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Utilization of perfluoroalkanoate-derived aluminium acetals as the convenient fluorinated aldehyde precursors

Sumika Aoki, Tomoko Kawasaki-Takasuka, Takashi Yamazaki *

Division of Applied Chemistry, Institute of Engineering, Tokyo University of Agriculture and Technology, 2-24-16 Nakamachi, Koganei 184-8588, Japan

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ABSTRACT

Aluminium acetals from the DIBAL partial reduction of perfluoroalkanoates **1** were successfully employed as the convenient and useful fluorinated aldehyde precursors, and reactions of such intermediates with sodium salts from some β-dicarbonyl compounds **2** as well as their possible utility as the Michael acceptors after transformation to the corresponding alkylidene malonates **8** were also demonstrated.

1. Introduction

Aldehydes have wide recognition as one of the most typical and useful electrophiles conveniently employed in the field of synthetic organic chemistry. Effective electrophilic activation of the carbonyl carbon atom is known to be realized by direct attachment of a perfluoroalkyl (Rf) group due to its strongly electron-withdrawing nature, which causes significant decrease of LUMO energy levels.[1] As a consequence, RfCHO readily accepts nucleophilic attack even by such weak reagents as water or alcohols to very easily and smoothly afford the corresponding thermodynamically stable hydrates $RfCH(OH)_2$[2] or hemiacetals RfCH(OH)OR, respectively. In addition to problems associated with generation methods of RfCHO from these derivatives[3] usually requiring very harsh conditions, this characteristic property allowed to consider them as convenient as well as potential aldehyde precursors.[4] However, as long as we concern, commercially available hydrates and/or hemiacetals as well as their distributors are quite limited at present. This inconvenience would be one of the major reasons why this interesting synthetic process has not been employed frequently in the field of synthetic organofluorine chemistry. At this point, because preparative schemes to access these hemiacetals are usually by way of conventional hydride reduction,[5] we have reached to an idea to use the intermediary metal acetals as the intriguing in situ generated aldehyde precursors. If this concept is realized, skip of the isolation process would be quite helpful for handling of fluorine-containing compounds with higher volatility, and, of course, important from the economical as well as ecological points of view. Because our literature search revealed that quite limited numbers of reports have been appeared[6,7] thus far on the basis of this concept, we have decided to start our investigation for establishment of efficient utilization of intermediary aluminium acetals prepared from the DIBAL reduction of appropriate esters **1** with a Rf group for the reaction with anionic nucleophiles derived from β-keto carbonyl compounds **2**. Moreover, synthetic utility of the products **3** obtained was also clarified by way of the formal dehydration, followed by conjugate addition of hydrazines and an alcohol molecule.

2. Results and discussions

2.1. Reaction of aluminium acetals with β-carbonyl compounds

First of all, methyl tridecafluoroheptanoate **1a** was employed as the representative perfluoroalkanoate and its reaction after the partial reduction with DIBAL has been studied in detail with sodium enolate derived from diethyl malonate **2a** and sodium hydride as the model nucleophile (Table 1). 1.2 equiv of DIBAL was subjected to an Et_2O solution of **1a** at −80 °C, and to this mixture containing the resultant intermediary aluminium acetal was introduced the sodium salt of **2a** formed in THF in a separate flask at −80 °C and the temperature was increased after 5 min. Room

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* Corresponding author. E-mail address: tyamazak@cc.tuat.ac.jp (T. Yamazaki).

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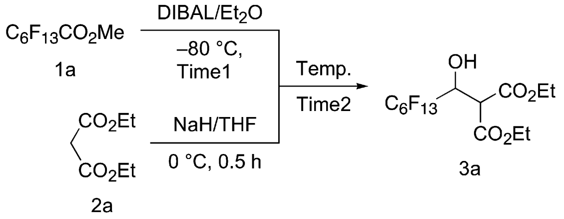
Table 1
Investigation of reaction conditions (1)



