BEILSTEIN JOURNAL OF ORGANIC CHEMISTRY

Enantioselective dioxytosylation of styrenes using lactate-based chiral hypervalent iodine(III)

Morifumi Fujita*, Koki Miura and Takashi Sugimura

Letter

Open Access

Address:
Graduate School of Material Science, University of Hyogo, Kohto, Kamigori, Hyogo 678-1297, Japan

Email:
Morifumi Fujita* - fuji@sci.u-hyogo.ac.jp

* Corresponding author

Keywords:
1,2-difunctionalization of alkenes; enantioselective synthesis; hypervalent iodine; oxidation

Beilstein J. Org. Chem. **2018,** *14,* 659–663.
doi:10.3762/bjoc.14.53

Received: 25 December 2017
Accepted: 06 March 2018
Published: 20 March 2018

This article is part of the Thematic Series "Hypervalent iodine chemistry in organic synthesis".

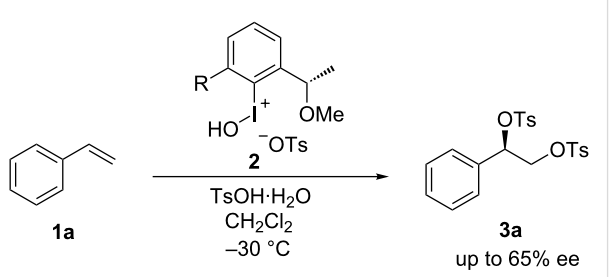
Guest Editor: T. Wirth

Abstract

A series of optically active hypervalent iodine(III) reagents prepared from the corresponding (*R*)-2-(2-iodophenoxy)propanoate derivative was employed for the asymmetric dioxytosylation of styrene and its derivatives. The electrophilic addition of the hypervalent iodine(III) compound toward styrene proceeded with high enantioface selectivity to give 1-aryl-1,2-di(tosyloxy)ethane with an enantiomeric excess of 70–96% of the (*S*)-isomer.

Findings

Hypervalent aryl-λ^3-iodanes have been widely used for metal-free oxidation with high selectivity in organic synthesis [1-3]. The reactivity of an aryl-λ^3-iodane is controlled by the electronic and steric properties of the aryl group and the heteroatomic ligand coordinated to the iodine atom. Optically active hypervalent iodine compounds contain chiral ligands or chiral aryl groups. Several types of optically active hypervalent iodine reagents and catalysts have been developed for highly stereocontrolled oxidative transformations [4-14]. The enantioselective vicinal difunctionalization of alkenes constitutes one type of attractive transformation achieved by chiral hypervalent iodine compounds. As a seminal example in this field, Wirth et al. [15-17] reported the dioxytosylation of styrene (**1a**, Scheme 1). Chiral hypervalent iodine reagents **2** bearing a 1-methoxyethyl side chain were used for enantiocontrol of the dioxytosylation, and the maximum enantiomeric excess (ee) of the product **3a** reached 65%. Despite recent rapid progress in the field of asymmetric oxidation achieved by chiral hypervalent iodine compounds, there has been no subsequent examination of dioxytosylation, which can be used as a standard reaction for comparing the enantiocontrolling ability of chiral hypervalent iodine reagents.



Scheme 1: Enantioselective dioxytosylation of styrene as a seminal example.

The design of chiral hypervalent iodine reagents using a lactate motif has been employed for several types of oxidation reaction since we first reported this procedure [18]. Enantioselective oxidative transformations include the dearomatization of phenols [19-24], α-functionalization of carbonyl compounds [25-29], and vicinal difunctionalization of alkenes [18,30-50]. Here, the efficiency of the lactate-based chiral hypervalent iodine reagents **4a–e** (Figure 1) was assessed using the dioxytosylation of styrenes as a reference reaction.

A series of lactate-derived aryl-λ^3-iodanes **4a–e** was used for the oxidation of styrenes **1** in the presence of *p*-toluenesulfonic acid (TsOH) in dichloromethane. The reaction proceeded at −50 °C to give the 1,2-dioxytosylated product **3** and the rearranged product **5**. The yields of **3** and **5** were determined by ^{1}H NMR using an internal standard. The ee of **3** was determined by chiral HPLC analysis. The results for the yields and ee are summarized in Table 1.

