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Organometallic Enantiomeric Scaffolding: Organometallic Chirons. Total Synthesis of (−)-Bao Gong Teng A by a Molybdenum-Mediated [5+2] Cycloaddition

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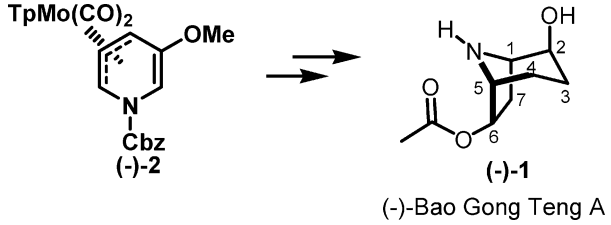
Abstract: Bao Gong Teng A, an optically active tropane alkaloid with hypotensive and miotic activity isolated from the Chinese herb *Erycibe obtusifolia* Benth, was synthesized by an "organometallic chiron" strategy in which single enantiomers of $TpMo(CO)_2(\eta^3$-pyridinyl) complexes are produced in quantity and then elaborated easily and efficiently to generate, after demetalation, highly enantiopure advanced synthetic intermediates possessing the tropane core.

Introduction

In recent years both $TpMo(CO)_2(\eta^3$-pyranyl) and $TpMo(CO)_2$-$(\eta^3$-pyridinyl) complexes have begun to be developed as versatile organometallic enantiomeric scaffolds for the asymmetric construction of a wide variety of heterocyclic systems [Tp = hydridotris(pyrazolyl)borate].[1] Readily available and easily synthesized single enantiomers of these conceptually simple organometallic π-complexes function as *organometallic chirons*[2] from which widely differing families of complex organic structures can be elaborated in an enantiospecific fashion.[3,1b,d−g,i,j] Herein is described an example of the synthetic versatility of the *organometallic chiron* approach, the total synthesis of the Chinese herbal medicine (−)-Bao Gong Teng A **1** from the multipurpose enantiomeric scaffold **2** (Scheme 1).

Scheme 1. (−)-Bao Gong Teng A from "Organometallic Chiron" **2**



Bao Gong Teng A is an optically active tropane alkaloid that was isolated from the Chinese herb *Erycibe obtusifolia* Benth.[4] It has hypotensive and miotic activities and has been used for the treatment of glaucoma.[5] Bao Gong Teng A's biological activity along with its structural features and a limited availability from natural resources has stimulated interest in its synthesis.[6] Two earlier syntheses of **1**[6a,b] utilized an attractive strategy whereby the basic carbon skeleton was constructed via a 1,3-dipolar cycloaddition of dipolarophiles to the betaine of a 3-hydroxypyridinium salt, a reaction developed by Katritzky.[7]

(1) (a) Shu, C.; Liebeskind, L. S. *J. Am. Chem. Soc.* **2003**, *125*, 2878. (b) Arrayás, R. G.; Liebeskind, L. S. *J. Am. Chem. Soc.* **2003**, *125*, 9026. (c) Alcudia, A.; Arrayás, R. G.; Liebeskind, L. S. *J. Org. Chem.* **2002**, *67*, 5773. (d) Shu, C.; Alcudia, A.; Yin, J.; Liebeskind, L. S. *J. Am. Chem. Soc.* **2001**, *123*, 12477. (e) Arrayás, R. G.; Liebeskind, L. S. *J. Am. Chem. Soc.* **2001**, *123*, 6185. (f) Yin, J.; Llorente, I.; Villanueva, L. A.; Liebeskind, L. S. *J. Am. Chem. Soc.* **2000**, *122*, 10458. (g) Moretto, A. F.; Liebeskind, L. S. *J. Org. Chem.* **2000**, *65*, 7445. (h) Malinakova, H. C.; Liebeskind, L. S. *Org. Lett.* **2000**, *2*, 4083. (i) Malinakova, H. C.; Liebeskind, L. S. *Org. Lett.* **2000**, *2*, 3909. (j) Yin, J.; Liebeskind, L. S. *J. Am. Chem. Soc.* **1999**, *121*, 5811. (k) Ward, Y. D.; Villanueva, L. A.; Allred, G. D.; Liebeskind, L. S. *J. Am. Chem. Soc.* **1996**, *118*, 897.

(2) Three fundamentally different approaches have been widely used to address the requirement for control of absolute stereochemistry in organic synthesis: (i) syntheses that use materials originating from the "chiral pool" either as "chirons" (Hanessian, S. *Pure Appl. Chem.* **1993**, *65*, 1189; Hanessian, S. *Total Synthesis of Natural Products: The "Chiron" Approach*; Pergamon Press: Oxford, U.K., 1983) or as auxiliaries (Blaser, H. U. *Chem. Rev.* **1992**, *92*, 935); (ii) enzymatic (Humphrey, A. J.; Turner, N. J. In *Enzyme Chemistry*; 3rd ed.; Suckling, C. J., Gibson, C. L., Pitt, A. R., Eds.; Blackie Academic & Professional: London, 1998; pp 105−136) or classical resolutions; and (iii) metallo- (Ojima, I., Ed. *Catalytic Asymmetric Synthesis*, 2nd ed.; Wiley: New York, 2000) or organocatalytic (Dalko, P. I.; Moisan, L. *Angew. Chem.* **2004**, *43*, 5138; Seayad, J.; List, B. *Org. Biomol. Chem.* **2005**, *3*, 719) asymmetric transformations. *Organometallic chirons* represent a fourth conceptual approach to enantiocontrolled bond construction. This strategy entails the production, in quantity, of a single enantiomer of a metal π-complex of an unsaturated organic ligand and the subsequent synthetic elaboration of the scaffold over a number of steps to generate, after demetalation, an advanced compound possessing multiple stereocenters. In this strategy the stoichiometric nature of the chemistry is mitigated by the use of a *single metal moiety* either to activate the organic ligand for *multiple enantiocontrolled functionalizations* or to open pathways for *unique bond constructions* not easily achieved by traditional synthetic manipulations. Particularly versatile organometallic chirons are conceptually simple yet allow the construction of widely differing families of structures.

(3) Transition metal π-complexes are powerful scaffolds for the enantiocontrolled construction of complex carbo- and heterocycles: (a) Pearson, A. J. In *Advances in Metal-Organic Chemistry*; Liebeskind, L. S., Ed.; JAI: Stamford, CT, 1989; Vol. 1, p 1. (b) Harman, W. D. *Chem. Rev.* **1997**, *97*, 1953. (c) Li, C.-L.; Liu, R. S. *Chem. Rev.* **2000**, *100*, 3127. (d) Pape, A. R.; Kaliappan, K. P.; Kundig, E. P. *Chem Rev.* **2000**, *100*, 2917. (e) Paley, R. S. *Chem. Rev.* **2002**, *102*, 1493. (f) Harman, W. D. *Top. Organomet. Chem.* **2004**, *7*, 95. Also see footnotes 1 and 8.

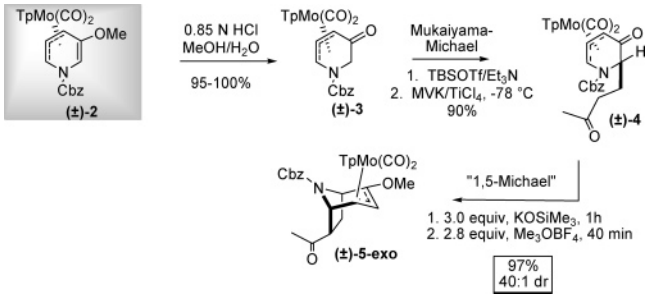
(4) (a) Yao, T.-R.; Chen, Z.-N. *Yaoxue Xuebao* **1979**, *14*, 731; *Chem. Abstr.* **1980**, *93*, 101406n. (b) Yao, T.; Chen, Z.; Yi, D.; Xu, G. *Yaoxue Xuebao* **1981**, *16*, 582; *Chem. Abstr.* **1982**, *96*, 48972c.

(5) (a) Shanger Department of Pharmacology. *Yaoxue Tongbao* **1981**, *16*, 51; *Chem. Abstr.* **1981**, *95*, 126046z. (b) Shanghai Second Medical College. *Yaoxue Tongbao* **1981**, *16*, 55; *Chem. Abstr.* **1981**, *95*, 138453t.

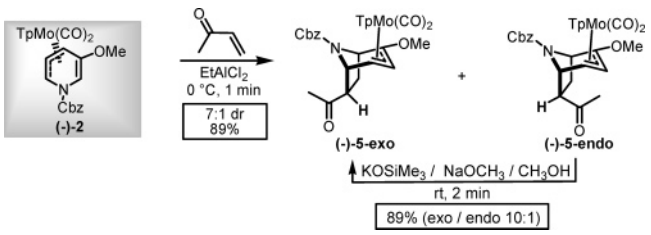
(6) (a) Racemic synthesis: Jung, M. E.; Zeng, L.; Peng, T.; Zeng, H.; Le, Y.; Su, J. *J. Org. Chem.* **1992**, *57*, 3528. (b) Asymmetric synthesis: Pham, V. C.; Charlton, J. L. *J. Org. Chem.* **1995**, *60*, 8051. (c) Synthesis of 6-endo diastereomer: Pei, X. F.; Shen, J. X. *Heterocycles* **1993**, *36*, 2549.

(7) Dennis, N.; Katritzky, A. R.; Takeuchi, T. *Angew. Chem., Int. Ed. Engl.* **1976**, *15*, 1.

Scheme 2. Synthesis of the Racemic Tropane Core **5** via a "1,5-Michael" Reaction



Scheme 3. Synthesis of (−)-**5** via a [5+2] Cycloaddition



Results and Discussion

Organometallic chiron **2** provides the opportunity for two novel molybdenum-mediated approaches to the azabicyclo-[3.2.1]octane framework of Bao Gong Teng A. First, an intramolecular "1,5-Michael" reaction of an enolate to an internal oxo-η^3-allylmolybdenum moiety, as depicted in the conversion **2** → **3** → **4** → **5** in Scheme 2, was explored with racemic **5**, which was easily constructed by (i) gentle acidic hydrolysis of the racemic scaffold **2**[1g,i] to give the oxo-η^3-pyridinyl complex **3** in 95−100% yield followed by (ii) a Mukaiyama-Michael reaction with methyl vinyl ketone (90% yield). Then, by use of the recently described 1,5-Michael procedure,[8] racemic **4** was transformed into (±)-**5** in 97% yield and with 40:1 exo−endo diastereoselectivity.

