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# Highly efficient and selective methoxymethylation of alcohols and phenols catalyzed by high-valent tin(IV) porphyrin

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### 1. Introduction

Hydroxyl group is a versatile functional group and a wide variety of methods such as trimethylsilylation, tetrahydropyranylation, acetylation and methoxymethylation have been used for protection of hydroxyl groups [1,2]. Methoxymethyl ethers (MOM) are synthesized by the reaction of a hydroxyl compound with chloromethyl methyl ether. Due to the high carcinogenicity of this methoxymethylating agent [3], MOM-ethers are prepared by the reaction of alcohols or phenols with formaldehyde dimethyl acetal (FDMA) [4]. FDMA is a cheap and commercially available compound and its handling is easy which has poor methoxymethylating power in the absence of a suitable catalyst and needs forceful conditions. To overcome this limitation, a number of catalysts such as P<sub>2</sub>O<sub>5</sub> [5], p-toluenesulfonic acid [6], Nafion-H [7], TMSI [8], BF<sub>3</sub> [9], Envirocat [10], NaY-zeolite [11], expansive graphite [12], sulfated metal oxides [13], silica sulfuric acid [14], Sc(OTf)<sub>3</sub> [15], Bi(OTf)<sub>3</sub> [16], ZrCl<sub>4</sub> [17], MoO<sub>2</sub>(acac)<sub>2</sub> [18], H<sub>3</sub>PMo<sub>12</sub>O<sub>40</sub> [19], anhydrous FeCl<sub>3</sub> dispersed on 3A molecular sieve [20], TiO<sub>2</sub>/  $SO_4^{2-}$  [21],  $H_3PW_{12}O_{40}$  [22] and  $H_3PW_{12}O_{40}$  supported on silica and zirconia [23] have been reported.

Electron-deficient metalloporphyrins have been used as mild Lewis acids catalysts [24–29]. Suda group has reported the use of

### ABSTRACT

An efficient and selective method for methoxymethylation of alcohols and phenols with formaldehyde dimethyl acetal (FDMA) catalyzed by electron deficient tin(IV)tetraphenylporphyrinato trifluoromethanesulfonate, [Sn<sup>IV</sup>(TPP)(OTf)<sub>2</sub>], is reported. A variety of primary, secondary and tertiary alcohols as well as phenols were converted to their corresponding methoxymethyl ethers with FDMA in the presence of a high-valent tin(IV) porphyrin. This catalyst can be used for selective methoxymethylation of primary, secondary and tertiary alcohols in the presence of phenols or tertiary alcohols. The present method offers several advantages such as short reaction times, high yields, simple procedure, selectivity and applicability for both alcohols and phenols.

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chromium and iron porphyrins in organic synthesis. They used Cr(tpp)Cl for regioselective [3,3] rearrangement of aliphatic allyl vinyl ethers and for Claisen rearrangement of simple aliphatic allyl vinyl ethers, Fe(tpp)OTf for rearrangement of  $\alpha$ , $\beta$ -epoxy ketones into 1,2-diketones and Cr(tpp)OTf for highly regio- and stereose-lective rearrangement of epoxides to aldehydes [30–33].

Recently, we reported the use of tin(IV)tetraphenylporphyrinato perchlorate [34,35], tin(IV)tetraphenylporphyrinato trifluoromethanesulfonate [36,37], and tin(IV)tetraphenylporphyrinato tetrafluoroborate [38,39] in organic transformations.

In this paper, an efficient method for methoxymethylation of alcohols and phenols with FDMA catalyzed by high-valent  $[Sn^{IV}(TPP)(OTf)_2]$  at room temperature is reported (Scheme 1).

### 2. Experimental

Chemicals were purchased from Merck chemical company. <sup>1</sup>H NMR spectra were recorded in CDCl<sub>3</sub> solvent on a Bruker AM 80 MHz or a Bruker AC 500 MHz spectrometer using TMS as an internal standard. Infrared spectra were run on a Philips PU9716 or Shimadzu IR-435 spectrophotometer. All analyses were performed on a Shimadzu GC-16A instrument with a flame ionization detector using silicon DC-200 or Carbowax 20M columns and *n*-decane was used as internal standard. The tetraphenylporphyrin was prepared and metallated according to the literature [40,41].





