Metalloporphyrin as an Efficient Catalyst in the Regioselective Isomerization of Epoxides to Carbonyl Compounds

Toshikatsu Takanami, Rina Hirabe, Masayoshi Ueno, Fumio Hino, and Kohji Suda*
Meiji College of Pharmacy, 1-35-23, Nozawa, Setagaya-ku, Tokyo 154

(Received August 22, 1996)

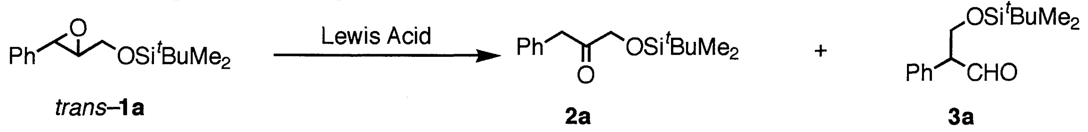
Regioselective ring-opening isomerization of epoxides to carbonyl compounds can effectively be catalyzed by iron (III) tetraphenylporphyrin, $\mathrm{Fe(tpp)ClO_4}$.

Brϕnsted or Lewis acid-promoted conversion of epoxides to carbonyl compounds is a well known but still challenging topic in organic synthesis.[1–3] Despite a number of methods in this field, only a few *catalytic* conversion systems have been appeared.[2] Most of the reactions being reported so far required more than a stoichiometric amount of reagents, *e.g.*, $\mathrm{BF_3}$ and its etherate, lithium and magnesium halides, *etc.*[1–3] In addition, the ring opening with these reagents frequently lacks regioselectivity, giving a mixture of products, unless any structural and streochemical bias is present in the substrates.[1,3] Recently, we have reported that manganese (III) tetraphenylporphyrin, Mn(tpp)Cl, is a regio- and stereoselective catalyst for the rearrangement of *N*–arylspirooxaziridins into lactams.[4] We now report here that high valent metalloporphyrins, especially iron (III) tetraphenylporphyrin, $\mathrm{Fe(tpp)ClO_4}$, work as a mild and characteristic Lewis acid catalyst for the regioselective isomerization of di- and trisubstituted epoxides (**1**) into the corresponding ketones (**2**).

As a model substrate for the catalytic isomerization, *trans*-2-(*t*-butyldimethylsiloxy)methyl-3-phenyloxirane (*trans*-**1a**) was chosen, and the catalytic isomerization with various tetraphenylporphyrin complexes was investigated. The reaction of *trans*-**1a** was carried out in 1, 2-dichloroethane at 80 °C with 2 mol% of a tetraphenylporphyrin complex. As shown in Table 1, $\mathrm{Fe(tpp)ClO_4}$ was the most effective catalyst examined, and the total yield and the ratio of ketone **2a** and aldehyde **3a** were in the order: Mn(tpp)Cl (0%) ≈ Fe(tpp)Cl (0%) << $\mathrm{Mn(tpp)ClO_4}$ (98%, **2a**:**3a**=54:46) < $\mathrm{Fe(tpp)ClO_4}$ (~100%, **2a**:**3a**=67:33) (runs 1–4).[5] In the $\mathrm{Fe(tpp)ClO_4}$ catalyzed rearrangement, the selectivity between **2a** and **3a** was dramatically changed with the solvents used. For example, highly regioselective trans-formation of *trans*-**1a** to **2a** *via* a hydride shift occurred in dioxane at 80 °C (**2a**:**3a**=99:1) (run 5). In contrast to this catalytic system, the use of an equimolar amount of $\mathrm{BF_3}$ etherate, which is one of the most widely employed reagents for the epoxides ring opening, could not take place the isomerization, only the starting material *trans*-**1a** being decomposed (run 6).

