JOC*Note*
pubs.acs.org/joc

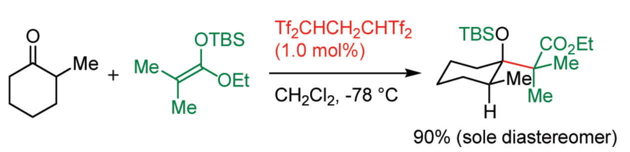
Carbon Acid Induced Mukaiyama Aldol Type Reaction of Sterically Hindered Ketones

Hikaru Yanai, Yasuhiro Yoshino, Arata Takahashi, and Takeo Taguchi*

School of Pharmacy, Tokyo University of Pharmacy and Life Sciences, 1432-1 Horinouchi, Hachioji, Tokyo 192-0392, Japan

taguchi@toyaku.ac.jp

Received May 10, 2010



1,1,3,3-Tetrakis(trifluoromethanesulfonyl)propane (Tf$_2$CHCH$_2$CHTf$_2$) is one of the most effective Brønsted acid precatalysts for the Mukaiyama aldol type reactions of sterically hindered ketones. By using Tf$_2$CHCH$_2$CHTf$_2$ in a range from 0.5 to 2.0 mol %, the vinylogous Mukaiyama aldol reaction of α-substituted cyclohexanones with 2-silyloxyfurans smoothly proceeded to give the aldol products in excellent yield without the loss of diastereoselectivity. Under similar conditions, acyclic ketene silyl acetals also performed as nice nucleophiles toward sterically hindered ketones. These findings suggest that Tf$_2$CHCH$_2$CHTf$_2$ induced Mukaiyama aldol type reactions can overcome the steric hindrance between reaction sites.

The construction of quaternary carbon in functionalized molecules remains as a formidable task in the field of organic synthesis. Especially, the construction of consecutive quaternary carbons by polar reactions, such as the aldol type reaction, is a great challenge. To overcome steric repulsion around reaction sites in the bond-forming step, the use of modern silicon Lewis acids such as Me$_3$SiNTf$_2$[1] (Tf = CF$_3$SO$_2$) and Me$_3$SiC(C$_6$F$_5$)Tf$_2$[2] should be a promising approach.[3] According to Childs' acidity index exemplified by ^{1}H NMR shift differences of crotonaldehyde caused by its coordination to the acids,[4] the electrophilic activation of carbonyl substrates by silicon Lewis acids such as Me$_3$SiNTf$_2$ and Me$_3$SiC(C$_6$F$_5$)Tf$_2$ is significantly stronger than that by conventionally used Lewis acids such as BF$_3$, AlCl$_3$, and TiCl$_4$.[5] This fact supports the idea that strong electrophilic activation of carbonyl substrates by silicon Lewis acids makes the effective nucleophilic addition to sterically hindered carbonyl electrophiles possible. Since the reactivity of ketones is lower than that of aldehydes due to steric and electronic reasons, the Mukaiyama aldol reaction of ketones often required the use of stoichiometric or substoichiometric amounts of suitable Lewis acids such as TiCl$_4$ and BF$_3$ to obtain the corresponding aldol products in good to excellent yield.[6,7] Meanwhile, the required catalyst loading of highly active silicon Lewis acids to complete the reaction is relatively low.[8] As an elegant example according to this concept, Sawamura and co-workers reported that the Mukaiyama aldol reaction of acetophenone and dimethylketene silyl acetal smoothly proceeds in the presence of only 1 mol % of toluene-coordinated silylium borate [Et$_3$Si(toluene)]B(C$_6$F$_5$)$_4$, which shows a strong cationic silicon character.[9] Furthermore, Yamamoto and co-workers demonstrated that 1 mol % of R$_3$SiNTf$_2$, generated in situ from Tf$_2$NH and enol silyl ethers, is enough to complete the Mukaiyama aldol reaction with simple ketone substrates.[10] However, the extension to stereoselective reactions was not examined in these studies.

