; (e) Resek, J. E. *J. Org. Chem.* **2008**, *73*, 9792–9794; (f) Pira, S. L.; Wallace, T. W.; Graham, J. P. *Org. Lett.* **2009**, *11*, 1663–1666; (g) Amat, M.; Fabregat, R.; Griera, R.; Bosch, J. *J. Org. Chem.* **2009**, *74*, 1794–1797 and references cited therein; (h) Husain, S. M.; Fröhlich, R.; Schepmann, D.; Wünsch, B. *J. Org. Chem.* **2009**, *74*, 2788–2793.
8. For methods involving cyclic imides, see: (a) Yamazaki, N.; Ito, T.; Kibayashi, C. *Org. Lett.* **2000**, *2*, 465–467; (b) Yamazaki, N.; Dokoshi, W.; Kibayashi, C. *Org. Lett.* **2001**, *3*, 193–196; for related works, see: (c) Mukaiyama, T.; Yamashita, H.; Asami, M. *Chem. Lett.* **1983**, 385–388; (d) Teran, J. L.; Gnecco, D.; Galindo, A.; Juarez, J.; Bernes, S.; Enriquez, R. G. *Tetrahedron: Asymmetry* **2001**, *12*, 357–360.
9. (a) Meyers, A. I.; Lefker, B. A.; Sowin, T. J.; Westrum, L. J. *J. Org. Chem.* **1989**, *54*, 4243–4246; (b) Penhoat, M.; Leleu, S.; Dupas, G.; Papamicaes, C.; Marsais, F.; Levacher, V. *Tetrahedron Lett.* **2005**, *46*, 8385–8389.
10. For selected examples on the Grignard addition to imides, see: (a) Evans, D. A.; Thomas, E. W.; Cherpeck, R. E. *J. Am. Chem. Soc.* **1982**, *104*, 3695–3700; (b) Inoue, Y.; Tazawa, N.; Watanabe, A.; Aoki, Y.; Kakisawa, H. *Bull. Chem. Soc. Jpn.* **1992**, *65*, 2866–2868; (c) Yoda, H.; Kitayama, H.; Yamada, W.; Katagiri, T.; Takabe, K. *Tetrahedron: Asymmetry* **1993**, *4*, 1451–1454; (d) James, G. D.; Mills, S. D.; Pattenden, G. *J. Chem. Soc., Perkin Trans. 1* **1993**, 2567–2579; (e) Kato, Y.; Takemoto, M.; Achiwa, K. *Chem. Pharm. Bull.* **1993**, *41*, 2003–2006; (f) Huang, P.-Q.; Wang, S.-L.; Ye, J.-L.; Ruan, Y.-P.; Huang, Y.-Q.; Zheng, H.; Gao, J. X. *Tetrahedron* **1998**, *54*, 12547–12560; (g) Kim, G.; Lee, E. *Tetrahedron: Asymmetry* **2001**, *12*, 2073–2076; (h) Lebrun, S.; Couture, A.; Deniau, E.; Grandclaudon, P. *Tetrahedron: Asymmetry* **2003**, *14*, 2625–2632; (i) Bailey, P. D.; Morgan, K. M.; Smith, D. I.; Vernon, J. M. *Tetrahedron* **2003**, *59*, 3369–3378; (j) Bahajaj, A. A.; Moore, M. H.; Vernon, J. M. *Tetrahedron* **2004**, *60*, 1235–1246; (k) Kossenjans, M.; Soeberdt, M.; Wallbaum, S.; Harms, K.; Martens, J.; Aurich, H. G. *J. Chem. Soc., Perkin Trans. 1* **1999**, 2353–2365; (l) Garcia, E.; Arrasate, S.; Ardeo, A.; Lete, E.; Sotomayor, N. *Tetrahedron Lett.* **2001**, *42*, 1511–1513.
11. (a) Chen, M.-D.; Zhou, X.; He, M.-Z.; Ruan, Y.-P.; Huang, P.-Q. *Tetrahedron* **2004**, *60*, 1651–1657; (b) Chen, M.-D.; He, M.-Z.; Zhou, X.; Huang, L.-Q.; Ruan, Y.-P.; Huang, P.-Q. *Tetrahedron* **2005**, *61*, 1335–1344.
