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Synthesis and Application of α-Trifluoromethylated Aldehydes

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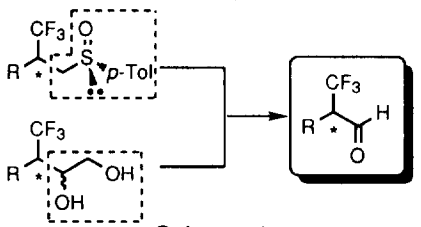
Abstract: Two methods for the synthesis of α-trifluoromethylated aldehydes are described. One is a synthetic method *via* Pummerer rearrangement followed by the hydrolysis under the weakly basic condition, giving the racemic aldehyde. The other is *via* the oxidative cleavage of the corresponding diol under the acidic condition, affording the optically active compound for the first time. Furthermore, both aldehydes underwent the reaction with some nucleophiles in good yields.

INTRODUCTION

In recent years, trifluoromethylated materials have been receiving much attention in various fields such as those of polymers or pharmacology because of their unique physiological and physical properties.[1] Therefore, various kinds of synthetic methods have been developed thus far. Trifluoromethylation[2] and halogen-exchange reaction[3] are possible methods for constructing CF_3 compounds, but these suffer from low reactivity and low selectivity. An alternative approach is the preparation and application of trifluoromethylated synthetic blocks.[4] As widely applicable intermediates, α-CF_3 aldehydes are considered to be one of the most important starting materials on the basis of the extensive information on the nonfluorinated counterparts.[5] In spite of their utilities and some reports concerning α-CF_3 aldehydes bearing heteroatom at their α-position,[6] only a few have been published thus far on the preparation without any heteroatoms at this position.[7] This might be because such aldehydes are very difficult to be produced due to ready enolization[8] or defluorination[9] effected by a strongly electronwithdrawing CF_3 group.



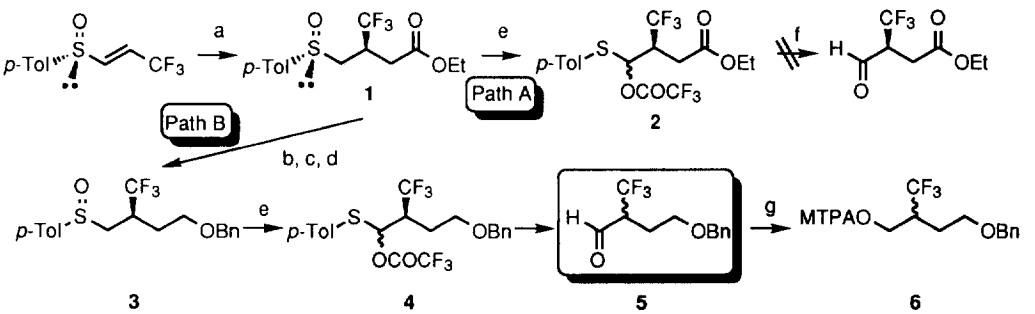
Scheme 1

During the course of our studies on the exploitation of the optically pure Michael adducts derived from vinyl sulfoxide,[10] we have found two synthetic routes to α-CF_3 aldehydes *via* Pummerer rearrangement,[11] and the oxidative cleavage of diol, both of which would permit a ready access to a broad variety of CF_3 compounds (Scheme 1). Especially, the latter path realized, although not in an optically pure form, the first synthesis of the optically active α-CF_3 aldehyde. Described herein are our results on the preparations and applications of these aldehydes in detail.

RESULTS AND DISCUSSION

Synthesis of α-CF_3 Aldehyde via Pummerer Rearrangement. It is well known that Pummerer rearrangement is among the aldehyde preparation methods, and that the reaction condition of its variant[12] is considered to be mild enough to prevent various kinds of side reactions, for example, defluorination and/or epimerization. In fact, transformation of the optically pure Michael adduct **1**[10] in CH_3CN proceeded smoothly to

afford the crude material **2** in a diastereorandom manner (Scheme 2). However, the following hydrolysis with copper (II) chloride only gave a complex mixture (Path A). This might be because an ester functional group is unstable under the condition used. Therefore, we converted this group into the corresponding ether (Path B). Thus, Michael adduct **1** was reduced by LAH, followed by protection of the resultant hydroxy group as the benzyl ether. Then, the sulfide was oxidized by *m*-chloroperbenzoic acid (*m*-CPBA) to afford a 3:2 diastereomeric sulfoxide **3** in 77% total yield from **1**. For this sulfoxide **3**, Pummerer rearrangement was performed in a similar way to give the *S,O*-acetal **4** . The hydrolysis of acetal **4** proceeded sluggishly, and the complex mixture was again obtained, while its ^{1}H NMR has shown the existence of the aldehyde proton (9.6-9.7 ppm). Then, hydrolytic conditions[12] were thoroughly examined. The results are summarized in Table 1. Among various conditions examined, the best result was obtained when Pummerer rearrangement proceeded in an ether solution and the subsequent hydrolysis was performed with $NaHCO_3$ [3 equiv relative to $(CF_3CO)_2O$] in the presence of $Et_3BnN^+Cl^-$ as a phase transfer catalyst (Entry 7). This rearrangement in THF also proceeded smoothly to give **4**, however, the hydrolysis yielded only a complex mixture. Furthermore, Pummerer rearrangement did not proceed completely in CH_2Cl_2. Thus, it is important to use diethyl ether as the solvent. The enantiomeric excess (ee) of the obtained aldehyde was determined by the corresponding Mosher's ester **6** to be found out that the ee value was 0%. This result unambiguously demonstrated the high acidity of the α-proton of **5**, which was easily abstracted by such a weak base as $NaHCO_3$.



Scheme 2 a) LDA, CH_3CO_2Et b) LAH c) NaH, BnBr d) *m*-CPBA e) $(CF_3CO)_2O$, 2,6-lutidine f) $CuCl_2$ aq. g) i) DIBAL-H ii) MTPA-Cl, Et_3N

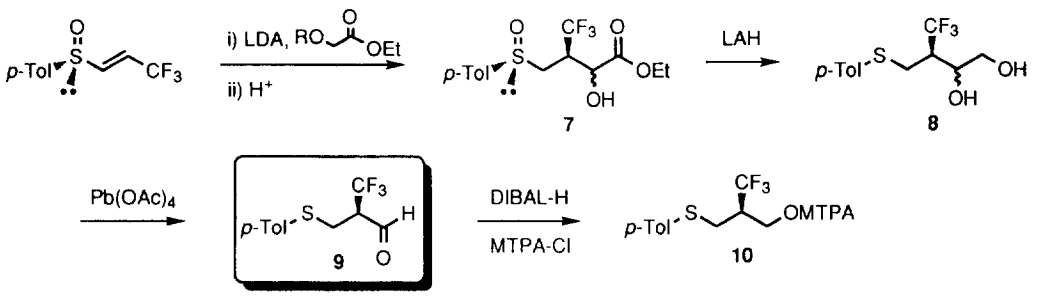
Table 1 Hydrolysis of *S,O*-acetal 4

Entry	Reagent	Solvent	Yield of 5 (%)[a]
1	$CuCl_2$	H_2O / CH_3CN	33
2	$CuCl_2$	H_2O / THF	-
3	$Cu(OAc)_2$ / $Et_3BnN^+Cl^-$	H_2O / Et_2O	42
4	$CuSO_4$ / $Et_3BnN^+Cl^-$	H_2O / Et_2O	-
5	$NaHCO_3$	H_2O / CH_3CN	-
6	$NaHCO_3$ (1 equiv)[b] / $Et_3BnN^+Cl^-$	H_2O / Et_2O	-
7	$NaHCO_3$ (3 equiv)[b] / $Et_3BnN^+Cl^-$	H_2O / Et_2O	73[c]
8	Na_2CO_3 / $Et_3BnN^+Cl^-$	H_2O / Et_2O	-
9	$HgCl_2$	H_2O / CH_3CN	23
10	I_2	MeOH / Et_2O[d]	49