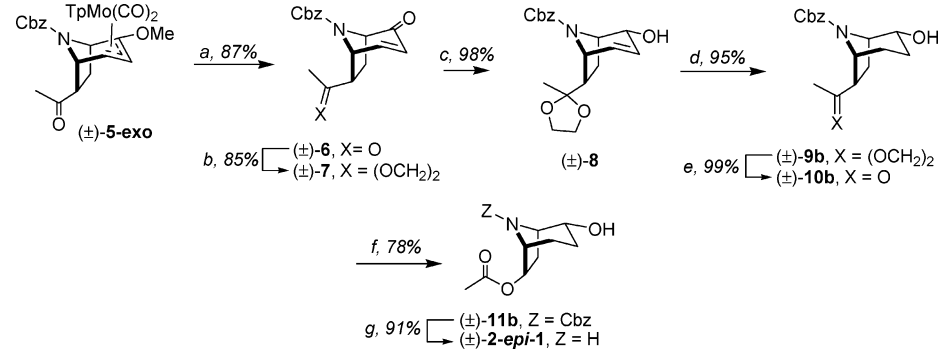
In comparison, the same tropane core **5** could be prepared in one step directly from the $TpMo(CO)_2(\eta^3$-pyridinyl) scaffold **2** by a regio- and stereocontrolled [5+2] cycloaddition of methyl vinyl ketone,[1h,i] albeit with lower exo−endo diastereoselectivity than the "1,5-Michael" sequence (Scheme 3). Nevertheless, the undesired endo isomer was easily epimerized to the desired exo isomer, making the [5+2] protocol the shorter and preferred method for rapidly constructing quantities of the tropane core. Thus, treatment of 3.9 g of >99% ee 5-methoxy η^3-pyridinyl-molybdenum complex (−)-**2** (easily prepared on a 10 g scale according to a previously established protocol[1i]) with 2 equiv of methyl vinyl ketone in the presence of 0.5 equiv of $EtAlCl_2$ furnished a mixture of the two diastereomeric [5+2] cycloadducts (exo/endo = 5:1−7:1) in very high yield within 1 min at 0 °C without degradation of the enantiomeric excess.[9−11] These epimers were readily separated by flash column chromatography. The undesired isomer (−)-*endo*-**5** was then converted to the exo isomer via a base-catalyzed epimerization rendering the [5+2] route to the azabicyclo[3.2.1] core highly efficient overall. In the previous syntheses of Bao Gong Teng A the 1,3-dipolar cycloaddition used to construct the bicyclic skeleton proceeded with lower selectivities (exo/endo = 3:2;[6a] diastereoselectivity + enantioselectivity = 13:7[6b]).

The envisioned total synthesis of Bao Gong Teng A was first probed in the racemic series. As with the previously reported syntheses,[6a,b] two major synthetic challenges must be overcome in elaborating the Bao Gong Teng A substituent pattern: (1) the 2-hydroxyl group must be formed with high exo (axial) stereoselectivity by reduction of the carbonyl group, and 2) the 6-exo acetoxy group must be generated with high efficiency by a Baeyer−Villiger oxidation of the corresponding acetyl group. Beginning with (±)-*exo*-**5**, which was generated with high efficiency from molybdenum scaffold **2** (see Scheme 2), ceric ammonium nitrate- (CAN-) mediated oxidative demetalation afforded the requisite bicyclic diketone (±)-**6** in 87% yield (Scheme 4). Chemoselective protection of the saturated carbonyl group was best accomplished by Lewis acid-promoted ketal exchange[12] between 2-ethyl-2-methyl-1,3-dioxolane and (±)-**6** to produce the enone (±)-**7** in 85% yield. Luche reduction[13] of (±)-**7** gave a single endo (equatorial) diastereomer (±)-**8** of an allylic alcohol in quantitative yield.[14] Catalytic hydrogenation with 5% Pd−C led to reduction of the olefinic double bond as well as cleavage of the *N*-Cbz protecting group to give a secondary amine that was reprotected in situ with CbzCl to provide (±)-**9b** in 95% yield. Subsequent ketone deprotection promoted by catalytic $Pd(CH_3CN)_2Cl_2$[15] gave (±)-**10b**, which was followed by Baeyer−Villiger oxidation to afford racemic *N*-Cbz-2-*epi*-Bao Gong Teng A (±)-**11b** in 77% overall yield from (±)-**9b**.[16] Unfortunately, all attempts to invert the C-2 hydroxyl stereochemistry of **9** by Mitsunobu chemistry led only to the recovery of the endo isomer (±)-**9b**,[17] suggesting a possible double inversion sequence caused by participation of Cbz group.[18] Completion of a synthesis of (±)-2-*epi*-**1** proceeded by removal of the Cbz protecting group via hydrogenolysis (91%).

The inability to invert the stereochemistry of 2-*epi*-**1** necessitated a slightly modified strategy to produce the desired axial C-2 hydroxyl directly from a ketonic precursor. Given our experience with the racemic series chemistry, the successful strategy was carried out with the highly enantiopure exo isomer (−)-**5a** that was produced by the [5+2] cycloaddition of >99% ee 5-methoxy η^3-pyridinylmolybdenum complex (−)-**2** with

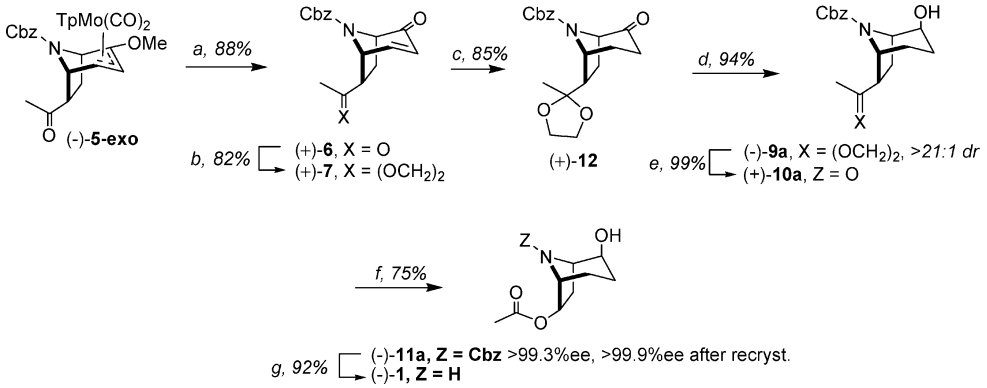
(8) Zhang, Y.; Liebeskind, L. S. *J. Am. Chem. Soc.* **2005**, *127*, 11258.
(9) All molybdenum complexes used in this study are air-stable, yellow to orange solids, and are easily accessible on a multigram scale by simple benchtop techniques.
(10) Previously described conditions for the molybdenum-mediated [5+2] cycloadditions involved the potential risk of partial racemization of the molybdenum complex;[1j] therefore improved conditions described within the Experimental Section were developed to minimize the racemization of (−)-**2**.
(11) The yields are significantly dependent on the quality of the Lewis acid $EtAlCl_2$ and can vary in the range of 40−95%.
(12) McMurry, J. E.; Isser, S. J. *J. Am. Chem. Soc.* **1972**, *94*, 7132.
(13) Gemal, A. L.; Luche, J.-L. *J. Am. Chem. Soc.* **1981**, *103*, 5454.
(14) Reduction of (±)-**7** with $NaBH_4$ in refluxing ethanol afforded a 1:1 mixture of (±)-**8** and its α,β-saturated analogue (±)-**9b** with complete endo selectivity in 85% yield.
(15) Lipshutz, B. H.; Pollart, D.; Monforte, J.; Kotsuki, H. *Tetrahedron Lett.* **1985**, *26*, 705. Alternate methods of deprotection were not as efficient.
(16) Baeyer−Villiger oxidation for this type of bicyclic compound with mCPBA is a slow and low-yielding reaction (54% after 7 days in $CHCl_3$;[6a] 52% after 10 days in 1:2 benzene/$CHCl_3$[6b]). Fortunately, however, Baeyer−Villiger oxidation of (±)-**10b** with recrystallized mCPBA in benzene for 5 days produced the desired ester (±)-**11b** in 77% yield along with the recovery of about 10% of the starting material (±)-**10b**.
(17) Although the intermediate *p*-nitrobenzoate was not isolated, TLC and HPLC analysis of the Mitsunobu reaction mixture showed the disappearance of the starting material and the formation of the new product (assumed to be the *p*-nitrobenzoate). Subsequent basic hydrolysis resulted in the isolation of the endo alcohol rather than its exo isomer.
(18) See references for neighboring-group participation of the Cbz group: (a) Coward, J. K.; Lok, R. *J. Org. Chem.* **1973**, *38*, 2546. (b) Ginsburg, S.; Wilson, I. B. *J. Am. Chem. Soc.* **1964**, *86*, 4716.

Scheme 4. Total Synthesis of (±)-2-*epi*-Bao Gong Teng A



[a] CAN, Et_3N, THF/H_2O, 0 °C to room temperature, 87%. [b] 2-Ethyl-2-methyl-1,3-dioxolane, $BF_3{\cdot}Et_2O$, $CHCl_3$, 35 min, 85%. [c] $NaBH_4$, $CeCl_3{\cdot}7H_2O$, $CHCl_3$/EtOH, −78 °C, 10 min, 98%. [d] (i) Pd/C, H_2, MeOH; (ii) CbzCl, $NaHCO_3$, H_2O/CH_3OH/THF, 95%. [e] $Pd(CH_3CN)_2Cl_2$ (8 mol %), acetone, 99%. [f] mCPBA, benzene, 78%. [g] $Pd(OH)_2$/C, H_2, EtOH/EtOAc, 91%.