As our achievement in this field, we reported that 1,1,3,3-tetrakis(trifluoromethanesulfonyl)propane **1** (Tf$_2$CHCH$_2$CHTf$_2$)[11] performs as an excellent Brønsted acid precatalyst for the diastereoselective vinylogous Mukaiyama−Michael (VMM) reaction of α,β-unsaturated ketones with 2-silyloxyfurans. It was also reported that its activity is significantly higher than that of TfOH, Tf$_2$NH, or Tf$_2$CHC$_6$F$_5$.[12−14] In this reaction

---

(1) (a) Mathieu, B.; de Fays, L.; Ghosez, L. *Tetrahedron Lett.* **2000**, *41*, 9561–9564. (b) Mathieu, B.; Ghosez, L. *Tetrahedron* **2002**, *58*, 8219–8226.

(2) Hasegawa, A.; Ishihara, K.; Yamamoto, H. *Angew. Chem., Int. Ed.* **2003**, *42*, 5731–5733.

(3) (a) Oishi, M. Silicon(IV) Lewis Acids. In *Lewis Acids in Organic Synthesis*; Yamamoto, H., Ed.; Wiley-VCH: Weinheim, Germany, 2000; Vol. 1, pp 355−393. (b) Dilman, A. D.; Ioffe, S. L. *Chem. Rev.* **2003**, *103*, 733–772. (c) Hosomi, A.; Miura, K. Si(IV) Lewis Acids. In *Acid Catalysis in Modern Organic Synthesis*; Yamamoto, H., Ishihara, K., Eds.; Wiley-VCH: Weinheim, Germany, 2008; Vol. 1, pp 469−516.

(4) Childs, R. F.; Mulholland, D. L.; Nixon, A. *Can. J. Chem.* **1982**, *60*, 801–808.

(5) Acidities were expressed as chemical shift difference $\Delta\delta$ of MeCH=CHCHO. Selected $\Delta\delta$ values (ppm) are as follows: BBr$_3$ (1.49),[4] BCl$_3$ (1.39),[4] BF$_3$ (1.17),[4] AlCl$_3$ (1.23),[4] TiCl$_4$ (1.03),[4] Me$_3$SiNTf$_2$ (1.74),[1] and Me$_3$SiCTf$_2$C$_6$F$_5$ (1.99).[2]

(6) For a systematic study on the steric limitation of TiCl$_4$ promoted Mukaiyama aldol reaction, see: Wenke, G.; Jacobsen, E. N.; Totten, G. E.; Karydas, A. C.; Rhodes, Y. E. *Synth. Commun.* **1983**, *13*, 449–458.

(7) For selected papers on catalytic Mukaiyama aldol reactions of ketones, see: (a) Hollis, T. K.; Robinson, N. P.; Bosnich, B. *Tetrahedron Lett.* **1992**, *33*, 6423–6426. (b) Oishi, M.; Aratake, S.; Yamamoto, H. *J. Am. Chem. Soc.* **1998**, *120*, 8271–8272. (c) Marx, A.; Yamamoto, H. *Angew. Chem., Int. Ed.* **2000**, *39*, 178–181. (d) Denmark, S. E.; Fan, Y. *J. Am. Chem. Soc.* **2002**, *124*, 4233–4235. (e) Oisaki, K.; Zhao, D.; Kanai, M.; Shibasaki, M. *J. Am. Chem. Soc.* **2006**, *128*, 7164–7165. (f) Hatano, M.; Takagi, E.; Ishihara, K. *Org. Lett.* **2007**, *9*, 4527–4530.

