Mercuric Triflate Catalyzed Hydroxylative Carbocyclization of 1,6-Enynes

Mugio Nishizawa,* Veejendra K. Yadav,[†] Mariusz Skwarczynski, Hiroko Takao, Hiroshi Imagawa, and Takumichi Sugihara

Faculty of Pharmaceutical Sciences, Tokushima Bunri University Yamashiro-cho, Tokushima 770-8514, Japan

General procedure: Mercuric triflate was prepared by adding triflic anhydride to a stirred suspension of yellow mercuric oxide in CH₃CN. To a solution of an enyne (1 mmol) and H₂O (5 mmol) in CH₃NO₂ (9 mL) was added a 0.1 M solution of Hg(OTf)₂ in CH₃CN (0.01 mmol), and the resulting mixture was stirred for 20 h at room temperature. The reaction was quenched with saturated aqueous NaCl and NaHCO₃ (5 mL each) and the product was extracted into EtOAc that was dried and concentrated. Column chromatography of the crude material with mixtures of hexane and EtOAc afforded the product.

1. ¹H NMR (300 MHz, CDCl₃): δ 5.38-5.31 (1H, m), 4.14-4.13 (2H, dd, J = 2.4, 0.9 Hz), 4.08-4.05 (2H, dd, J = 7.2, 0.3 Hz), 2.44-2.42 (1H, dt, J = 2.4, 0.9 Hz), 1.77 (3H, s), 1.71 (3H, s). ¹³C NMR (50 MHz, CDCl₃): δ 138.4, 120.1, 80.0, 74.1, 65.9, 56.7, 25.8, 18.0.

Miura, K.; Saito, H.; Fujisawa, N.; Hosomi, A. *J. Org. Chem.* **2000**, *65*, 8119-8122.

2. ¹H NMR (300 MHz, CDCl₃): δ 5.19-5.16 (1H, q, J = 2.4 Hz), 5.10-5.09 (1H, q, J = 2.1 Hz), 4.37-4.22 (2H, m), 4.03-3.98 (1H, dd, J = 9.6, 3.3 Hz), 3.94-3.88 (1H, dd, J = 9.6, 6.6 Hz), 2.71-2.67 (1H, m), 1.87 (1H, bs), 1.25 (3H, s), 1.23 (3H, s). ¹³C NMR (50 MHz, CDCl₃): δ 148.8, 107.5, 71.91, 71.88, 71.0, 54.8, 27.3, 26.9. Calcd m/z for C₈H₁₃O₂ [M-H]⁺ = 141.0916; observed m/z = 141.0899. Mendez, M.; Munoz, M. P.; Nevado, C.; Cardenas, D. J.; Echavarren, A. M. *J. Am. Chem. Soc.* **2001**, *123*, 10511-10520; Mendez, M.; Muniz, M. P.; Echavarren, A. M. *J. Am. Chem. Soc.* **2000**, *122*, 11549-11550.

4. ¹H NMR (300 MHz, CDCl₃): δ 7.41-7.22 (5H, m), 6.68-6.62 (1H, d, J = 15.9 Hz), 6.33-6.23 (1H, dt, J = 15.9, 6 Hz), 4.26-4.23 (2H, dd, J = 6.3, 1.5 Hz), 4.21-4.20 (2H, dd, J = 2.4, 0.6 Hz), 2.47-2.45 (1H, dt, J = 2.4, 0.3 Hz). ¹³C NMR (75 MHz, CDCl₃): δ 136.4, 133.4, 128.5, 127.8, 126.5, 124.9, 79.6, 74.5, 70.2, 57.0. Miura, K.; Saito, H.; Fujisawa, N.; Hosomi, A. *J. Org. Chem.* **2000**, *65*, 8119-8122; Trost, B. M.; Edstrom, E. D.; C.-Petillo, M. B. *J. Org. Chem.* **1989**, *54*, 4489-4490; Barluenga, J.; Aznar, F.; Liz, R.; Bayod, M. *J. Org. Chem.* **1987**, *52*, 5190-5194.