The reaction of styrene (**1a**) with **4a** gave the 1,2-dioxytosylated product **3a** with 70% ee of the (*S*)-isomer (Table 1, entry 1). An ee of equal to or greater than 70% was also achieved in the reactions with the other lactate-based reagents **4b–e** (Table 1, entries 2–5). The reaction with the 2,6-bis(lactate)aryl reagent **4e** provided a high ee of 92%. The reactions of *p*-chlorostyrene (**1b**) gave **3b** with a similar ee, and the ratios of **3** to **5** (**3b** to **5b**) were higher than those in the reaction of **1a** (Table 1, entries 6–8). In the reactions of *o*-methylstyrene (**1c**), the ee of the 1,2-dioxytosylated product **3c** was slightly higher than those of **3a** and **3b**, but the regioselectivity for **3c** over **5c** was poor (Table 1, entries 9 and 10).

Scheme 2 illustrates possible reaction pathways that lead to **3** and the achiral byproduct **5**. The treatment of (diacetoxyiodo)benzene with TsOH readily gives Koser's reagent [PhI(OH)OTs] [51], which has a higher electrophilicity toward the carbon–carbon double bond in **1**. The dioxytosylation of alkenes with Koser's reagent was found to proceed via an S_N2 reaction of a cyclic intermediate such as $\mathbf{I_1}$, judging from the *syn* selectivity of the dioxytosylation [52,53]. The attack of the tosylate ion on $\mathbf{I_1}$ possibly takes place at the benzylic position or at the methylene carbon atom. The positive charge of $\mathbf{I_1}$ may be stabilized by the aryl group and localized at the benzylic position. This may allow the preferential formation of $\mathbf{I_3}$ from $\mathbf{I_1}$. If $\mathbf{I_2}$ was the major intermediate in the pathway leading to **3**, the stereochemical purity of **3** would have decreased owing to the facile elimination of the iodonium group [54] at the benzylic position of $\mathbf{I_2}$ (S_N1). The high enantiomeric ratio of **3** can be rationalized via a preference for the $\mathbf{I_1}\rightarrow\mathbf{I_3}\rightarrow\mathbf{3}$ pathway over the $\mathbf{I_1}\rightarrow\mathbf{I_2}\rightarrow\mathbf{3}$ pathway. The product ratio of **3** to **5** was affected by the ring substituent in styrenes **1**: the electron-withdrawing chloro substituent in **1b** increased the amount of **3**, whereas the electron-donating methyl substituent in **1c** decreased the amount of **3**. An electron-donating aryl group increases the rate of participation of the aryl group ($\mathbf{I_3}\rightarrow\mathbf{I_4}$). In other words, a reaction pathway that bifurcates from $\mathbf{I_3}$ to **3** and **5** agrees well with the regioselectivity for **3** over **5** observed for the substituted styrenes. The phenonium cation intermediate $\mathbf{I_4}$ contains two reaction sites on the ethylene bridge. Electron donation due to the lone pair on the oxygen atom of the internal tosyloxy group may weaken the bond between the tosyloxy-bonded carbon and the quaternary carbon in $\mathbf{I_4}$.

The reaction of styrene with **4a–e** preferentially gave (*S*)-**3**, which forms via an electrophilic addition of the iodane toward the *Si* face of styrene, followed by an S_N2 reaction with the