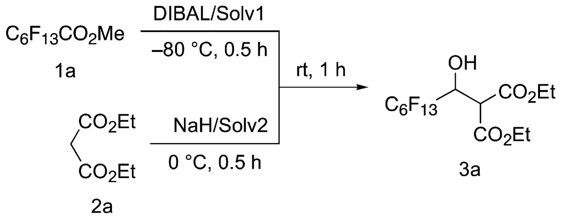
Entry	Time 1 (h)	Temp (°C)	Time 2 (h)	Yield[a] (%)
1	0.5	0	1.0	19
2	0.5	0	3.0	26
3	0.5	rt	1.0	47
4	0.5	rt	24.0	38
5	0.5	60	1.0	47
6	1.0	rt	1.0	52
7	2.0	rt	1.0	61
8	3.0	rt	1.0	43

[a] Determined by ^1H NMR spectroscopy.

temperature was found to be sufficient (entries 1,3, and 5) and 1 h stirring after mixing both solutions (Time 2) seemed to be appropriate for the construction of the desired alcohol **3a** in good chemical yield (entries 3 and 4). It is interesting to note that the duration of the DIBAL reduction also affected the yield to some extent (entries 3, 6, 7, and 8), and 2 h at −80 °C was found to be the best out of other time conditions examined.

At the next stage, the solvent effect was briefly checked both for the DIBAL partial reduction and the enolate formation from **2a** (Table 2). For the former instance, relatively low polar solvents were usually preferred for avoidance of overreduction,[7] and CH_2Cl_2 was actually proved to work adequately (entries 1,3, and 5). When the formation of the sodium salt from **2a** was performed in DMF with high polarity and this mixture was added to the other solution containing the aluminium acetal, only a sluggish result was obtained possibly due to stronger coordinating property of this solvent. On the other hand, efficiency of THF was unexpectedly similar to the one of Et_2O (entries 1 vs 3) in spite of their Lewis basicity difference. As a consequence, in connection with the results in Table 1, entry 7 in Table 2 was eventually determined to be the conditions of choice for the construction of **3a**.

Table 2
Investigation of reaction conditions (2)



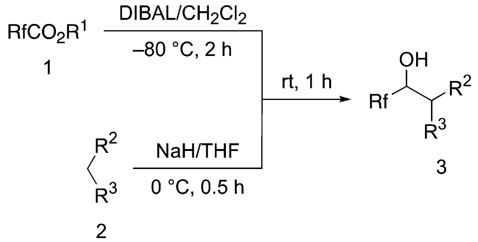
			NaH	2a	
Entry	Solv 1	Solv 2	(equiv)		Yield[a] (%)
1	Et_2O	THF	1.2	1.1	47
2	Et_2O	DMF	1.2	1.1	18
3	THF	THF	1.2	1.1	41
4	THF	THF	2.2	2.0	51
5	THF	THF	3.3	3.0	59
6	CH_2Cl_2	THF	1.2	1.1	69
7[b]	CH_2Cl_2	THF	3.3	3.0	82

[a] Determined by ^1H NMR spectroscopy.
[b] DIBAL reduction was performed for 2 h.

In spite of the selection of the best conditions as above, soon it appeared that sometimes this procedure gave inconsistent chemical yields in a range of ca. 30%. After our detailed search, this discrepancy was found to stem from the combination ratio of two different solvents, CH_2Cl_2 as Solv 1 and THF as Solv 2 in Table 2. Actually, increase of the CH_2Cl_2/THF ratio from 1/5 to 2/1 rendered the total polarity to be lowered and the yield to be largely decreased from 82% to 43%. This was understood from the standpoint of the role of THF as a Lewis base, which would coordinate to the aluminium atom of the DIBAL reduction intermediate with adequately weakening the Al–O bond. Then, the corresponding aldehyde would be readily released to be quickly trapped by the nucleophile. Thus, our initial irreproducibility was concluded on the basis of the use of the different amount of THF not only as the reaction solvent but also as the rinsing liquid after transfer of the sodium salt of malonate to the other flask, and was completely solved by strict control of the CH_2Cl_2/THF ratio to 1/5.