5. ^1H NMR (300 MHz, CDCl_3): δ 7.32-7.22 (5H, m), 4.87 (1H, d, J = 2.1 Hz), 4.66-4.63 (1H, d, J = 6.9 Hz), 4.46 (1H, d, J = 2.1 Hz), 4.28-4.15 (2H, m), 4.10-4.05 (1H, dd, J = 9, 4.8 Hz), 3.82-3.77 (1H, dd, J = 9, 6.6 Hz), 3.02 (1H, bs), 2.98-2.92 (1H, m). ^{13}C NMR (75 MHz, CDCl_3): δ 147.6, 142.4, 128.1, 127.5, 126.4, 106.3, 74.4, 71.6, 70.4, 50.9. Calcd m/z for $\text{C}_{12}\text{H}_{13}\text{O}$ $[\text{M}-\text{H}_2\text{O}+\text{H}^+] = 173.0966$; observed $m/z = 173.0947$. Galland, J.-C.; Dias, S.; Savignac, M.; Genet, J.-P. *Tetrahedron* **2001**, 57, 5137-5148. Mendez, M.; Munoz, M. P.; Nevado, C.; Cardenas, D. J.; Echavarren, A. M. *J. Am. Chem. Soc.* **2001**, 123, 10511-10520; Mendez, M.; Munoz, M. P.; Echavarren, A. M. *J. Am. Chem. Soc.* **2000**, 122, 11549-11550; Galland, J.-C.; Savignac, M.; Genet, J.-P. *Tetrahedron Lett.* **1997**, 38, 8695-8698.

6. ^1H NMR (200 MHz, CDCl_3): δ 5.37-5.28 (1H, m), 5.12-5.04 (1H, m), 4.12 (2H, d, J = 1.8 Hz), 4.08 (2H, d, J = 7 Hz), 2.41 (1H, t, J = 1.8 Hz), 2.18-1.98 (4H, m), 1.69 (3H, s), 1.67 (3H, s), 1.59 (3H, s). ^{13}C NMR (50 MHz, CDCl_3): δ 141.6, 131.6, 123.9, 119.8, 80.0, 74.0, 65.8, 56.5, 39.5, 26.2, 25.6, 17.5, 16.3. Chodnekar, M. S.; Pfiffner, A.; Rigassi, N.; Schwieter, U.; Suchy, M. *Ger. Offen.* **1971**, GWXXBX DE 2115673 19711021 (CAN 76:55261, AN 1972:55261); *Ger. Offen.* 1971, GWXXBX DE 2038958 19710218 (CAN 75:64037, AN 1971:464037).

7. ^1H NMR (300 MHz, CDCl_3): δ 5.13-5.05 (3H, m), 4.33-4.18 (2H, m), 4.11-4.07 (1H, dd, J = 9.3, 3.3 Hz), 3.90-3.85 (1H, dd, J = 9.3, 6.9 Hz), 2.74-2.71 (1H, m), 2.17-2.00 (2H, m), 1.98 (1H, bs), 1.66 (3H, d, J = 0.9 Hz), 1.61 (3H, bs), 1.61-1.46 (2H, m), 1.17 (3H, s). ^{13}C NMR (75 MHz, CDCl_3): δ 148.6, 131.8, 124.2, 107.3, 73.8, 72.0, 70.6, 53.6, 39.1, 25.6, 23.9, 22.1, 17.6. Calcd m/z for $\text{C}_{13}\text{H}_{23}\text{O}_2$ $[\text{M}+\text{H}^+] = 211.1698$; observed $m/z = 211.1671$.

8. ^1H NMR (300 MHz, CDCl_3): δ 5.17-5.10 (1H, mt, J = 7.2, 1.5 Hz), 4.16 (2H, d, J = 2.4 Hz), 3.51 (2H, t, J = 7.2 Hz), 2.42 (1H, t, J = 2.4 Hz), 2.35-2.27 (2H, tq, J = 7.2, 0.9 Hz), 1.71 (3H, d, J = 0.9 Hz), 1.64 (3H, d, J = 0.3 Hz). ^{13}C NMR (75 MHz, CDCl_3): δ 133.8, 120.0, 79.9, 74.1, 69.9, 58.0, 28.5, 25.7, 17.8.

