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tert-Butylsulfinyl-fluoroacetate: versatile reagent for the preparation of fluoroethylidenoate derivatives

David Chevrie, Thierry Lequeux* and Jean-Claude Pommelet

Laboratoire de Chimie Moléculaire et Thio-organique, UMR-CNRS 6507, Université de Caen—ISMRA, 6 Bd du Maréchal Juin, 14050 Caen Cedex, France

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Abstract—The preparation of (*Z*)-α-fluoroalkenoates from readily available methyl-*tert*-butylsulfanyl- or *tert*-butylsulfinylfluoroacetate **1** or **5** is described. This short synthesis, based on a direct extrusion of SO_2 from β-hydroxysulfoxides, presents a moderate to high selectivity and affords (*Z*)-α-fluoroalkenoates in 40–81% overall yields without purifications of the intermediates. This procedure was applied to functionalised aldehydes and ketone. The mechanistic aspect of the reaction was also discussed.

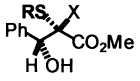
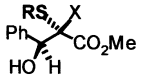
1. Introduction

The α-fluoroalkenoate derivatives are of great interest in biology, agrochemistry or polymer fields.[1] Concerning their synthesis, the widely used strategy is the Horner–Wadsworth–Emmons reaction (HWE), involving the commercially available triethyl-2-fluoro-2-phosphonoacetate and aldehydes.[2] Other alternative approaches were reported to build such fluorinated carbon–carbon double bonds: the combination of phenylselenenyl fluoride equivalent and diazoesters,[3] the reaction of methyl dichlorofluoroacetate with carbonyl compounds under bimetallic catalyst system,[4] the Peterson olefination involving aldehydes and α-fluoro-α-silylacetate,[5] the carbonylation of fluoroalkenyliodonium salt,[6] the dehydrofluorination of 1,2-difluoroalkenes,[7] and the olefination of α,β-unsaturated ketones through 'abnormal' Michael reaction using the diethyl fluoromalonate.[8] On the other hand, it has been shown that the mixed organosulfur and organofluorine chemistry appeared to be helpful to prepare fluoroalkenes as reported by Allmendinger[9] and Yamakawa.[10] The first methodology produces (*Z*)-fluoroalkenoates selectively from primary alkylhalides through a concerted elimination of sulfenic acid, and the second presents a moderate selectivity with the advantage to be applied to aldehydes. Recently, we described a stereoselective synthesis of (*Z*)-α-fluoroalkenoates using aldehydes and methyl *tert*-butylsulfanylfluoroacetate **1** as starting materials (Scheme 2). This methodology is based on the direct extrusion of sulfur dioxide from readily available β-hydroxyfluorosulfoxides.[11] In this paper are reported our full results concerning the scope and the limitation of this strategy.

2. Results and discussion

The synthesis of fluoroalkenoates has been investigated from methyl *tert*-butylsulfanylfluoroacetate **1** easily available by fluorination of sulfides (Scheme 2).[12] At first, the synthesis of β-hydroxysulfides was achieved from **1** and benzaldehyde. The anion of **1** was formed at −78°C using LDA, and trapped with the electrophile at −78°C. As previously reported, after hydrolysis at this temperature, a 1/1 mixture of diastereoisomers was obtained. Both diastereoisomers were separated by flash chromatography. The relative configurations of the C2–C3 stereogenic centres were deduced by comparison with previous X-ray analysis of the single 2,3-*syn*-β-hydroxysulfide (Table 1).[12] The chemical shift of the methoxycarbonyl group in ^{1}H NMR spectra allowed us to differentiate the two isomers. The methoxy group signal was more shielded in the 2,3-*syn*

Table 1. Representative chemical shift of the OCH_3 (in ppm)

Entry	R	 2,3-*syn*	 2,3-*anti*
1	$PhCH_2$, X=F[a]	3.53 (X-ray)[a]	3.68
2	Ph; X=H[b]	3.55	3.65
3	**12** Ph; X=F	3.30	3.49
4	CH_3CH_2; X=F[a]	3.64	3.82
5	**2a** $(CH_3)_3C$; X=F	3.62	3.86

[a] See Ref. 12.
[b] See Ref. 13.

Keywords: butylsulfanylacetate; fluoroethylidenoate derivatives; hydroxysulfides.

* Corresponding author. Tel.: +33-231452854; fax: +33-231452877; e-mail: lequeux@ismra.fr

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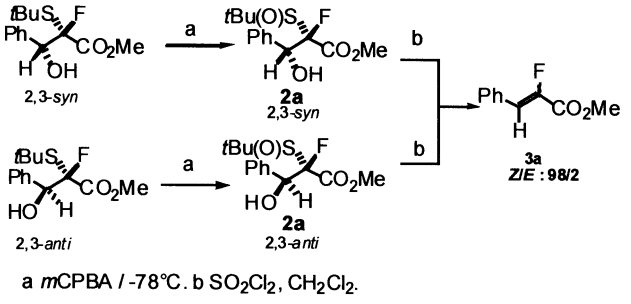
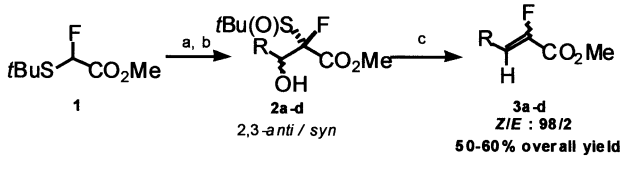


Scheme 1.

isomer than in the 2,3-*anti* isomer (Table 1, entry 1). In addition, as reported by Kurth and Hoye,[13] we also observed that the 2,3-*syn*-β-hydroxysulfide was a less polar compound.

The oxidation of each pure isomer was performed at −78°C using *m*CPBA (Scheme 1). The 2,3-*syn*-isomer afforded single sulfoxide **2a** (exhibiting a doublet at −184.2 ppm in ^{19}F NMR and a singlet methoxy signal at 3.42 ppm in ^{1}H NMR spectrum). As demonstrated by Lucchi et al.,[14] we assumed that the oxidation occurred at the same side as the hydroxyl group. On the other hand the 2,3-*anti*-isomer afforded a mixture of sulfoxides **2a** in 1/1 ratio (located at −167.5 and −171.4 ppm in ^{19}F NMR spectrum). Each of the crude sulfoxides **2a** was separately treated with sulfuryl chloride in dichloromethane at room temperature. Following the reaction by ^{19}F NMR analysis, we observed that the olefination was slow and led selectively to the (*Z*)-α-fluoroalkenoate **3a** in both cases (Scheme 1).

The synthesis of fluoroalkenoates was explored from other aldehydes, in three steps without any purification or isolation between each step (Scheme 2). The anion of **1** formed by LDA at −78°C was trapped with aldehydes and the crude products were then oxidized with *m*CPBA at low temperature. Addition of sulfuryl chloride to the resulting crude sulfoxides produced the corresponding (*Z*)-α-fluoroalkenoates **3a–d** in fair yields. The observed selectivity and overall yields from **1** were reported in Table 2.[11]

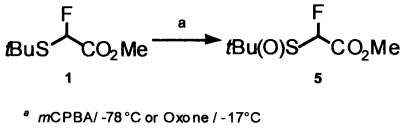


Scheme 2.

Table 2. Selective synthesis of (*Z*)-α-fluoro-α,β-unsaturated esters

Entry	R	Products	Yield (%)[a]	*Z*/*E*ratio[b]
1	Ph	**3a**[15]	53	99/1
2	*p*(NO$_2$)Ph	**3b**[10]	61	95/5
3	*n*-C$_5$H$_{11}$	**3c**[15]	47	88/12
4	*n*-C$_8$H$_{17}$	**3d**[10]	60	94/6

[a] Isolated overall yields from **1**.
[b] Determined by ^{19}F NMR of the crude products.



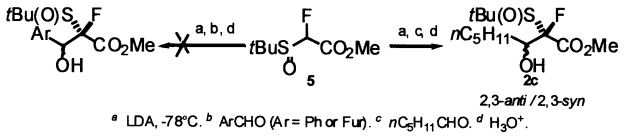
Scheme 3.