(8) (a) Murata, S.; Suzuki, M.; Noyori, R. *J. Am. Chem. Soc.* **1980**, *102*, 3248–3249. (b) Mukai, C.; Hashizume, S.; Nagami, K.; Hanaoka, M. *Chem. Pharm. Bull.* **1990**, *38*, 1509–1512. (c) Kawai, M.; Onaka, M.; Izumi, Y. *Bull. Chem. Soc. Jpn.* **1988**, *61*, 1237–1245. (d) Davis, A. P.; Plunkett, S. J. *J. Chem. Soc., Chem. Commun.* **1995**, 2173–2174. (e) Davis, A. P.; Plunkett, S. J.; Muir, J. E. *Chem. Commun.* **1998**, 1797–1798. (f) Davis, A. P.; Muir, J. E.; Plunkett, S. J. *Tetrahedron Lett.* **1996**, *37*, 9401–9402. (g) Oishi, M.; Aratake, S.; Yamamoto, H. *J. Am. Chem. Soc.* **1998**, *120*, 8271–8272.

(9) Hara, K.; Akiyama, R.; Sawamura, M. *Org. Lett.* **2005**, *7*, 5621–5623.

(10) Ishihara, K.; Hiraiwa, Y.; Yamamoto, H. *Synlett* **2001**, *12*, 1851–1854.

(11) Koshar, R. J.; Barber, L. L. US Patent 4053519, 1977.

(12) (a) Takahashi, A.; Yanai, H.; Zhang, M.; Sonoda, T.; Mishima, M.; Taguchi, T. *J. Org. Chem.* **2010**, *75*, 1259–1265. (b) Takahashi, A.; Yanai, H.; Taguchi, T. *Chem. Commun.* **2008**, 2385–2387.

(13) For our papers in relation to carbon acid mediated reactions, see: (a) Yanai, H.; Takahashi, A.; Taguchi, T. *Tetrahedron* **2007**, *63*, 12149–12159. (b) Yanai, H.; Takahashi, A.; Taguchi, T. *Tetrahedron Lett.* **2007**, *48*, 2993–2997.

DOI: 10.1021/jo100915e
Published on Web 06/28/2010
© 2010 American Chemical Society

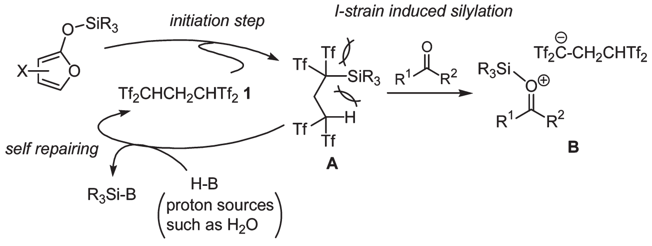
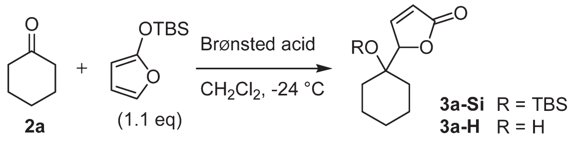


FIGURE 1. Electrophilic activation of carbonyl substrates in the $Tf_2CHCH_2CHTf_2$/2-silyloxyfuran system.

system, silyl methide species $R_3Si\text{-}CTf_2CH_2CHTf_2$ **A** in situ generated by the reaction of **1** with 2-silyloxyfurans activates α,β-unsaturated ketone substrates,[15] and the following C−C bond formation between the resultant oxocarbenium **B** (R^1 = CH=CHR′) with 2-silyloxyfuran results in the formation of the VMM product with excellent anti-selectivity (Figure 1). Due to the high silylating activity (Lewis acidity) of silyl methide **A** through notably large I-strain[1] and its "self-repairing" pathway,[16] the required loading of **1** was significantly low (typically, in a range from 0.05 to 1.0 mol %). As a next challenge, we became interested in the application of carbon acid (C−H acid) **1** to the stereoselective Mukaiyama aldol type reaction of sterically hindered ketones because the 1,2-addition is more sensitive toward the steric crowding around the reaction site, compared to the 1,4-addition.[17] In this paper, we demonstrate that **1** performs as an excellent Brønsted acid precatalyst for not only previously reported 1,4-addition chemistry[12] but also the Mukaiyama aldol type 1,2-addition reaction of sterically hindered ketones proceeding in an excellent diastereoselective manner.