Scheme 5. Total Synthesis of (−)-Bao Gong Teng A, (−)-**1**



[a] CAN, Et_3N, THF/H_2O, 0 °C to room temperature, 88%. [b] 2-Ethyl-2-methyl-1,3-dioxolane, $BF_3{\cdot}Et_2O$, $CHCl_3$, 35 min, 82%. [c] $ClRh(PPh_3)_3$, *t*-BuOH/THF, 24 h, 85%. [d] L-Selectride, THF, −78 °C, 1 h, >21:1 dr, 94%. [e] $Pd(CH_3CN)_2Cl_2$ (8%), acetone, 99%. [f] mCPBA, benzene, 75%. [g] $Pd(OH)_2$/C, H_2, EtOH/ EtOAc, 92%.

methyl vinyl ketone (followed by base-induced equilibration of the endo to the exo cycloadduct) as shown in Scheme 3. The reaction sequence from **(−)-*exo*-5** through (+)-**6** to selectively protected (+)-**7** mimicked that used for the racemic series, described above. Rather than attempt reduction on the unsaturated ketone **(+)-7**, the requisite axial C-2 alcohol **(−)-9a** was established after hydrogenation of the double bond of (+)-**7** with Wilkinson's catalyst. Dramatically, reduction of the saturated ketone **(+)-12** with L-Selectride furnished the desired carbinol (−)-**9a** as a colorless oil in high yield (94%) and with excellent stereoselectivity (**9a**:**9b** >21:1). Various other hydride reducing agents such as $NaBH_4$, $LiAl(O\textit{t}\text{-}Bu)_3H$, $LiAlH_4$, and DIBAL in various solvents afforded the undesired endo isomer **9b** as the major component (**9a**:**9b** = 1:20). It is of interest to note that, in the previously published syntheses, hydride reduction of *N-benzyl protected* analogues of the saturated ketone **12** did afford the desired 2-exo alcohol in varying yields and selectivities (for $NaBH_4$, exo/endo = 18:1, yield 59%;[6a] for $LiAl(O\textit{t}\text{-}Bu)_3H$, exo/endo = 3:1, yield 83%[6b]). It is not clear why, in comparison to other reducing agents, L-Selectride is so highly selective for generating the desired axial alcohol when the nitrogen atom of the saturated ketone **(+)-12** is protected with a Cbz group.

Having established the requisite axial alcohol, mild deprotection of the carbonyl group of **(−)-9a** followed by Baeyer−Villiger oxidation furnished *N*-Cbz (−)-Bao Gong Teng A, (−)-**11a**, in 74% overall yield and 99.3% ee with complete retention of configuration at C-6. The ee was further increased to >99.9% by recrystallization from a mixture of methylene chloride and hexanes. Finally, the total synthesis was completed by hydrogenolytic removal of the Cbz protecting group to afford (−)-Bao Gong Teng A (−)-**1** (240 mg), whose spectroscopic data (HRMS, ^1H, ^{13}C NMR) were in good agreement with those reported in the literature.[4,6a,6b,19] This synthesis, together with the X-ray structure of (−)-**11a**, confirmed the proposed absolute configuration of (−)-Bao Gong Teng A.[20] We note that (−)-Bao Gong Teng A produced from this work is a colorless crystalline material with a melting point of 76−8 °C, while the previously reported Bao Gong Teng A, either synthesized[6a,b] or isolated from nature,[4a] was claimed as an oily product. The benzoic acid salt of (−)-Bao Gong Teng A was also prepared and crystallized as colorless needles from benzene (mp 141−3 °C, lit.[4a] 138−9 °C).

Conclusion

The ability of a high enantiopurity $TpMo(CO)_2(\eta^3$-pyridinyl) complex to function as an "organometallic chiron" has been demonstrated by an efficient, concise, and enantiocontrolled construction of (−)-Bao Gong Teng A (Scheme 5). Under the

(19) Bao Gong Teng A from this work: mp 76−78 °C; $[\alpha]^{25}_D$ −29.6° (c = 0.97, EtOH); $[\alpha]^{25}_D$ −21.3° (c = 1.83, H_2O). Bao Gong Teng A benzoic acid salt from this work: mp 141−143 °C [lit.[4a] 138−139 °C]; $[\alpha]^{25}_D$ −13.8° (c = 1.32, EtOH); $[\alpha]^{25}_D$ −10.8° (c = 0.8, H_2O) [lit.[4b] $[\alpha]^{28}_D$ −7.21° (c = 0.97, H_2O)]. Pham and Charlton[6b] reported that the optical rotation of Bao Gong Teng A in their asymmetric synthesis is $[\alpha]^{23}_D$ −7.6° (c = 0.34, H_2O).

(20) Wang, P.; Yao, T.; Chen, Z. *Huaxue Xuebao* **1989**, *47*, 1002; *Chem. Abstr.* **1990**, *113*, 78746.

influence of $EtAlCl_2$ >99% ee (−)-(2*R*)-dicarbonyl[hydridotris-(1-pyrazolyl)borato][(η^3-2,3,4)-1-benzoxycarbonyl -5-methoxy-1,2-dihydropyridin-2-yl]molybdenum reacts with methyl vinyl ketone within 1 min at 0 °C to generate a tropane core [5+2] adduct in 89% yield without loss of ee. This cycloadduct was easily and very efficiently transformed into (−)-Bao Gong Teng A, with a key step being the highly selective generation of the 2-exo alcohol of the natural product.

In the "organometallic chiron" strategy, single enantiomers of a metal π-complex are produced, in quantity, and then elaborated easily and efficiently to generate, after demetalation, highly enantiopure advanced synthetic intermediates. The stoichiometric nature of the depicted chemistry is mitigated by the low cost of molybdenum and the use of a *single metal moiety* to activate the organic ligand for unique bond constructions not easily achieved by traditional synthetic manipulations. Related as well as divergent "organometallic chiron" strategies for the synthesis of other heterocyclic natural products of biological interest are under development.

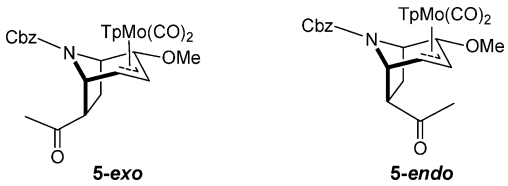
Experimental Section

Since almost all of the Tp molybdenum complexes decompose at about 180−200 °C, melting points are not significant and are not shown in the Experimental Section. Unless otherwise specified, all reactions were carried out under a nitrogen or argon atmosphere, and all reaction flasks were flamed or oven-dried prior to use. The nomenclature for determining the chirality of the molybdenum complexes is straightforward.[21]

Preparation of the Molybdenum Complexes. The racemate (±)-**2** was prepared according to a literature procedure.[1g,i] The experimental procedures and characterization data for **(−)-2** and its precursors are given in the Supporting Information.

(A) (±)-Dicarbonyl[hydridotris(1-pyrazolyl)borato][(2*R*,6*R*)−(η^3-2,3,4)-1-benzyloxycarbonyl-5-oxo-5,6-dihydro-2*H*-pyridin-2-yl]-molybdenum [(±)-3]. To a round-bottomed flask charged with molybdenum complex (±)-**2** (4.51 g, 7.41 mmol) in CH_2Cl_2 (10 mL) was added a solution of HCl in methanol (50 mL, 37% HCl:MeOH: H_2O = 1:12:1 v/v/v) at 0 °C. The solution was stirred for 5 h at room temperature to give an orange suspension. The suspension was extracted with CH_2Cl_2 (50 mL × 3). The organic phases were combined and washed with brine (20 mL × 3). The solvent was removed under reduced pressure to give (±)-**3** as an orange solid (4.4 g, 100%). TLC (R_f = 0.62, hexanes−EtOAc 1:1). IR (CH_2Cl_2, cm^{-1}) 1961 (s), 1864 (s), 1702 (s), 1664 (s). ^{1}H NMR (a mixture of two rotamers): δ 8.45 (d, J = 1.9 Hz, 0.4 H), 8.42 (d, J = 1.9 Hz, 0.6 H), 8.31 (d, J = 1.9 Hz, 0.6 H), 7.76 (d, J = 1.9 Hz, 0.4 H), 7.74 (d, J = 1.9 Hz, 0.6 H), 7.70 (d, J = 1.9 Hz, 0.4 H), 7.65 (d, J = 1.9 Hz, 0.6 H), 7.62 (d, J = 1.9 Hz, 0.6 H), 7.60 (d, J = 1.9 Hz, 0.4 H), 7.58 (d, J = 1.9 Hz, 0.4 H), 7.47−7.52 (m, 1.6 H), 7.40−7.44 (m, 2.0 H), 7.27−7.38 (m, 3.0 H), 7.22 (dd, J = 6.4 and 1.9 Hz, 0.4 H), 6.28−6.30 (m, 1.6 H), 6.22−6.24 (m, 1.0 H), 5.97 (t, J = 2.2 Hz, 0.4 H), 5.27 (AB quartet, J = 11.4 Hz, 0.4 H), 5.24 (s, 0.6 H), 4.74−4.77 (m, 1.0 H), 4.09 (t, J = 6.4 Hz, 0.6 H), 3.98 (t, J = 6.4 Hz, 0.4 H), 3.41 (AB quartet, J = 20.0 Hz, 0.4 H), 3.39 (AB quartet, J = 19.7 Hz, 0.6 H). ^{13}C NMR: δ 225.2, 224.7, 222.8, 222.1, 193.7, 193.0, 154.8, 154.0, 147.5, 147.4, 144.7, 143.6, 141.6, 141.5, 136.7, 136.62, 136.48, 136.44, 135.7, 135.5, 135.0, 129.1, 128.9, 128.8, 128.7, 128.4, 128.0, 106.36, 106.34, 106.1, 106.0, 94.0, 92.4, 69.1, 68.3, 64.7, 64.4, 64.1, 63.6, 48.1, 48.0. HRMS (ESI) calcd for $C_{24}H_{23}BMoN_7O_5$ ($[M + H]^+$): 598.0908. Found: 598.0905.