9. ^1H NMR (300 MHz, CDCl_3): δ 5.09 (1H, bs), 5.01 (1H, bs), 4.24-4.20 (1H, d, J = 12 Hz), 4.02-3.98 (1H, d, J = 12 Hz), 3.99-3.94 (1H, m), 3.69-3.62 (1H, m), 2.35 (1H, t, J = 6.3 Hz), 1.93-1.84 (2H, m), 1.33 (3H, s), 1.30 (3H, s). ^{13}C NMR (75 MHz, CDCl_3): δ 143.8, 113.5, 72.9, 72.6, 66.0, 49.9, 29.1, 28.5. Calcd m/z for $\text{C}_9\text{H}_{17}\text{O}_2$ $[\text{M}+\text{H}]^+ = 157.1229$; observed $m/z = 157.1205$.

10. ^1H NMR (300 MHz, CDCl_3): δ 5.14-5.07 (1H, mt, J = 7.2, 1.2 Hz), 4.00 (2H, s), 3.44 (2H, t, J = 7.2 Hz), 2.33-2.26 (2H, q, J = 6.9 Hz), 2.13 (3H, s), 1.67 (3H, d, J = 1.2 Hz), 1.60 (3H, bs). ^{13}C NMR (75 MHz, CDCl_3): δ 207.2, 133.9, 119.8, 76.3, 71.4, 28.5, 26.2, 25.6, 17.7. Calcd m/z for $\text{C}_9\text{H}_{15}\text{O}_2$ $[\text{M}-\text{H}]^+ = 155.1072$; observed $m/z = 155.1048$.

11. ¹H NMR (300 MHz, CDCl₃): δ 5.14-5.07 (1H, m), 4.13 (2H, d, J = 1.8 Hz), 3.50 (2H, t, J = 6.5 Hz), 2.41 (1H, t, J = 1.8 Hz), 2.09-2.01 (2H, q, J = 6.9 Hz), 1.69 (3H, s), 1.60 (3H, s), 1.68-1.58 (2H, m). ¹³C NMR (75 MHz, CDCl₃): δ 132.0, 123.7, 80.0, 74.0, 69.7, 58.0, 29.6, 25.7, 24.4, 17.6.

12. ¹H NMR (300 MHz, CDCl₃): δ 5.08-5.03 (1H, m), 3.96 (2H, s), 3.42 (2H, t, J = 6.6 Hz), 2.11 (3H, s), 2.06-1.98 (2H, q, J = 7.5 Hz), 1.66-1.58 (2H, m), 1.64 (3H, s), 1.55 (3H, s). ¹³C NMR (75 MHz, CDCl₃): δ 207.2, 131.9, 123.5, 76.3, 71.1, 29.5, 26.2, 25.5, 24.2, 17.5. Calcd m/z for C₁₀H₁₉O₂ [M+H]⁺ = 171.1385; observed m/z = 171.1353.

13. ¹H NMR (300 MHz, CDCl₃): δ 4.88-4.82 (1H, qt, J = 7.8, 1.5 Hz), 3.69 (6H, s), 2.73 (2H, d, J = 7.5 Hz), 2.72 (2H, d, J = 2.7 Hz), 1.97 (1H, t, J = 2.7 Hz), 1.66 (3H, s), 1.61 (3H, s). ¹³C NMR (75 MHz, CDCl₃): δ 170.7, 137.2, 117.1, 79.5, 71.4, 57.4, 52.9, 31.0, 26.3, 22.7, 18.1. Trost, B. M.; Braslau, R. *Tetrahedron Lett.* **1988**, 29, 1231-1234; Mook, R. Jr.; Sher, P. M. *Org. Synth.* **1988**, 66, 75-86.