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#### 2.1. Preparation of the catalyst

To a solution of  $[Sn(TPP)Cl_2]$  (1.03 g, 1 mmol) in 100 mL of THF, AgCF<sub>3</sub>SO<sub>3</sub> (0.54 g, 2 mmol) was added and the solution was stirred

at 55 °C for 30 min. The AgCl precipitate was filtered through a 0.45  $\mu$ M filter. The resulting solution was evaporated at room temperature. Then, the [Sn<sup>IV</sup>(TPP)(OTf)<sub>2</sub>] was extracted with CH<sub>2</sub>Cl<sub>2</sub>. The [Sn<sup>IV</sup>(TPP)(OTf)<sub>2</sub>] crystals obtained by evaporation of solvent at room temperature [37] (see Table 1).

# 2.2. General procedure for the methoxymethylation of alcohols and phenols

The catalyst,  $[Sn^{IV}(TPP)(OTf)_2]$  (10 mg, 0.01 mmol), was added to a mixture of alcohol or phenol (1 mmol) and FDMA (7 mmol), and stirred at room temperature for appropriate time (Table 2).

## Table 1

Protection of alcohols with FDMA catalyzed by [Sn<sup>IV</sup>(TPP)(OTf)<sub>2</sub>] at room temperature.

Entry	Alcohol	MOM-ether	Time (min)	Yield (%)
1	ОН	OCH2OCH3	10	95
2	Me <sub>3</sub> C OH	Me <sub>3</sub> C OCH <sub>2</sub> OCH <sub>3</sub>	15	96
3	МеО	MeO OCH <sub>2</sub> OCH <sub>3</sub>	20	96
4	CI	Cl OCH2OCH3	15	97
5	Br	Br OCH <sub>2</sub> OCH <sub>3</sub>	15	98
6	O2N OH	O <sub>2</sub> N OCH <sub>2</sub> OCH <sub>3</sub>	20	95
7	ОН	OCH <sub>2</sub> OCH <sub>3</sub>	15	96
8	ОН	OCH <sub>2</sub> OCH <sub>3</sub>	15	95
9	Ме	Me OCH <sub>2</sub> OCH <sub>3</sub>	15	95







Table 2 Protection of phenols with FDMA catalyzed by  $[{\rm Sn}^{\rm IV}({\rm TPP})({\rm OTf})_2]$  at room temperature.

Entry	Phenol	MOM-ether	Time (min)	Yield (%) <sup>a</sup>
1	ОН	OCH <sub>2</sub> OCH <sub>3</sub>	20	94
2	СІ—————————————————————————————————————	Cl————————————————————————————————————	20	96
3	СІ	Cl	25	95
4	ОМе	OCH <sub>2</sub> OCH <sub>3</sub>	25	95
5	O <sub>2</sub> N-OH	O <sub>2</sub> N — OCH <sub>2</sub> OCH <sub>3</sub>	20 (continued on	97 next page)

Table 2 (continued)



<sup>a</sup> Isolated yield.



The progress of the reaction was monitored by GC or TLC. After completion of the reaction, the solvent was evaporated,  $Et_2O$  (15 mL) was added and then the catalyst was filtered. The filtrates were washed with brine and dried over  $Na_2SO_4$  and concentrated under reduced pressure to afford the crude product, which was confirmed by <sup>1</sup>H NMR and IR spectral data.