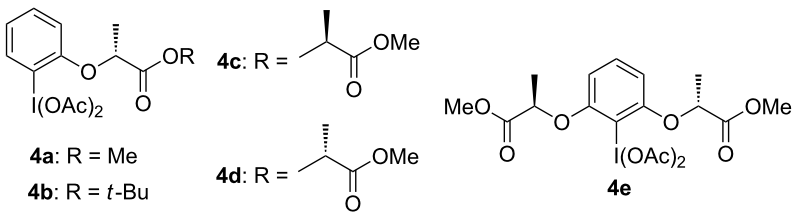
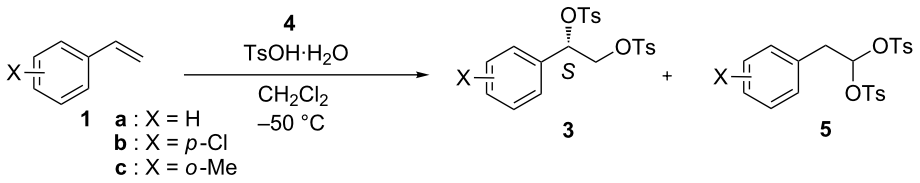


Figure 1: Series of lactate-based hypervalent iodine reagents.

Table 1: Enantioselective dioxytosylation of styrenes **1** using aryl-λ^3-iodanes **4**.[a]

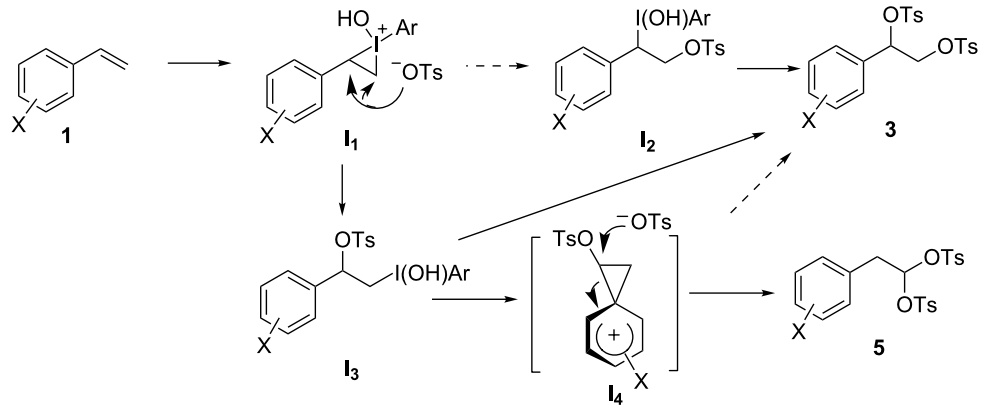


Entry	Substrate	Reagent	Yield (%)[b]		ee of **3** (%)[c,d]
			3	**5**	
1	**1a** (X = H)	**4a**	53	15	70 (*S*)
2	**1a** (X = H)	**4b**	49	16	80 (*S*)
3	**1a** (X = H)	**4c**	41	14	78 (*S*)
4	**1a** (X = H)	**4d**	41	22	70 (*S*)
5	**1a** (X = H)	**4e**	80	20	92 (*S*)
6	**1b** (X = *p*-Cl)[e]	**4a**	63	6	70
7	**1b** (X = *p*-Cl)[e]	**4b**	46	5	76
8	**1b** (X = *p*-Cl)[e]	**4e**	79	5	90
9	**1c** (X = *o*-Me)	**4a**	7	34	79
10	**1c** (X = *o*-Me)	**4e**	10	35	96

[a]The reaction was carried out at −50 °C in dichloromethane containing **4** (47 mM), TsOH (86 mM), and **1** (43 mM) for 4 h. [b]The yield was determined by ^{1}H NMR using an internal standard. [c]The ee was determined by chiral HPLC using a Daicel CHIRALPAK AD column (ø 4.6 mm × 250 mm). [d]Preferential configuration of product **3**. The absolute stereochemistry of **3b** and **3c** was not determined. [e]The reaction was carried out for 20 h.

tosylate ion. If an S_N1 mechanism were involved in the oxytosylation of $\mathbf{I_1}$, the enantiomeric ratio of **3** would decrease owing to the planar structure of the benzylic cation. Thus, the tosylate ion may act as an effective nucleophile for the S_N2 reaction of $\mathbf{I_1}$. The stereoface-differentiation in the dioxytosylation reaction using the lactate-derived aryl-λ^3-iodanes is similar to that in preceding reactions [14], which include the diacetoxylation [38,39,50] and diamination [30,49] of styrene.