Because we successfully found out the best and reproducible process for the reaction of **1a** and **2a**, various esters **1** were treated under these conditions with some β-dicarbonyl compounds **2** whose results are summarized in Table 3. Nucleophilic attack of diethyl malonate **2a** proceeded nicely to aluminium acetals from tridecafluoroheptanoate (**1a**), trifluoroacetate (**1b**), and pentafluoropropionate (**1c**) to furnish the corresponding adducts in good to excellent yields (entries 1–3). In the case of **3a**, a small amount of impurity was noticed by ^1H NMR, which was proved to be the corresponding methyl ester formed by alcohol exchange of the original ethyl ester **3a**. Formation of such a byproduct would be mediated by the 'waste' i-Bu_2AlOMe eliminated from the aluminium acetal when the aldehyde was liberated.[8] The fact that this problem was not encountered when **1a** was reacted with dimethyl malonate **2b** supported this assumption and a similar level of chemical yield was recorded for the adduct **3d** (entry 4). Synthesis of **3b** with a CF_3 group was reported by only two researchers until now,[9] both starting from the isolated trifluoroacetaldehyde hemiacetals as the CF_3 source. It is the clear predominance of the present method that the intermediary aluminium acetals were not required to be isolated for obtaining a similar outcome.

Table 3
DIBAL-mediated reaction of perfluoroalkanoates **1** with β-dicarbonyl compounds **2**



Entry	Rf	1	R^1	R^2	R^3	3	Yield[a,b] (%)
1	C_6F_{13}	**a**	Me	CO_2Et	CO_2Et	**a**	82
2	CF_3	**b**	Et	CO_2Et	CO_2Et	**b**	64
3	C_2F_5	**c**	Me	CO_2Et	CO_2Et	**c**	67
4	C_6F_{13}	**a**	Me	CO_2Me	CO_2Me	**d**	74
5	C_6F_{13}	**a**	Me	C(O)Me	CO_2Et	**e**	68 [55:45]
6	C_2F_5	**c**	Me	C(O)Me	CO_2Et	**f**	47 [51:49]
7	CHF_2	**d**	Et	CO_2Et	CO_2Et	**g**	(62)
8	$CClF_2$	**e**	Me	CO_2Et	CO_2Et	**h**	(36)

[a] Isolated yields are shown and the ones determined by ^1H NMR are described in parenthesis.
[b] In the brackets are shown the diastereomer ratios.

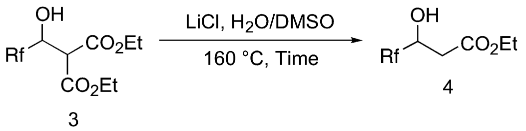
Esters **1a** and **1c** were also employed to form a new carbon–carbon bond with ethyl 3-oxobutanoate **2c** and the resultant adducts **3e** and **3f** were produced in good yields in a stereo random manner (entries 5 and 6). On the other hand, 1,3-diphenylpropane-

1,3-dione (R^2=R^3=PhC(O)) as well as ethyl nitroacetate (R^2=CO_2Et, R^3=NO_2) were not the adequate reagents and construction of the corresponding adducts was confirmed in only 10–20% yields. Difluoro- or chlorodifluoroacetate (**1d** or **1e**) were treated in the same system to afford the desired products **3g** or **3h**, respectively, but because of inseparability from the excess amount of malonate used, their purification were not carried out at this stage.

2.2. Synthetic utilization of fluorine-containing malonate derivatives 3

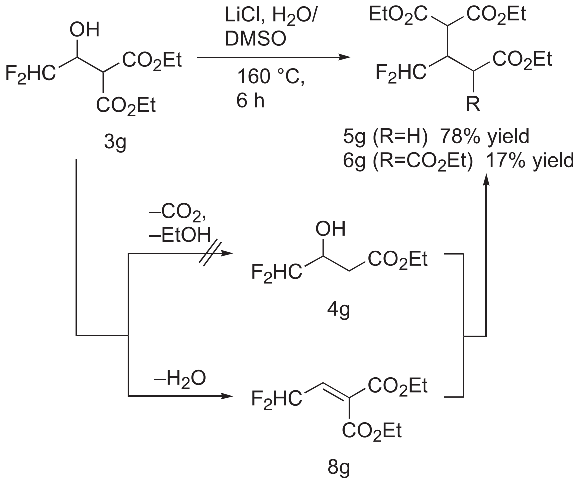
As described in the previous section, because of their close R_f values, the crude mixture containing **3** and **2** was employed for the next decarboxylation step without further tedious purification. With referring to the method described in the literature,[10] a variety of conditions were examined to the model substrate **3a**. As shown in Table 4, search for the optimal reaction time and an amount of H_2O clarified that 6 h and 22.5 equiv were the best, respectively (entries 1–3), while elongation of the time seemed to decrease the yield (entry 4). It is interesting to note that, during this transformation, the C_6F_{13}-containing glutarate **7a** was concomitantly formed as a byproduct to some extent (entries 1–3). Different substrates **3b**, **3c**, **3h**, and **3g** were also treated under the conditions shown in entry 3 and the corresponding 3-hydroxy-3-perfluoroalkylated propionates **4** were obtained in high yields (entries 5–7). On the other hand, **3g** (Rf=CHF_2) was the special case and a mixture of mono- and bisethoxycarbonylated glutarates **5g** and **6g** was isolated in 78 and 17% yields, respectively, without detection of the desired **4g** (Scheme 1).