Under the conditions adopted in run 5, we next examined the rearrangement of various epoxides **1**. The catalytic transformation of **1a**–**f** was carried out in dioxane at 80 °C with a catalytic amount of $\mathrm{Fe(tpp)ClO_4}$ (2 mol%).[6] The results are summarized in Table 2. In the reactions of phenylepoxides, *trans*–**1a** and *cis*–**1a**, both substrates were regioselectively converted to the corresponding ketone **2a** in quantitative yields, regardless of their stereochemistry. Other phenyl derivatives **1b** and **1c** also gave ketones **2b** and **2c**, respectively, in excellent yields. The ring opening of cyclic epoxides **1d**–**f** are noteworthy. The reactions of cyclic epoxides with conventional Lewis acids, such as $\mathrm{ZnBr_2}$, $\mathrm{BF_3}$, *etc.*, have been reported to give a mixture of the corresponding cyclic ketones and the ring contracted aldehydes.[1] However, the present catalytic transformation of **1d**–**f** was completely regioselective, providing the corresponding cyclic ketones **2d**–**f** as the sole products without any ring contraction. Based on the results obtained, the present catalytic transformation of epoxides is rationalized as follows:

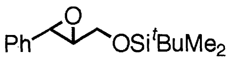
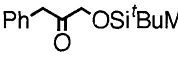
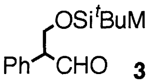
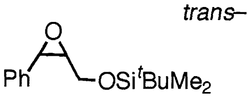
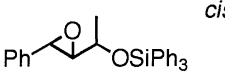
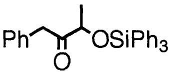
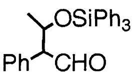
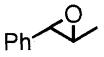
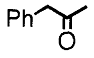
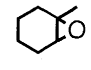
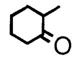
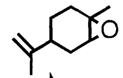
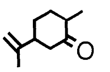
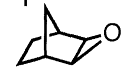
Table 1. Lewis acid promoted rearrangement of *trans*–**1a**



Run	Lewis Acid (mol%)	Conditions	Yield (%)[a]	Ratio (**2a**:**3a**)[b]
		solvent / time / temp		
1	Mn(tpp)Cl (2)	$\mathrm{(CH_2)_2Cl_2}$ / 48 h / 80 °C	no reaction	
2	Fe(tpp)Cl (2)	$\mathrm{(CH_2)_2Cl_2}$ / 48 h / 80 °C	no reaction	
3	$\mathrm{Mn(tpp)ClO_4}$ (2)	$\mathrm{(CH_2)_2Cl_2}$ / 1 h / 80 °C	98	54:46
4	$\mathrm{Fe(tpp)ClO_4}$ (2)	$\mathrm{(CH_2)_2Cl_2}$ / 1 h / 80 °C	100	67:33
5	$\mathrm{Fe(tpp)ClO_4}$ (2)	dioxane / 0.5 h / 80 °C	100	99:1
6	$\mathrm{BF_3{\bullet}OEt_2}$ (100)	$\mathrm{(CH_2)_2Cl_2}$ / 48 h / 80 °C	decompd.	

[a] Isolated yield. [b] Determined by 270 MHz ^{1}H-NMR analysis of the crude reaction mixture.

Table 2. Fe(tpp)ClO_4 catalyzed isomerization of epoxides **1** to ketones **2**

Run	Substrate	Time (h)	Products		Yield (%)[a]
1	 *trans*-**1a**	0.5	 **2a**	 **3a**	100 (**2a**:**3a**=99:1)[b]
2	 *cis*-**1a**	0.5	**2a**	+ **3a**	100 (**2a**:**3a**=96:4)[b]
3	 **1b**	1.0	 **2b**	 **3b**	91 (**2b**:**3b**=96:4)[b]
4	 **1c**	2.5	 **2c**		90
5	 **1d**	5.5	 **2d**		83
6	 **1e**[c]	8.0	 **2e**[c]		73
7	 **1f**	3.0	 **2f**		77

[a] Isolated yield. [b] The isomer ratios were determined by 270MHz ^{1}H-NMR analysis of the crude reaction mixture.
[c] A 1:1 mixture of *cis* and *trans* isomers.