(B) (±)-Dicarbonyl[hydridotris(1-pyrazolyl)borato][(2*R*,6*R*)-(η^3-2,3,4)-1-benzyloxycarbonyl-5-oxo-6-(3′-oxobutyl)-5,6-dihydro-2*H*-pyridin-2-yl]molybdenum [(±)-4]. To a 30 mL CH_2Cl_2 solution of (±)-**3** (3.0 g, 5.04 mmol) were successively added Et_3N (775 μL, 5.55 mmol) and TBSOTf (1.27 mL, 5.55 mmol). The reaction mixture was stirred at room temperature for about 10 min and was then cooled to −78 °C. To this cold solution was rapidly added a premixed 25 mL CH_2Cl_2 solution of methyl vinyl ketone (MVK; 585 μL, 7.21 mmol) and titanium tetrachloride (1.0 M in CH_2Cl_2, 6.55 mL, 6.55 mmol) via syringe. [The MVK was first dissolved in 10 mL of CH_2Cl_2 and then cooled to −78 °C. To this cold solution was then added titanium chloride (1.0 M solution in CH_2Cl_2) via syringe.] The reaction mixture was stirred at −78 °C for 10 min, quenched with 1 mL of saturated sodium bicarbonate aqueous solution at −78 °C, and then partitioned between brine and dichloromethane. The organic layer was separated and the aqueous layer was extracted with dichloromethane. The organic layers were combined and dried with Na_2SO_4, and solvent was removed under vacuum to afford a crude product. The crude product was purified by flash column chromatography (hexanes−EtOAc 1:1) to afford (±)-**4** as an orange solid (3.03 g, 90%). (±)-**4**: TLC (R_f = 0.58, hexanes−EtOAc 1:1). IR (cm^{-1}): 1969 (s), 1864 (s), 1706 (m), 1664 (m). ^{1}H NMR (a mixture of two rotamers): δ 8.56 (d, J = 1.9 Hz, 0.5 H), 8.42 (d, J = 1.9 Hz, 0.5 H), 8.37 (d, J = 1.9 Hz, 0.5 H), 7.70 (d, J = 1.9 Hz, 0.5 H), 7.67 (s, 1H), 7.64 (d, J = 2.2 Hz, 0.5 H), 7.62 (d, J = 2.2 Hz, 0.5 H), 7.58 (d, J = 2.4 Hz, 0.5 H), 7.53 (d, J = 2.2 Hz, 0.5 H), 7.48−7.52 (m, 2 H), 7.40−7.43 (m, 1 H), 7.35−7.38 (m, 2 H), 7.33 (dd, J = 6.4 and 1.5 Hz, 0.5 H), 7.08 (dd, J = 6.4 and 1.6 Hz, 0.5 H), 6.27−6.30 (m, 1.5 H), 6.23 (t, J = 2.2 Hz, 0.5 H), 6.21 (t, J = 2.2 Hz, 0.5 H), 5.81 (t, J = 2.2 Hz, 0.5 H), 5.24 (s, 0.5 H), 5.23 (AB quartet, J = 11.4 Hz, 0.5 H), 4.74 (dd, J = 6.0 and 1.9 Hz, 0.5 H), 4.71 (dd, J = 6.0 and 1.9 Hz, 0.5 H), 4.03 (t, J = 6.2 Hz, 0.5 H), 3.91 (t, J = 6.2 Hz, 0.5 H), 3.69 (t, J = 6.7 Hz, 0.5 H), 3.61 (dd, J = 7.0 and 5.1 Hz, 0.5 H), 2.44−2.71 (m, 2 H), 2.17 (s, 1.5 H), 2.10 (s, 1.5 H), 2.05−2.15 (m, 2 H). ^{13}C NMR: δ 225.9, 225.2, 222.9, 221.7, 207.8, 207.4, 197.5, 196.9, 154.9, 153.9, 147.6, 147.5, 147.1, 144.6, 140.8, 140.5, 136.7, 136.6, 136.46, 136.39, 135.7, 135.4, 135.09, 135.04, 129.00, 128.96, 128.8, 128.6, 128.4, 106.5, 106.4, 106.05, 106.01, 98.4, 95.3, 69.4, 68.7, 65.2, 64.5, 59.6, 58.8, 57.5, 57.4, 39.6, 39.1, 30.1, 27.3, 26.7. HRMS (FAB) calcd for $C_{28}H_{28}BMoN_7O_6$ (M^+): 667.1248. Found: 667.1245.



(±)-Dicarbonyl[hydridotris(1-pyrazolyl)borato][(1*R*,2*R*,5*S*,6*S*)−(η^3-2,3,4)-6-acetyl-8-benzyloxycarbonyl-2-methoxy-8-azabicyclo-[3.2.1]oct-3-en-2-yl]molybdenum [(±)-*exo*-5], (±)-Dicarbonyl[hydridotris(1-pyrazolyl)borato][(1*R*,2*R*,5*S*,6*R*)−(η^3-2,3,4)-6-acetyl-8-benzyloxycarbonyl-2-methoxy-8-azabicyclo[3.2.1]oct-3-en-2-yl]molybdenum [(±)-*endo*-5], (−)-Dicarbonyl[hydridotris(1-pyrazolyl)borato][(1*R*,2*R*,5*S*,6*S*)-(η^3-2,3,4)-6-acetyl-8-benzyloxycarbonyl-2-methoxy-8-azabicyclo[3.2.1]oct-3-en-2-yl]molybdenum [(−)-*exo*-5], and (−)-Dicarbonyl[hydridotris(1-pyrazolyl)borato][(1*R*,2*R*,5*S*,6*R*)−(η^3-2,3,4)-6-acetyl-8-benzyloxycarbonyl-2-methoxy-8-azabicyclo[3.2.1]oct-3-en-2-yl]molybdenum [(−)-*endo*-5]: (A) 1,5-Michael-Type Addition Reactions to Generate (±)-5. To a solution of the molybdenum complex (±)-**4** (100 mg, 0.15 mmol) in CH_2Cl_2 (7.5 mL) was added solid potassium trimethylsilanolate (57.9 mg, 0.45 mmol). The reaction mixture was stirred at room temperature for 1 h. Me_3OBF_4 (55.5 mg, 0.723 mmol) was added as a solid and the mixture was then stirred at room temperature for 40 min. The reaction mixture was directly poured on a short pad of silica gel. Elution with 50% ethyl acetate in hexanes, concentration, and then flash chromatographic purification afforded the molybdenum complexes (±)-*exo*-**5** (97 mg, 95%) and (±)-*endo*-**5** (2 mg, 2%). Note: the diastereoselectivity is

(21) Sloan, T. E. *Top. Stereochem.* **1981**, *12*, 1.

strongly correlated to the trapping time with the Meerwein salt. HPLC analysis of the reaction mixture indicated a ratio of exo/endo = 17:1 in 4 h after addition of Meerwein salt. Prolongation of the reaction time to 15 h resulted in a ratio of exo/endo = 5:1. (±)-*exo*-**5**: TLC (R_f = 0.49, hexanes−EtOAc 1:1). IR (cm^{-1}): 1930 (s), 1841 (s), 1710 (s). ^1H NMR (a mixture of two rotamers): δ 8.42 (d, J = 1.6 Hz, 0.4 H), 8.39 (d, J = 1.6 Hz, 0.6 H), 7.97 (d, J = 1.9 Hz, 0.6 H), 7.95 (d, J = 1.6 Hz, 0.4 H), 7.63 (d, J = 1.6 Hz, 0.4 H), 7.60 (m, 2.6 H), 7.47 (d, J = 2.2 Hz, 1 H), 7.27−7.34 (m, 5 H), 6.23 (t, J = 2.2 Hz, 1.2 H), 6.18−6.21 (m, 0.8 H), 6.14−6.15 (m, 1 H), 5.08 (AB quartet, J = 12.4 Hz, 0.8 H), 5.03 (AB quartet, J = 12.1 Hz, 1.2 H), 4.77(d, J = 6.0 Hz, 0.6 H), 4.69 (d, J = 3.8 Hz, 0.4 H), 4.65 (d, J = 5.8 Hz, 0.4 H), 4.57 (d, J = 4.1 Hz, 0.6 H), 4.11 (dd, J = 7.6 and 4.1 Hz, 0.4 H), 4.03 (dd, J = 7.6 and 4.1 Hz, 0.6 H), 3.39−3.41 (m, 1 H), 3.33−3.36 (m, 1 H), 3.30 (s, 1.8 H), 3.22 (s, 1.2 H), 2.55−2.61 (m, 1 H), 2.31 (s, 1.2 H), 2.12 (s, 1.8 H), 2.05 (dd, J = 12.4 and 7.9 Hz, 0.6 H), 1.98 (dd, J = 12.9 and 8.1 Hz, 0.4 H). ^{13}C NMR: δ 228.6, 228.3, 227.6, 227.5, 206.0, 205.9, 153.65, 153.56, 146.4, 144.8, 140.68, 140.60, 136.8, 136.6, 136.5, 136.1, 135.70, 135.66, 134.5, 128.5, 128.4, 128.3, 128.1, 127.9, 105.8, 105.6, 67.4, 62.8, 62.4, 59.5, 59.3, 59.14, 59.13, 58.5, 56.8, 56.6, 52.7, 52.4, 33.9, 33.7, 29.2, 29.1. HRMS (FAB) calcd for $C_{29}H_{30}BMoN_7O_6$ (M^+): 681.1405. Found: 681.1415. (±)-*endo*-**5**: TLC (R_f = 0.69, hexanes−EtOAc 1:1). IR (cm^{-1}): 1930 (s), 1845 (s), 1702 (s). ^1H NMR (a mixture of two rotamers): δ 8.42, 8.40 (two singlets, 1 H total), 7.97 (s, 1 H), 7.61, 7.60 (s, 2 H), 7.49 (d, J = 1.9 Hz, 1 H), 7.46 (d, J = 1.9 Hz, 1 H), 7.32−7.44 (m, 6 H), 6.22 (s, 1 H), 6.19 (s, 1 H), 6.15 (t, J = 1.9 Hz, 1 H), 5.18 (AB quartet, J = 12.4 Hz, 0.8 H), 5.15 (AB quartet, J = 12.4 Hz, 1.2 H), 4.94 (s, 0.6 H), 4.87 (s, 0.4 H), 4.67 (d, J = 5.2 Hz, 0.4 H), 4.58 (d, J = 5.2 Hz, 0.6 H), 3.71 (dd, J = 7.6 and 4.3 Hz, 1 H), 3.44 (m, 0.6 H), 3.37 (m, 1 H), 3.31 (m, 0.4 H), 3.27 (s, 1.2 H), 3.23 (s, 1.8 H), 2.60 (m, 1 H), 2.38 (s, 1.8 H), 2.36 (s, 1.2 H), 2.10 (m, 0.4 H), 1.94 (m, 0.6 H). ^{13}C NMR: δ 229.4, 229.0, 227.7, 227.4, 205.32, 205.31, 153.9, 153.4, 146.2, 144.8, 140.3, 140.2, 136.6, 136.5, 136.1, 135.6, 135.4, 134.5, 128.5, 128.1, 105.7, 105.6, 67.6, 59.3, 58.5, 58.2, 57.8, 57.1, 57.0, 56.9, 56.8, 56.0, 53.6, 53.4, 33.0, 32.6, 30.74, 30.67, 29.8. HRMS (FAB) calcd for $C_{29}H_{30}BMoN_7O_6$ (M^+): 681.1405. Found: 681.1418.