a) The yield was determined by ^{19}F NMR using $PhCF_3$ as an internal standard. Formation of a complex mixture was indicated by "dash (-)". b) The quantity of $NaHCO_3$ was relative to the one of $(CF_3CO)_2O$. c) Isolated yield. d) This reaction was carried out under reflux condition.

Preparation of α-CF_3 Aldehyde under the Acidic Condition. As the alternative route to access the chiral aldehydes, preparation of **9** was attempted as outlined in Scheme 3 under acidic conditions to prevent the unfavorable epimerization.

Michael addition of dianion from glycolate to the vinyl sulfoxide was carried out, while it did not proceed at all with quantitative recovery of the substrate. Then a variety of hydroxy-protected glycolates were examined thoroughly. The results are summarized in Table 2.



Scheme 3

Table 2 Michael Reaction to Vinyl Sulfoxide with Glycolate

Entry	R	Yield of **7** (%)[a]	Diastereoselectivity[b]
1	H	-	-
2	MEM	69	55 : 45
3	Bn	56	55 : 45
4	EE	82[c]	68 : 32
5	THP	71[c]	73 : 27
6	TBS	64[c]	53 : 47

a) Isolated yield. b) Determined by ^{19}F NMR. c) These values refer to total yields of Michael reaction and the following deprotection.

In the case of (methoxyethoxy)methyl (MEM) and benzyl (Bn) groups, Michael addition proceeded but they were difficult to be removed. More labile 1-ethoxyethyl (EE), tetrahydropyranyl (THP), and *tert*-butyldimethylsilyl (TBS) groups were examined to be found out that the EE protection gave the best results of 82% yield and a 68:32 ratio of separable diastereomers. On the basis of our previous work,[10] the chirality on the sulfur would be completely transferred to the carbon bearing a CF_3 group with high (*R*) stereoselectivity.

The oxidative cleavage of the diol **8** to the aldehyde **9** after reduction of Michael adduct **7** with LAH, was attempted. The reaction with $Pb(OAc)_4$ was finished in several hours and the simple distillation yielded the pure aldehyde after the reaction mixture was passed through Florisil. It was essential to carry out the reaction under nitrogen or argon atmosphere as well as to add the diol very slowly in a highly diluted condition (for example, 5 mmol diol / 300 mL CH_2Cl_2) for preventing overoxidation and obtaining a good yield.

The optical purity of the crude **9** which was not distilled, was clarified to be 60% ee by derivatization into the corresponding Mosher's ester **10**. In this case, racemization at the CF_3-attached carbon atom was suppressed only to 20%, and to the best of our knowledge, compound **10** is the first example of chiral non-racemic aldehyde of this type, without any heteroatom at α-position. However, partial racemization occurred during distillation of **9** and the optical purity was slightly decreased to 42% ee.

Application of the Aldehydes. The reaction of the aldehyde **5** obtained with nucleophiles was attempted at the next stage. The results are given in Table 3. Lithium enolates derived from esters or ketones furnished products **11**-**13** in good yields (Entry 1,2). On the other hand, success of the alkyl introduction was

highly dependent on the metal used (Entry 4 vs 5 and 6). Thus, cuprates and Grignard reagent yielded the correct products, while the corresponding lithium reagents gave unidentified mixtures. Lewis acid-promoted reaction (Entry 7) did not proceed at all and the substrate was recovered in high yield.

In the non-fluorinated system, Tsuchihashi and coworkers[13] have reported that the 4-benzyloxy-2-methylbutanal, the non-fluorinated protocol of the aldehyde **5**, reacted with MeMgBr in THF only in a slightly *syn* preferred manner (*syn* : *anti* = 1.2 : 1). They have suggested that this *syn* selectivity was due to the Felkin-Anh model with a $BnO(CH_2)_2$- group occupying the perpendicular position to the carbonyl group. Thus, in this case, the bulkiness of the methyl and the benzyloxyethyl groups can be considered to be similar as long as this model was considered. However, in the present case the diastereoselectivity increased in every instance (70:30~90:10).This might be conveniently elucidated as follows: thus, a CF_3 group, considered to be similar in size to an isopropyl group,[14] must be regarded as the larger substituent than a benzyloxyethyl moiety on the basis of the above discussion and their steric difference should be bigger too than the one between methyl and benzyloxyethyl groups. This hypothesis assumes that the products was obtained in an *anti* selective manner (Figure 2). In addition, MNDO calculation[15] was attempted to predict the relative stereochemistry of **11** through the energetic differences of TSs leading to both *syn* and *anti* isomers. The aldol reaction of 2-(trifluoromethyl)propanal with lithium enolate derived from acetaldehyde was selected as the model reaction with two additional H_2O on the lithium for the modification of THF coordination. The results are described below (Figure 3). The above five TSs in a range of 3 kcal/mol of free energy at -78 °C from the most stable TS were devided into two types as *anti* selectivity or *syn* selectivity leading to the *anti* or *syn* isomers, respectively. Each TS was characterized by analytical harmonic frequency calculation, giving only one negative eigenvalue. Percentages in Figure 3 express the probability of their existence. As a result, the selectivity is considered to be *anti* : *syn* = 68 : 32 at -78 °C. Compared with the experimental results (70:30~90:10), relatively lower selectivity might stem from the assumption that the difference between methyl and benzyloxyethyl groups in the model