Table 4
Decarboxylation of **3**



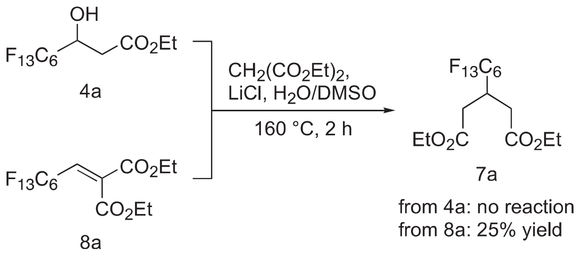
Entry	Rf	3	H_2O (equiv)	Time (h)	4	Yield[a] (%)
1	C_6F_{13}	**a**	3.3	2	**a**	75 (20)
2	C_6F_{13}	**a**	15	5	**a**	81 (16)
3	C_6F_{13}	**a**	22.5	6	**a**	94 (3)
4	C_6F_{13}	**a**	30	15	**a**	74
5	CF_3	**b**	22.5	6	**b**	quant
6	C_2F_5	**c**	22.5	6	**c**	66
7	$CClF_2$	**h**	22.5	6	**h**	75

[a] In the parenthesis was shown the yield of the corresponding glutarate **7a**.



Scheme 1. Decarboxylation of **3g**.

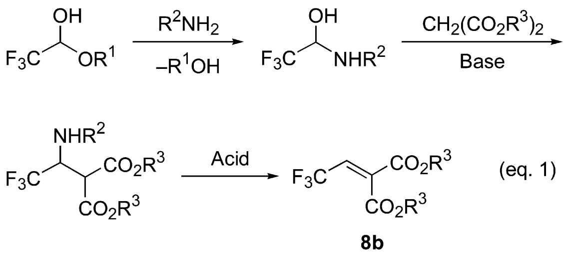
For the clarification of the mechanism to access to the byproduct **7a** as mentioned above, the isolated **4a** was subjected to the same decarboxylation condition in the presence of malonate **2a** to result in the recovery of **4a** in 89% yield (Scheme 2). In contrast, the other possible substrate **8a** actually led to the formation of **7a** in 25% yield. Comparison of these independent reactions unambiguously indicated that the production of **7a** would be initiated by the dehydration of **3a** to form **8a** at the first stage, which could further accept Michael addition of diethyl malonate **2a** present in a crude mixture, followed by hydrolysis–decarboxylation, both by the action of Lewis acidic LiCl.



Scheme 2. Reaction of **4a** and **8a** under the decarboxylation condition.

Then, even under the same reaction conditions, what factor affected the different outcome when starting from **3a** and **3g**: thus the former afforded **4a** but the latter a mixture of **5g** and **6g**, not **4g**? This discrepancy would be elucidated as follows. Due to significant electron-withdrawing nature of a Rf group, its attachment geminal to the hydroxy moiety is believed to strengthen the neighboring Rf–*C*–*O* bond.[11] Moreover, because of difference in electron-withdrawing ability,[12] electron density of the oxygen atom proximate to the C_6F_{13} moiety in **3a** should be lower than the one in **3g**. Thus, because this effect might render the C_6F_{13}–*C*–*O* bond stronger and this oxygen less Lewis basic, the LiCl-mediated dehydration of **3a** was assumed to be more difficult than the case of **3g**. On the other hand, smooth activation of an ester group in **3a** was realized by this Lewis acid because the carbonyl oxygen atom is two more bonds apart from the C_6F_{13} moiety. This is our interpretation why the present sharp contrast in reactivity was observed.