(B) [5+2] Cycloadditions to (±)-5 and (−)-5. The previously reported procedure[1i] for [5+2] cycloadditions was modified to shorten the reaction time by increasing the mole percentage of Lewis acid, increasing the mole percentage of MVK, and conducting the reaction at low temperature (0 °C), which increased the yield and reduced the potential risk of racemization of products. To a solution of the molybdenum complex (±)-**2** (3.20 g, 5.38 mmol) and methyl vinyl ketone (874 μL, 10.78 mmol) in dichloromethane (80 mL) at 0 °C was added a 1.0 M solution of $EtAlCl_2$ in hexanes (8.06 mL, 8.06 mmol) via syringe. The reaction was stirred 0 °C for only 1 min. The reaction mixture was poured directly onto a short pad of silica gel. Elution with 50% ethyl acetate in hexanes, concentration, and then flash chromatographic purification afforded the molybdenum complexes (±)-*exo*-**5** (3.66 g, 76.1%) and (±)-*endo*-**5** (0.73 g, 15.2%).

To a solution of the molybdenum complex (−)-**2** (3.64 g, 5.98 mmol) and methyl vinyl ketone (970 μL, 11.96 mmol) in dichloromethane (100 mL) was added a 1.0 M solution of $EtAlCl_2$ in hexanes (2.99 mL, 2.99 mmol) via syringe. The reaction was stirred 0 °C for 1 min. A similar workup afforded the molybdenum complexes (−)-*exo*-**5** (3.27 g, 78%) and (−)-*endo*-**5** (0.46 g, 11%). (−)-*exo*-**5**, $[\alpha]^{25}_D$ −260° (c = 0.83, CH_2Cl_2). (−)-*endo*-**5**, $[\alpha]^{25}_D$ −235° (c = 0.89, CH_2Cl_2).

(C) Base-Catalyzed Isomerization from Endo to Exo Isomers. To a solution of the pure endo isomer (−)-*endo*-**5** (400 mg, 0.587 mmol) in 10 mL of CH_2Cl_2 were added potassium trimethylsilanolate (7.6 mg, 0.059 mmol) and 25 wt % sodium methoxide in methanol (27 μL, 0.119 mmol). The reaction mixture was stirred at ambient temperature for 10 min. HPLC analysis of the mixture indicated a ratio of exo:endo = 10:1. Flash column chromatographic purification afforded the exo isomer (−)-*exo*-**5** (321 mg, 80%) and the endo isomer (−)-*endo*-**5** (35 mg, 9%). Other bases gave poor results (Et_3N, no isomerization; 25 wt % sodium methoxide in methanol overnight, exo:endo = 9.5:1; potassium trimethylsilanolate overnight, exo:endo = 5.2:1; potassium *tert*-butoxide overnight, exo:endo = 1:3.3.).

Synthesis of (±)-2-*epi*-Bao Gong Teng A: (A) (±)-(1*R*,5*R*,6*S*)-6-Acetyl-8-benzyloxycarbonyl-8-azabicyclo[3.2.1]oct-3-en-2-one [(±)-6] and (+)-(1*R*,5*R*,6*S*)-6-Acetyl-8-benzyloxycarbonyl-8-azabicyclo-[3.2.1]oct-3-en-2-one [(+)-6]. To an orange solution of the molybdenum complex (±)-*exo*-**5** (2.23 g, 3.27 mmol) and triethylamine (684 μL, 4.92 mmol) in a 3:1 mixture of THF/H_2O (160 mL) at 0 °C (ice bath) open to air was added a solution of ceric ammonium nitrate (14.33 g, 26.2 mmol) in H_2O (80 mL) dropwise over 5 min. After completion of the addition, the color faded and a light yellow solution formed. The ice bath was removed and the reaction mixture was stirred for an additional 10 min at room temperature and then partitioned between dichloromethane (100 mL) and water (100 mL). The organic layers were washed with brine and dried with Na_2SO_4, and solvents were removed under vacuum to provide the crude product. The crude product was purified by flash chromatography to afford (±)-**6** (850 mg, 87%) as a colorless oil.

(±)-**6.** TLC (R_f = 0.27, hexanes−EtOAc 1:1). IR (cm^{-1}): 1702 (s). ^1H NMR: (a mixture of two rotamers) δ 7.28−7.38 (m, 6 H), 6.03 (dd, J = 9.8 and 1.6 Hz, 1 H), 5.11 (AB quartet, J = 12.4 Hz, 2 H), 5.06 (br s, 1 H), 4.80 (br s, 0.4 H), 4.73 (br s, 0.6 H), 3.04 (dd, J = 9.2 and 3.8 Hz, 1 H), 2.82 (br s, 0.6 H), 2.66 (br s, 0.4 H), 2.29 and 2.24 (br s, 3.4 H), 1.91 (br s, 1.6 H). ^{13}C NMR: δ 204.7, 204.5, 195.5, 195.1, 154.3, 154.1, 151.9, 150.9, 135.9, 128.7, 128.4, 128.15, 128.06, 67.9, 64.3, 56.5, 56.0, 54.8, 53.9, 29.9, 28.5, 27.5, 27.3. HRMS (FAB) calcd for $C_{17}H_{18}NO_4$ ($[M + H]^+$): 300.1236. Found: 300.1230.

Similar treatment of (−)-*exo*-**5** (2.66 g, 3.91 mmol) with triethylamine (816 μL, 5.86 mmol) and CAN (17.14 g, 31.3 mmol) in a 1:1 mixture of THF/H_2O (240 mL) afforded (+)-**6** (1.03 g, 88%) as a colorless oil, $[\alpha]^{25}_D$ +106.5° (c = 0.84, CH_2Cl_2).

(B) (±)-(1*R*,5*R*,6*S*)-8-Benzyloxycarbonyl-6-(1-methyl-1,1-dioxacyclopentyl)-8-azabicyclo[3.2.1]oct-3-en-2-one [(±)-7] and (+)-(1*R*,5*R*,6*S*)-8-Benzyloxycarbonyl-6-(1-methyl-1,1-dioxacyclopentyl)-8-azabicyclo[3.2.1]oct-3-en-2-one [(+)-7]. To a solution of (±)-**6** (1.14 g, 3.76 mmol), 2-ethyl-2-methyl-1,3-dioxolane (2.63 g, 22.6 mmol), and ethylene glycol (67.8 mg, 0.75 mmol) in 150 mL of chloroform was added boron trifluoride diethyl etherate (520 μL, 4.14 mmol) via syringe. The reaction mixture was stirred at ambient temperature for 35 min. Gas chromatographic−mass spectrometric (GC-MS) analysis of the reaction mixture indicated a mixture of three different compounds, (±)-**7** (96%), (±)-**6** (1%), and the doubly protected product (3%). The reaction was quenched with 1 mL of saturated sodium bicarbonate and then partitioned between dichloromethane (50 mL) and brine (100 mL). The organic layer was separated and the aqueous layer was extracted with dichloromethane (30 mL × 2). The organic layers were combined and dried with sodium sulfate, and solvents were removed under vacuum to afford an oily residue. The residue was further purified by flash chromatography to afford (±)-**7** (1.12 g, 85%). Note: the doubly protected product and the starting material (±)-**6** could not be separated efficiently by flash column chromatography. However, treatment of the mixture (~10%) with boron trifluoride etherate in acetone for 7 h gave the starting material (±)-**6** that could be used in the next protection reaction in good yield. This treatment avoided the loss of the starting material (±)-**6**.

(±)-**7.** TLC (R_f = 0.42, hexanes−EtOAc 1:1). IR (cm^{-1}): 1702 (s). ^1H NMR (a 60:40 mixture of two rotamers): δ 7.43 (dd, J = 9.5 and 5.4 Hz, 0.6 H), 7.28−7.37 (m, 5.4 H), 5.97 (d, J = 9.5 Hz, 0.6 H), 5.96 (d, J = 9.5 Hz, 0.4 H), 5.12 (AB quartet, J = 12.4 Hz, 0.8 H), 5.11 (AB quartet, J = 12.4 Hz, 1.2 H), 4.87 (d, J = 5.4 Hz, 0.6 H), 4.76 (m, 1.4 H), 3.88−4.05 (m, 3.6 H), 3.75−3.78 (m, 0.4 H), 2.28−2.39 (m, 2 H), 1.80−1.89 (m, 1 H), 1.28 (s, 1.8 H), 1.25 (s, 1.2 H). ^{13}C NMR: δ 196.4, 196.0, 154.3, 153.9, 152.9, 136.4, 128.72, 128.67, 128.4, 128.3, 128.2, 127.9, 127.5, 127.3, 110.35, 110.28, 67.5, 67.4,

65.4, 65.2, 65.0, 64.83, 64.78, 64.68, 55.8, 55.6, 51.4, 50.5, 28.1, 27.2, 22.3, 21.7. HRMS (FAB) calcd for $C_{19}H_{22}NO_5$ ([M + H]$^+$): 344.1498. Found: 344.1486.

Similar treatment of a mixture of (+)-**6** (1.02 g, 3.41 mmol), 2-ethyl-2-methyl-1,3-dioxolane (2.37 g, 20.5 mmol), and ethylene glycol (61.4 mg, 0.68 mmol) in 120 mL of chloroform with boron trifluoride diethyl etherate (471 μL, 3.75 mmol) afforded (+)-**7** (0.96 g, 82%) as a colorless oil, $[\alpha]^{25}_D$ +95.5° (c = 0.94, CH_2Cl_2).