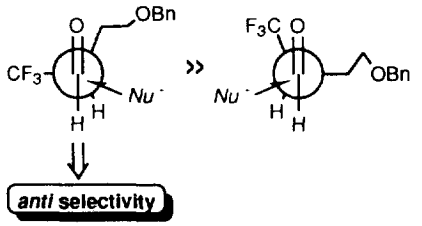


Figure 2

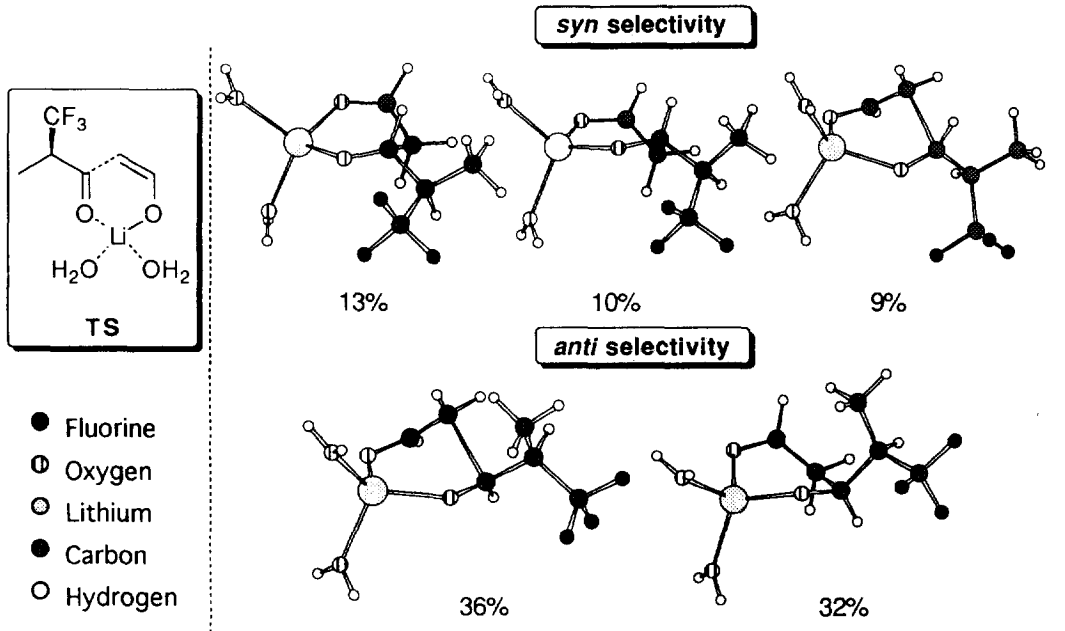


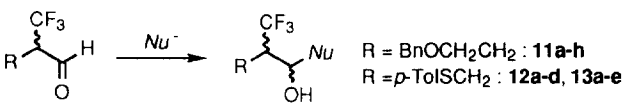
Figure 3

compounds for the calculation did not cause significant change in their steric sizes. However, the calculation results qualitatively support that lithium enolates preferentially attack the *Si* face of the carbonyl carbon of the aldehyde, avoiding the largest CF_3 group, to give the same *anti* secondary alcohols as in the case of the reaction of the aldehyde with MeMgBr.

The nucleophilic reactions to the aldehyde **9** also proceeded in good yields. In the case of Grignard reagent, better yield was obtained compared to the instance with the aldehyde **5** (Entry 10), while lithium enolates gave comparable or unfavorable results (Entry 9). Moreover, the enol silyl ether (Entry 13) led to the total decomposition of the substrate when treated with tetra-*n*-butylammonium fluoride (TBAF) which affords the so-called " naked " enolate. Lewis acid-promoted reactions proceeded smoothly and cleanly, but was highly dependent on the Lewis acid employed. Comparison of Entry 15 and 16, for example, clearly showed this trend: thus BF_3 preferentially afforded one diastereomer in 31% yield, while $TiCl_4$ gave much better chemical yield in a diastereorandom manner. On the other hand, subjection of enol silyl ether derived from acetophenone to the $TiCl_4$-mediated condition only produced a complex mixture (Entry 18). The relatively lower conversion and higher diastereoselectivity in the BF_3 system was also noted.

The selectivity of the above nucleophilic addition to **9** could be explained by the discussion similar to the case of **5**. Thus, nucleophiles might attack the carbonyl carbon, avoiding the largest substituent, a CF_3 group, which occupies the perpendicular position to the carbonyl moiety, to afford *anti* product. On the other hand, low selectivity in the case of $TiCl_4$ is somewhat ambiguous on the basis of the result of the similar aldehyde, 3-(benzyloxy)isobutyraldehyde (12:1 *anti* selectivity by using $SnCl_4$ and allyltrimethylsilane[5a]).

Table 3 Nucleophilic Reaction to Aldehydes



Entry	Aldehyde	Products	Nucleophiles	Yield (%)[a]	Ds[b]
1	**5**	**11a**	$(CH_3)_2C{=}C(OLi)OEt$	81[c]	87 : 13[d]
2		**11b**	$(CH_3)_3CC(OLi){=}CH_2$	69[c]	72 : 28[d]
3		**11c**	$(n\text{-}Bu)_2CuLi$	40	72 : 28[d]
4			MeLi	-	-
5		**11d**	MeMgBr	45	77 : 23[d]
6		**11d**	$(CH_3)_2CuLi$	49	73 : 27
7			$PhC(OTMS){=}CH_2$, $BF_3{\cdot}OEt_2$	-	-
8		**11e**	$(EtO)_2P(O)CHNaCO_2Et$	58	*trans* only[e]
9	**9**	**12a**	$(CH_3)_2C{=}C(OLi)OEt$	59	71 : 29
10		**12b**	MeMgBr	62	57 : 43
11			$PhC{\equiv}CLi$	0	-
12		**12c**	$PhC{\equiv}CMgBr$[f]	38	79 : 21
13			$CH_2{=}C(OTMS)C(CH_3)_3$ / TBAF	0	-
14		**13a**	$CH_2{=}CHCH_2TMS$, $TiCl_4$	76	50 : 50
15		**12b**	$CH_2{=}C(OTMS)C(CH_3)_3$, $TiCl_4$	73	54 : 46
16		**12b**	$CH_2{=}C(OTMS)C(CH_3)_3$, $BF_3{\cdot}OEt_2$	31	95 : 5
17		**13b**	TMSCN, $BF_3{\cdot}OEt_2$	61	87 : 13
18		**13c**	$CH_2{=}C(OTMS)Ph$, $BF_3{\cdot}OEt_2$	41	89 : 11

a) Isolated yield. b) Diastereoselectivity was determined by ^{19}F NMR. c) The three step total yield from sulfoxide was shown. d) Determined by GC. e) Determined by ^1H NMR. f) The presence of some impurities was observed by ^{19}F NMR.

CONCLUSION

In summary, we have established two versatile synthetic methods leading to α-CF_3 aldehydes. One route *via* Pummerer rearrangement was found to cause complete epimerization due to the labile α-proton even under aqueous $NaHCO_3$ condition. The other pathway *via* the acidic oxidative cleavage of the diol dramatically suppressed epimerization to allow the synthesis of the desired enantiomerically enriched aldehyde for the first time. In addition, the fact that the nucleophilic addition reactions to the aldehydes **5** and **9** proceeded smoothly without defluorination clarifies the importance of α-CF_3 aldehydes as useful intermediates to construct a variety of CF_3-containing materials.

Experimental

General.[16] Gas liquid chromatography (GLC) was performed using Silicone GE XE-60 or ULBON HR-20M on Chromosorb W, 30 m x 3 mm. NMR patterns of minor isomers are the same as those of major one, with an exception of signals indicated.