In summary, the reaction of styrenes with lactate-derived aryl-λ^3-iodanes gave the dioxytosylated product with an ee of 70–96%.



Scheme 2: Plausible pathways in dioxytosylation of styrenes.

Supporting Information

Supporting Information File 1

Experimental procedures, characterization data, and copies of ^{1}H and ^{13}C NMR spectra are available.
[https://www.beilstein-journals.org/bjoc/content/supplementary/1860-5397-14-53-S1.pdf]

Acknowledgements

Financial support from University of Hyogo is gratefully acknowledged.

ORCID® iDs

Morifumi Fujita - https://orcid.org/0000-0003-1006-1416

References

1. Zhdankin, V. V. *Hypervalent Iodine Chemistry;* John Wiley & Sons: Chichester, U.K., 2014.
2. Yoshimura, A.; Zhdankin, V. V. *Chem. Rev.* **2016,** *116,* 3328–3435. doi:10.1021/acs.chemrev.5b00547
3. Wirth, T., Ed. *Hypervalent Iodine Chemistry;* Springer: Basel, Switzerland, 2016. doi:10.1007/978-3-319-33733-3
4. Ngatimin, M.; Lupton, D. W. *Aust. J. Chem.* **2010,** *63,* 653–658. doi:10.1071/CH09625
5. Liang, H.; Ciufolini, M. A. *Angew. Chem., Int. Ed.* **2011,** *50,* 11849–11851. doi:10.1002/anie.201106127
   Angew. Chem. **2011,** *123,* 12051–12053. doi:10.1002/ange.201106127
6. Uyanik, M.; Ishihara, K. *J. Synth. Org. Chem., Jpn.* **2012,** *70,* 1116–1122. doi:10.5059/yukigoseikyokaishi.70.1116
7. Parra, A.; Reboredo, S. *Chem. – Eur. J.* **2013,** *19,* 17244–17260. doi:10.1002/chem.201302220
8. Singh, F. V.; Wirth, T. *Chem. – Asian J.* **2014,** *9,* 950–971. doi:10.1002/asia.201301582
9. Romero, R. M.; Wöste, T. H.; Muñiz, K. *Chem. – Asian J.* **2014,** *9,* 972–983. doi:10.1002/asia.201301637
10. Harned, A. M. *Tetrahedron Lett.* **2014,** *55,* 4681–4689. doi:10.1016/j.tetlet.2014.06.051
11. Zheng, Z. S.; Zhang-Negrerie, D.; Du, Y. F.; Zhao, K. *Sci. China: Chem.* **2014,** *57,* 189–214. doi:10.1007/s11426-013-5043-1
12. Berthiol, F. *Synthesis* **2015,** *47,* 587–603. doi:10.1055/s-0034-1379892
13. Basdevant, B.; Guilbault, A.-A.; Beaulieu, S.; Lauriers, A. J.-D.; Legault, C. Y. *Pure Appl. Chem.* **2017,** *89,* 781–789. doi:10.1515/pac-2016-1212
14. Fujita, M. *Tetrahedron Lett.* **2017,** *58,* 4409–4419. doi:10.1016/j.tetlet.2017.10.019
15. Wirth, T.; Hirt, U. H. *Tetrahedron: Asymmetry* **1997,** *8,* 23–26. doi:10.1016/S0957-4166(96)00469-7
16. Hirt, U. H.; Spingler, B.; Wirth, T. *J. Org. Chem.* **1998,** *63,* 7674–7679. doi:10.1021/jo980475x
17. Hirt, U. H.; Schuster, M. F. H.; French, A. N.; Wiest, O. G.; Wirth, T. *Eur. J. Org. Chem.* **2001,** 1569–1579. doi:10.1002/1099-0690(200104)2001:8<1569::AID-EJOC1569>3.0.CO;2-T
18. Fujita, M.; Okuno, S.; Lee, H. J.; Sugimura, T.; Okuyama, T. *Tetrahedron Lett.* **2007,** *48,* 8691–8694. doi:10.1016/j.tetlet.2007.10.015
19. Uyanik, M.; Yasui, T.; Ishihara, K. *Angew. Chem., Int. Ed.* **2010,** *49,* 2175–2177. doi:10.1002/anie.200907352
    Angew. Chem. **2010,** *122,* 2221–2223. doi:10.1002/ange.200907352
20. Uyanik, M.; Yasui, T.; Ishihara, K. *Angew. Chem., Int. Ed.* **2013,** *52,* 9215–9218. doi:10.1002/anie.201303559
    Angew. Chem. **2013,** *125,* 9385–9388. doi:10.1002/ange.201303559