(C) (±)−(1*R*,2*R*,5*R*,6*S*)-8-Benzyloxycarbonyl-(1-methyl-1,1-dioxacyclopentyl)-8-azabicyclo[3.2.1]oct-3-en-2-ol [(±)-8]. A solution of (±)-**7** (1.00 g, 2.91 mmol) and cerium(III) chloride heptahydrate (1.19 g, 3.19 mmol) in a mixture of ethanol (35 mL) and chloroform (20 mL) was stirred at ambient temperature for 20 min until the cerium salts completely dissolved. The reaction mixture was cooled to −78 °C (dry ice/acetone bath) and then a solution of sodium borohydride (127 mg, 3.35 mmol) in 5 mL of ethanol was added via syringe. The mixture was stirred for 10 min. TLC monitoring of the reaction indicated a very clean conversion. The reaction was quenched with 1 mL of water and then partitioned between dichloromethane (50 mL) and brine (100 mL). The organic layer was separated and the aqueous layer was extracted with dichloromethane (30 mL × 2). The organic layers were combined and dried with sodium sulfate, and solvents were removed under vacuum to afford an oily residue. The residue was further purified by flash column chromatography to afford (±)-**8** (984 mg, 98%) as a colorless oil. (±)-**8**: TLC (R_f = 0.24, hexanes−EtOAc 1:1). IR (cm^{-1}): 3428 (br, s), 1698 (s), 1436 (s). ^{1}H NMR: (a 50:50 mixture of two rotamers) δ 7.30−7.36 (m, 5 H), 6.13 (ddd, J = 9.5, 5.2, and 1.4 Hz, 0.5 H), 6.07 (ddd, J = 9.5, 4.8, and 1.4 Hz, 0.5 H), 5.50 (td, J = 9.8 and 1.9 Hz, 0.5 H), 5.47 (td, J = 9.5 and 1.9 Hz, 0.5 H), 5.14 (AB quartet, J = 12.4 Hz, 1.0 H), 5.13 (AB quartet, J = 12.4 Hz, 1.0 H), 4.81 (d, J = 4.8 Hz, 0.5 H), 4.69 (d, J = 4.8 Hz, 0.5 H), 4.52 (t, J = 6.0 Hz, 0.5 H), 4.50 (d, J = 5.2 Hz, 0.5 H), 4.48 (t, J = 5.7 Hz, 0.5 H), 4.41 (d, J = 5.2 Hz, 0.5 H), 3.83−4.02 (m, 3.5 H), 3.72−3.76 (m, 0.5 H), 2.44 (t, J = 8.8 Hz, 0.5 H), 2.42 (t, J = 8.8 Hz, 0.5 H), 2.35−2.38 (m, 1 H), 2.03 (d, J = 5.2 Hz, 0.5 H), 1.94 (ddd, J = 10.5, 7.6, and 2.9 Hz, 0.5 H), 1.90 (ddd, J = 11.0, 8.1, and 2.9 Hz, 0.5 H), 1.75 (d, J = 6.2 Hz, 0.5 H), 1.22 (s, 1.5 H), 1.18 (s, 1.5 H). ^{13}C NMR: δ 153.7, 153.5, 137.1, 136.9, 134.5, 133.7, 128.7, 128.6, 128.2, 128.1, 128.0, 127.9, 110.71, 110.66, 68.8, 68.3, 67.1, 66.9, 66.3, 65.0, 64.9, 64.6, 57.9, 57.8, 54.5, 54.1, 53.4, 52.7, 25.2, 24.3, 21.8, 21.3. HRMS (FAB) calcd for $C_{19}H_{24}NO_5$ ([M + H]$^+$): 346.1631. Found: 346.1653. Calcd for $C_{19}H_{23}LiNO_5$ ([M + Li]$^+$): 352.1736. Found: 352.1719.

(D) (1) (±)−(1*R*,2*R*,5*R*,6*S*)-8-Benzyloxycarbonyl-6-(1-methyl-1,1-dioxacyclopentyl)-8-azabicyclo[3.2.1]octan-2-ol [(±)-9b]. To a solution of (±)-**8** (100 mg, 0.332 mmol) in methanol (10 mL) was added 5% Pd−C (30 mg). The mixture was stirred overnight under a hydrogen atmosphere and then filtered through a layer of Celite to remove the Pd−C catalyst. The solvent was removed under vacuum to afford the secondary amine (quantitative yield) as a white solid. The solid was dissolved in 12 mL of acetone. To the solution were added potassium carbonate (68.7 mg, 0.448 mmol) and benzyl chloroformate (52.1 μL, 0.365 mmol). The mixture was refluxed for 8 h and the solvent was removed under vacuum. The residue was partitioned between dichloromethane (10 mL) and brine (10 mL). The organic layer was separated and the aqueous layer was extracted with dichloromethane (5 mL × 3). The organic layers were combined and dried with sodium sulfate, and solvents were removed under vacuum to afford an oily crude product. The crude product was further purified by flash column chromatography to afford (±)-**9b** (75 mg, 75%) as a colorless oil.

(2) Alternative Approach to (±)-9b. The free amine (250 mg, 1.18 mmol) was dissolved with a mixture of solvents (12 mL, H_2O:MeOH:THF = 2:1:1). To this solution were added sodium bicarbonate (199 mg, 2.37 mmol) and benzyl chloroformate (236 μL, 1.65 mmol). After the mixture was stirred at ambient temperature for 2 h, brine was added and the mixture was extracted with dichloromethane. The organic layer was dried with sodium sulfate and concentrated under vacuum. The residue was purified by flash column chromatography to afford (±)-**9b** (369 mg, 95%) as a colorless oil.

(±)-**9b.** TLC (R_f = 0.18, hexanes−EtOAc 1:1). IR (cm^{-1}): 3424 (br, s), 1698 (s). ^{1}H NMR (a 55:45 mixture of two rotamers): δ 7.30−7.36 (m, 5 H), 5.133 (AB quartet, J = 12.4 Hz, 1.1 H), 5.132 (s, 0.9 H), 4.31 (br s, 0.45 H), 4.29 (dd, J = 6.7 and 3.3 Hz, 0.55 H), 4.25 (dd, J = 6.7 and 3.3 Hz, 0.45 H), 3.86−4.03 (m, 4.0 H), 3.76−3.79 (m, 1.0 H), 2.09−2.18 (m, 3.0 H), 1.66−1.92 (m, 3.0 H), 1.40−1.56 (m, 2.0 H), 1.25 (s, 1.25 H), 1.21 (s, 1.65 H). ^{13}C NMR: δ 153.7, 153.4, 137.2, 137.0, 128.6, 128.2, 128.1, 127.9, 111.5, 111.4, 68.8, 68.0, 66.9, 66.8, 65.2, 65.0, 64.8, 59.1, 55.0, 54.9, 54.5, 49.9, 49.4, 30.2, 29.6, 26.7, 26.4, 26.2, 25.6, 21.4, 20.9. HRMS (FAB) calcd for $C_{19}H_{26}NO_5$ ([M + H]$^+$): 348.1811. Found: 348.1815.

(E) (±)-(1*R*,2*R*,5*R*,6*S*)-6-Acetyl-8-benzyloxycarbonyl-8-azabicyclo-[3.2.1]octan-2-ol [(±)-10b]. To a solution of (±)-**9b** (41 mg, 0.139 mmol) in acetone (5 mL) was added $Pd(CH_3CN)_2Cl_2$ (1.58 mg, 0.011 mmol). The mixture was stirred at ambient temperature overnight. Water (1 mL) was added to quench the reaction, and the solvent was removed under vacuum. The residue was partitioned between brine and dichloromethane. The organic layer was separated and the aqueous layer was extracted with dichloromethane (5 mL × 3). The organic layers were combined and dried with sodium sulfate, and solvents were removed under vacuum to afford an oily crude product. The crude product was further purified by flash column chromatography to afford (±)-**10b** (36 mg, 99%) as a colorless oil.

(±)-**10b.** TLC (R_f = 0.14, hexanes−EtOAc 1:1). IR (cm^{-1}): 3420 (br, m), 1698 (s). ^{1}H NMR (a 50:50 mixture of two rotamers): δ 7.32−7.38 (m, 5.0 H), 5.09−5.15 (m, 2.0 H), 4.47 (br s, 1.0 H), 4.33 (br s, 0.5 H), 4.26 (br s, 0.5 H), 3.90 (br s, 0.5 H), 3.81 (br s, 0.5 H), 2.84 (m, 1.0 H), 2.16 (s, 1.5 H), 2.22 (s, 1.5 H), 2.07−2.30 (m, 2.0 H), 1.88−2.01 (m, 2.0 H), 1.61−1.78 (m, 2.0 H), 1.42−1.49 (m, 1.0 H). ^{13}C NMR: δ 207.3, 153.8, 153.7, 136.7, 128.7, 128.2, 128.1, 128.0, 68.2, 67.6, 67.2, 59.1, 55.7, 55.2, 54.5, 53.9, 29.7, 29.2, 28.2, 28.1, 26.3, 25.9, 25.4, 25.2. HRMS (FAB) calcd for $C_{17}H_{22}NO_4$ ([M + H]$^+$): 304.1549. Found: 304.1537. Calcd for $C_{17}H_{21}LiNO_4$ ([M + Li]$^+$): 310.1631. Found: 310.1635.

(F) (±)-(1*R*,2*R*,5*R*,6*S*)-6-Acetyloxy-8-benzyloxycarbonyl-8-azabicyclo[3.2.1]octan-2-ol [(±)-11b]. To a solution of (±)-**10b** (85 mg, 0.28 mmol) in 6 mL of benzene was added *m*-chloroperbenzoic acid (purified by recrystallization of the commercially available material from CH_2Cl_2 until the ^{1}H NMR spectrum showed it was pure) (146 mg, 0.84 mmol). The reaction mixture was stirred at ambient temperature for 2 days, and an additional amount of mCPBA (97 mg, 0.56 mmol) was added. The mixture was stirred for an additional 3 days. Brine and saturated aqueous $NaHCO_3$ solution were added, the organic layer was separated, and the aqueous layer was extracted with dichloromethane (5 mL × 3). The organic layers were combined, washed with a 1:1 mixture of brine and saturated aqueous $NaHCO_3$ solution and then with saturated aqueous $Na_2S_2O_3$ solution, and dried with sodium sulfate. The solvents were removed under vacuum to afford an oily crude product. The crude product was further purified by flash column chromatography to afford (±)-**11b** (69.8 mg, 78%) as a colorless solid.