14. ¹H NMR (300 MHz, CDCl₃): δ 5.06 (1H, m), 4.99 (1H, m), 3.69 (3H, s), 3.68 (3H, s), 2.83 (2H, m), 2.68-2.55 (2H, m), 2.01-1.90 (1H, m), 1.80 (1H, bs), 1.19 (3H, s), 1.16 (3H, s). ¹³C NMR (75 MHz, CDCl₃): δ 171.77, 171.70, 148.3, 111.1, 72.4, 58.6, 52.6, 52.4, 43.3, 36.0, 27.8, 26.0. Calcd m/z for C₁₀H₁₄O₄ [M-CH₃COCH₃]⁺ = 198.0892; observed m/z = 198.0881. Mendez, M.; Munoz, M. P.; Nevado, C.; Cardenas, D. J.; Echavarren, A. M. *J. Am. Chem. Soc.* **2001**, 123, 10511-10520; Mendez, M.; Munoz, M. P.; Echavarren, A. M. *J. Am. Chem. Soc.* **2000**, 122, 11549-11550.

15. ¹H NMR (300 MHz, CDCl₃): δ 5.12-5.05 (1H, m), 3.73 (6H, 2s), 2.84 (2H, d, J = 2.7 Hz), 2.11-2.03 (2H, m), 2.00 (1H, t, J = 2.7 Hz), 1.92-1.84 (2H, m), 1.67 (3H, d, J = 0.9 Hz), 1.58 (3H, bs). ¹³C NMR (50 MHz, CDCl₃): δ 170.6, 132.7, 122.7, 78.8, 71.3, 56.6, 52.7, 32.0, 25.6, 22.8, 22.7, 17.5. Calcd m/z for C₁₄H₂₃O₄ [M+H]⁺ = 253.1440; observed m/z = 253.1449.

16. ¹H NMR (300 MHz, CDCl₃): δ 4.89 (1H, bs), 4.77 (1H, bs), 3.60 (6H, s), 2.76 (1H, d, J = 13.2 Hz), 2.62 (1H, d, J = 13.2 Hz), 2.24-2.13 (1H, m), 2.06-2.02 (1H, m), 1.93-1.84 (1H, m), 1.76-1.70 (2H, q, J = 6 Hz), 1.17 (3H, s), 1.14 (3H, s). ¹³C NMR (50 MHz, CDCl₃): δ 172.0, 171.3, 143.7, 114.6, 72.4, 56.2, 52.4, 52.2, 51.2, 38.6, 28.7, 28.6, 28.2, 23.7. Calcd m/z for C₁₄H₂₃O₅ [M+H]⁺ = 271.1545; observed m/z = 271.1536.

17. ¹H NMR (300 MHz, CDCl₃): This material is contaminated with some other product. The following absorptions are characteristic of the title compound. δ 5.03 (1H, t, J = 0.9 Hz), 4.93 (1H, t, J = 1.2 Hz), 3.73 (6H, s), 3.00-2.95 (1H, dd, J = 13.8, 2.5 Hz), 2.63-2.58 (1H, btd, J = 13.8 Hz), 0.96 (3H, d, J = 6.9 Hz), 0.80 (3H, d, J = 6.9 Hz).

18. ^1H NMR (300 MHz, CDCl_3): δ 4.99 (1H, mt, $J = 7.2$ Hz), 3.68 (6H, s), 3.10 (2H, s), 2.12 (3H, s), 2.02-1.92 (2H, m), 1.90-1.78 (2H, m), 1.62 (3H, s), 1.53 (3H, s). ^{13}C NMR (75 MHz, CDCl_3): δ 205.0, 171.1, 132.6, 122.7, 55.0, 52.5, 46.0, 33.4, 30.1, 25.5, 23.3, 17.4. Calcd m/z for $\text{C}_{14}\text{H}_{23}\text{O}_5$ $[\text{M}+\text{H}^+]$ = 271.1545; observed m/z = 271.1559.

19. ^1H NMR (300 MHz, CDCl_3): δ 4.92-4.90 (1H, m), 4.85-4.84 (1H, m), 3.74 (6H, s), 2.84 (2H, s), 2.83 (2H, d, $J = 2.7$ Hz), 2.03 (1H, t, $J = 2.7$ Hz), 1.65 (3H, d, $J = 1.2$ Hz). ^{13}C NMR (75 MHz, CDCl_3): δ 170.5, 139.7, 116.3, 79.1, 71.7, 56.4, 52.7, 39.5, 23.1, 22.6. Mendez, M.; Munoz, M. P.; Nevado, C.; Cardenas, D. J.; Echavarren, A. M. *J. Am. Chem. Soc.* **2001**, *123*, 10511-10520; Gomez, A. M.; Company, M. D.; Valverde, S.; Lopez, J. C. *Org. Lett.* **2002**, *4*, 383-386.