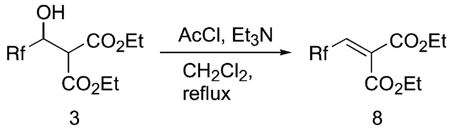
Although alkylidene malonates **8** seems to be readily accessible from **3** by the formal dehydration, it was quite interesting to note that **8** with a Rf group at the terminal carbon atom were reported only for the one possessing a CF_3 group **8b**,[4k,13] and their syntheses basically followed the same protocol: thus, as shown in Eq. 1, conversion of the commercially available CF_3-containing hemiacetals to the corresponding *N*,*O*-acetals, then introduction of malonate, followed by acid-mediated deamination afforded **8b** in about 40% overall yield. So, construction of **8** was carried out from a couple of substrates **3** for opening a new route to access to these interesting compounds possessing not only a CF_3 group but some other Rf moieties starting from more versatile and easy-to-handle perfluoroalkanoates **1**.



(eq. 1)

Theoretically, 1 equiv of AcCl and Et_3N were required for acetylation of the hydroxy group, and introduction of another equiv of the same base would facilitate smooth elimination of an acetic acid molecule to furnish **8** initiated by removal of the acidic methine proton. As shown in Table 5, the desired compounds **8** were cleanly constructed by the action of AcCl and Et_3N in refluxing CH_2Cl_2. Although the reason was not clarified yet, **3b** and **3c** seemed to be less reactive than the case of **3a**, and twice amounts of both reagents were required for attainment of good isolated yields of the products **8**.

Table 5
Dehydration from **3**

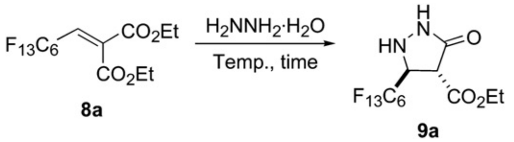


Entry	Rf	3	AcCl (equiv)	Et_3N (equiv)	Time (h)	8	Yield[a] (%)
1	C_6F_{13}–	**a**	1.5	3.0	6	**a**	93
2	CF_3–	**b**	1.5	3.0	4	**b**	2[b] (>99)[b]
3	CF_3–	**b**	3.0	6.0	4	**b**	70
4	C_2F_5–	**c**	1.5	3.0	4	**c**	52[b] (43)[b]
5	C_2F_5–	**c**	3.0	6.0	4	**c**	61

[a] In the parenthesis was shown the recovery of **3**.
[b] Determined by ^1H NMR.

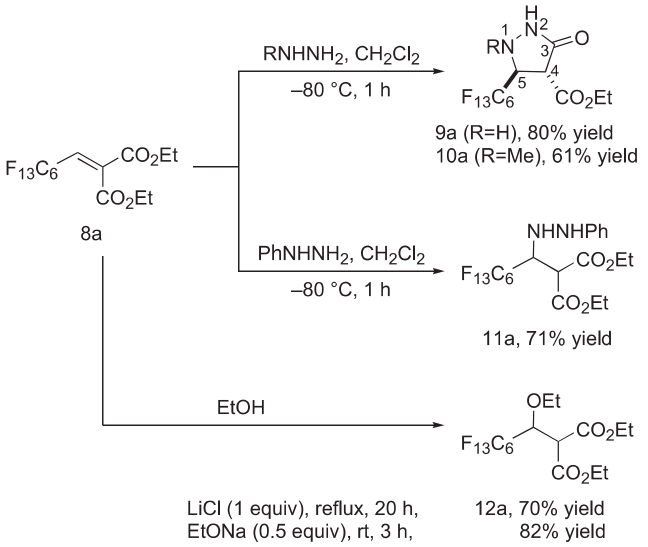
Alkylidenemalonates **8** thus obtained were expected to be excellent Michael acceptors due to three electron-withdrawing substituents installed to the one ethylene unit, and the reaction of **8a** with hydrazine hydrate was carried out for validation of their utility (Table 6). As our expectation, conjugate addition of hydrazine was very quick either in ethanol or methylene chloride and almost complete conversion was confirmed even after 5 min at ambient temperature (entries 1 and 2). The product obtained was not the simple Michael adduct but the pyrazolidin-3-one **9a** as the result of the intramolecular cyclization after the initial 1,4-addition. Efficient increase of the yield of **9a** was realized by the application of the non-aqueous workup method (see the Experimental section), which successfully attained much better material balance. Further brief investigation on the amount of $NH_2NH_2 \cdot H_2O$, reaction time, and temperature allowed us to determine the conditions shown in entry 8 as the best, which were employed for the reaction of **8a** with three representative hydrazines whose results are described in Scheme 3.