(3*R*,*RS*)-Ethyl 3-(trifluoromethyl)-4-(4-methylphenylsulfinyl)butanoate (1) To a LDA solution in THF (16.1 mmol in 50 mL) was added 16.3 mmol of ethyl acetate and the whole was stirred for 0.5 h at -78 °C. To the enolate formed 14.4 mmol of (***R***)-(***E***)-vinyl sulfoxide was added in 10 mL of THF and stirring was continued for 1.5 h at that temperature, followed by 0.5 h at 0 °C. The reaction was quenched with sat. NH_4Cl aq, the organic material was extracted with CH_2Cl_2, washed with water and sat. NaCl aq successively, dried over anhydrous $MgSO_4$, and evaporated to afford, after chromatographic separation, the desired Michael adduct. Yield : 83%. IR (neat) ν 3060, 3000, 2950, 2880, 1740 cm^{-1}. $[\alpha]^{21}_D$ +183.13 (*c* 1.3, $CHCl_3$). ^1H NMR δ 1.28 (3 H, t, *J* = 7.14 Hz), 2.43 (3 H, s), 2.67 (2 H, d, *J* = 6.33 Hz), 2.91 (1 H, dd, *J* = 7.32 Hz, 13.71 Hz), 2.99 (1 H, dd, *J* = 5.72, 13.69 Hz), 3.39 (1 H, ddtq, *J* = 5.78, 6.33, 7.30, 8.57 Hz), 4.19 (2 H, q, *J* = 7.16 Hz), 7.3-7.6 (4 H, m). ^{13}C NMR δ 14.10, 21.46, 33.23 (q, *J* = 2.5 Hz), 36.32 (q, *J* = 28.0 Hz), 56.16 (q, *J* = 1.4 Hz), 61.38, 124.03, 130.25, 140.45, 142.34, 126.51 (q, *J* = 280.1 Hz), 169.82. ^{19}F NMR δ 7.47 (d, *J* = 8.30 Hz).

(*R*)-4-(Benzyloxy)-2-(trifluoromethyl)-1-(4-methylphenylsulfinyl)butane (3) To a stirring slurry of lithium aluminium hydride (2.09 g, 55.3 mmol) in THF (100 mL) was added a solution of the above sulfoxide (14.8 g, 46.1 mmol) in THF (20 mL) at 0 °C and the whole was stirred overnight at room temperature. The reaction was quenched with 4 *N* KOH aq, and the usual workup gave the crude materials. To a stirring slurry of 55% NaH (2.06 g, 46.7 mmol) in THF (100 mL), the materials was added at 0 °C and the whole was stirred for 0.5 h. After this solution was treated with benzyl bromide (4.66 mL, 39.3 mmol), the reaction mixture was stirred overnight. The reaction was quenched with water and HCl aq, and the usual workup gave the crude benzyl ether. To a solution of the benzyl ether in CH_2Cl_2 (200 mL) was added *m*-CPBA (7.51 g, 43.5 mmol) at 0 °C and the whole was stirred for 0.5 h at that temperature. Workup with sat. Na_2SO_3 aq, followed by the extraction with CH_2Cl_2, washed with water, dried over anhydrous $MgSO_4$, giving the crude materials, which were purified by silica gel column chromatography to afford the corresponding sulfoxide (13.4 g, 35.9 mmol) as an inseparable diastereomer mixture. Yield : 77%. D.s. = 60 : 40. IR (neat) ν 3025, 2925, 2850 cm^{-1}. $[\alpha]^{22}_D$ +38.4 (*c* 1.0, $CHCl_3$). **major isomer** ^1H NMR δ 1.7-2.3 (2 H, m), 2.41 (3 H, s), 2.8-3.1 (3 H, m), 3.5-3.7 (2 H, m), 4.51 (2 H, s), 7.2-7.4 (9 H, m). ^{13}C NMR δ 21.47, 28.78 (q, *J* = 2.4 Hz), 36.20 (q, *J* = 27.07 Hz), 57.11 (q, *J* = 1.6 Hz), 66.71, 73.14, 127.22 (q, *J* = 280.2 Hz), 124.00, 124.15, 127.73, 127.74, 127.76, 127.82, 128.44, 130.13, 137.91, 140.16, 141.98, 142.15. ^{19}F NMR δ 7.75 (d, *J* = 6.89 Hz). **minor isomer** ^1H NMR δ 2.39 (3 H, s), 4.49 (2 H, s). ^{13}C NMR δ 21.44, 27.67 (q, *J* = 1.9 Hz), 36.44 (q, *J* = 27.3 Hz), 56.93 (q, *J* = 2.2 Hz), 66.88, 73.18, 124.00, 124.15, 127.73, 127.74, 127.76, 127.82, 128.44, 130.13, 137.91, 140.16, 141.98, 142.15. ^{19}F NMR δ 8.10 (d, *J* = 6.89 Hz).

4-(Benzyloxy)-2-(trifluoromethyl)butanal (5) To an ether solution (8 mL) of the sulfoxide (0.31 g, 0.81 mmol) and 2,6-lutidine (0.18 mL, 1.62 mmol) was added trifluoroacetic anhydride (0.22 mL, 1.62 mmol) at 0 °C. After the reaction mixture was stirred at 0 °C for 30 min, an aqueous solution of sodium hydrogen carbonate (0.39 g, 4.81 mmol) in H_2O (4 mL) and a catalytic amount of $Et_3BnN^+Cl^-$ was added. Then the

mixture was stirred at room temperature for several hours. The resultant aldehyde was extracted with ether, and the ether extract was washed with dilute HCl aq and brine. The organic layer was then dried over anhydrous $MgSO_4$ and the volatiles were evaporated. The residual oil was purified by column chromatography to afford the aldehyde (0.15 g, 0.59 mmol). Yield : 73%. IR (neat) ν 3090, 3080, 3030, 2880, 2860, 1740 cm^{-1}. ^1H NMR δ 2.0-2.3 (2 H, m), 3.28 (1 H, dddq, *J* = 2.15, 4.53, 8.75, 9.52 Hz), 3.5-3.6 (2 H, m), 4.47 (2 H, s), 7.1-7.4 (5 H, m), 9.6-9.7 (1 H, m). ^{13}C NMR δ 24.23 (q, *J* = 2.0 Hz), 52.95 (q, *J* = 24.5 Hz), 66.26, 73.10, 125.18 (q, *J* = 280.5 Hz), 127.72, 127.85, 128.48, 194.55 (q, *J* = 3.5 Hz). ^{19}F NMR δ 11.92 (d, *J* = 9.65 Hz).