### 3. Results and discussion

# 3.1. Methoxymethylation of alcohols and phenols with FDMA catalyzed by $[Sn^{IV}(TPP)(OTf)_2]$

Although metalloporphyrins are widely used as redox catalysts, there have been few studies on their catalytic activity as Lewis acids [24–39]. Since the metalloporphyrins are mild Lewis acids, we decided to explore their ability in the methoxymethylation of hydroxy compounds. First, in order to choose the appropriate catalyst, different metalloporphyrins were applied as catalysts in the methoxymethylation of 4-chlorobenzyl alcohol with FDMA. The catalytic activity of these catalysts in this reaction was appeared in the following order:  $[Sn^{IV}(TPP)(OTf)_2]$  (97%)  $\gg$   $[Fe^{III}(TPP)(OTf)]$  (45%) >  $[Mn^{III}(TPP)(OTf)]$  (40%) >  $[Sn^{IV}(TPP)Cl_2]$  (30%) >  $[Fe^{III}(TPP)-Cl]$  (15%) >  $[Mn^{III}(TPP)Cl]$  (8%) > [Cu(TPP)] (3%). The results which

# Table 3 Selective methoxymethylation of alcohols and phenols catalyzed by $[Sn^{IV}(TPP)(OTf)_2]$ .

Row	ROH	MOM-ether	Time (min)	Yield (%)
1	сі———СН2ОН	CI-CH2OCH2OCH3		97
	Me Me OH	Me, Me OCH <sub>2</sub> OCH <sub>3</sub>	15	0
2	СІ———СН2ОН	CI-CH2OCH2OCH3	15	97
	ОН	OCH <sub>2</sub> OCH <sub>3</sub>		0
3	OH CH <sub>3</sub>	OCH <sub>2</sub> OCH <sub>3</sub> CH <sub>3</sub>	15	95





obtained in the case of tin porphyrins clearly indicated that introducing of OTf instead of Cl has increased the electron deficiency of [Sn<sup>IV</sup>(TPP)(OTf)<sub>2</sub>] which in turn increases its catalytic activity.

Therefore, [Sn<sup>IV</sup>(TPP)(OTf)<sub>2</sub>] was used as catalyst for methoxymethylation of different alcohols with FDMA at room temperature. The optimized conditions which obtained for methoxy- methylation of 4-chlorobenzyl alcohol were alcohol, FDMA and catalyst in a molar ratio of 1:7:100. Under the optimized reaction conditions, which obtained for methoxymethylation of 4chlorobenzyl alcohol, a wide variety of primary, secondary and tertiary alcohols were subjected to methoxymethylation with FDMA in the presence of catalytic amounts of [Sn<sup>IV</sup>(TPP)(OTf)<sub>2</sub>] and at room temperature. The results, which are summarized in Table 2, showed that all primary, secondary and tertiary alcohols including aromatic, aliphatic and cyclic ones were completely converted efficiently to their corresponding methoxymethyl ethers in 10-25 min. In the case of aromatic alcohols, the nature of substituents has no significant effect on the methoxymethylation yield. No dehydration product was observed in the case of tertiary alcohols.

In order to show the role of catalyst, a probable mechanism has been proposed in Scheme 2. On the basis of this mechanism, FDMA is activated by  $[Sn^{IV}(TPP)(OTf)_2]$  and produces **1**. The alcohol at-

tacks **1** to give **2** which in turn produces the methoxymethyl ether **3** and releases the catalyst for the next catalytic cycle.

The successful application of this catalyst in the methoxymethylation of alcohols with FDMA, prompted us to investigate its catalytic activity in the methoxymethylation of phenols. Under the same reaction conditions obtained for alcohols, different phenols were subjected to methoxymethylation with FDMA and the corresponding ethers were obtained in excellent yields in 20– 25 min.

The chemoselectivity of the present method was investigated in a set of competitive reactions which was conducted between primary or secondary and tertiary alcohols or phenols (Table 3). The results indicated that the present protocol is potentially applicable for the chemoselective conversion of primary and secondary or tertiary alcohols to their MOM-ethers in the presence of phenols and alcohols.

Table 4, shows the effectiveness of this method in comparison with some of those reported in the literature for the methoxymethylation of hydroxyl compounds. The results, which are for the methoxymethylation of benzyl alcohol, show that our method is superior in terms of catalyst amount or reaction time or product yield.

#### Table 4

Comparison of the results obtained for the methoxymethylation of benzyl alcohol catalyzed by Sn<sup>IV</sup>(TPP)(OTf)<sub>2</sub> with those obtained by the recently reported catalysts.