From fluorosulfide **1** and benzaldehyde, (*Z*)-α-fluoroalkenoate, **3a** was obtained stereoselectively in 53% overall yield (Table 2, entry 1). This procedure was extended to aromatic or non-functionalised aliphatic aldehydes (Table 2). The selectivity was still high and fair overall yields were observed. However, this method was limited. For example, after reaction of the sulfide **1** with (*E*)-cinnamaldehyde under basic conditions, the oxidation step of the crude hydroxysulfides led to a mixture of various products. In order to explore the scope of this olefination strategy, we investigated the synthesis and the reactivity of the sulfinyl derivative **5** (Scheme 3). The oxidation of fluorosulfides was well documented.[16]

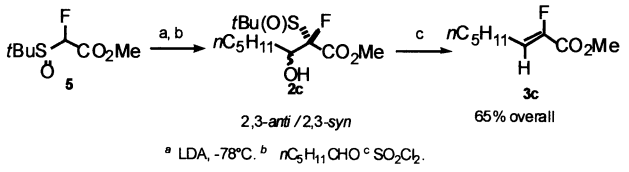
Using *m*CPBA, the oxidation of **1** was performed at −78°C for 2 h to produce the sulfoxide **5** in 88% yields. At higher temperatures, the oxidation was not controlled and traces of sulfone were still present. Oxone furnished a similar result, and the oxidation was successful when performed at −17°C for 1 h. In this case, the sulfoxide was isolated in 68% yield.

Allmendinger already described the alkylation of ethyl phenylsulfinylfluoroacetate using primary or secondary alkyl halides.[9] However, to the best of our knowledge, no addition of this anion to carbonyl compounds has been reported in the literature. First, we investigated the synthesis of β-hydroxysulfoxide from **5** and benzaldehyde. As described with the sulfides **1**, the anion of **5** was prepared using LDA at −78°C. Contrary to **1**, even on addition of freshly distilled benzaldehyde, the starting materials were recovered. The same result was observed from 2-furaldehyde. The effective formation of the anion was observed when it was trapped with deuterium oxide (the deuterated product exhibiting two triplets at −199.2 and −185.1 ppm, $^{2}J_{FD}$=7.2 Hz in the ^{19}F NMR spectrum). The results observed with aromatic aldehydes, were attributed to a retro-reaction.[17] From aliphatic aldehydes β-hydroxysulfoxides **2** were obtained in fair yields. From hexanal, a diastereomeric mixture of two sulfoxides **2c** in 6/4 ratio, was isolated in 55% yield[18] (Scheme 4).

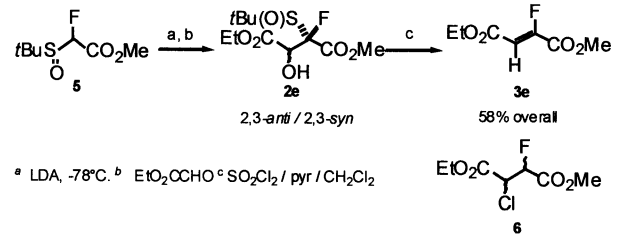
The synthesis of alkenoates **3** from **5** has been studied without any purification of the intermediates. The crude aldol products obtained from hexanal, were used in the olefin formation using our previous procedure. The solution of crude hydroxysulfoxide **2c** in CH_2Cl_2 was treated with an excess sulfuryl chloride, and let to stand for several hours at room temperature. The formation of the olefin was monitored by ^{19}F NMR. The conversion was slow and completed



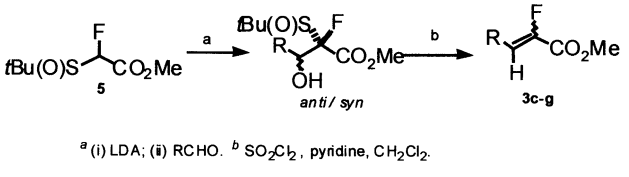
Scheme 4.



Scheme 5.



Scheme 6.



Scheme 7.

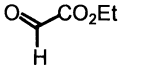
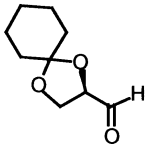
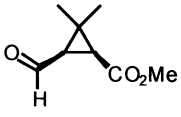
after 76 h at room temperature. The olefination was still highly stereoselective (*Z*/*E*: 95/5) and the alkenoate **3c** was isolated in 65% overall yield (Scheme 5).

Using ethyl glyoxalate, resonance due to another by-product was observed at −200 ppm region in ^{19}F NMR spectrum. After isolation and full characterization, chlorofluoroalkane **6** was identified as the by-product (Scheme 6). The formation of **6** was avoided by addition of pyridine. In this way, alkene **3e** was obtained in 58% overall yield. The observed selectivity was still good with a *Z*/*E* ratio of 87/13 (Scheme 7; Table 3). It was also observed in this case that the rate of the olefination step was faster. The reaction performed in presence of pyridine was completed after 2 h at room temperature.

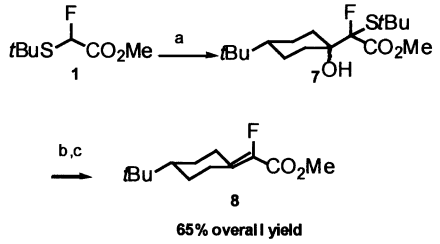
This particular enhancement of the rate of olefination was investigated for other previous examples, which usually need longer reaction time. With hexanal, the olefination step was performed from the crude mixture of hydroxysulfoxides **2c** in presence of pyridine (Scheme 7). The olefination was completed after 2 h at room temperature instead of initially 76 h. By using these conditions, the final overall yield of the fluoroalkenoate was improved and increased from 65 to 81% (Table 3, entry 1). On the other hand, no influence of the presence of pyridine on the selectivity was observed. This procedure was extended to other aliphatic aldehydes. The results are reported in Table 3.

From aliphatic and functionalised aldehydes, moderate to good overall yields (60–80%) were obtained. The selectivity was still high to moderate. However, when alpha-heteroatom is present lower overall yield and selectivity were obtained (entry 4). This strategy can tolerate functionalised aliphatic aldehydes, but this could not be applied to aromatic aldehydes, since retro-reaction occurred in the reaction with the anion of **5**. On applying this strategy to cyclic ketone such as 4-*tert*-butylcyclohexanone, no expected products were obtained. As for the aromatic aldehydes the starting sulfoxide was recovered. Alternatively,

Table 3. Selective synthesis of α-fluoro-α,β-unsaturated esters from **5**

Entry	RCHO	Products	Yield (%),[a] *Z*/*E* ratio[b]
1	*n*-C_5H_{11}-CHO	**3c**[15]	81, 95/5
2	*n*-C_8H_{17}-CHO	**3d**[10]	76, 98/2
3		**3e**	58, 87/13
4		**3f**	40, 43/57
5		**3g**	76, 77/23

[a] Isolated overall yields from **5**.
[b] Determined by ^{19}F NMR of the crude products.



[a] (i) LDA. (ii) 4-*t*BuCyclohexanone. [b] *m*CPBA, CH_2Cl_2. [c] SO_2Cl_2, pyridine, CH_2Cl_2.

Scheme 8.

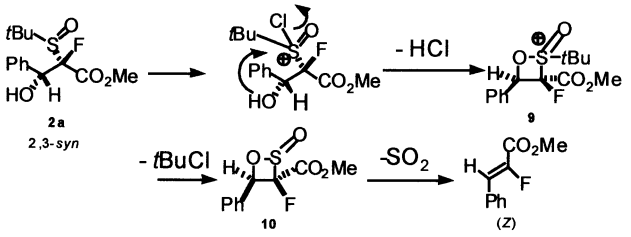
we preliminarily applied the initial strategy from the sulfide **1** to 4-*tert*-butylcyclohexanone (Scheme 8). The enolate of **1** was reacted with the ketone to produce a crude hydroxysulfides **7**, which was then oxidized by *m*CPBA. Addition of pyridine and sulfuryl chloride in CH_2Cl_2 to the crude mixture of **7**, afforded, after 2 h at room temperature, the expected fluoroalkene **8** in 65% overall yield.

3. Mechanistic considerations

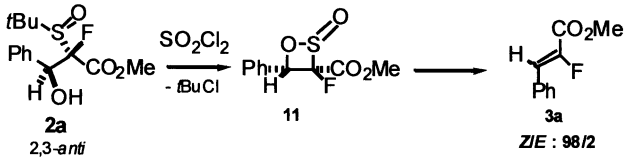
The pioneering report of Durst described full mechanistic considerations of the formation of olefins. It has been noted that the SO_2 extrusion from β-hydroxysulfoxides was stereospecific, and 'decomposition of each purified diastereoisomer led to isomerically pure olefin' in a few minutes.[19] On the other hand, it has been suggested that this stereospecific olefination reflected the particular diastereoselectivity of the condensation of aldehydes and the enolate.[20] In the present case, the olefination step is very slow and is highly stereoselective despite a poor diastereoselectivity in the addition of the sulfide **1** or the sulfoxide **5** with aldehydes.