21. Zhang, D.-Y.; Xu, L.; Wu, H.; Gong, L.-Z. *Chem. – Eur. J.* **2015,** *21,* 10314–10317. doi:10.1002/chem.201501583
22. Yoshida, Y.; Magara, A.; Mino, T.; Sakamoto, M. *Tetrahedron Lett.* **2016,** *57,* 5103–5107. doi:10.1016/j.tetlet.2016.10.016
23. Uyanik, M.; Sasakura, N.; Mizuno, M.; Ishihara, K. *ACS Catal.* **2017,** *7,* 872–876. doi:10.1021/acscatal.6b03380
24. Jain, N.; Xu, S.; Ciufolini, M. A. *Chem. – Eur. J.* **2017,** *23,* 4542–4546. doi:10.1002/chem.201700667
25. Mizar, P.; Wirth, T. *Angew. Chem., Int. Ed.* **2014,** *53,* 5993–5997. doi:10.1002/anie.201400405
    Angew. Chem. **2014,** *126,* 6103–6107. doi:10.1002/ange.201400405
26. Wu, H.; He, Y.-P.; Xu, L.; Zhang, D.-Y.; Gong, L.-Z. *Angew. Chem., Int. Ed.* **2014,** *53,* 3466–3469. doi:10.1002/anie.201309967
    Angew. Chem. **2014,** *126,* 3534–3537. doi:10.1002/ange.201309967
27. Basdevant, B.; Legault, C. Y. *Org. Lett.* **2015,** *17,* 4918–4921. doi:10.1021/acs.orglett.5b02501
28. Feng, Y.; Huang, R.; Hu, L.; Xiong, Y.; Coeffard, V. *Synthesis* **2016,** *48,* 2637–2644. doi:10.1055/s-0035-1561442
29. Cao, Y.; Zhang, X.; Lin, G.; Zhang-Negrerie, D.; Du, Y. *Org. Lett.* **2016,** *18,* 5580–5583. doi:10.1021/acs.orglett.6b02816
30. Muñiz, K.; Barreiro, L.; Romero, R. M.; Martínez, C. *J. Am. Chem. Soc.* **2017,** *139,* 4354–4357. doi:10.1021/jacs.7b01443
31. Gelis, C.; Dumoulin, A.; Bekkaye, M.; Neuville, L.; Masson, G. *Org. Lett.* **2017,** *19,* 278–281. doi:10.1021/acs.orglett.6b03631
32. Qurban, J.; Elsherbini, M.; Wirth, T. *J. Org. Chem.* **2017,** *82,* 11872–11876. doi:10.1021/acs.joc.7b01571
33. Shimogaki, M.; Fujita, M.; Sugimura, T. *J. Org. Chem.* **2017,** *82,* 11836–11840. doi:10.1021/acs.joc.7b01141
34. Banik, S. M.; Medley, J. W.; Jacobsen, E. N. *Science* **2016,** *353,* 51–54. doi:10.1126/science.aaf8078
35. Banik, S. M.; Medley, J. W.; Jacobsen, E. N. *J. Am. Chem. Soc.* **2016,** *138,* 5000–5003. doi:10.1021/jacs.6b02391
36. Woerly, E.; Banik, S. M.; Jacobsen, E. N. *J. Am. Chem. Soc.* **2016,** *138,* 13858–13861. doi:10.1021/jacs.6b09499
37. Ahmad, A.; Silva, L. F., Jr. *J. Org. Chem.* **2016,** *81,* 2174–2181. doi:10.1021/acs.joc.5b02803
38. Haubenreisser, S.; Wöste, T. H.; Martínez, C.; Ishihara, K.; Muñiz, K. *Angew. Chem., Int. Ed.* **2016,** *55,* 413–417. doi:10.1002/anie.201507180
    Angew. Chem. **2016,** *128,* 422–426. doi:10.1002/ange.201507180
39. Wöste, T. H.; Muñiz, K. *Synthesis* **2016,** *48,* 816–827. doi:10.1055/s-0035-1561313
40. Mizar, P.; Niebuhr, R.; Hutchings, M.; Farooq, U.; Wirth, T. *Chem. – Eur. J.* **2016,** *22,* 1614–1617. doi:10.1002/chem.201504636
41. Brown, M.; Kumar, R.; Rehbein, J.; Wirth, T. *Chem. – Eur. J.* **2016,** *22,* 4030–4035. doi:10.1002/chem.201504844
42. Shimogaki, M.; Fujita, M.; Sugimura, T. *Angew. Chem., Int. Ed.* **2016,** *55,* 15797–15801. doi:10.1002/anie.201609110
    Angew. Chem. **2016,** *128,* 16029–16033. doi:10.1002/ange.201609110
43. Alhalib, A.; Kamouka, S.; Moran, W. J. *Org. Lett.* **2015,** *17,* 1453–1456. doi:10.1021/acs.orglett.5b00333
44. Takesue, T.; Fujita, M.; Sugimura, T.; Akutsu, H. *Org. Lett.* **2014,** *16,* 4634–4637. doi:10.1021/ol502225p