At first, to examine the efficiency of Brønsted acids, we carried out the reaction of cyclohexanone **2a** with 2-TBSO-furan as a model reaction (Table 1). In the presence of 1.0 mol % of **1**, the vinylogous Mukaiyama aldol (VMA) reaction of **2a** with 2-TBSO-furan smoothly completed within 1 h at −78 °C to give the aldol adduct **3a-Si** and its desilylated derivative **3a-H** in 67 and 25% yield, respectively (entry 1; combined yield of **3a-Si** and **3a-H**, 92%). We also found that the slow addition of 2-TBSO-furan was notably effective for obtaining aldol product **3a** in good yield. That is, when 2-TBSO-furan was added to the solution of **2a** and carbon acid **1** in CH_2Cl_2 at −24 °C over 1.5 h, the resultant mixture was stirred at the same temperature for an additional 1 h and the VMA product **3a** was obtained in 82% yield (entry 3 vs 2). In contrast, by using 0.5 mol % of nitrogen acid Tf_2NH or oxygen acid TfOH instead of **1** under the same conditions, the product yield was significantly reduced (entries 4 and 5).

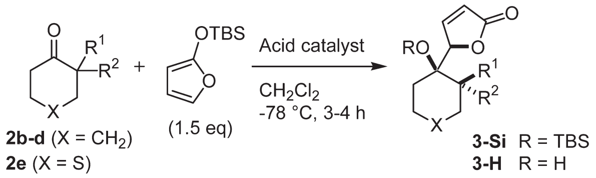
TABLE 1. Survey of Effective Brønsted Acid Precatalyst for the VMA Reaction



entry	Brønsted acid (mol %)	time (h)	yield[a] (**3a-Si** + **3a-H**, %)	ratio[b] (**3a-Si**/**3a-H**)
1[c]	**1** (1.0)	1	92	2.7:1
2	**1** (0.5)	2	49	2.3:1
3[d]	**1** (0.5)	2.5	82	4.1:1
4[d]	Tf_2NH (0.5)	2.5	63	2.9:1
5[d]	TfOH (0.5)	2.5	25	1:3.1

[a] Isolated yield. [b] Based on isolated yield. [c] Reaction was carried out at −78 °C. [d] 2-TBSO-furan was slowly added over 1.5 h.

TABLE 2. Diastereoselective VMA Reaction of α-Substituted Cyclic Ketones



entry	2	R^1	R^2	acid (mol %)	3	yield[a] (%)	dr[b]
1	**2b**	Me	H	**1** (0.5)	**3b**	78	11:1
2[c]	**2b**	Me	H	$TiCl_4$ (40)	**3b**	70	10:1
3[d]	**2b**	Me	H	$Bi(OTf)_3$ (5)	**3b**	65	12:1:1:0.5
4	**2c**	allyl	H	**1** (1.0)	**3c**	78	13:1
5[e]	**2d**	Me	Me	**1** (2.0)	**3d**	53	single
6	**2e**	Me	H	**1** (0.5)	**3e**	70	12:1

[a] Combined yield of isolated **3-Si** and **3-H**. [b] Based on ^{1}H NMR of the crude mixture. [c] From ref 18. [d] From ref 19. 2-TMSO-furan was also used as a nucleophile. [e] Reaction was carried out at −24 °C.