In the Durst's mechanism, the determining step leading to the sultines **10** is the cyclization of the hydroxysulfoxides activated by the sulfuryl chloride leading to **9** (Scheme 9). This process is effectively observed from the sulfoxide **2a** obtained by oxidation of the 2,3-*syn* isomer: the conservation of the relative configuration of the C2–C3 stereogenic centres in the starting 2,3-*syn* diastereoisomers was maintained during the process, and reflected the configuration of the double bond of the final product.

If the same olefination process was involved with the pure 2,3-*anti* diastereoisomer, the formation of the *E*-fluoroolefin via the more hindered sultine **11** is expected (Scheme 10). However, from the mixture issued from isolated 2,3-*anti*



Scheme 9.



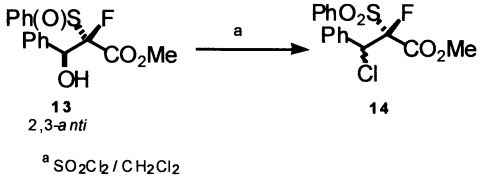
Scheme 10.

sulfoxide **2a**, the selective formation of the *Z*-fluoroolefin was still observed, and only some traces of the (*E*) isomer were present. On the other hand, we observed that the crude *E*-alkene prepared by HWE reaction,[15] was stable in the medium and no isomerisation was detected even after a long reaction time or under reflux (CH_2Cl_2) in the presence of sulfuryl chloride, APTS or HCl gas. Attempts to isolate the sultine **11** from the 2,3-*anti* diastereisomer **2a** failed.

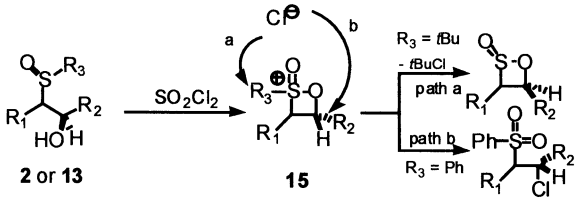
We investigated the synthesis of the β-hydroxysulfoxides **13** from the phenylsulfanylfluoroacetate and benzaldehyde. After oxidation of the sulfide **12**, the 2,3-*anti* β-hydroxysulfoxide **13** was isolated in a pure form. In order to verify if the same mechanism could occur with this sulfoxide, **13** was then treated with sulfuryl chloride in DCM. In this case the chlorosulfones **14** were formed and isolated in 59% yield, as a 1/1 mixture of diastereoisomers (Scheme 11).

As proposed by Durst,[21] the formation of this chlorosulfones clearly showed the formation of the intermediate cyclic sulfonium **15**, in which the C–O bond was cleaved by attack of the chloride ion (Scheme 12, path b).

The steric hindrance between the alkyl chains and the ester function in the 2,3-*anti*-diastereoisomer **13** appears to be no limitation in the formation of **15**. This suggests that the common intermediate **15** could be formed from the β-hydroxy *tert*-butylsulfinyl derivative **2**. In this case, **15** should afford the sultine **11** (Scheme 12, path a). The particular *Z* selectivity observed from the 2,3-*anti* diastereoisomer would probably be a thermodynamic equilibration between the sultines **11** and **10** before the SO_2 extrusion.



Scheme 11.



Scheme 12.

4. Conclusion

We showed that the organosulfur–organofluorine chemistry appears to be helpful for the selective preparation of fluoroalkenoates from readily available fluorosulfides. This additional method presents a good selectivity, is complementary to the HWE reaction and appears as an alternative to the Peterson olefination. By this three- or two-step synthesis without purifications of intermediates, the synthesis of fluoroalkenoates from aldehydes was achieved in moderate to good yields and in a 8/2 to 9/1 selectivity in favour of the (*Z*) isomer. This method seems to be general and the synthesis can be performed from the *tert*-butylsulfanyl- or sulfinylfluoroacetates **1** or **5**, depending on the nature of the electrophiles. The sulfide **1** allowed the olefination of aromatic aldehydes, and ketones in relative short reaction time, using the combination of pyridine and sulfuryl chloride. On the other hand, the sulfoxide **5** is preferred for olefination of functionalised aliphatic aldehydes.

5. Experimental

5.1. General

All chemicals were used as received, solvents were dried before use. All reported NMR spectra were recorded at 250 MHz (^{1}H), 100.6 MHz (^{13}C) and 235.5 MHz (^{19}F) using TMS or $CFCl_3$ as internal references in $CDCl_3$.

5.1.1. Methyl-2-chloro-2-*tert*-butylsulfanylacetate. To a solution of methyl-2-*tert*-butylsulfanylacetate[22] (13.65 g, 0.084 mol) in dichloromethane (500 mL) cooled at −17°C was slowly added sulfuryl chloride (6.7 mL, 0.084 mol) in order to keep the temperature below −5°C. The reaction mixture was stirred for 30 min and concentrated under vacuum. The crude methyl-2-chloro-2-*tert*-butylsulfanylacetate obtained as a yellow oil (16.35 g, 98%) was directly involved in the next step. ^{1}H NMR ($CDCl_3$) δ 1.44 (s, 9H, *t*BuS), 3.83 (s, 3H, CO_2Me), 5.48 (s, 1H, CHCl); ^{13}C NMR ($CDCl_3$) δ 30.7 (*t*Bu), 46.2 (*t*Bu), 53.5 (OMe), 60.9 (CHCl), 167.1 (C═O); MS *m/z* (relative intensity) 198 (2), 196 (3), 140 (2), 105 (2), 57 (100); IR (NaCl) 1750 cm^{-1}.

5.1.2. Methyl-2-fluoro-2-*tert*-butylsulfanylacetate (1). To a solution of methyl-2-chloro-2-*tert*-butylsulfanyl-acetate (32 g, 0.162 mol) in anhydrous acetonitrile (150 mL), triethylamine trihydrofluoride (37%) (51 mL, 0.312 mol) was slowly added. The solution was refluxed for 2 h. After cooling at room temperature, the solution was diluted in dichloromethane (75 mL) and the organic layer was washed by a saturated aqueous solution of $NaHCO_3$. The aqueous layer was extracted with dichloromethane, and the organic layer was washed with brine until neutral pH, dried and concentrated under vacuum. The crude oil was distilled under reduced pressure to give the methyl-2-fluoro-2-*tert*-butylsulfanylacetate **1** (22.5 g, 77%) as a yellow liquid; bp 90°C/0.4 Torr. ^{1}H NMR ($CDCl_3$) δ 1.44 (s, 9H, $3CH_3$), 3.82 (s, 3H, CO_2Me), 6.11 (d, $^2J_{HF}$=56.2 Hz, 1H, CHF); ^{19}F NMR ($CDCl_3$) δ −157.3 (d, $^2J_{HF}$=56.2 Hz, 1F, CHF); ^{13}C NMR ($CDCl_3$) δ 32.9 (*t*Bu), 47.1 (d, $^3J_{CF}$=5.0 Hz, *t*Bu), 54.4 (OMe), 93.1 (d, $^1J_{CF}$=227.0 Hz, CHF), 168.6 (d, $^2J_{CF}$=28.3 Hz, C═O); MS *m/z* (relative intensity) 180 (8), 179 (42), 178 (65), 121 (27), 97 (32), 59 (98), 55 (65), 45 (67), 43 (100); IR (NaCl) 1750 cm^{-1}; HRMS (EI) *m/z* calcd for $C_7H_{13}O_2SF$ $(M)^+$ 180.0620, found 180.0651.