Table 6
Reaction of **8** with hydrazine



Entry	Solv	NH_2NH_2 (equiv)	Temp (°C)	Time (min)	Yield[a] (%)
1	EtOH	1.1	rt	5	50
2	EtOH	1.1	rt	30	32
3	EtOH	1.1	0	5	46
4	CH_2Cl_2	1.1	0	5	48
5[b]	CH_2Cl_2	1.1	0	5	73
6[b]	CH_2Cl_2	2.2	0	5	60
7[b]	CH_2Cl_2	1.1	−30	60	83
8[b]	CH_2Cl_2	1.1	−80	60	98 (80)

[a] Yields determined by ^1H NMR and in the parenthesis is shown the isolated yield.
[b] Non-aqueous workup was performed.



Scheme 3. Reaction of **8a** with three hydrazines and EtOH.

Unsubstituted and methylated hydrazines furnished the corresponding pyrazolidin-3-one **9a** and **10a** in good yields, respectively, and it is worth noting that the latter product **10a** was not contaminated by the regioisomer with the methyl group at the 2-position.[14] On the other hand, only Michael addition proceeded by the action of phenyl hydrazine toward **8a**. In the case of methylhydrazine, the more electronegative and sterically not quite encumbered nitrogen atom with a CH_3 group would preferentially attack the β-carbon to the ester moiety, followed by the cyclization to furnish **10a**. If the opposite reaction order is operative, the intramolecular Michael reaction of the initially formed amide should proceed in a 5-*endo-trig* manner, which is known to be the disfavored mode on the basis of the Baldwin's rule.[15] This interpretation is supported by the regiospecific formation of **11a**, where only conjugate addition by the possibly more anionic and less hindered nitrogen atom was observed. Although relative stereochemistry of the chiral centers in **9a** and **10a** has not been clarified yet, the *anti* isomer was believed to be predominantly obtained. This expectation was on the basis of the fact that (1) these products possessed an acidic proton at the 4-position where the ready epimerization would be occurred under the reaction conditions employed and (2) the *anti* model isomer (carbomethoxy and CF_3 groups at the 4 and 5 positions of **9a** (R=H), respectively) was calculated[16] to be 4.3 kcal/mol more stable than the corresponding cis counterpart.

It was also observed that the 1,4-addition of EtOH to **8a** was facilitated in the presence of either LiCl or EtONa, leading to the construction of **12a** in high yields. Much smoother reaction under the latter conditions would be understood as the reflection of the low LUMO energy levels of **8a**, while the other Lewis acid-catalyzed reaction should be retarded by the lower HOMO level, rendering the coordination of LiCl more or less difficult.

2.3. Conclusion

As shown above, we have successfully demonstrated the utility of aluminium acetals, readily obtained by the partial reduction of perfluoroalkanoates **1** by DIBAL, for the smooth acceptance of the nucleophilic attack of anionic species from β-dicarbonyl compounds. The fact that no isolation of intermediary Rf-containing hemiacetals is required is the strong indication of the advantage of the present method from the standpoint of efficiency. Our interest in this area prompted us to study further synthetic application of such aluminium acetals, which will be published in due course.