On the basis of the above finding of high efficiency of the carbon acid for the VMA reaction of **2a**, we examined the diastereoselective VMA reaction of α-substituted cyclohexanones with 2-TBSO-furan (Table 2). Recently, Romo reported that, in the presence of 40 mol % of $TiCl_4$, the VMA reaction of 2-methylcyclohexanone **2b** with 2-TBSO-furan proceeds with an excellent diastereoselectivity to give a mixture of **3b-Si** and **3b-H** in 70% yield (entry 2; TON = 1.75).[18] Furthermore, from a viewpoint of catalyst loading, $Bi(OTf)_3$ was found to be a more effective Lewis acid catalyst for the similar reaction (entry 3; TON = 13).[19] On the other hand, under the optimized conditions, only 0.5 mol % of **1** was enough to complete the VMA reaction of **2b** with 2-TBSO-furan, giving rise to **3b** in 78% yield without the decrease in the diastereoselectivity (entry 1, dr = 11:1; TON = 156). Synthetically more useful 2-allylcyclohexanone **2c** also reacted with 2-TBSO-furan in the presence of 1.0 mol %

---

(14) Other examples of the carbon acid catalyzed reactions: (a) Ishihara, K.; Hasegawa, A.; Yamamoto, H. *Angew. Chem., Int. Ed.* **2001**, *40*, 4077–4079. (b) Ishihara, K.; Hasegawa, A.; Yamamoto, H. *Synlett* **2002**, 1296–1298. (c) Ishihara, K.; Hasegawa, A.; Yamamoto, H. *Synlett* **2002**, 1299–1301. (d) Kokubo, Y.; Hasegawa, A.; Kuwata, S.; Ishihara, K.; Yamamoto, H.; Ikariya, T. *Adv. Synth. Catal.* **2005**, *347*, 220–224. (e) Hasegawa, A.; Naganawa, Y.; Fushimi, M.; Ishihara, K.; Yamamoto, H. *Org. Lett.* **2006**, *8*, 3175–3178.

(15) Selected examples for *in situ* generation of silicon Lewis acid: (a) Takasu, K. *Synlett* **2009**, 1905–1914. (b) Inanaga, K.; Takasu, K.; Ihara, M. *J. Am. Chem. Soc.* **2005**, *127*, 3668–3669. (c) Jung, M. E.; Ho, D. G. *Org. Lett.* **2007**, *9*, 375–378.

(16) Boxer, M. B.; Yamamoto, H. *J. Am. Chem. Soc.* **2006**, *128*, 48–49.

(17) It has been known that Lewis acid mediated 1,4-addition of silicon enolates often proceeds via single electron transfer mechanism. See: Otera, J.; Fujita, Y.; Sakuta, N.; Fujita, M.; Fukuzumi, S. *J. Org. Chem.* **1996**, *61*, 2951–2962.

(18) Kong, K.; Romo, D. *Org. Lett.* **2006**, *8*, 2909–2912.

(19) Ollevier, T.; Bouchard, J.-E.; Desyroy, V. *J. Org. Chem.* **2008**, *73*, 331–334.

SCHEME 1. VMA Reaction of 2b with 4-Substituted 2-TBSO-Furans

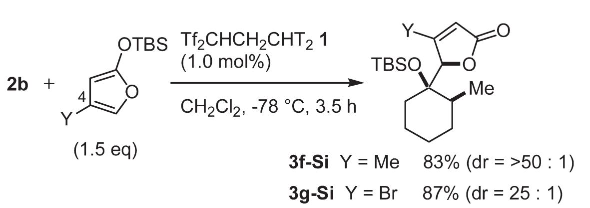
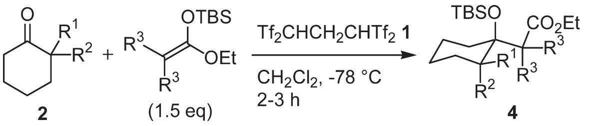