5.1.3. Methyl-2-fluoro-2-*tert*-butylsulfinylacetate (5). To a solution of the methyl-2-fluoro-2-*tert*-butylsulfanyl-acetate (**1**) (9.3 g, 51 mmol) in methanol and water (50/50) was added at −17°C the Oxone® (23.83 g, 38 mmol). The solution was stirred for 1 h. The organic layer was washed with brine, dried over anhydrous $MgSO_4$, concentrated under vacuum and purified by chromatography. Elution with petroleum ether/ethyl acetate (60/40) afforded a diastereoisomeric mixture of sulfoxides (6.75 g, 68%). ^{1}H NMR ($CDCl_3$) δ 1.37 (d, $^4J_{HF}$=1 Hz, 9H, *t*BuSO **5a**), 1.40 (d, $^4J_{HF}$=1 Hz, 9H, *t*BuSO **5b**), 3.91 (s, 3H, CO_2Me **5a**), 3.93 (s, 3H, CO_2Me **5b**), 5.65 (d, $^2J_{HF}$=51.2 Hz, 1H, CHF **5a**), 5.69 (d, $^2J_{HF}$=48.5 Hz, 1H, CHF **5b**); ^{19}F NMR ($CDCl_3$) δ −198.8 (d, $^2J_{HF}$=48.9 Hz, 1H, CHF **5b**), −184.2 (d, $^2J_{HF}$=51.3 Hz, 1H, CHF **5a**); ^{13}C NMR ($CDCl_3$) δ 22.9 (d, $^4J_{CF}$=1.4 Hz, CH_3 *t*Bu **5a**), 23.7 (d, $^4J_{CF}$=2.4 Hz, CH_3 *t*Bu **5b**), 53.3 (OMe, **5a**), 53.6 (OMe, **5b**), 56.3 (d, $^3J_{CF}$=3.5 Hz, *t*Bu **5a**), 57.3 (*t*Bu **5b**), 94.4 (d, $^1J_{CF}$=247.7 Hz, CF **5b**), 97.2 (d, $^1J_{CF}$=228.7 Hz, CF **5a**), 163.9 (d, $^2J_{CF}$=21.2 Hz, C═O **5a**), 164.8 (d, $^2J_{CF}$=24.7 Hz, C═O **5b**); MS *m/z* (relative intensity) 196 (14), 141 (3), 92 (1.4), 57 (100); IR (NaCl) 1760 cm^{-1} (C═O); HRMS (EI) *m/z* calcd for $C_7H_{13}O_3SF$ $(M)^+$ 196.0578, found 196.0569.

5.2. Methyl-2-*tert*-butylsulfinyl-2-fluoro-3-hydroxy-3-phenylpropanoate *syn*/*anti* (2a)

5.2.1. Methyl-2-*tert*-butylsufanyl-2-fluoro-3-hydroxy-3-phenylpropanoate. To a solution of diisopropylamine (512 mL, 3.66 mmol) in anhydrous THF (10 mL) cooled at −78°C was slowly added BuLi (1.2 M in hexane, 2.9 mL, 3.49 mmol). The solution was warmed up at −20°C for 20 min. The mixture was cooled at −78°C and the methyl-2-fluoro-2-*tert*-butylsulfanylacetate **1** (600 mg, 3.33 mmol) was added to the LDA solution. After 30 min, benzaldehyde (338 mL, 3.33 mmol) was slowly introduced and the reaction mixture was stirred for 2 h. The solution was hydrolysed by addition of an aqueous solution of NH_4Cl and extracted with dichloromethane. The organic layer was washed with saturated NaCl solution, dried over $MgSO_4$ and concentrated under vacuum. The purification by flash column chromatography using light petroleum ether/ethyl acetate (7/3), led successively to the 2,3-*syn* isomer (less polar compound: 270 mg, 29%) and the 2,3-*anti* isomer (more polar compound: 475 mg, 49%). 2,3-*syn* methyl-2-*tert*-butyl-2-fluoro-3-hydroxy-3-phenylpropanoate ^{1}H NMR ($CDCl_3$) δ 1.32 (s, 9H, $3CH_3$, *t*Bu), 3.12 (d, $^3J_{HOH}$=4.2 Hz, 1H, OH); 3.62 (s, 3H, CO_2Me), 4.91 (dd, $^3J_{HF}$=19.1 Hz, $^3J_{HOH}$=4.2 Hz, 1H, CHOH), 7.20–7.27 (m, 5H, Ph);^{13}C NMR ($CDCl_3$) δ 31.6 (d, $^4J_{CF}$=1.6 Hz, $3CH_3$, *t*Bu), 47.6 (*t*Bu), 52.5 (OCH_3), 77.1 (d, $^2J_{CF}$=19.3 Hz, COH), 104.0 (d, $^1J_{CF}$=243.9 Hz, CF), 127.8, 128.0, 128.8, 135.3 (Ph), 168.4 (d, $^2J_{CF}$=31.4 Hz, C═O); ^{19}F NMR ($CDCl_3$) δ −153.7 (d, $^3J_{HF}$=19.1 Hz, 1F, CF); MS *m/z* (relative intensity) 286 (1), 269 (8), 180 (76), 124 (100), 108 (60), 107 (52), 79 (79), 78 (30), 77 (73); IR (KBr) 1756 cm^{-1} (C═O). Anal. calcd for $C_{14}H_{19}O_3SF$ (%) C, 58.72; H, 6.69 Found (%) C, 58.32; H, 6.85. 2,3-*anti* methyl-

2-*tert*-butyl-2-fluoro-3-hydroxy-3-phenylpropanoate ^{1}H NMR ($CDCl_3$) δ 1.33 (s, 9H, $3CH_3$, *t*Bu), 2.92 (dd, $^3J_{HOH}$=7.6 Hz, $^4J_{HF}$=1.62 Hz, 1H, OH), 3.86 (s, 3H, CO_2Me), 5.06 (dd, $^3J_{HF}$=17.8 Hz, $^3J_{HOH}$=7.6 Hz, 1H, CHOH), 7.33–7.41 (m, 5H, Ph); ^{13}C NMR ($CDCl_3$) δ 31.4 ($3CH_3$, *t*Bu), 47.5 (*t*Bu), 52.9 (OCH_3), 77.5 (d, $^2J_{CF}$=20.5 Hz, COH), 104.0 (d, $^1J_{CF}$=243.9 Hz, CF), 128.0, 128.7, 136.9 (Ph), 169.1 (d, $^2J_{CF}$=33.9 Hz, C=O); ^{19}F NMR ($CDCl_3$) δ −152.45 (d, $^3J_{HF}$=17.8 Hz, 1F, CF); MS *m*/*z* (relative intensity) 286 (2), 227 (3), 180 (41), 124 (100), 107 (82), 79 (45), 77 (30), 57 (49), IR (KBr) ν=1748 cm^{-1} (C=O).

5.2.2. Methyl-2,3-*syn*-2-*tert*-butylsulfinyl-2-fluoro-3-hydroxy-3-phenylpropoanoate (2a). *meta*-Chloroperbenzoic acid (116 mg, 0.674 mmol) was added in one portion to a solution of methyl-2,3-*syn*-2-*tert*-butylsulfanyl-2-fluoro-3-hydroxy-3-phenylpropanoate (193 mg, 0.674 mmol) in dichloromethane (10 mL) at −20°C. After 2 h stirring, the reaction was quenched by addition of an aqueous solution of $NaHCO_3$ (5 mL). The organic layer was washed twice with $NaHCO_3$ and brine, and the aqueous layer was extracted with CH_2Cl_2. The organic layer was dried over $MgSO_4$, and concentrated under vacuum. Crude methyl-2,3-*syn*-2-*tert*-butylsulfinyl-2-fluoro-3-hydroxy-3-phenylpropanoate **2a** (183 mg, 90%) was obtained as a yellow oil. ^{1}H NMR ($CDCl_3$) δ 1.28 (d, $^5J_{HF}$=1 Hz, 9H, $3CH_3$ *t*Bu), 3.42 (s, 3H, CO_2Me), 5.43 (s br, 1H, OH), 5.55 (d, $^3J_{HF}$=17.6 Hz, $^3J_{HOH}$=7.7 Hz, 1H, CHOH), 7.23–7.31 (m, 5H, Ph); ^{13}C NMR ($CDCl_3$) δ 23.5 (d, $^4J_{CF}$=4 Hz, $3CH_3$ *t*Bu), 52.8 (OCH_3), 60.4 (d, $^3J_{CF}$=2.2 Hz, *t*Bu), 77.2 (d, $^2J_{CF}$=18.3 Hz, COH), 106.2 (d, $^1J_{CF}$=268.5 Hz, CF), 127.7 (d, J_{CF}=0.5 Hz, Ph), 128.2, 129.4, 134.4 (Ph), 165.1 (d, $^2J_{CF}$=23.9 Hz, C=O); ^{19}F NMR ($CDCl_3$) δ −184.2 (d, $^3J_{HF}$=17.6 Hz, 1F, CF).MS *m*/*z* (relative intensity) 318 ([M]$^{+\cdot}$) IR (KBr) 1756 cm^{-1} (C=O).