(*R*)-3-(Trifluoromethyl)-4-(4-methylphenylsulfenyl)butane-1,2-diol (8) To a solution of 0.21 mL (1.5 mmol) of diisopropylamine in freshly distilled 5 mL of THF was added 0.60 mL (1.5 mmol) of *n*-BuLi at -78 °C and the whole was stirred for 30 min. To this LDA solution was dropped a THF solution of the α-alkoxyester (1.5 mmol) followed by additional stirring for 0.5 h at that temperature, and after further addition of 234 mg (1 mmol) of the chiral vinyl sulfoxide in 3 mL of THF, stirring was continued for 5 h at -78 °C. The reaction was quenched with sat. NH_4Cl solution, the organic material was extracted with ethyl acetate, washed with water and brine, dried over anhydrous $MgSO_4$ and the evaporation of the solvent afforded the crude Michael adduct. The obtained compounds was stirred for 2 h in the mixture of THF/3 *N* HCl, followed by the usual workup. To a stirring slurry of lithium aluminium hydride (0.05 g, 1.23 mmol) and Et_2O (5 mL) was added a solution of the crude sulfoxide at -78 °C and the whole was allowed to warm to room temperature and was stirred for 2 h at that temperature. The reaction was quenched with sat. Na_2SO_4 aq and the usual workup gave the crude materials, which were purified by silica gel column chromatography to afford alcohol (0.16 g, 0.56 mmol). Yield : 56 %. IR (neat) ν 3300, 3025, 2925, 2875 cm^{-1}. **major isomer** $[\alpha]^{24}_D$ -38.11 (*c* 0.35, $CHCl_3$). ^1H NMR δ 2.31(3 H, s), 2.2-2.5 (1 H, m), 3.12 (1 H, dd, *J* = 8.43, 13.78 Hz), 3.22 (1 H, dd, *J* = 4.78, 13.91 Hz), 3.0-3.3 (1 H, m), 3.39 (1 H, dd, *J* = 3.30, 11.39 Hz), 3.77 (1 H, dd, *J* = 8.01, 11.54 Hz), 3.5-3.8 (1 H, m), 4.1-4.3 (1 H, m), 7.0-7.3 (4 H, m). ^{13}C NMR δ 21.03, 30.21 (q, *J* = 3.0 Hz), 44.69 (q, *J* = 24.4 Hz), 64.53 (q, *J* = 2.6 Hz), 69.51, 126.53 (q, *J* = 282.2 Hz), 130.08, 130.32, 130.82, 137.43. ^{19}F NMR δ 11.02 (d, *J* = 8.92 Hz). HRMS for $C_{12}H_{15}O_2F_3S$ M^+ 280.0745, found 280.0763. **minor isomer** $[\alpha]^{21}_D$ -17.95° (*c* 0.13, $CHCl_3$). ^1H NMR δ 2.32 (3 H, s), 2.3-2.6 (1 H, m), 2.6-2.8 (2 H, m), 3.1-3.2 (2 H, m), 3.62 (1 H, dd, *J* = 4.05, 11.37 Hz), 3.76 (1 H, dd, *J* = 7.62, 11.43 Hz), 4.1-4.2 (1 H, m), 7.0-7.4 (4 H, m). ^{13}C NMR δ 21.03, 28.56 (q, *J* = 2.4 Hz), 45.46 (q, *J* = 24.2 Hz), 64.47 (q, *J* = 1.4 Hz), 68.89 (q, *J* = 2.4 Hz), 126.68 (q, *J* = 281.1 Hz) 130.1, 130.73, 130.91, 137.41. ^{19}F NMR δ 13.86 (d, *J* = 8.98 Hz). HRMS for $C_{12}H_{15}O_2F_3S$ M^+ 280.0745, found 280.0731.

(*R*)-2-(Trifluoromethyl)-3-(4-methylphenylsulfenyl)propanal (9) To a solution of $Pb(OAc)_4$ (3.00 g) in 300 mL of CH_2Cl_2 under the nitrogen atmosphere was added 1.4 g of diol **8** (5.00 mmol) in 100 mL of CH_2Cl_2 at 0 °C over 4 h. The whole was allowed to warm to room temperature and was stirred for several hours. The mixture was passed through Florisil and evaporated, and the oily residue was distilled to afford the pure aldehyde (0.99 g, 4.0 mmol, 42% ee). Yield : 80%. IR (neat) ν 3075, 3025, 2980, 2925, 2860, 2730, 1740 cm^{-1}. $[\alpha]^{28}_D$ -18.50 (*c* 0.26, $CHCl_3$). ^1H NMR δ 2.34 (3 H, s), 3.1-3.5 (3 H, m), 7.1-7.4 (4 H, m), 9.6-9.7 (1 H, m). ^{13}C NMR δ 21.11, 28.15 (q, *J* = 2.3 Hz), 55.02 (q, *J* = 24.8 Hz), 124.07 (q, *J* = 282.0 Hz), 129.5, 130.27, 131.80, 138.19, 192.92 (q, *J* = 2.8 Hz). ^{19}F NMR δ 12.97 (d, *J* = 6.89 Hz).

General procedure for the reaction of the aldehyde with nucleophiles. To a THF solution of nucleophiles (lithium enolates derived from carbonyl compounds, Grignard reagents, lithium alkyl cuprates synthesized from alkyl lithium and copper iodide, Horner-Wittig reagent, and acetylide generated using MeMgBr) was added a THF solution of the aldehyde **5** or **9** at -78 °C. After stirring for 30 min, the reaction was quenched with water and diluted HCl aq, and the usual workup gave the crude material, which was purified by silica gel column chromatography to afford the corresponding materials.

Ethyl 6-(benzyloxy)-4-(trifluoromethyl)-3-hydroxy-2,2-dimethylhexanoate (11a) Yield : 81%. D.s. = 87 : 13. IR (neat) ν 3500, 3090, 3080, 3050, 2975, 2940, 2875, 1720 cm^{-1}. **major isomer** ^1H NMR δ 1.21 (3 H, s), 1.23 (3 H, s), 1.24 (3 H, t, *J* = 7.13 Hz), 1.83 (1 H, ddt, *J* = 5.02, 8.16, 15.48 Hz), 2.0-2.2 (1 H, m), 2.55 (1 H, dddq, *J* = 1.63, 3.20, 8.12, 10.23 Hz), 3.2-3.3 (1 H, br), 3.45-3.70 (2 H, m), 4.14 (2

H, dq, *J* = 0.90, 7.14 Hz), 4.0-4.2 (1 H, m), 4.50 (2 H, s), 7.2-7.4 (5 H, m). ^{13}C NMR δ 13.99, 20.19, 22.55, 23.88 (q, *J* = 2.0 Hz), 40.64 (q, *J* = 24.0 Hz), 47.34, 61.08, 67.92 (q, *J* = 1.7 Hz), 72.22 (q, *J* = 3.0 Hz), 73.04, 128.46 (q, *J* = 280.9 Hz), 127.52, 127.63, 128.38, 138.13, 177.17. ^{19}F NMR δ 11.12 (d, *J* = 9.60 Hz). **minor isomer** ^{1}H NMR δ 1.16 (3 H, s), 1.35 (3 H, s), 1.26 (3 H, t, *J* = 7.16 Hz). ^{13}C NMR δ 13.93, 127.78, 128.46, 128.61, 137.01. ^{19}F NMR δ 12.83 (d, *J* = 9.65 Hz).