20. ^1H NMR (300 MHz, CDCl_3): δ 5.06-5.04 (1H, m), 5.00-4.97 (1H, m), 3.79 (3H, s), 2.99-2.93 (1H, md, $J = 15$ Hz), 2.73-2.67 (1H, td, $J = 11.7, 2.4$ Hz), 2.58-2.51 (2H, m), 2.38-2.31 (1H, qd, $J = 15, 2.4$ Hz), 2.04 (1H, d, $J = 11.7$ Hz), 1.53 (3H, s). ^{13}C NMR (75 MHz, CDCl_3): δ 173.1, 169.3, 137.7, 117.2, 82.9, 55.6, 52.8, 45.7, 43.3, 38.2, 24.3. Calcd m/z for $\text{C}_{11}\text{H}_{14}\text{O}_4$ = 210.0892; observed m/z = 210.0889.

21. ^1H NMR (300 MHz, CDCl_3): δ 5.03-5.02 (1H, q, $J = 1.8$ Hz), 4.93-4.91 (1H, q, $J = 1.8$ Hz), 3.73 (3H, s), 3.72 (3H, s), 3.02-2.96 (1H, td, $J = 13.8, 1.8$ Hz), 2.53-2.46 (1H, td, $J = 14.4, 2.1$ Hz), 2.32-2.13 (4H, m), 2.05-2.00 (1H, $J = 14.4$ Hz), 1.28 (3H, s). ^{13}C NMR (75 MHz, CDCl_3): δ 172.2, 171.7, 140.3, 114.0, 69.9, 54.6, 52.7, 52.5, 47.2, 42.0, 38.5, 30.1. Calcd m/z for $\text{C}_{12}\text{H}_{18}\text{O}_5$ = 242.1154; observed m/z = 242.1160.

22. ^1H NMR (300 MHz, CDCl_3): δ 7.88-7.85 (2H, m), 7.61-7.47 (3H, m), 5.14-5.07 (1H, m), 4.08 (2H, d, $J = 2.4$ Hz), 3.84 (2H, d, $J = 7.2$ Hz), 1.96 (1H, t, $J = 2.4$ Hz), 1.73 (3H, d, $J = 0.9$ Hz), 1.68 (3H, d, $J = 0.9$ Hz). ^{13}C NMR (75 MHz, CDCl_3): δ 139.2, 139.1, 132.6, 128.8, 127.7, 117.7, 89.4, 73.3, 44.0, 35.4, 25.9, 17.8. Calcd m/z for $\text{C}_{14}\text{H}_{18}\text{NO}_2\text{S}$ $[\text{M}+\text{H}^+]$ = 264.1058; observed m/z = 264.1055. Cao, P.; Wang, B.; Zhang, X. *J. Am. Chem. Soc.* **2000**, *122*, 6490-6491.

23. ^1H NMR (300 MHz, CDCl_3): δ 7.85-7.81 (2H, m), 7.65-7.52 (3H, m), 5.12-5.08 (2H, m), 3.94-3.87 (1H, qd, $J = 13.8, 1.5$ Hz), 3.78-3.72 (1H, td, $J = 13.8, 1.8$ Hz), 3.49-3.44 (1H, dd, $J = 10.2, 3.3$ Hz), 3.31-3.25 (1H, dd, $J = 10.2, 7.8$ Hz), 2.69-2.64 (1H, m), 1.70 (1H, bs), 1.17 (3H, s), 1.16 (3H, s). ^{13}C NMR (75 MHz, CDCl_3): δ 144.59, 135.5, 132.9, 129.0, 127.7, 111.2, 71.9, 53.8, 52.8, 50.0, 27.0, 26.9. Calcd m/z for $\text{C}_{14}\text{H}_{20}\text{NO}_3\text{S}$ $[\text{M}+\text{H}]^+$ = 282.1164; observed m/z = 282.1168.