5.2.3. Methyl-2,3-*anti*-2-*tert*-butylsulfinyl-2-fluoro-3-hydroxy-3-phenylpropoanoate (2a). Following the experimental procedure in Section 5.2.2, from the 2,3-*anti*-2-*tert*-butylsulfinyl-2-fluoro-3-hydroxy-3-phenyl-propanoate (44 mg, 0.153 mmol) and *meta*-chloroperbenzoic acid (26.5 mg, 0.153 mmol), a crude mixture of two stereoisomers of the 2,3-*anti*-2-*tert*-butylsulfinyl-2-fluoro-3-hydroxy-3-phenylpropanoate was obtained (45 mg, 98%). ^{1}H NMR ($CDCl_3$) δ 1.22 (d, $^5J_{HF}$=1.6 Hz, 9H, $3CH_3$ *t*Bu), 1.31 (s, 9H, $3CH_3$), 3.62 (s, 3H, CO_2Me), 3.90 (s, 3H, CO_2Me), 5.39 (s br, 1H, OH), 5.38 (d, $^3J_{HF}$=9.6 Hz, 1H, CHOH), 5.55 (d, $^3J_{HF}$=25 Hz, 1H, CHOH), 7.31–7.58 (m, 5H, Ph); ^{13}C NMR ($CDCl_3$) δ 23.1 (d, $^4J_{CF}$=2.8 Hz, $3CH_3$), 24.0 (d, $^4J_{CF}$=3.4 Hz, $3CH_3$), 52.8 (OCH_3), 53.0 (d, $^4J_{CF}$=0.8 Hz, OCH_3), 58.2 (*t*Bu), 58.9 (d, $^3J_{CF}$=1.8 Hz, *t*Bu), 72.5 (d, $^2J_{CF}$=28.5 Hz, COH), 75.2 (d, $^2J_{CF}$=17.7 Hz, COH), 104.2 (d, $^1J_{CF}$=236.4 Hz, CF), 108.2 (d, $^1J_{CF}$=254.7 Hz, CF), 126.7, 126.7, 128.1, 128.3, 128.5, 128.7, 129.1, 134.7, 135.2 (Ph, 2 dia.), 165.4 (d, $^2J_{CF}$=22.6 Hz, C=O), 165.46 (d, $^2J_{CF}$=22.4 Hz, C=O). ^{19}F NMR ($CDCl_3$) δ −167.5 (d, $^3J_{HF}$=9.6 Hz, 1F, CF), −171.4 (d, $^3J_{HF}$=25 Hz, 1F, CF).

5.2.4. Methyl-2-*tert*-butylsulfinyl-2-fluoro-3-hydroxy-octanoate (2c). To a solution of anhydrous THF (10 mL) cooled at −78°C was added diisopropylamine (1.2 equiv., 1.22 mmol, 0.171 mL). After 15 min, 1.2 M *n*-BuLi/hexane solution (1.1 equiv., 1.12 mmol, 0.935 mL) was slowly added and the solution warmed up at −20°C. After 20 min, the mixture was cooled at −78°C and methyl-2-fluoro-2-*tert*-butylsulfinylacetate (1 equiv., 1.02 mmol, 200 mg) was added. After 30 min, the hexanal (1 equiv.) was introduced into the solution maintained at −78°C. The reaction mixture was stirred for 2 h and diluted at −78°C with an aqueous solution of ammonium chloride. The solution was extracted with dichloromethane, washed with saturated NaCl solution, dried over $MgSO_4$ and concentrated in vacuo. The residue was purified by flash chromatography to afford (**2c**) as a mixture of stereoisomers (6/4 ratio) (166 mg, 0.56 mmol, 55%). ^{1}H NMR ($CDCl_3$) δ 0.85 (t, $^3J_{HH}$=6.8 Hz, 3H, CH_3), 1.23–1.48 (m, 8H, CH_2), 1.33 (s, 9H, *t*Bu), 3.65 and 3.87 (s, 3H, OCH_3), 3.89 (s, 1H, OH), 4.10–4.35 (m, 1H, C*H*OH); ^{19}F NMR ($CDCl_3$) δ −170.8 (d, 1F, $^3J_{HF}$=7.1 Hz, major isomer), −180.7 (d, 1F, $^3J_{HF}$=21.6 Hz, minor isomer); ^{13}C NMR ($CDCl_3$) δ 13.9 (CH_3), 22.5 (CH_2), 23.9 (CH_3, *t*Bu), 25.3 (CH_2), 30.7 (CH_2), 31.4 (CH_2), 53.1 (*t*Bu), 58.7 (OCH_3), 70.9 (d, $^2J_{CF}$=28.1 Hz, CHOH), 108.6 (d, $^1J_{CF}$=253 Hz, CF), 166.3 (d, $^2J_{CF}$=23.8 Hz, CO).

5.3. Two steps synthesis of α,β-unsaturated esters (3c–f) from methyl-2-fluoro-2-*tert*-butylsulfinylacetate (5)

To a solution of anhydrous THF (10 mL) cooled at −78°C was added diisopropylamine (1.2 equiv., 1.83 mmol, 0.257 mL). After 20 min, 1.2 M BuLi/hexane solution (1.1 equiv., 1.68 mmol, 1.40 mL) was slowly added and the solution warmed up at −20°C. After 15 min, the mixture was cooled at −78°C and methyl-2-fluoro-2-*tert*-butylsulfinylacetate (**5**) (1 equiv., 300 mg, 1.53 mmol) was added to the LDA solution. After 30 min, the aldehyde (1 equiv.) was introduced into the solution maintained at −78°C. The reaction mixture was stirred for 2 h and hydrolysed at −78°C with an aqueous solution of ammonium chloride. The solution was extracted with dichloromethane, washed with saturated NaCl solution, dried over $MgSO_4$ and concentrated under vacuum. The crude mixture of the hydroxy sulfoxides was diluted in dichloromethane (5 mL) and used without purification. Pyridine (0.37 mL, 3 equiv.) and sulfuryl chloride (0.245 mL, 2 equiv.) were successively introduced into the solution and the reaction mixture was stirred for 2 h. The solution was extracted with dichloromethane, washed with a solution of ammonium chloride and with brine. The fluoroalkenes were isolated by distillation or column chromatography (silica gel; petroleum ether/ethylacetate: 95/5).

5.3.1. Methyl-(*Z*)-2-fluoro-undeca-2-eneoate (3d). Colourless oil, 251 mg, yield 76%, selectivity *Z*/*E*: 98/2. ^{1}H NMR ($CDCl_3$) δ 0.88 (t, $^3J_{HH}$=6.8 Hz, 3H, CH_3), 1.27–1.50 (m, 12H), 2.24 (dt, $^4J_{HF}$=1.8 Hz, $^3J_{HH}$=7.1 Hz, 2H, CH_2), 3.81 (s, 3H, CO_2Me), 6.12 (dt, $^3J_{HF}$=33 Hz, $^3J_{HH}$=7.9 Hz, 1H, CH=CF); ^{19}F NMR ($CDCl_3$) δ −131.7 (d, $^3J_{HF}$=33 Hz, 1F, CF); ^{13}C NMR ($CDCl_3$) δ 13.9 (CH_3), 22.5 (CH_2), 24.0 (d, $^3J_{CF}$=2.6 Hz, CH_2), 28.2 (d, $^4J_{CF}$=1.8 Hz, CH_2), 29.0 (CH_2), 31.6 (CH_2), 47.2 (CH_2), 52.0 (OCH_3), 120.9 (d, $^2J_{CF}$=11.6 Hz, CH=CF), 147.6 (d, $^1J_{CF}$=254.8 Hz, CF=CH), 161.1 (d, $^2J_{CF}$=35.0 Hz, C=O); MS *m*/*z* (relative intensity) 216 (6), 118 (22), 105 (77), 57

(100), 43 (83); HRMS (EI) *m/z* calcd for $C_{12}H_{21}FO_2$ 216.1525, found 216.1565.