45. Kong, W.; Feige, P.; de Haro, T.; Nevado, C. *Angew. Chem., Int. Ed.* **2013,** *52,* 2469–2473. doi:10.1002/anie.201208471
Angew. Chem. **2013,** *125,* 2529–2533. doi:10.1002/ange.201208471
46. Farid, U.; Malmedy, F.; Claveau, R.; Albers, L.; Wirth, T. *Angew. Chem., Int. Ed.* **2013,** *52,* 7018–7022. doi:10.1002/anie.201302358
Angew. Chem. **2013,** *125,* 7156–7160. doi:10.1002/ange.201302358
47. Fujita, M.; Mori, K.; Shimogaki, M.; Sugimura, T. *RSC Adv.* **2013,** *3,* 17717–17725. doi:10.1039/c3ra43230k
48. Farid, U.; Wirth, T. *Angew. Chem., Int. Ed.* **2012,** *51,* 3462–3465. doi:10.1002/anie.201107703
Angew. Chem. **2012,** *124,* 3518–3522. doi:10.1002/ange.201107703
49. Röben, C.; Souto, J. A.; González, Y.; Lishchynskyi, A.; Muñiz, K. *Angew. Chem., Int. Ed.* **2011,** *50,* 9478–9482. doi:10.1002/anie.201103077
Angew. Chem. **2011,** *123,* 9650–9654. doi:10.1002/ange.201103077
50. Fujita, M.; Wakita, M.; Sugimura, T. *Chem. Commun.* **2011,** *47,* 3983–3985. doi:10.1039/c1cc10129c
51. Koser, G. F.; Wettach, R. H. *J. Org. Chem.* **1977,** *42,* 1476–1478. doi:10.1021/jo00428a052
52. Koser, G. F.; Rebrovic, L.; Wettach, R. H. *J. Org. Chem.* **1981,** *46,* 4324–4326. doi:10.1021/jo00334a057
53. Rebrovic, L.; Koser, G. F. *J. Org. Chem.* **1984,** *49,* 2462–2472. doi:10.1021/jo00187a032
54. Okuyama, T.; Takino, T.; Sueda, T.; Ochiai, M. *J. Am. Chem. Soc.* **1995,** *117,* 3360–3367. doi:10.1021/ja00117a006

License and Terms