(±)-**11b.** TLC (R_f = 0.41, hexanes−EtOAc 1:3). M.p. 89−90 °C. IR (cm^{-1}): 3428 (br, m), 1729 (sh, s), 1702 (s). ^{1}H NMR (a 55:45 mixture of two rotamers): δ 7.32−7.38 (m, 5.0 H), 5.16 (s, 0.9 H), 5.15 (AB quartet, J = 12.4 Hz, 1.1 H), 4.992 (dd, J = 7.6 and 2.9 Hz, 0.45 H), 4.986 (dd, J = 7.7 and 2.4 Hz, 0.55 H), 4.39 (dd, J = 7.2 and 2.9 Hz, 0.55 H), 4.31 (dd, J = 7.2 and 2.9 Hz, 0.45 H), 4.20 (br s, 0.45 H), 4.15 (br s, 0.55 H), 3.88 (dt, J = 9.9 and 4.9 Hz, 0.55 H), 3.79 (dd, J = 9.3 and 5.0 Hz, 0.45 H), 2.49 (dd, J = 13.6 and 4.5 Hz, 0.45 H), 2.48 (dd, J = 13.6 and 4.5 Hz, 0.55 H), 2.05 (s, 1.35 H), 2.00 (s, 1.65 H), 1.84−1.95 (m, 2.0 H), 1.60−1.79 (m, 3.0 H), 1.26−1.36 (m, 1.0 H). ^{13}C NMR: δ 171.14, 171.10, 154.3, 154.0, 136.7, 128.7, 128.3, 128.2, 127.9, 77.2, 76.4, 67.7, 67.20, 67.16, 67.12, 59.6, 59.3,

58.98, 58.89, 32.4, 31.5, 26.6, 26.5, 26.1, 25.8, 21.34, 21.27. HRMS (FAB) calcd for $C_{17}H_{22}NO_5$ ([M + H]$^+$): 320.1498. Found: 320.1503.

(G) (±)-(1*R*,2*R*,5*R*,6*S*)-6-Acetyloxy-8-azabicyclo[3.2.1]octan-2-ol [(±)-2-*epi*-1]. To a solution of (±)-**11b** (189 mg, 0.59 mmol) in 16 mL of mixed solvents (EtOH/EtOAc = 1:1) was added 20% $Pd(OH)_2/C$ (33 mg, 0.047 mmol). The mixture was stirred overnight under a hydrogen atmosphere and filtered through a piece of filter paper to remove the Pd−C catalyst. The solvents were removed under vacuum to afford (±)-2-*epi*-**1** (100 mg, 91%) as a colorless crystalline solid. (±)-2-*epi*-**1**: mp=146−148 °C. IR (cm^{-1}): 3462 (sh, m), 3281 (br, m), 1725 (s), 1656 (w). ^{1}H NMR: 5.01 (dd, *J* = 7.2 and 2.4 Hz, 1.0 H), 3.80 (ddd, *J* = 10.0, 5.7, and 3.6 Hz, 1.0 H), 3.57 (dd, *J* = 7.2 and 3.3 Hz, 1.0 H), 3.30 (br s, 1.0 H), 2.44 (dd, *J* = 14.3 and 7.2 Hz, 1.0 H), 2.07−2.23 (br s, exchangeable, 2.0 H), 2.05 (s, 3.0 H), 1.91 (td, *J* = 13.9 and 5.2 Hz, 1.0 H), 1.67−1.71 (m, 2.0 H), 1.58 (ddt, *J* = 13.3, 9.1, and 3.3 Hz, 1.0 H), 1.18 (ddt, *J* = 13.3, 10.5, and 6.2 Hz, 1.0 H). ^{13}C NMR: δ 171.0, 78.4, 69.2, 60.8, 60.2, 33.8, 27.35, 27.17, 21.5. HRMS (FAB) calcd for $C_9H_{16}NO_3$ ([M + H]$^+$): 186.1130. Found: 186.1132.

Synthesis of (−)-Bao Gong Teng A: (A) (±)-(1*R*,5*R*,6*S*)-8-Benzyloxycarbonyl-6-(1-methyl-1,1-dioxacyclopentyl)-8-azabicyclo[3.2.1]octan-2-one [(±)-12] and (+)-(1*R*,5*R*,6*S*)-8-Benzyloxycarbonyl-6-(1-methyl-1,1-dioxacyclopentyl)-8-azabicyclo[3.2.1]octan-2-one [(+)-12]. To a solution of (±)-**7** (747 mg, 2.18 mmol) in 40 mL of mixed solvents (*t*-BuOH/THF = 1:1) was added $ClRh(PPh_3)_3$ (161 mg, 0.174 mmol). The mixture was stirred under a hydrogen atmosphere for 24 h. Brine (1 mL) was added to quench the reaction and the solvent was removed under vacuum. The residue was partitioned between brine and dichloromethane. The organic layer was separated and the aqueous layer was extracted with dichloromethane. The organic layers were combined and dried with sodium sulfate, and solvents were removed under vacuum to afford an oily crude product. The crude product was further purified by flash column chromatography to afford (±)-**12** (642 mg, 86%) as a colorless oil.

(±)-**12.** TLC (R_f = 0.36, hexanes−EtOAc 1:1). IR (cm^{-1}): 1729 (sh, s), 1702 (s). ^{1}H NMR (a 60:40 mixture of two rotamers): δ 7.31−7.37 (m, 5.0 H), 5.15 (AB quartet, *J* = 11.9 Hz, 0.8 H), 5.13 (AB quartet, *J* = 12.4 Hz, 1.2 H), 4.59 (d, *J* = 8.1 Hz, 0.4 H), 4.53−4.55 (m, 1.2 H), 4.46 (br s, 0.4 H), 3.89−4.05 (m, 3.6 H), 3.76−3.82 (m, 0.4 H), 2.39−2.46 (m, 3.0 H), 2.12−2.26 (m, 2.0 H), 1.86−1.99 (m, 2.0 H), 1.29 (s, 1.8 H), 1.25 (s, 1.2 H). ^{13}C NMR: δ 205.39, 205.34, 154.0, 153.8, 136.6, 128.6, 128.33, 128.26, 128.15, 127.8, 110.9, 67.4, 67.2, 65.30, 65.25, 65.13, 65.06, 64.98, 64.85, 55.0, 54.7, 50.1, 49.4, 33.0, 31.3, 30.9, 30.7, 30.4, 21.7, 21.3. HRMS (FAB) calcd for $C_{19}H_{24}NO_5$ ([M + H]$^+$): 346.1654. Found: 344.1653. Calcd for $C_{19}H_{23}LiNO_5$ ([M + Li]$^+$): 352.1736. Found: 352.1719.

Similar treatment of a mixture of (+)-**7** (800 mg, 2.33 mmol) and $ClRh(PPh_3)_3$ (173 mg, 0.186 mmol) in 60 mL of mixed solvents (*t*-BuOH/THF = 1:1) afforded (+)-**12** (684 mg, 85%) as a colorless oil, $[\alpha]^{25}_D$ +26.2° (*c* = 0.91, CH_2Cl_2).

(B) (±)-(1*R*,2*S*,5*R*,6*S*)-8-Benzyloxycarbonyl-6-(1-methyl-1,1-dioxacyclopentyl)-8-azabicyclo[3.2.1]octan-2-ol [(±)-9a] and (−)-(1*R*,2*S*,5*R*,6*S*)-8-Benzyloxycarbonyl-6-(1-methyl-1,1-dioxacyclopentyl)-8-azabicyclo[3.2.1]octan-2-ol [(−)-9a]. A solution of (±)-**12** (149 mg, 0.432 mmol) in THF (20 mL) was cooled to −78 °C. To this solution was added L-Selectride (1.0 M in THF, 1.08 mL, 1.08 mmol) via syringe. The mixture was stirred at the same temperature for 1 h. Water (1 mL) was added to quench the reaction, and the mixture was extracted with dichloromethane. The organic layer was dried with sodium sulfate and concentrated under vacuum. The residue was purified by flash column chromatography to afford (±)-**9b** (7.4 mg, 4%) and (±)-**9a** (154 mg, 90%) as colorless oils.

(±)-**9a.** TLC (R_f = 0.2, hexanes−EtOAc 1:3). IR (cm^{-1}): 3439 (br, m), 1687 (s). ^{1}H NMR (a 60:40 mixture of two rotamers): δ 7.27−7.38 (m, 5 H), 5.164 (AB quartet, *J* = 12.9 Hz, 1.2 H), 5.145 (AB quartet, *J* = 12.4 Hz, 0.8 H), 4.42−4.36 (m, 1.0 H), 4.39 (dd, *J* = 7.6 and 2.9 Hz, 0.4 H), 4.29 (br s, 0.6 H), 3.86−4.01 (m, 3.4 H), 3,81 (br s, 0.6 H), 3.76−3.81 (m, 0.6 H), 3.70 (br s, 0.4 H), 2.25 (m, 1.0 H), 2.00−2.02 (m, 1.0 H), 1.91−1.97 (m, 1.0 H), 1.62−1.79 (m, 4.0 H), 1.37−1.46 (m, 1.0 H), 1.24 (s, 1.2 H), 1.20 (s, 1.8 H). ^{13}C NMR: δ 155.2, 154.4, 137.1, 136.9, 128.5, 127.93, 127.86, 127.84, 127.66, 111.3, 111.2, 69.7, 69.0, 66.9, 66.6, 65.1, 64.9, 64.7, 64.6, 59.7, 59.2, 55.6, 55.1, 48.4, 48.0, 29.5, 28.7, 27.4, 27.0, 24.7, 24.5, 21.6, 20.8. HRMS (FAB) calcd for $C_{19}H_{26}NO_5$ ([M + H]$^+$): 348.1811. Found: 348.1798.

Similar treatment of (+)-**12** (730 mg, 2.14 mmol) with L-Selectride (5.36 mL, 5.36 mmol) in 70 mL of THF at −78 °C afforded (−)-**9b** (29 mg, 4%) [$[\alpha]^{25}_D$ −12.0° (*c* = 1.51, CH_2Cl_2)] and (−)-**9a** (655 mg, 90%) [$[\alpha]^{25}_D$ −9.4° (*c* = 0.90, CH_2Cl_2)].

(C) (±)-(1*R*,2*S*,5*R*,6*S*)-6-Acetyl-8-benzyloxycarbonyl-8-azabicyclo-[3.2.1]octan-2-ol [(±)-10a] and (+)-(1*R*,2*S*,5*R*,6*S*)-6-Acetyl-8-benzyloxycarbonyl-8-azabicyclo[3.2.1]octan-2-ol [(+)-10a]. To a solution of (±)-**9a** (750 mg, 2.16 mmol) in acetone (50 mL) was added $Pd(CH_3CN)_2Cl_2$ (24.6 mg, 0.173 mmol). The mixture was stirred at ambient temperature overnight. Water (5 mL) was added to quench the reaction and the solvent was removed under vacuum. The residue was partitioned between brine and dichloromethane. The organic layer was separated, and the aqueous layer was extracted with dichloromethane. The organic layers were combined and dried with sodium sulfate, and solvents were removed under vacuum to afford an oily crude product. The crude product was further purified by flash column chromatography to afford (±)-**10a** (648 mg, 99%) as a colorless oil.