12. Jiang, L.-J.; Lan, H.-Q.; Zheng, J.-F.; Ye, J.-L.; Huang, P.-Q. *Synlett* **2009**, 297–301.
13. For other methods, see: (a) Allin, S. M.; Northfield, C. J.; Page, M. I.; Slawin, A. M. Z. *J. Chem. Soc., Perkin Trans. 1* **2000**, 1715–1721; (b) Pérard-Viret, J.; Prangé, T.; Tomas, A.; Royer, J. *Tetrahedron* **2002**, *58*, 5103–5108; (c) Deniau, E.; Enders, D.; Couture, A.; Grandclaudon, P. *Tetrahedron: Asymmetry* **2003**, *14*, 2253–2258; (d) Comins, D. L.; Hiebel, A.-C. *Tetrahedron Lett.* **2005**, *46*, 5639–5642; (e) Sun, X.-W.; Liu, M.; Xu, M.-H.; Lin, G.-Q. *Org. Lett.* **2008**, *10*, 1259–1262; (f) Deniau, E.; Couture, A.; Grandclaudon, P. *Tetrahedron: Asymmetry* **2008**, *19*, 2735–2740 and references cited therein.
14. For reviews, see: (a) Kursanov, D. N.; Parnes, Z. N.; Loim, N. M. *Synthesis* **1974**, 633–651; (b) Nagai, Y. *Org. Prep. Proced. Int.* **1980**, *12*, 13–48.
15. For recent reviews, see: (a) Speckamp, W. N.; Moolenaar, M. J. *Tetrahedron* **2000**, *56*, 3817–3856; (b) Maryanoff, B. E.; Zhang, H.-C.; Cohen, J. H.; Turchi, I. J.; Maryanoff, C. A. *Chem. Rev.* **2004**, *104*, 1431–1628; (c) Royer, J. *Chem. Rev.* **2004**, *104*, 2311–2352; (d) Yazici, A.; Pyne, S. G. *Synthesis* **2009**, 339–368; (e) Yazici, A.; Pyne, S. G. *Synthesis* **2009**, 513–541.
16. For reviews, see: (a) Royles, B. J. L. *Chem. Rev.* **1995**, *95*, 1981–2001; (b) Henning, H.-G.; Gelbin, A. *Advances in Heterocyclic Chemistry*; Academic Press: San Diego, CA, 1993; Vol. 57, pp 139–185; (c) Ghisalberti, E. L. *Studies in Natural Products Chemistry, Part 9*; Elsevier: 2003; Vol. 28, pp 109–163; (d) Schobert, R.; Schlenk, A. *Bioorg. Med. Chem.* **2008**, *16*, 4203–4221.
17. For selected methods for the synthesis of optically active tetramic acids and tetramates, see: (a) Fustero, S.; Torre, M. G.; Sanz-Cervera, J. F.; Arellano, C. R.; Piera, J.; Simon, A. *Org. Lett.* **2002**, *4*, 3651–3654; (b) Detsi, A.; Afantitis, A.; Athanasellis, G.; Markopoulos, J.; Igglessi-Markopoulou, O.; Skylaris, C.-K. *Eur. J. Org. Chem.* **2003**, 4593–4600; (c) Jones, R. C. F.; Pillainayagam, T. A. *Synlett* **2004**, 2815–2817; (d) Schobert, R.; Jagusch, C. *Tetrahedron* **2005**, *61*, 2301–2307; (e) Schobert, R.; Dietrich, M.; Mullen, G.; Urbina-Gonzalez, J.-M. *Synthesis* **2006**, 3902–3914; (f) Farran, D.; Parrot, I.; Martinez, J.; Dewynter, G. *Angew. Chem., Int. Ed.* **2007**, *46*, 7488–7490 and references cited therein.
18. Huang, P.-Q.; Lan, H.-Q.; Chen, M.-D.; Zhang, H.-K. *Chin. J. Org. Chem.* **2000**, *20*, 790–794 (in Chinese).