OH Catalyst OCH <sub>2</sub> OCH <sub>3</sub>						
Entry	Catalyst	Catalyst (mol%)	Temperature	Time (h)	Yield (%)	Ref.
1	Sn <sup>IV</sup> (TPP)(OTf) <sub>2</sub>	1	R.T.	0.16	95	
2	NaY-zeolite	27 mg	Reflux	6	80	[11]
3	Expansive graphite	20 mg	Reflux	6	91	[12]
4	Sulfated metal oxides	50 mg	R.T.	3	91	[13]
5	Silica sulfuric acid	200 mg	Reflux	1.5	85	[14]
6	Sc(OTf) <sub>3</sub>	5	Reflux	3	98	[15]
7	Bi(OTf) <sub>3</sub>	5	Reflux	1	95	[16]
8	ZrCl <sub>4</sub>	10	R.T.	1	97	[17]
9	$MoO_2(acac)_2$	2	Reflux	4	85	[18]
10	H <sub>3</sub> PMo <sub>12</sub> O <sub>40</sub>	5	Reflux	3	90	[19]
11	Anhydrous FeCl <sub>3</sub> @ 3A molecular sieve	90	R.T.	1	90	[20]
12	$TiO_2/SO_4^{2-}$	20	Reflux	6	92	[21]
13	$H_3PW_{12}O_{40}$	0.4	R.T.	3	91	[22]
14	H <sub>3</sub> PW <sub>12</sub> O <sub>40</sub> @ Silica	0.4	R.T.	1	94	[23]
15	H <sub>3</sub> PWo <sub>12</sub> O <sub>40</sub> @ Zirconia	0.4	R.T.	2.5	84	[23]

### 4. Conclusion

In conclusion, different primary and secondary as well as tertiary alcohols and phenols efficiently converted to their corresponding methoxymethyl ethers (MOM-ethers) with formaldehyde dimethyl acetal (FDMA) in the presence of catalytic amounts of  $[Sn^{IV}(TPP)(OTf)_2]$  at room temperature. Short reaction times, easy preparation of catalyst, high product yield, solvent free conditions and applicability for both alcohols and phenols are the advantages of this catalytic system.

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#### References

- [1] M. Schelhaas, H. Waldmann, Angew. Chem., Int. Ed. Engl. 35 (1996) 2056.
- [2] T.W. Greene, P.G.M. Wuts, Protective Groups in Organic Synthesis, Wiley, New York, 1991.
- [3] P.J. Kocienski, Protecting Groups, Georg Thieme, Stuttgart, 1994.
- [4] G.A. Olah, A. Husain, B.G.B. Gupta, S.C. Narang, Synthesis (1983) 896.
- [5] K. Fuji, S. Nakano, E. Fujita, Synthesis (1975) 276.
- [6] J.P. Yarley, H. Fletcher, Synthesis (1976) 244.
- [7] G.A. Olah, A. Husain, B.G.B. Gupta, S.C. Narang, Synthesis (1981) 471.
- [8] G.A. Olah, A. Husain, S.C. Narang, Synthesis (1983) 896.
- [9] R.L. Danheiser, K.R. Romines, H. Koyama, S.K. Gee, C.R. Johnson, J.R. Medich, Org. Synth. 71 (1992) 133.
- [10] B.P. Bandgar, C.T. Hajare, P.P. Wadgaonkar, J. Chem. Res. (S) (1996) 90.
- [11] P. Kumar, S.V.N. Raja, R.S. Reddy, B. Pandy, Tetrahedron Lett. 35 (1994) 1289.
- [12] T.S. Jin, T.S. Li, Y.T. Gao, Synth. Commun. 28 (1998) 837.
- [13] C.-H. Lin, M.-Y. Wan, Y.-M. Huang, Catal. Lett. 87 (2003) 253.
- [14] K. Niknam, M.A. Zolfigol, A. Khorramabadi-Zad, R. Zare, M. Shayegh, Catal. Commun. 7 (2006) 494.
- [15] B. Karimi, L. Ma'mani, Tetrahedron Lett. 44 (2003) 6051.