5.3.2. Methyl-(*Z*),(*E*)-2-fluoro-3-ethoxycarbonylprop-2-enoate (3e). Colourless oil, 156 mg, yield 58%, selectivity *Z*/*E*: 87/13. ^{1}H NMR ($CDCl_3$) δ 1.31 (t, $^3J_{HH}$=7.0 Hz, 3H, Me *E*), 1.32 (t, $^3J_{HH}$=7.2 Hz, 3H, Me *Z*), 3.89 (s, 3H, OMe *E*), 3.90 (s, 3H, OMe *Z*), 4.26 (q, $^3J_{HH}$=7.0 Hz, CH_2 *E*), 4.26 (q, $^3J_{HH}$=7.2 Hz, CH_2 *Z*), 6.09 (d, $^3J_{HF}$=16.0 Hz, CH=CF *E*), 6.35 (d, $^3J_{HF}$=29.0 Hz, CH=CF *Z*); ^{19}F NMR ($CDCl_3$) δ −111.6 (d, $^3J_{HF}$=16.5 Hz, 1F, CF=CH *E*), −107.5 (d, $^3J_{HF}$=28.2 Hz, 1F, CF=CH *Z*); ^{13}C NMR ($CDCl_3$) δ 13.8 (Me *E*), 13.9 (Me *Z*), 52.9 (OCH_3 *E*), 53.2 (OCH_3 *Z*), 61.2 (CH_2 *Z*), 61.6 (CH_2 *E*), 108.0 (d, $^2J_{CF}$=3.1 Hz, CH *Z*), 108.9 (d, $^2J_{CF}$=21.4 Hz, CH *E*), 153.7 (d, $^1J_{CF}$=288.3 Hz, CH *Z*), 162.2 (d, $^2J_{CF}$=34.8 Hz, C=O *Z*), 162.9 (d, $^2J_{CF}$=2.8 Hz, C=O *Z*); MS *m/z* (relative intensity) 176 (5), 161 (1.82), 131 (31), 59 (40), 53 (21), 45 (100), 43 (72); IR (NaCl) 1732 cm^{-1} (C=O). HRMS (EI) *m/z* calcd for $C_7H_9FO_4$ 176.0484, found 176.0475.

5.3.3. Methyl-2-fluoro-4,5-*O*,*O*-cyclohexylidendioxy-pent-2-enoate (3f). Colourless oil, 149 mg, yield 40%, selectivity *Z*/*E*: 43/57) ^{1}H NMR ($CDCl_3$) δ 1.40–1.42 (m, 10H, cyclohexyl *Z*), 1.59–1.67 (m, 10H, cyclohexyl *E*), 3.66 (dd, $^3J_{HH}$=6.4, 8.3 Hz, 1H, CH *E*), 3.69 (dd, $^3J_{HH}$=6.8, 8.4 Hz, 1H, CH *Z*), 3.84 (s, 3H, CO_2Me *Z*), 3.85 (s, 3H, CO_2Me *E*), 4.20 (dd, $^3J_{HH}$=6.3, 8.3 Hz, 1H, CH *Z*), 4.28 (ddd, $^3J_{HH}$=6.8, 7.9 Hz, $^5J_{HF}$=0.4 Hz, 1H, CH *E*), 5.02 (dddd, $^3J_{HH}$=8.0, 6.5, 6.5 Hz, $^4J_{HF}$=1.5 Hz, 1H, CH *Z*), 5.39 (ddd, $^3J_{HH}$=7.5, 6.2, 6.2 Hz, 1H, CH *E*), 6.03 (dd, $^3J_{HH}$=6.0, 19.2 Hz, CH *E*), 6.19 (dd, $^3J_{HH}$=6.1, 33.0 Hz, CH *Z*); ^{19}F NMR ($CDCl_3$) δ −126.4 (dd, $^4J_{HF}$=2.3 Hz, $^3J_{HF}$=32.9 Hz, CF *Z*), −121.0 (d, $^3J_{HF}$=21.1 Hz, CF *E*); ^{13}C NMR ($CDCl_3$) δ 23.8, 23.9 (CH_2 cyclohexyl *E*), 25.0 (CH_2 cyclohexyl *Z*), 25.2 (CH_2 cyclohexyl *E*), 27.0 (CH_2 cyclohexyl *Z*), 34.9 (CH_2 cyclohexyl *E*), 35.1, 36.2 (CH_2 cyclohexyl *Z*), 36.3 (CH_2 cyclohexyl *E*), 37.3 (CH_2 cyclohexyl *Z*), 52.5 (OMe), 52.7 (OMe), 68.4 (d, $^4J_{CF}$=2.8 Hz, CH_2 *Z*), 68.9 (d, $^3J_{CF}$=3.5 Hz, CH *Z*), 69.1 (d, $^4J_{CF}$=3.6 Hz, CH_2 *E*), 70.4 (d, $^3J_{CF}$=7.8 Hz, CH *E*), 110.6 (C_{IV} *E*), 110.7 (C_{IV} *Z*), 118.9 (d, $^2J_{CF}$=8.4 Hz, CH *Z*), 123.5 (d, $^2J_{CF}$=18.2 Hz, CH *E*), 147.3 (d, $^1J_{CF}$=261.6 Hz, CF *E*), CF *Z* isomer not observable, 160.8 (d, $^1J_{CF}$=34.7 Hz, C=O *E*), C=O *Z* isomer not observable; MS *m/z* (relative intensity) 244 (32), 215 (27), 201 (100), 55 (79); IR (NaCl) 1740 (C=O *E*), 1672 cm^{-1} (C=O *Z*); HRMS (EI) *m/z* calcd for $C_{12}H_{17}FO_4$ 244.1110, found 244.1123.

5.3.4. (*Z*),(*E*)-*cis*-Methyl-2,2-dimethyl-3-(2-fluoro-2-methoxycarbonyl)ethylidene)cyclopropanecarboxylate (3g). Colourless oil, 266 mg, yield 76%, selectivity *Z*/*E*: 77/23. [113894-36-3]: *E* isomer ^{1}H NMR ($CDCl_3$) δ 1.27 (s, 6H, $2CH_3$ cyclopropyl), 1.91 (dd, $^3J_{HH}$=8.5, 10.3 Hz, 1H, CH cyclopropyl), 2.84 (t, $^3J_{HH}$=8.5 Hz, 1H, CH cyclopropyl), 3.66 (s, 3H, CO_2Me), 3.84 (s, 3H, CO_2Me), 6.44 (dd, $^3J_{HH}$=10.3 Hz, $^3J_{HF}$=20.8 Hz, 1H, CH=CF); ^{19}F NMR ($CDCl_3$) δ −121.3 (dd, $^4J_{HF}$=1.0 Hz, $^3J_{HF}$=20.8 Hz, 1F, (*E*) CF=CH); ^{13}C NMR ($CDCl_3$) δ 14.7 (Me), 28.4 (Me), 28.4 (C_{IV}), 28.8 (d, $^3J_{CF}$=7.4 Hz, CH), 32.4 (CH), 51.4 (OMe), 52.0 (OMe), 120.0 (d, $^2J_{CF}$=24.6 Hz, CH), 147.8 (d, $^1J_{CF}$=252.1 Hz, CF), 161.6 (d, $^2J_{CF}$=34.5 Hz, C=O), 170.9 (C=O); *Z* isomer ^{1}H NMR ($CDCl_3$) δ 1.27 and 1.31 (s, 6H, CH_3), 1.96 (d, $^3J_{HH}$=8.4 Hz, 1H, CH), 2.21 (dd, $^3J_{HH}$=8.4, 10.4 Hz, 1H, CH cyclopropyl), 3.68 (s, 3H, CO_2Me), 3.81 (s, 3H, CO_2Me), 6.61 (dd, $^3J_{HH}$=10.4 Hz, $^3J_{HF}$=32.4 Hz, 1H, CH=CF); ^{19}F NMR ($CDCl_3$) δ −132.7 (d, $^3J_{HF}$=32.4 Hz, 1F, (*Z*) CF=CH), ^{13}C NMR ($CDCl_3$) δ 14.8 (Me), 27.9 (d, $^3J_{CF}$=4.9 Hz, CH), 28.3 (Me), 28.4 (C_{IV}), 32.8 (CH), 51.5 (OMe), 52.2 (OMe), 116.4 (d, $^2J_{CF}$=7.2 Hz, CH), 149.0 (d, $^1J_{CF}$=253.9 Hz, CF), 160.7 (d, $^2J_{CF}$=35.6 Hz, C=O), 170.7 (C=O); MS *m/z* (relative intensity) 230 (13), 200 (6), 199 (4), 172 (12), 59 (54), 40 (100); IR (NaCl) 1732 cm^{-1}; HRMS (EI) *m/z* calcd for $C_{11}H_{15}O_4F$ 230.0954, found 230.0972.