3. Experimental section

3.1. General

Most of reactions where an organic solvent was employed were performed under argon with magnetic stirring using flame-dried glassware. Unless otherwise noted, materials were obtained from commercial suppliers including anhydrous THF, Et_2O, and CH_2Cl_2 and were used without further purification. Analytical thin-layer chromatography (TLC) was routinely used for monitoring reactions by generally using a mixture of *n*-hexane and ethyl acetate (v/v). Spherical neutral silica gel (63–210 μm or 40–50 μm) was employed for usual column or flush chromatography, respectively. ^{1}H, ^{13}C, and ^{19}F NMR spectra were recorded (^{1}H: 300 MHz; ^{13}C: 75 MHz; ^{19}F: 283 MHz) at 25 °C whose data were reported as follows: chemical shift (δ scale) in parts per million (ppm) downfield from Me_4Si (δ 0.00 for ^{1}H and ^{13}C NMR) or C_6F_6 (δ −162.2 for ^{19}F NMR) as internal standards, number of protons or fluorines, multiplicity (singlet, s; doublet, d; triplet, t; quartet, q; multiplet, m; broad peak, br; etc.), and coupling constants (*J* in Hz). ^{13}C NMR spectra were usually reported only for carbons without fluorine atoms because of significant multiple coupling between these nuclei, rendering visualization extraordinarily difficult even after a long data acquisition time. Infrared (IR) spectra were reported in wave number (cm^{-1}).

3.2. Reaction of aluminium acetals with active methylene compounds

*3.2.1. Diethyl 2-(2,2,3,3,4,4,5,5,6,6,7,7,7-tridecafluoro-1-hydroxyheptyl)malonate, **3a***. To a CH_2Cl_2 (3.0 mL) solution of methyl tridecafluoroheptanoate **1a** (1.134 g, 3.00 mmol) was slowly added DIBAL (0.86 M, 3.8 mL, 3.3 mmol) at −80 °C under an argon atmosphere and stirring was continued for 2 h at that temperature. To a THF (10 mL) solution of NaH (0.235 g, 9.78 mmol) in a different flask was added diethyl malonate (1.36 mL, 9.03 mmol) at 0 °C under an argon atmosphere and stirring was continued for 30 min. The latter mixture was introduced to the former with the aid of cannula and after transfer of the mixture, the inside of the flask was washed with the additional 5 mL of THF. The resultant mixture was reacted at −80 °C for 5 min, followed by at room temperature for 1 h, and then was quenched with 1 M HCl aq so as to make the pH of the mixture at 6 to 7. The solution was filtered with the aid of a pad of Celite, and the filtrate was extracted three times with AcOEt, and the combined AcOEt layer was washed with satd NaCl aq. The organic layer was dried over anhydrous Na_2SO_4, filtered, and the volatiles were evaporated in vacuo to give a crude material, which was chromatographed on a silica gel to afford 1.250 g (2.460 mmol) of the title compound **3a**. Yield 82%. R_f=0.50 (AcOEt:hexane=1:4). ^{1}H NMR δ 1.31 (3H, t, *J*=7.2 Hz), 1.33 (3H, t, *J*=7.2 Hz), 3.77 (1H, d, *J*=3.3 Hz), 4.28 (2H, q, *J*=7.2 Hz), 4.27–4.37 (2H, m), 4.76 (1H, d, *J*=9.9 Hz), 4.88 (1H, tdd, *J*=2.8, 9.6, 20.4 Hz). ^{13}C NMR δ 13.7, 13.8, 49.6, 62.6, 62.8, 69.7 (dd, *J*=21.7, 28.6 Hz), 165.8, 168.5. ^{19}F NMR δ −128.13 (1F, dm, *J*=289.4 Hz), −126.70 (1F, dm, *J*=285.2 Hz), −124.77 (1F, dm, *J*=305.5 Hz), −124.26 (1F, dm, *J*=214.2 Hz), −123.19 (1F, dm, *J*=214.2 Hz), −123.07 to −122.04 (3F, m), −119.03 (2F, td, *J*=18.4, 278.1 Hz), −82.05 (3F, t, *J*=10.3 Hz). IR (neat) ν 3480, 2989, 2946, 2913, 2879, 1752, 1377,1349, 1239, 1349, 1203, 1146, 1121, 1097, 1029, 862, 744, 699, 656 cm^{-1}. Anal. Calcd for $C_{14}H_{13}F_{13}O_5$: C, 33.09; H, 2.58. Found: C, 33.17; H, 2.64.