8-(Benzyloxy)-6-(trifluoromethyl)-5-hydroxy-2,2-dimethyloctan-3-one (11b) Yield : 69%. D.s. = 72 : 28. IR (neat) ν 3500, 2970, 2870, 1700 cm^{-1}. HRMS for $C_{18}H_{25}O_3F_3$ M$^+$ 346.1756, found 346.1740. **major isomer** ^{1}H NMR δ 1.10 (9 H, s), 1.9-2.1 (2 H, m), 2.3-2.6 (1 H, m), 2.63 (1 H, dd, *J* = 3.48, 17.95 Hz), 2.79 (1 H, dd, *J* = 8.49, 17.70 Hz), 3.2-3.3 (1 H, br), 3.5-3.7 (2 H, m), 4.42 (1 H, dt, *J* = 3.51, 8.74 Hz), 4.51 (2 H, s), 7.2-7.4 (5 H, m). ^{13}C NMR δ 24.10 (q, *J* = 2.2 Hz), 26.18, 41.12 (q, *J* = 1.2 Hz), 44.36, 44.65 (q, *J* = 24.2 Hz), 65.18 (q, *J* = 2.9 Hz), 67.91, 73.10, 127.75 (q, *J* = 280.9 Hz), 127.71, 127.80, 128.44, 137.86, 138.02, 216.26. ^{19}F NMR δ 11.00 (d, *J* = 9.65 Hz). **minor isomer** ^{1}H NMR δ 1.12 (9 H, s). ^{13}C NMR δ 24.84 (q, *J* = 2.7 Hz), 65.37 (q, *J* = 2.4 Hz), 67.64. ^{19}F NMR δ 12.96 (d, *J* = 9.60 Hz).

8-(Benzyloxy)-3-(trifluoromethyl)octan-4-ol (11c) Yield : 40%. D.s. = 72 : 28. IR (neat) ν 3450, 3100, 3075, 3050, 2975, 2940, 2875 cm^{-1}. HRMS for $C_{16}H_{23}O_2F_3M^+$ 304.1650, found 304.1661. **major isomer** ^{1}H NMR δ 0.8-1.0 (3 H, m), 1.2-2.6 (10 H, m), 3.4-3.7 (2 H, m), 3.9-4.0 (1 H, m), 4.52 (2 H, s), 7.2-7.4 (5 H, m). ^{13}C NMR δ 14.01, 22.51, 23.56 (q, *J* = 2.2 Hz), 28.13, 35.09, 45.35 (q, *J* = 23.2 Hz), 67.88, 68.86 (q, *J* = 2.7 Hz), 73.13, 128.17 (q, *J* = 281.9 Hz), 127.69, 127.80, 128.45, 137.81. ^{19}F NMR δ 12.77 (d, *J* = 9.65 Hz,). **minor isomer** ^{1}H NMR δ 3.8-3.9 (1 H, m), 4.53 (2 H, s). ^{13}C NMR δ 22.57, 24.54 (q, *J* = 2.4 Hz), 28.48, 33.21 (q, *J* = 1.7 Hz), 47.07 (q, *J* = 23.4 Hz), 68.16, 69.38 (q, *J* = 2.1 Hz), 73.23, 128.53, 137.48. ^{19}F NMR δ 10.83 (d, *J* = 9.65 Hz).

5-(Benzyloxy)-3-(trifluoromethyl)pentan-2-ol (11d) Yield : 45%. D.s. = 77 : 23 (Nucleophile was MeMgBr). Yield : 49%. D.s. = 73 : 27. (Nucleophile was $(CH_3)_2$CuLi.) IR (neat) ν 3400, 3025, 2975, 2930, 2850 cm^{-1}. HRMS for $C_{13}H_{17}O_2F_3M^+$ 262.1181, found 262.1157. **major isomer** ^{1}H NMR δ 1.27 (3 H, dq, *J* = 0.91, 6.52 Hz), 1.79-2.10 (2 H, m), 2.14-2.40 (1 H, m), 2.50-2.80 (1 H, m), 3.45-3.73 (2 H, m), 4.14 (1 H, dq, *J* = 4.04, 6.52 Hz), 4.52 (2 H, s), 7.20-7.40 (5 H, m). ^{13}C NMR δ 21.64 (q, *J* = 1.4 Hz), 24.12 (q, *J* = 2.4 Hz), 47.01 (q, *J* = 23.3 Hz), 68.36 (q, *J* = 2.8 Hz), 73.17, 127.92 (q, *J* = 281.7 Hz), 127.73, 127.98, 128.49, 137.74. ^{19}F NMR δ 8.56 (d, *J* = 10.65 Hz). **minor isomer** ^{1}H NMR δ 1.24 (3 H, dq, *J* = 0.98, 6.57 Hz), 4.53 (2 H, s). ^{13}C NMR δ 19.26 (q, *J* = 1.7 Hz), 23.63 (q, *J* = 2.5 Hz), 68.36 (q, *J* = 2.8 Hz), 73.26, 127.84, 128.07, 128.57, 137.43. ^{19}F NMR δ 9.08 (d, *J* = 11.06 Hz).

(*E*)-Ethyl 6-(benzyloxy)-4-(trifluoromethyl)hex-2-enoate (11e) Yield : 56%. IR (neat) ν 2990, 2925, 2860, 1720, 990 cm^{-1}. ^{1}H NMR δ 1.30 (3 H, t, *J* = 7.15 Hz), 1.72 (1 H, ddt, *J* = 4.31, 10.57, 14.17 Hz), 2.18 (1 H, dddd, *J* = 3.93, 5.60, 9.53, 14.17 Hz), 3.1-3.3 (1 H, m), 3.38 (1 H, dt, *J* = 4.39, 9.62 Hz), 3.45-3.60 (1 H, m), 4.21 (2 H, q, *J* = 7.14 Hz), 4.42 (1 H, d, *J* = 11.91 Hz), 4.52 (1 H, d, *J* = 11.91 Hz), 5.95 (1 H, d, *J* = 15.56 Hz), 6.68 (1 H, dd, *J* = 9.57, 15.63 Hz), 7.2-7.4 (5 H, m). ^{13}C NMR δ 14.19, 27.69 (q, *J* = 2.2 Hz), 43.57 (q, *J* = 27.6 Hz), 60.76, 65.58, 73.04, 126.32 (q, *J* = 279.6 Hz), 127.37, 127.80, 127.84, 128.48, 137.90, 139.49 (q, *J* = 2.7 Hz), 165.34. ^{19}F NMR δ 8.24 (d, *J* = 8.98 Hz). HRMS for $C_{16}H_{19}O_3F_3M^+$ 316.1286, found 316.1287.