Coordination of the metalloporphyrin, Fe(tpp)ClO_4, to the epoxide oxygen is followed by the regioselective cleavage of the C–O bond to give the most stable carbocation which is transformed into the ketone *via* 1, 2-shift of the hydride.

In summary, Fe(tpp)ClO_4 is an efficient and highly regioselective catalyst for the isomerization of various epoxides to carbonyl compounds. Generalization and application of this unique catalytic system utilizing high valent metalloporphyrins are a matter of continuing concern in this laboratory.

This research was supported in part by a Grant-in-Aid for Scientific Research (C) (No. 08672454) from the Ministry of Education, Science, Sports, and Culture, Japan, and The Science Research Promotion Fund from Japan Private School Promotion Foundation.

References and Notes

1 a) B. Rickborn, in "*Comprehensive Organic Synthesis*," ed by B. M. Trost and I. Fleming, Pergamon Press, New York (1991), Vol. 3, p. 733. b) J. G. Smith, *Synthesis*, **1984**, 629, and references cited therein.

2 Following Lewis and none-Lewis acid catalyzed reactions have been reported. a) [Pd(0) complexes] S. Kulasegaram, and R. Kulawiec, *J. Org. Chem.*, **59**, 7195 (1994). b) [Tris-(pentafluorophenyl)boron] K. Ishihara, N. Hanaki, and H. Yamamoto, *Synlett*, **1995**, 721. c) [EGA (electrogenerated acid)] K. Uneyama, A. Ishimura, K. Fujii, and S. Torii, *Tetrahedron Lett.*, **24**, 2857 (1983). d) [Ph_3SiClO_4] T. Inokuchi, M. Kusumoto, S. Matsumoto, H. Okada, and S. Torii, *Chem. Lett.*, **1991**, 2009. e) [TCNE (tetracyanoethylene)] Y. Masaki, T. Miura, and M. Ochiai, *Chem. Lett.*, **1993**, 17, and references cited therein.

3 Several Lewis-acid reagents have been reported for the regioselective isomerization of epoxides. a) [Organoboron reagents] see Ref. 2b. b) [Organoaluminum reagents] K. Maruoka, N. Murase, R. Bureau, T. Ooi, and H. Yamamoto, *Tetrahedron*, **50**, 3663 (1994). c) [5M $LiClO_4$ in ether] R. Sudha, K. M. Narasimhan, V. G. Saraswathy, and S. Sankararaman, *J. Org. Chem.*, **61**, 1877 (1996), and references cited therein.

4 K. Suda, M. Sashima, M. Izutsu, and F. Hino, *J. Chem. Soc., Chem. Commun.*, **1994**, 949.

5 Fe(tpp)ClO_4 and Mn(tpp)ClO_4 were prepared from Fe(tpp)Cl and Mn(tpp)Cl, respectively, by the axial ligand exchange with $AgClO_4$ in THF followed by recrystallization (hexane-CH_2Cl_2). These complexes were characterized by UV–VIS spectroscopy, cyclic voltammetry and elemental analysis.

6 General procedure: An epoxide **1** (1 mmol) was heated at 80 °C with 0.02 mmol of Fe(tpp)ClO_4 in dioxane (3 ml). After completion of the reaction (monitored by TLC), the mixture was directly passed through a silica gel short column (1:1 hexane–ethyl acetate) to remove the catalyst. The eluate was concentrated under a reduced pressure, and the residue was then chromatographed on silica gel (1:1 hexane–ethyl acetate) to afford the corresponding ketones **2**. All the products gave satisfactory IR, NMR, and high resolution mass spectra. For example, ^{1}H-NMR (270 MHz, $CDCl_3$) data of **2a** and **2b** are as follows. **2a**: δ 0.12 (6H, s), 0.97 (9H, s), 3.86 (2H, s), 4.29 (2H, s), 7.25–7.41 (5H, m); **2b**: δ 1.33 (3H, d, J = 6.6 Hz), 3.75 and 3.90 (each 1H, d, J = 16.5 Hz), 4.47 (1H, q, J = 6.6 Hz), 6.97–7.67 (20H, m).