TABLE 3. Diastereoselective Mukaiyama Aldol Reaction with Acyclic Ketene Silyl Acetals



entry	**2**	R^1	R^2	R^3	**1** (mol %)	**4**	yield[a] (%)
1	**2a**	H	H	H	0.05	**4a**	98
2	**2b**	Me	H	H	0.05	**4b**	94
3	**2c**	allyl	H	H	0.05	**4c**	90
4	**2f**	Bn	H	H	0.05	**4d**	96
5	**2d**	Me	Me	H	0.5	**4e**	96
6	**2b**	Me	H	Me	1.0	**4f**	90
7	**2c**	allyl	H	Me	1.5	**4g**	81

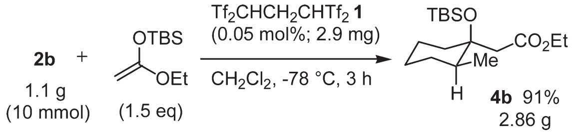
[a] Isolated yield.

of carbon acid **1** to give the corresponding VMA product **3c** in 78% yield as a mixture of two diastereomers in a ratio of 13:1 (entry 4). While the reactivity of 2,2-dimethylcyclohexanone **2d** is significantly reduced by the steric and electronic effects around the carbonyl group, the reaction of **2d** with 2-TBSO-furan in the presence of 2.0 mol % of carbon acid **1** gave the VMA product **3d-Si** in moderate yield as a sole diastereomer without the formation of desilylated product (entry 5). Likewise, in the presence of 0.5 mol % of **1**, α-methylated dihydrothiopyran-4-one **2e** was also converted to the VMA product **3e-Si** in 70% with an excellent diastereoselectivity (entry 6).

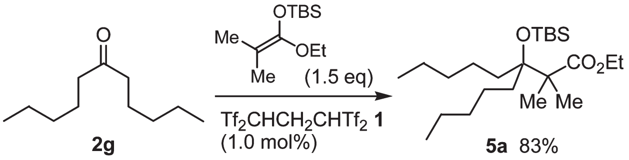
In this carbon acid induced VMA reaction, 4-substituted 2-TBSO-furans can be used (Scheme 1). For example, the reaction of **2b** with 4-methyl-2-TBSO-furan was promoted by 1.0 mol % of **1** at −78 °C to give the corresponding VMA adduct **3f-Si** in 83% as a mixture of two diastereomers in a ratio of >50:1 without the formation of the desilylated alcohol product. Under similar conditions, *β*-bromolactone **3g-Si** was also obtained in 87% yield with an excellent diastereoselectivity.

Next, we examined the efficiency of **1** in the Mukaiyama aldol reaction using acyclic ketene silyl acetals (Table 3). In this case, in the presence of only 0.05 mol % of **1**, the reaction of cyclohexanone **2a** with ketene silyl acetal derived from ethyl acetate (R_3 = H) rapidly completed at −78 °C to give the desired adduct **4a** in 98% yield (entry 1; TON = 1960). Remarkably, in all reactions of α-monosubstituted cyclohexanones **2b**, **2c**, and **2f** with simple ketene silyl acetal, the

SCHEME 2. Mukaiyama Aldol Reaction of 2b in Gram Scale



SCHEME 3. Mukaiyama Aldol Reaction of 2g with Dimethylketene Silyl Acetal



equatorial adducts **4b**, **4c**, and **4d** were obtained in excellent yields without the formation of diastereomers (entries 2−4).[20−22] Relatively less reactive **2d** was also found to be a nice substrate (entry 5, 96% yield). In addition, although it has been known that the treatment of ketones with dimethylketene silyl acetal (R^3 = Me) frequently results in the formation of enol silyl ether of ketones through silyl transfer reaction without the aldol type C−C bond formation,[23] the carbon acid induced Mukaiyama aldol chemistry realized the clean C−C bond formation between consecutive quaternary carbons with the perfect equatorial selectivity. That is, in the presence of 1.0 mol % of carbon acid **1**, the Mukaiyama aldol reaction of **2b** with dimethylketene silyl acetal smoothly proceeded to give the desired equatorial adduct **4f** in 90% yield (entry 6).[24] Likewise, the aldol product **4g** was obtained in 81% yield by the reaction of 2-allylcyclohexanone with dimethylketene silyl acetal under the same conditions (entry 7).