24. ^1H NMR (300 MHz, CDCl_3): δ 7.28-7.23 (1H, m), 6.94-6.91 (2H, m), 6.85-6.82 (1H, m), 4.58 (3H, s), 4.17 (2H, dd, $J = 2.4, 0.9$ Hz), 3.80 (2H, d, $J = 0.6$ Hz), 2.46 (1H, dt, $J = 2.4, 0.9$ Hz). ^{13}C NMR (75 MHz, CDCl_3): δ 159.7, 138.8, 129.4, 120.2, 113.6, 113.2, 79.6, 74.6, 71.3, 57.0, 55.1. Calcd m/z for $\text{C}_{11}\text{H}_{12}\text{O}_2 = 176.0837$; observed $m/z = 176.0834$. Ishikawa, T.; Okano, M.; Aikawa, T.; Saito, S. *J. Org. Chem.* **2001**, *66*, 4635-4642; Montecocchi, P. C.; Navacchia, M. L. *J. Org. Chem.* **1998**, *63*, 537-542.

25. ^1H NMR (300 MHz, CDCl_3): δ 7.22 (1H, d, $J = 8.4$ Hz), 7.13 (1H, d, $J = 8.4$ Hz), 6.76-6.73 (1H, dd, $J = 8.7, 2.7$ Hz), 6.73-6.69 (1H, dd, $J = 8.7, 2.4$ Hz), 6.58 (1H, d, $J = 2.7$ Hz), 6.48 (1H, d, $J = 2.4$ Hz), 6.33 (1H, s), 4.92 (2H, s), 4.85-4.73 (2H, dd, $J = 21.6, 15.3$ Hz), 3.82 (1H, d, $J = 11.4$ Hz), 3.78 (3H, s), 3.75 (3H, s), 3.38 (1H, d, $J = 11.4$ Hz), 2.73 (1H, d, $J = 14.4$ Hz), 2.59 (1H, d, $J = 14.4$ Hz), 1.13 (3H, s). ^{13}C NMR (75 MHz, CDCl_3): δ 158.3, 157.6, 143.6, 134.8, 134.2, 129.9, 127.4, 125.4, 122.2, 112.7, 112.5, 110.2, 108.4, 73.8, 69.0, 68.6, 55.3, 55.2, 37.5, 36.5, 22.9. Calcd m/z for $\text{C}_{22}\text{H}_{24}\text{O}_4 = 352.1675$; observed $m/z = 352.1669$.

27. ^1H NMR (300 MHz, CDCl_3): δ 7.29-7.23 (1H, dt, $J = 7.5, 0.9$ Hz), 6.93-6.90 (2H, m), 6.86-6.82 (1H, m), 4.56 (2H, s), 4.05 (2H, s), 3.79 (3H, s), 2.14 (3H, s). ^{13}C NMR (75 MHz, CDCl_3): δ 206.3, 159.6, 138.6, 129.3, 113.3, 112.9, 75.0, 72.9, 55.0, 26.2. Calcd m/z for $\text{C}_{11}\text{H}_{14}\text{O}_3 = 194.0943$; Observed $m/z = 194.0932$.

i: ^1H NMR (300 MHz, CDCl_3): δ 5.15-5.08 (1H, mt, $J = 7.2, 0.9$ Hz), 4.12 (2H, d, $J = 2.1$ Hz), 3.74-3.69 (1H, dd, $J = 9.6, 3.6$ Hz), 3.62-3.56 (1H, dd, $J = 9.6, 6.3$ Hz), 3.18 (1H, bs), 2.43 (1H, t, $J = 2.1$ Hz), 2.17-1.95 (1H, m), 1.70 (3H, bs), 1.67-1.59 (1H, m), 1.61 (3H, bs), 1.27 (3H, s), 1.20 (3H, s). ^{13}C NMR (75 MHz, CDCl_3): δ 133.2, 123.3, 79.4, 75.0, 73.2, 70.8, 58.7, 48.8, 29.3, 26.5, 26.06, 26.05, 18.0. Calcd m/z for $\text{C}_{13}\text{H}_{21}\text{O}_2$ $[\text{M}-\text{H}]^+ = 209.1542$; Observed $m/z = 209.1534$.