Ethyl 4-(trifluoromethyl)-3-hydroxy-2,2-dimethyl-5-(4-methylphenylsulfenyl)pentanoate (12a) Yield : 59%. D.s. = 71 : 29 (separable). **major isomer** IR (neat) ν 3400, 3075, 3000, 2950, 2875, 1720 cm^{-1}. ^{1}H NMR δ 1.15, 1.22 (6 H, s), 1.26 (3 H, t, *J* = 7.14 Hz), 2.33 (3 H, s), 2.51 (1 H, dddq, *J* = 1.58, 4.32, 6.53, 9.72 Hz), 3.08 (1 H, dd, *J* = 6.57, 14.20 Hz), 3.1-3.3 (1 H, m), 3.3-3.4 (1 H, m), 4.0-4.2 (3 H, m), 7.0-7.4 (4 H, m). ^{13}C NMR δ 13.98, 20.13, 23.49, 21.05, 28.76 (q, *J* = 2.1 Hz), 44.69 (q, *J* = 24.1 Hz), 46.09, 61.26, 72.71 (q, *J* = 2.9 Hz), 127.43 (q, *J* = 281.1 Hz), 129.84, 131.68, 131.82, 137.16, 177.16. ^{19}F NMR δ 9.10 (d, *J* = 8.98 Hz). HRMS for $C_{17}H_{23}O_3F_3SM^+$ 364.1320, found 364.1306. **minor isomer** IR (neat) ν 3450, 2975, 2925, 2875, 1700 cm^{-1}. ^{1}H NMR δ 1.06, 1.42 (6 H, s), 1.25 (3 H, t, *J* = 7.14 Hz), 2.33 (3 H, s), 2.2-2.5 (1 H, m), 3.22 (1 H, dd, *J* = 9.52, 13.89 Hz), 3.32 (1 H, dd, *J* = 3.73, 13.88 Hz), 4.00 (1 H, dquint, *J* = 2.07, 10.21 Hz), 4.15 (2 H, dq, *J* = 1.83, 7.17 Hz), 4.36 (1 H, d, *J* = 10.26 Hz),

7.0-7.3 (4 H, m). ^{13}C NMR δ 13.89, 21.05, 21.62, 27.51, 31.42 (q, J = 3.1 Hz), 43.57 (q, J = 23.6 Hz), 44.18, 61.06, 75.71 (q, J = 1.0 Hz), 126.64 (q, J = 281.7 Hz), 130.01, 130.57, 130.74, 137.20, 177.75. ^{19}F NMR δ 15.02 (d, J = 8.92 Hz). HRMS for $C_{17}H_{23}O_3F_3SM^+$ 364.1320, found 364.1334.

3-(Trifluoromethyl)-4-(4-methylphenylsulfenyl)butan-2-ol (12b) Yield : 62%. D.s. = 65 : 35. IR (neat) ν 3425, 3075, 3025, 2975, 2925, 2870 cm^{-1}. HRMS for $C_{12}H_{15}OF_3SM^+$ 264.0796, found 264.0792. **major isomer** ^{1}H NMR δ 1.27-1.42 (3 H, m), 2.33 (3 H, s), 2.3-2.5 (1 H, m), 3.09 (1 H, dd, J = 6.41, 14.10 Hz), 3.19 (1 H, dd, J = 5.31, 14.08 Hz), 3.4-3.7 (1 H, m), 4.2-4.4 (1 H, m), 7.0-7.4 (4 H, m). ^{13}C NMR δ 20.31 (q, J = 1.9 Hz), 21.05, 29.64 (q, J = 3.9 Hz), 49.35 (q, J = 23.3 Hz), 65.07 (q, J = 2.4 Hz), 127.08 (q, J = 281.7 Hz), 129.83, 129.97, 130.04, 130.84, 132.02, 137.30, 137.65. ^{19}F NMR δ 11.84 (d, J = 9.65 Hz). **minor isomer** ^{1}H NMR δ 4.6-4.8 (1 H, m). ^{13}C NMR δ 22.02 (q, J = 2.2 Hz), 29.23 (q, J = 2.6 Hz), 48.51 (q, J = 23.2 Hz), 65.24 (q, J = 2.2 Hz), 129.83, 129.97, 130.04, 130.84, 132.02, 137.30, 137.65. ^{19}F NMR δ 13.27 (d, J = 9.60 Hz).

4-(Trifluoromethyl)-5-(4-methylphenylsulfenyl)-1-phenylpent-1-yn-3-ol (12c) Yield : 38%. D.s. = 79 : 21. IR (neat) ν 3450, 2950, 2925, 2850 cm^{-1}. HRMS for $C_{19}H_{17}OF_3SM^+$ 350.0953, found 350.0977. **major isomer** ^{1}H NMR δ 2.30 (3 H, s), 2.6-2.8 (1 H, m), 3.29 (2 H, d, J = 6.41 Hz), 5.1-5.2 (1 H, m), 7.0-7.5 (7 H, m). ^{13}C NMR δ 21.04, 29.87 (q, J = 2.2 Hz), 49.01 (q, J = 23.6 Hz), 60.69 (q, J = 3.0 Hz), 85.71, 87.25, 121.71, 123.47, 128.30, 128.90, 129.08, 129.86, 129.98, 130.13, 130.73, 131.22, 131.74, 137.37. ^{19}F NMR δ 8.99 (d, J = 9.5 Hz). **minor isomer** ^{1}H NMR δ 2.33 (3 H, s). ^{13}C NMR δ 30.34 (q, J = 2.2 Hz), 121.71, 123.47, 128.30, 128.90, 129.08, 129.86, 129.98, 130.13, 130.73, 131.22, 131.74, 137.37. ^{19}F NMR δ 7.91 (d, J = 8.0 Hz).

General procedure for Lewis acid-promoted reaction of the aldehyde with nucleophiles

To a solution of the aldehyde (0.10 g, 0.40 mmol) and silylated nucleophile (1.20 mmol) in toluene (5 mL) was added Lewis acid (BF_3·OEt_2, $TiCl_4$, or $SnCl_4$, 1.20 mmol) at -78 °C, and the mixture was stirred at that temperature for 4 h. After diluted with ether (2 mL), the reaction mixture was poured into aqueous solution of 3 *N* HCl. The organic layer was separated and the aqueous layer was extracted with ether twice. The combined organic layers were washed with water and brine, dried over anhydrous $MgSO_4$ and evaporated. Chromatography on silica gel afforded the corresponding alcohol.

2-(Trifluoromethyl)-1-(4-methylphenylsulfenyl)hex-5-en-3-ol (13a) Yield : 76%. D.s. = 50 : 50. IR (neat) ν 3450, 3075, 3025, 2975, 2925 cm^{-1}. HRMS for $C_{14}H_{17}OF_3SM^+$ 290.0952, found 290.0954. **major isomer** ^{1}H NMR δ 2.32 (3 H, s), 2.3-2.6 (3 H, m), 2.9-3.1 (2 H, m), 4.0-4.3 (1 H, m), 5.0-5.2 (2 H, m), 5.6-5.9 (1 H, m), 7.0-7.4 (4 H, m). ^{13}C NMR δ 21.05, 30.24 (q, J = 2.9 Hz), 39.64 (q, J = 1.1 Hz), 46.98 (q, J = 23.7 Hz), 68.11 (q, J = 1.8 Hz), 118.94, 126.74 (q, J = 282.3 Hz), 130.00, 130.06, 130.85, 131.06, 131.40, 134.32, 134.17. ^{19}F NMR δ 10.69 (d, J = 10.00 Hz). **minor isomer** ^{13}C NMR δ 28.67 (q, J = 2.4 Hz), 39.12 (q, J = 1.9 Hz), 47.42 (q, J = 23.8 Hz), 67.78 (q, J = 2.5 Hz), 119.25, 127.11 (q, J = 281.5 Hz), 130.00, 130.06, 130.85, 131.06, 131.40, 134.32, 134.70. ^{19}F NMR δ 7.61 (d, J = 10.00 Hz).