This diastereoselective Mukaiyama aldol reaction can be carried out in gram scale. For instance, by using 2.9 mg of carbon acid **1**, 1.1 g of **2b** smoothly converted to the desired aldol product **4b** in excellent yield without loss of diastereoselectivity (Scheme 2).

The present conditions using carbon acid **1** was also effective in the C−C bond formation between acyclic ketone with dimethylketene silyl acetal. It is known that, in the presence of 1 molar equiv of $TiCl_4$, the reaction of highly hindered undecan-6-one **2g** with dimethylketene silyl acetal does not give the desired aldol product.[6] In contrast, the use of **1** realized the clean formation of aldol adduct **5a** (Scheme 3, also see Supporting Information). This result strongly supports the idea that the present conditions are highly useful for the formation of the C−C bond between sterically hindered substrates.

As an initiation step of this Mukaiyama aldol type reaction, we propose the generation of silyl methide species **A** by

---

(20) Similar equatorial selectivity has been known in some Lewis acid mediated reactions of α-substituted cyclohexanones with silicon enolates. See: (a) Nakamura, E.; Horiguchi, Y.; Shimada, J.; Kuwajima, I. *J. Chem. Soc., Chem. Commun.* **1983**, 796–797. (b) Chen, J.; Sakamoto, K.; Orita, A.; Otera, J. *J. Org. Chem.* **1998**, *63*, 9739–9745. (c) Bandini, E.; Martelli, G.; Spunta, G.; Bongini, A.; Panunzio, M. *Synlett* **1999**, 1735–1738.

(21) For the hetero-Diels−Alder reaction of α-substituted cyclohexanone with Rawal's diene, see: Huang, Y.; Rawal, V. H. *J. Am. Chem. Soc.* **2002**, *124*, 9662–9663.

(22) The Mukaiyama aldol reaction of **2b** with ketene trimethylsilyl acetal required at least 1.0 mol % of $Tf_2CHCH_2CHTf_2$ to complete the reaction (see Supporting Information).

(23) (a) Hydrio, J.; Van de Weghe, P.; Collin, J. *Synthesis* **1997**, 68–72. (b) Song, J. J.; Tan, Z.; Reeves, J. T.; Fandrick, D. R.; Yee, N. K.; Senanayake, C. H. *Org. Lett.* **2008**, *10*, 877–880.

(24) By the reaction of highly hindered α,α-dimethylcyclohexanone with dimethylketene silyl acetal in the presence of 1.0 mol % of carbon acid **1**, the corresponding enol silyl ether was obtained in 76% yield without the formation of the desired aldol product (see Supporting Information).

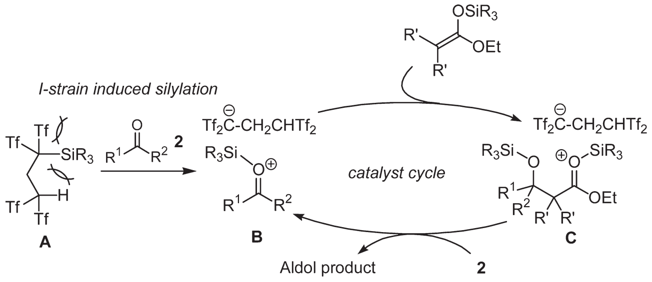


FIGURE 2. Catalyst cycle of the present aldol reaction.

the reaction of **1** with ketene silyl acetals and the following electrophilic activation of ketone substrate **2** through carbonyl silylation by silyl methide **A** (Figure 2).[12,25] Since this electrophilic activation by silyl methide would be significantly strong, the nucleophilic attack of ketene silyl acetal to intermediate **B** smoothly proceeds to give intermediate **C**. The resultant intermediate **C** would also show an excellent silylating activity; therefore, the aldol product is formed by the silylation of carbonyl substrate **2** by intermediate **C** along with the regeneration of intermediate **B**.[26]