5.3.5. Methyl-3-ethoxycarbonyl-3-chloro-3-fluoro-propanoate (6). ^{1}H NMR ($CDCl_3$) δ 1.24 (q, $^3J_{HH}$=7.2 Hz, 3H, Me **6a**), 1.27 (q, $^3J_{HH}$=7.2 Hz, 3H, Me **6b**), 3.75 (d, $^5J_{HF}$=0.9 Hz, 3H, OMe **6b**), 3.79 (d, $^5J_{HF}$=1.0 Hz, 3H, OMe **6a**), 4.16–4.30 (m, 4H, OCH_2 **6a** and **b**), 4.60 (d br, $^3J_{HF}$=30.9 Hz, 1H, CHCl **6a**), 4.63 (dd, $^3J_{HF}$=23.9 Hz, $^3J_{HH}$=2.0 Hz, 1H, CHCl **6b**), 5.19 (d, $^2J_{HF}$=47.3 Hz, 1H, CHF **6a**), 5.20 (d, $^2J_{HF}$=47.3 Hz, 1H, CHF **6b**); ^{19}F NMR ($CDCl_3$) δ −202.6 (dd, $^2J_{HF}$=47.3 Hz, $^3J_{HF}$=23.9 Hz, 1F, CHF **6b**), −207.5 (dd, $^2J_{HF}$=47.3 Hz, $^3J_{HF}$=30.9 Hz, 1F, CHF **6a**); ^{13}C NMR ($CDCl_3$) δ 13.8 (Me **6b**), 13.9 (Me **6a**), 52.5 (OMe **6b**), 52.7 (OMe **6a**), 62.7 (OCH_2 **6b**), 62.8 (OCH_2 **6a**), 71.1 (d, $^2J_{CF}$=20.86 Hz, CHCl **6a**), 71.3 (d, $^2J_{CF}$=21.8 Hz, CHCl **6b**), 88.8 (d, $^1J_{CF}$=192.7 Hz, CHF **6a**), 89.7 (d, $^1J_{CF}$=193.5 Hz, CHF **6b**), 166.7 (d, $^2J_{CF}$=23.7 Hz, C=O **6b**), 166.9 (d, $^2J_{CF}$=24.7 Hz, C=O **6a**), 169.5 (d, $^3J_{CF}$=8.6 Hz, C=O **6b**), 169.9 (d, $^3J_{CF}$=2.9 Hz, C=O **6a**).

5.3.6. Methyl-2-(4-*tert*-butyl-1-hydroxy-cyclohexyl)-2-terbutylsulfanyl-2-fluoroacetate (7). To a solution of anhydrous THF cooled at −78°C was added diisopropylamine (1.2 equiv., 3.34 mmol, 0.467 mL). After 20 min, 1.2 M BuLi/hexane solution (1.1 equiv., 3.06 mmol, 2.54 mL) was slowly added and the solution warmed up at −20°C for 15 min. The mixture was cooled at −78°C and the fluorosulfide **1** (500 mg, 2.78 mmol) added to the LDA solution. After 30 min, 4-*tert*-butylcyclohexanone (1 equiv., 2.78 mmol, 428 mg) was introduced into the solution maintained at −78°C. The reaction mixture was stirred for 2 h and diluted at −78°C with an aqueous solution of ammonium chloride. The solution was extracted with dichloromethane, washed with saturated NaCl solution, dried over $MgSO_4$ and concentrated under vacuum. The α-fluoro β-hydroxy *tert*-butylsulfanyl ester (**7**) obtained as an oil (690 mg) was directly introduced in the next step without purification. ^{1}H NMR ($CDCl_3$) δ 0.71 (s, 9H, *t*Bu), 0.79–1.68 (m, 6H, cyclohexyl), 1.24 (s, 9H, *t*Bu), 1.90–1.99 (m, 2H, CH_2), 2.19–2.23 (m, 1H, CH), 2.59 (s, 1H, OH), 3.71 (s, 3H, CO_2Me); ^{19}F NMR ($CDCl_3$) δ −146.1 (s, 1F, CF); ^{13}C NMR ($CDCl_3$) δ 21.7 (d, $^3J_{CF}$=11.7 Hz, CH_2), 27.1 (CH_3), 27.2 (CH_2), 31.3 (CH_2), 31.4 (CH_3 *t*Bu), 31.9 (CH_2), 32.2 (d, $^4J_{CF}$=1.7 Hz, CH_2), 40.8 (*t*Bu), 46.28 (*t*Bu), 46.9 (CH cyclohexyl), 52.4 (OMe), 75.9 (d, $^2J_{CF}$=20.9 Hz, COH), 106.7 (d, $^1J_{CF}$=238.4 Hz, CF), 169.8 (d, $^2J_{CF}$=33.0 Hz, C=O); MS *m/z* (relative intensity) 334 (7), 180 (64), 155 (48), 137 (20), 124 (96), 98 (12) 81 (16), 57 (100); HRMS (EI) *m/z* calcd for $C_{17}H_{31}FO_3S$ 334.1978, found $(M)^+$ 334.1940.

5.3.7. Methyl-2-(4-*tert*-butyl-cyclohexylidene)-2-fluoro-acetate (8). A solution of **7** (690 mg, 2.06 mmol) in dichloromethane was cooled to −40°C for 15 min and *m*CPBA (356 mg, 2.06 mmol) was added to the solution. After 30 min, the reaction was quenched with an aqueous solution of $NaHCO_3$, and the solution extracted with dichloromethane. The organic layer was washed by an aqueous solution of $NaHCO_3$, dried over anhydrous $MgSO_4$ and concentrated under vacuum. After concentration, the residue was diluted in dichloromethane. Pyridine (0.5 mL, 6.2 mmol) and sulfuryl chloride (0.33 mL, 4.13 mmol) were added and the mixture stirred at room temperature for 2 h. The reaction mixture was washed with a saturated solution of ammonium chloride and finally with brine. The organic layer was dried over anhydrous $MgSO_4$ and the solvent evaporated under vacuum. The fluoroalkene was purified by column chromatography (silica gel; petroleum ether) (colourless oil, 412 mg, 1.8 mmol, overall yield 65%). ^{1}H NMR ($CDCl_3$) δ 0.86 (s, 9H, *t*Bu), 1.11–1.25 (m, 3H, CH), 1.73–1.82 (m, 1H, CH), 1.82–1.95 (m, 3H, CH), 2.99 (d, $^3J_{HH}$=16.6 Hz, 1H, CH), 3.63 (d, $^3J_{HH}$=13.4 Hz, 1H, CH), 3.80 (s, 3H, CO_2Me); ^{19}F NMR ($CDCl_3$) δ −132.2 (s, 1F, CF); ^{13}C NMR ($CDCl_3$) δ 27.4 (*t*Bu), 27.5 (d, $^4J_{CF}$=1.9 Hz, CH_2), 27.7 (CH_2), 28.1 (d, $^4J_{CF}$=1.8 Hz, CH_2), 31.5 (d, $^6J_{CF}$=3.2 Hz, C_{IV}), 32.3 (CH_2), 47.5 (CH), 51.7 (OMe), 136.6 (d, $^2J_{CF}$=11.9 Hz, C=C), 140.5 (d, $^1J_{CF}$=245.6 Hz, CF), 161.9 (d, $^2J_{CF}$=35.7 Hz, C=O); MS *m*/*z* (relative intensity) 228 (99, $M^{+\cdot}$), 172 (32), 152 (30), 113 (25), 93 (25), 91 (19), 59 (25), 57 (100), 55 (28); HRMS (EI) calcd for $C_{13}H_{21}O_2F$ $(M)^+$ 228.1525, found 228.1538.