(±)-**10a.** TLC (R_f = 0.18, hexanes−EtOAc 1:3). IR (cm^{-1}): 3439 (br, m), 1695 (s). ^{1}H NMR (50 °C): δ 7.27−7.38 (m, 5.0 H), 5.15 (s, 2.0 H), 4.55 (br s, 1.0 H), 4.46 (br s, 1.0 H), 3.79 (br s, 1.0 H), 2.91 (dd, *J* = 9.1 and 5.2 Hz, 1.0 H), 2.39 (br s, 1.0 H), 2.15−2.21 (m, 4.0 H), 1.71−1.80 (m, 3.0 H), 1.51 (s, 3.0 H). ^{13}C NMR: δ 207.1, 155.3, 154.8, 136.6, 128.6, 128.1, 127.9, 69.3, 68.8, 67.2, 59.6, 59.9, 56.3, 53.1, 52.6, 28.2, 27.1, 26.7, 24.4. HRMS (FAB) calcd for $C_{17}H_{22}NO_4$ ([M + H]$^+$): 304.1549. Found: 304.1540. Calcd for $C_{17}H_{21}LiNO_4$ ([M + Li]$^+$): 310.1631. Found: 310.1640.

Similar treatment of (−)-**9a** (643 mg, 1.85 mmol) with $Pd(CH_3CN)_2Cl_2$ (26.3 mg, 0.185 mmol) in 40 mL of acetone afforded (+)-**10a** (558 mg, 99%) [$[\alpha]^{25}_D$ +1.5° (*c* = 1.09, CH_2Cl_2)] as a colorless oil.

(D) (±)-(1*R*,2*S*,5*R*,6*S*)-6-Acetyloxy-8-benzyloxycarbonyl-8-azabicyclo[3.2.1]octan-2-ol [(±)-11a] and (−)-(1*R*,2*S*,5*R*,6*S*)-6-Acetyloxy-8-benzyloxycarbonyl-8-azabicyclo[3.2.1]octan-2-ol [(−)-11a]. To a solution of (±)-**10a** (280 mg, 0.924 mmol) in 20 mL of benzene was added *m*-chloroperbenzoic acid (478 mg, 2.77 mmol, recrystallized from CH_2Cl_2). The reaction mixture was stirred at ambient temperature for 2 days, and an additional amount of recrystallized mCPBA (319 mg, 1.85 mmol) was added. The mixture was stirred for an additional 2 days, and then an additional amount of recrystallized mCPBA (159 mg, 0.92 mmol) was added. The mixture was stirred for another 2 days. Brine and saturated aqueous $NaHCO_3$ solution were added, the organic layer was separated, and the aqueous layer was extracted with dichloromethane (10 mL × 3). The organic layers were combined, washed with a 1:1 mixture of brine and saturated aqueous $NaHCO_3$ solution and then with saturated aqueous $Na_2S_2O_3$ solution, and dried with sodium sulfate. The solvents were removed under vacuum to afford an oily crude product. The crude product was further purified by flash column chromatography to afford (±)-**11a** (220 mg, 75%) as a colorless oil and the recovered starting material (±)-**10a** (22 mg, 8%).

(±)-**11a.** TLC (R_f = 0.27, hexanes−EtOAc 1:1). IR (cm^{-1}): 3451 (br, m), 1737 (sh, s), 1695 (s). ^{1}H NMR (a 60:40 mixture of two rotamers): δ 7.32−7.38 (m, 5.0 H), 5.14−5.23 (m, 2.0 H), 5.08 (d, *J* = 6.7 Hz, 1.0 H), 4.54 (br s, 0.6 H), 4.45 (br s, 0.4 H), 4.33 (br s, 0.4 H), 4.23 (br s, 0.6 H), 3.80 (br s, 0.6 H), 3.70 (br s, 0.4 H), 2.44 (br s, 0.4 H), 2.17 (d, *J* = 7.1 Hz, 0.4 H), 2.15 (d, *J* = 7.1 Hz, 0.6 H), 1.95−2.03 (m, 5.0 H), 1.87 (br s, 0.6 H), 1.59−1.68 (m, 3.0 H). ^{13}C NMR: δ 171.0, 156.1, 155.1, 136.8, 128.7, 128.2, 128.1, 127.8, 76.5, 75.9, 69.3, 68.8, 67.2, 60.4, 60.2, 59.4, 59.0, 35.8, 35.1, 24.7, 24.6, 24.2,

23.6, 21.2. HRMS (FAB) calcd for $C_{19}H_{25}LiNO_5$ ([M + Li]$^+$): 326.1580. Found: 326.1571.

Similar treatment of (+)-**10a** (600 mg, 2.0 mmol) with *m*-chloroperbenzoic acid recrystallized from CH_2Cl_2 (2.07 g, 12.0 mmol), which was added in three portions at 2-day intervals (first portion, 6 mmol; second portion, 4 mmol; third portion, 2 mmol) in 42 mL of benzene afforded (−)-**11a** (472 mg, 75%) as a colorless crystalline solid and the recovered starting material (+)-**10a** (56 mg, 9%). (−)-**11a**: mp 141−142 °C. $[\alpha]^{25}_D$ −36.3° (c = 1.16, CH_2Cl_2).

(E) (±)-(1*R*,2*S*,5*R*,6*S*)-6-Acetyloxy-8-azabicyclo[3.2.1]octan-2-ol [(±)-1] and (±)-(1*R*,2*S*,5*R*,6*S*)-6-Acetyloxy-8-azabicyclo[3.2.1]octan-2-ol [(−)-1, (−)-Bao Gong Teng A]. To a solution of (±)-**11a** (210 mg, 0.66 mmol) in 20 mL of mixed solvents (EtOH/EtOAc = 1:1) was added 20% $Pd(OH)_2$/C (40 mg, 0.057 mmol). The mixture was stirred overnight under a hydrogen atmosphere and filtered through a piece of filter paper to remove the Pd−C catalyst. The solvents were removed under vacuum to afford (±)-**1** (109 mg, 90%) as a colorless crystalline solid.

(±)-**1.** mp= 86−7 °C. IR (cm^{-1}): 3385 (sh, s), 3300 (br, s), 1725 (s), 1656 (m). ^{1}H NMR: δ 5.14 (dd, J = 6.7 and 2.4 Hz, 1.0 H), 3.58−3.59 (m, 2.0 H), 3.33 (br s, 1.0 H), 2.30−2.99 (br s, exchangeable, 2.0 H), 2.18 (dd, J = 14.3 and 6.7 Hz, 1.0 H), 2.05 (s, 3.0 H), 1.87−1.92 (m, 1.0 H), 1.80 (ddd, J = 14.4, 7.2, and 1.7 Hz, 1.0 H), 1.50−1.60 (m, 3.0 H). ^{13}C NMR: δ 170.9, 78.2, 67.6, 61.3, 60.7, 37.4, 25.2, 24.9, 21.4. HRMS (FAB) calcd for $C_9H_{16}NO_3$ ([M + H]$^+$): 186.1130. Found: 186.1122.

Similar treatment of (−)-**11a** (410 mg, 1.29 mmol) with 20% $Pd(OH)_2$/C (72 mg, 0.103 mmol) in 36 mL of mixed solvents (EtOH/EtOAc = 1:1) afforded (−)-**1** (220 mg, 92%) as a colorless crystalline solid: mp 76−78 °C; $[\alpha]^{25}_D$ −29.6° (c = 0.97, EtOH); $[\alpha]^{25}_D$ −21.3° (c = 1.83, H_2O). [lit.[6b] $[\alpha]^{25}_D$ −7.6° (c = 0.34, H_2O)].

(F) (−)-Bao Gong Teng A Benzoic Acid Salts. To a solution of (−)-**1** (22 mg, 0.12 mmol) in 4 mL of mixed solvents (EtOH/$CHCl_3$ = 1:1) was added benzoic acid (16 mg, 0.131 mmol). The mixture was stirred at ambient temperature for 10 min. The solvents were removed under vacuum to afford a crude product. The crude product was washed three times with a 1:1 mixture of benzene and hexanes to afford (−)-Bao Gong Teng A benzoic acid salt (34 mg, 93%) as a colorless crystalline solid. This product could be further purified by recrystallization from benzene.

(−)-Bao Gong Teng A Benzoic Acid Salt. mp = 141−143 °C; (lit.[4a] mp = 138−9 °C). $[\alpha]^{25}_D$ −13.8° (c = 1.32, EtOH); $[\alpha]^{25}_D$ −10.8° (c = 0.8, H_2O). [lit.[4b] $[\alpha]^{28}_D$ −7.21° (c = 0.97, H_2O)]. IR (cm^{-1}): 3416 (sh, s), 3300 (br, s), 1725 (s), 1656 (m). ^{1}H NMR: δ 8.09 (dd, J = 7.2 and 1.0 Hz, 2.0 H), 7.55 (dt, J = 7.2 and 1.0 Hz, 1.0 H), 7.62 (t, J = 7.6 Hz, 2.0 H), 5.27 (br s, 3.0 H), 5.13 (dd, J = 7.2 and 1.9 Hz, 1.0 H), 3.94 (br s, 1.0 H), 3.76 (br s, 1.0 H), 3.62 (br s, 1.0 H), 2.25 (dd, J = 14.8 and 7.2 Hz, 1.0 H), 2.07−2.16 (m, 1.0 H), 2.00 (s, 3.0 H), 1.98−2.02 (m, 1.0 H), 1.63−1.73 (m, 1.0 H), 1.61−1.65 (m, 2.0 H). ^{13}C NMR: δ 173.0, 171.0, 131.5, 129.8, 128.2, 74.9, 66.8, 60.53, 60.57, 34.5, 24.0, 23.4, 21.0.

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Supporting Information Available: Experimental procedures, synthesis, and characterization of the molybdenum complex **(−)-2** and X-ray crystallographic studies of **(−)-11a** (21 pages, print/PDF); copies of ^{1}H and ^{13}C NMR spectra of all compounds in addition to HPLC analysis of **(±)-11a**, and (−)-**11a** (38 pages, print/PDF). This material is available free of charge via the Internet at http://pubs.acs.org.

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