In summary, we found that **1** performs as one of the most effective Brønsted acid precatalysts for the diastereoselective Mukaiyama aldol type reactions with low reactive ketones. By using carbon acid **1** in a range from 0.5 to 2.0 mol %, the VMA reaction of α-substituted cyclohexanones with 2-TBSO-furans smoothly proceeded to give the highly substituted γ-butenolides in excellent yield without any loss of diastereoselectivity. Under similar conditions, acyclic ketene silyl acetals also performed as nice nucleophiles. In the latter case, the required loading of carbon acid **1** can be reduced to 0.05−1.0 mol %. $Tf_2CHCH_2CHTf_2$ induced Mukaiyama aldol type reactions are remarkably useful for the C−C bond formation between sterically hindered substrates.

Experimental Section

General Procedure: Preparation of 5-(1-(*tert*-Butyldimethylsilyloxy)cyclohexyl)furan-2(5*H*)-one (3a-Si) and 5-(1-Hydroxycyclohexyl)furan-2(5*H*)-one (3a-H). To a solution of cyclohexanone **2a** (103.5 μL, 1.0 mmol) and $Tf_2CHCH_2CHTf_2$ **1** (2.86 mg, 5 μmol) in CH_2Cl_2 (1.0 mL) was added a solution of *tert*-butyl(furan-2-yloxy)dimethylsilane (218.1 mg, 1.1 mmol) in CH_2Cl_2 (1.0 mL) at −24 °C over 90 min via a syringe pump. After being stirred at the same temperature for 1 h, the reaction mixture was quenched with saturated $NaHCO_3$ solution (20 mL) and extracted with EtOAc (20 mL × 3). The organic layer was dried over anhydrous $MgSO_4$ and evaporated. The obtained residue was purified by column chromatography on silica gel (hexane/EtOAc = 10:1−1:1) to give the VMA product **3a-Si** in 66% yield (194.9 mg, 0.66 mmol) and its desilyated product **3a-H** in 16% yield (27.7 mg, 0.16 mmol). The structure of **3a-H** was confirmed by comparison of spectrum data with those reported in the literature.[19] For **3a-Si**: colorless crystals; mp 53.3−54.6 °C; IR (KBr) ν 3085, 2934, 2856, 1811, 1746, 1600, 1251, 1119, 772 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 0.09 (3H, s), 0.11 (3H, s), 0.83 (9H, s), 1.27−1.53 (5H, m), 1.58−1.72 (5H, m), 4.97−5.02 (1H, br s), 6.10 (1H, dd, J = 5.8, 2.0 Hz), 7.47 (1H, dd, J = 5.8, 1.3 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ −2.3, −1.8, 18.5, 22.0, 22.1, 25.3, 25.8, 34.4, 34.9, 76.2, 87.5, 122.5, 154.0, 173.0; MS (ESI-TOF) m/z 319 $[M + H]^+$; HRMS calcd for $C_{16}H_{28}NaO_3Si$ $[M + Na]^+$ 319.1705, found 319.1688. Anal. Calcd for $C_{16}H_{28}O_3Si$: C, 64.82; H, 9.52. Found: C, 64.58; H, 9.41.

Supporting Information Available: Detailed experimental procedure, compound characterization data, ^1H and ^{13}C NMR spectra. This material is available free of charge via the Internet at http://pubs.acs.org.

---

(25) Hollis, T. K.; Bosnich, B. *J. Am. Chem. Soc.* **1995**, *117*, 4570–4581.

(26) For a mechanistic investigation of $R_3Si\text{-}CTf_3$ induced Mukaiyama aldol reaction with enol silyl ethers, see: Hiraiwa, Y.; Ishihara, K.; Yamamoto, H. *Eur. J. Org. Chem.* **2006**, 1837–1844.