3-(Trifluoromethyl)-2-hydroxy-4-(4-methylphenylsulfenyl)butanenitrile (13b) Yield : 61%. D.s. = 87 : 13. IR (neat) ν 3410, 3025, 2925, 2855 cm^{-1}. HRMS for $C_{12}H_{12}OF_3NSM^+$ 275.0591, found 275.0582. **major isomer** ^{1}H NMR δ 2.34 (3 H, s), 2.6-2.8 (1 H, m), 3.14 (1 H, dd, J = 8.68, 14.58 Hz), 3.33 (1 H, dd, J = 4.83, 14.59 Hz), 3.5-3.7 (1 H, m), 5.0-5.1 (1 H, m), 7.1-7.4 (4 H, m). ^{13}C NMR δ 21.09, 29.27 (q, J = 2.2 Hz), 46.92 (q, J = 25.3 Hz), 58.41 (q, J = 2.9 Hz), 117.16, 125.24 (q, J = 282.0 Hz), 129.33, 130.31, 130.48, 131.47, 131.60, 138.22, 138.52. ^{19}F NMR δ 8.93 (d, J = 7.56 Hz). **minor isomer** ^{1}H NMR δ 3.21 (1 H, dd, J = 9.85 Hz, 14.71 Hz), 3.36 (1 H, dd, J = 4.62, 14.50 Hz), 3.9-4.0 (1 H, m). ^{13}C NMR δ 30.03 (q, J = 2.3 Hz), 46.70 (q, J = 25.7 Hz), 58.82 (q, J = 2.5 Hz), 124.79 (q, J = 281.9 Hz), 129.33, 130.31, 130.48, 131.47, 131.60, 138.22, 138.52. ^{19}F NMR δ 8.38 (d, J = 6.21 Hz).

4-(Trifluoromethyl)-3-hydroxy-5-(4-methylphenylsulfenyl)-1-phenylpentan-1-one (13c) Yield : 41%. D.s.= 89 : 11. IR (neat) ν 3400, 3060, 3025, 2925, 2975, 1680 cm^{-1}. **major isomer** ^{1}H NMR δ 2.32 (3 H, s), 2.4-2.6 (1 H, m), 3.1-3.5 (5 H, m), 4.8-4.9 (1 H, m), 7.0-8.0 (9 H, m). ^{13}C NMR δ 21.04, 30.01 (q, J = 2.8 Hz), 42.44 (q, J = 1.8 Hz), 47.35 (q, J = 23.9 Hz), 64.51 (q, J = 1.7 Hz), 126.78 (q, J =

282.2 Hz), 128.10, 128.76, 130.03, 130.63, 133.81, 136.31, 137.16, 199.69. ^{19}F NMR δ 14.71 (d, J = 8.92 Hz). **minor isomer** ^{19}F NMR δ 11.61 (d, J = 8.30 Hz).

REFERENCES

1. a) Welch, J. T. *Tetrahedron* **1987**, *43*, 3123. b) Bégué, J. P.; Bonnet-Delpon, D. *Tetrahedron* **1991**, *32*, 3207.
2. a) Wiemers, D. W.; Burton, D. J. *J. Am. Chem. Soc.* **1986**, *108*, 832. b) Umemoto, T.; Ando, A. *Bull. Chem. Soc. Jpn.* **1986**, *59*, 447. c) Kitazume, T.; Ishikawa, N. *J. Am. Chem. Soc.* **1985**, *107*, 5186. d) Prakash, G. K. S.; Krishnamurti, R.; Olah, G. A. *J. Am. Chem. Soc.* **1989**, *111*, 393.
3. Purrington, S. T.; Evertt, T. S.; Bungardner, C. L. *Tetrahedron Lett.* **1984**, *25*, 1329.
4. a) Bravo, P.; Frigerio, M.; Resnati, G. *Synthesis* **1988**, 955. b) Yamazaki, T.; Haga, J.; Kitazume, T. *Chem. Lett.* **1991**, 2175. c) Iseki, K.; Nagai, T.; Kobayashi, Y. *Tetrahedron Lett.* **1993**, *34*, 2169. d) Takada, E.; Hara, S.; Suzuki, A. *Tetrahedron Lett.* **1993**, *34*, 7067. e) Mikami, K.; Yajima, T.; Terada, M.; Uchimaru, T. *Tetrahedron Lett.* **1993**, *34*, 7591. f) Ramachandran, P. V.; Gong, B.; Brown, H. C. *J. Org. Chem.* **1995**, *60*, 41.
5. a) Still, W. C.; Schneider, J. A. *Tetrahedron Lett.* **1980**, *21*, 1035. b) Heathcock, C. H.; Flippin, L. A. *J. Am. Chem. Soc.* **1983**, *105*, 1667. c) Reetz, M. T.; Kesseler, K. *J. Chem. Soc., Chem. Commun.* **1984**, 1079.
6. Bravo, P.; Frigerio, M.; Resnati, G. *J. Org. Chem.* **1990**, *55*, 4216.
7. a) de Nanteuil, G. *Tetrahedron Lett.* **1991**, *32*, 2467. b) Ojima, I. *J. Organomet. Chem.* **1985**, *279*, 203. c) Iwaoka, T.; Sato, M.; Kaneko, C. *J. Chem. Soc., Chem. Commun.* **1991**, 1241.
8. Shi, G.; Xu, Y. *J. Org. Chem.* **1990**, *55*, 3383.
9. a) Fuchikami, T.; Shibata, Y.; Suzuki, Y. *Tetrahedron Lett.* **1986**, *27*, 3173. b) Xu, Y.; Jin, F.; Huang, W. *J. Org. Chem.* **1994**, *59*, 2638. We have recently reported that existence of metal cations played an important role for defluorination for the same type of α-CF_3 ketones. Yamazaki, T.; Hiraoka, S.; Kitazume, T. *J. Org. Chem.* **1994**, *59*, 5100.
10. a) Yamazaki, T.; Ishikawa, N. *Chem. Lett.* **1985**, 889. b) Yamazaki, T.; Ishikawa, N.; Iwatsubo, H.; Kitazume, T. *J. Chem. Soc., Chem. Commun.* **1987**, 1340.
11. de Lucchi, O.; Miotti, U.; Modena, G. *Org. React.* **1991**, *40*, 157.
12. Sugihara, H.; Tanikaga, R.; Kaji, A. *Synthesis* **1978**, 881.
13. Tomooka, K.; Okinaga, T.; Suzuki, K.; Tsuchihashi, G. *Tetrahedron Lett.* **1989**, *30*, 1563.
14. Bott, G.; Field, F. G.; Sternhell, S. *J. Am. Chem. Soc.* **1980**, *102*, 5618.
15. The TSs obtained here were calculated by MOPAC v 6 (MNDO) implemented in CAChe Worksystem (SONY/Tektronix Corporation) with reference to the following report. Bernardi, A.; Capelli, A. M.; Cassinari, A.; Comotti, A.; Gennari, C.; Scolastico, C. *J. Org. Chem.* **1992**, *57*, 7029.
16. Yamazaki, T.; Mizutani, K.; Kitazume, T. *J. Org. Chem.* **1993**, *58*, 4346.

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