5.3.8. Synthesis of methyl-2-fluoro-3-hydroxy-3-phenyl-2-phenylsulfanylpropanoate (12). To a solution of diisopropylamine (0.38 mL, 2.75 mmol) in THF (5 mL) was added dropwise butyllithium (2.2 mL, 1.2 M in hexane, 2.6 mmol) at −78°C and the mixture was warmed up at −20°C for 20 min. The solution was cooled at −78°C, and the methyl-2-fluoro-2-phenylsulfanylacetate (500 mg, 2.5 mmol) was added to the LDA solution. After stirring for 30 min at −78°C, benzaldehyde (0.25 mL, 2.5 mmol) was introduced and the reaction mixture stirred for 2.5 h. The reaction was hydrolysed by addition of aqueous HCl (1N) solution at −78°C. The solution was extracted with dichloromethane at room temperature, the combined organic layers dried over anhydrous $MgSO_4$, and concentrated under vacuum. The residue purified by column chromatography (silica gel; petroleum ether/ethyl acetate 80/20) led successively to the 2,3-*syn* isomer (less polar, 260 mg, 34%) and to the 2,3-*anti* isomer (more polar, 310 mg, 40%). *syn*-Methyl-2-phenylsulfanyl-2-fluoro-3-hydroxy-3-phenyl-propanoate: ^{1}H NMR ($CDCl_3$) δ 3.20 (d, $^3J_{HH}$=5.1 Hz, 1H, OH), 3.30 (s, 3H, CO_2Me), 5.35 (dd, $^3J_{HH}$=5.1 Hz, $^3J_{HF}$=18.2 Hz, 1H, CHCF), 7.29–7.51 (m, 10H, 2Ph); ^{19}F NMR ($CDCl_3$) δ −147.2 (d, $^3J_{HF}$=18.2 Hz, 1F, CHCF); ^{13}C NMR ($CDCl_3$) δ 52.5 (OMe); 76.4 (d, $^2J_{CF}$=21.4 Hz, CHOH), 107.1 (d, $^1J_{CF}$=244.5 Hz, CF), 127.7 (d, $^3J_{CF}$=1.9 Hz, Ph), 128.2 (Ph), 128.3, 128.9, 129.8, 136.1 (d, $^3J_{CF}$=1.4 Hz, Ph), 136.7 (Ph), 166.7 (d, $^2J_{CF}$=29.5 Hz, C=O); *anti*-methyl-2-phenylsulfanyl-2-fluoro-3-hydroxy-3-phenylpropanoate: ^{1}H NMR ($CDCl_3$) δ 3.00 (d, $^3J_{HH}$=7.3 Hz, 1H, OH), 3.49 (s, 3H, CO_2Me), 5.31 (dd, $^3J_{HH}$=7.3 Hz, $^3J_{HF}$=17.7 Hz, 1H, CHCF), 7.29–7.56 (m, 10H, 2Ph); ^{19}F NMR ($CDCl_3$) δ −150.4 (d, $^3J_{HF}$=17.7 Hz, 1F, CHCF); ^{13}C NMR ($CDCl_3$) δ 52.8 (OMe), 76.5 (d, $^2J_{CF}$=21.5 Hz, CHOH), 106.9 (d, $^1J_{CF}$=244.1 Hz, CF), 128.0 (d, $^3J_{CF}$=1.9 Hz, Ph), 128.1 (Ph), 128.4, 128.9, 129.2, 129.9, 135.9 (d, $^3J_{CF}$=1.4 Hz, Ph), 136.5 (Ph), 166.9 (d, $^2J_{CF}$=30.9 Hz, C=O); MS *m*/*z* (relative intensity) 306 (1), 200 (100), 167 (25), 141 (58), 121 (26), 109 (25), 107 (27), 105 (31); IR (KBr) 1736 cm^{-1} (C=O).

5.3.9. Synthesis of methyl-2-fluoro-2-phenylsulfinyl-3-hydroxy-3-phenylpropanoate (13). To a solution of 2,3-*anti*-methyl-2-phenylsulfanyl-2-fluoro-3-hydroxy-3-phenyl-propanoate (310 mg, 1.01 mmol) in dichloromethane was added *m*CPBA (174 mg, 1.01 mmol) at −50°C and the mixture was stirred for 1 h. The reaction mixture was diluted with an aqueous Na_2CO_3 solution, the organic layer washed with brine, dried over anhydrous $MgSO_4$ and concentrated. The 2,3-*anti* stereoisomers were isolated in a pure form (174 mg, 54%) by flash chromatography on silica gel (petroleum ether/ethyl acetate 60/40) ^{1}H NMR ($CDCl_3$) δ 3.40 (s, 3H, CO_2Me), 3.49 (s, 3H, CO_2Me), 4.34 (s broad, 1H, OH), 5.16 (d, $^3J_{HOH}$=5.4 Hz, 1H, OH), 5.45 (d, $^3J_{HF}$=9.9 Hz, 1H, CHCF), 5.50 (dd, $^3J_{HOH}$=5.4 Hz, $^3J_{HF}$=22.9 Hz, 1H, CHCF), 7.30–7.64 (m, 20H, 4Ph); ^{19}F NMR ($CDCl_3$) δ −175.6 (d, $^3J_{HF}$=22.9 Hz, 1F, CHCF), −171.5 (d, $^3J_{HF}$=9.9 Hz, 1F, CHCF); ^{13}C NMR ($CDCl_3$) δ 52.6 (OMe), 52.8 (OMe), 71.5 (d, $^2J_{CF}$=28.2 Hz, CHOH), 71.6 (d, $^2J_{CF}$=28.2 Hz, CHOH), 107.1 (d, $^1J_{CF}$=242.6 Hz, CF), 108.5 (d, $^1J_{CF}$=254.4 Hz, CF), 125.3 (d, $^3J_{CF}$=1.6 Hz, Car), 126.2, 126.4 (d, $^3J_{CF}$=1.4 Hz, Ph), 128.0, 128.2, 128.4, 128.6, 128.8, 129.0, 132.2, 132.4, 135.6 (Ph), 136.5 (Ph), 136.6 (d, $^3J_{CF}$=3.2 Hz, Ph), 137.3 (Ph), 163.7 (d, $^2J_{CF}$=25.6 Hz, C=O), 164.1 (d, $^2J_{CF}$=22.7 Hz, C=O); MS *m*/*z* (relative intensity) 323 (1), 197 (5), 126 (14), 125 (100), 109 (34), 97 (35), 77 (39), 51 (76); IR (KBr) 3380 (OH), 1760, 1738 cm^{-1} (C=O).

5.3.10. Methyl-2-fluoro-2-phenylsulfonyl-3-chloro-β-phenylpropanoate (14). To a solution of 2,3-*anti*-methyl-2-fluoro-2-phenylsulfinyl-3-hydroxy-3-phenylpropanoate (150 mg, 0.465 mmol) in dichloromethane was added sulfuryl chloride (75 μL, 0.931 mmol). The reaction mixture was stirred for 2 h at room temperature. The solution was extracted with dichloromethane, washed with a solution of ammonium chloride and with brine. The chlorosulfones (99 mg, 59% yield) were isolated by chromatography on silica gel as a diastereoisomeric mixture (1/1 ratio) (petroleum ether/EtOAc: 85/15). ^{1}H NMR ($CDCl_3$) δ 3.51 (s, 3H, OMe), 3.93 (s, 3H, OMe), 5.90 (d, $^3J_{HF}$=25.8 Hz, 1H, CHCl), 5.93 (d, $^3J_{HF}$=27.8 Hz, 1H, CHCl), 7.22–8.06 (m, 20H, 4Ph); ^{19}F NMR ($CDCl_3$) δ −166.1 (d, $^3J_{HF}$=27.8 Hz, 1F, CFCH), −165.3 (d, $^3J_{HF}$=25.8 Hz, 1F, CFCH); ^{13}C NMR ($CDCl_3$) δ 53.5 (OMe), 54.2 (OMe), 58.6 (d, $^2J_{CF}$=17.1 Hz, CHCl), 59.7 (d, $^2J_{CF}$=17.7 Hz, CHCl), 107.5 (d, $^1J_{CF}$=247.5 Hz, CF), 108.2 (d, $^1J_{CF}$=246.2 Hz, CF), 128.4, 128.5 (d, $^4J_{CF}$=1.8 Hz, Ph), 128.6, 128.8, 128.9, 129.83, 129.9, 130.0 (d, $^4J_{CF}$=1.5 Hz, Ph), 130.1 (d, $^4J_{CF}$=2.5 Hz, Ph), 130.8, 133.0 (Ph), 134.2 (Ph), 134.5 (Ph), 134.6, 135.3 (Ph), 161.8 (d, $^2J_{CF}$=25.0 Hz, C=O), 162.5 (d, $^2J_{CF}$=24.9 Hz, C=O); MS *m*/*z* (relative intensity) 356 (3), 245 (10), 215 (42), 189 (30), 180 (100), 141 (39), 77 (78), 59 (62), 48 (71); IR (KBr) 1770, 1748 cm^{-1} (C=O);

HRMS (CI CH_4) *m/z* calcd for $C_{16}H_{15}ClFO_4S$ 357.0363, found 357.0311.

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