- [16] B. Sreedhar, V. Swapna, Ch. Sridhar, Catal. Commun. 6 (2005) 293.
- [17] G.V.M. Sharma, K.L. Reddy, P.S. Lakshmi, P.R. Krishna, Tetrahedron Lett. 45 (2004) 9229.
- [18] M.L. Kantam, P.L. Santhi, Synlett (1993) 429.
- [19] M.A. Zolfigol, M. Shiri, Mendeleev Commun. 165 (2005) 165.
- [20] H.K. Patney, Synlett (1992) 567.
- [21] T.S. Jin, J.J. Guo, Y.H. Yin, S.L. Zhang, T.S. Li, J. Chem. Res. (S) (2002) 188.
- [22] I. Mohammadpoor-Baltork, M. Moghadam, S. Tangestaninejad, V. Mirkhani, A. Mirjafari, Can. J. Chem. 86 (2008) 831.
- [23] I. Mohammadpoor-Baltork, M. Moghadam, S. Tangestaninejad, V. Mirkhani, A. Mirjafari, Polyhedron 27 (2008) 2612.
- [24] K. Suda, M. Sashima, M. Izutsu, F. Hino, J. Chem. Soc., Chem. Commun. (1994) 949.
- [25] T. Takanami, R. Hirabe, M. Ueno, F. Hino, K. Suda, Chem. Lett. (1996) 1031.
- [26] H. Firouzabadi, A.R. Sardarian, Z. Khayat, B. Karimi, S. Tangestaninejad, Synth. Commun. 27 (1997) 2709.
- [27] H. Firouzabadi, Z. Khayat, A.R. Sardarian, S. Tangestaninejad, Iran. J. Chem. Chem. Eng. 15 (1996) 54.
- [28] S. Tangestaninejad, V. Mirkhani, Synth. Commun. 29 (1999) 2079.
- [29] S. Tangestaninejad, V. Mirkhani, J. Chem. Res. (S) (1999) 370.
- [30] T. Takanami, M. Hayashi, K. Iso, H. Nakamoto, K. Suda, Tetrahedron 62 (2006) 9467.
- [31] T. Takanami, M. Hayashi, K. Suda, Tetrahedron Lett. 46 (2005) 2893.
- [32] K. Suda, K. Baba, S. Nakajima, T. Takanami, Chem. Commun. (2002) 2570.
- [33] K. Suda, T. Kikkawa, S. Nakajima, T. Takanami, J. Am. Chem. Soc. 126 (2004) 9554.
- [34] S. Tangestaninejad, M.H. Habibi, V. Mirkhani, M. Moghadam, Synth. Commun. 32 (2002) 1337.
  [35] S. Tangestaninejad, M.H. Habibi, V. Mirkhani, M. Moghadam, J. Chem. Res. (S)
- (2001) 365.
   [36] M. Moghadam, S. Tangestaninejad, V. Mirkhani, N. Moghadam, S. Tangestaninejad, V. Mirkhani, I. Mohammadpoor-Baltork, R.
- Shaibani, J. Mol. Catal. A: Chem. 219 (2004) 73.
   [37] M. Moghadam, S. Tangestaninejad, V. Mirkhani, R. Shaibani, Tetrahedron 60
- (2004) 6105.
- [38] M. Moghadam, S. Tangestaninejad, V. Mirkhani, I. Mohammadpoor-Baltork, S.A. Taghavi, J. Mol. Catal. A: Chem. 274 (2007) 217.
- [39] M. Moghadam, S. Tangestaninejad, V. Mirkhani, I. Mohammadpoor-Baltork, S.A. Taghavi, Catal. Commun. 8 (2007) 2087.
- [40] A.D. Adler, F.R. Longo, J.D. Finarelli, J. Goldmacher, J. Assour, L. Korsakoff, J. Org. Chem. 32 (1967) 476.
- [41] A.D. Adler, F.R. Long, F. Kampas, J. Kim, J. Inorg. Nucl. Chem. 32 (1970) 2443.