*3.2.2. Diethyl 2-(2,2,2-trifluoro-1-hydroxyethyl)malonate, **3b**[9a]*. Yield 64%. R_f=0.39 (AcOEt:hexane=1:4). ^{1}H NMR 1.29 (3H, t, *J*=7.5 Hz), 1.31 (3H, t, *J*=7.2 Hz), 3.71 (1H, d, *J*=3.9 Hz), 4.22–4.38 (4H, m), 4.57–4.75 (2H, m). ^{19}F NMR δ −78.97 (d, *J*=6.8 Hz).

3.2.3. Diethyl 2-(2,2,3,3,3-pentafluoro-1-hydroxypropyl)-malonate,[3c]. Yield 67%. R_f=0.42 (CH_2Cl_2). ^{1}H NMR δ 1.31 (3H, t, *J*=7.2 Hz), 1.33 (3H, t, *J*=6.9 Hz), 3.76 (1H, d, *J*=2.7 Hz), 4.25–4.36 (4H, m), 4.78 (1H, d, *J*=9.9 Hz), 4.88 (1H, tdd, *J*=2.8, 9.9, 21.9 Hz). ^{13}C NMR δ 13.8, 13.9, 49.2, 62.6, 62.8, 69.3 (dd, *J*=21.4, 28.9 Hz), 111.3 (qt, *J*=39.5, 251.6 Hz), 118.2 (tq, *J*=35.6, 284.3 Hz), 165.8, 168.6. ^{19}F NMR δ −122.22 (1F, dd, *J*=21.8, 274.7 Hz), −121.51 (1F, d, *J*=276.1 Hz), −83.23 (3F, br s). IR (neat) ν 3470, 2988, 2944, 29,411, 1751, 1468, 1448, 1374, 1301, 1218, 1194, 1159, 1096, 1030, 1004, 864, 731, 688 cm^{-1}. Anal. Calcd for $C_{10}H_{13}F_5O_5$: C, 38.97; H, 4.25. Found: C, 39.16; H, 4.20.

*3.2.4. Dimethyl 2-(2,2,3,3,4,4,5,5,6,6,7,7,7-tridecafluoro-1-hydroxyhexyl)malonate, **3d***. Yield 74%. R_f=0.33 (AcOEt:hexane=1:4). Mp 39–41 °C. ^{1}H NMR δ 3.82 (1H, d, *J*=3.0 Hz), 3.83 (3H, s), 3.86 (3H, s), 4.66 (1H, d, *J*=9.9 Hz), 4.89 (1H, ddt, *J*=3.0, 9.9, 22.2 Hz). ^{13}C NMR δ 49.5, 53.2, 53.4, 69.6 (dd, *J*=23.6, 26.0 Hz), 166.2, 168.7. ^{19}F NMR δ −128.03 (1F, dm, *J*=292.0 Hz), −126.64 (1F, dm, *J*=298.8 Hz), −124.66 (1F, br d, *J*=301.0 Hz), −124.19 (1F, br d, *J*=214.2 Hz), −123.11 (1F, br d, *J*=214.2 Hz), −123.01 (2F, br s), −122.50 (1F, br d, *J*=214.2 Hz), −118.98 (1F, br d, *J*=280.7 Hz), −81.94 (3F, t, *J*=10.8 Hz). IR (neat) ν 3474, 1759, 1730, 1446, 1322, 1229, 1195, 1143, 1117, 1092, 1023, 935, 745, 700, 659 cm^{-1}. Anal. Calcd for $C_{12}H_9F_{13}O_5$: C, 30.02; H, 1.95. Found: C, 30.31; H, 1.95.

*3.2.5. Ethyl 2-acetyl-4,4,5,5,6,6,7,7,8,8,9,9,9-tridecafluoro-3-hydroxy-nonanoate, **3e***. Due to difficult identification between the major and the minor isomers, NMR data were described in a set of two peaks. Yield 68%. dr=55:45. R_f=0.67 (AcOEt:hexane=1:1). ^{1}H NMR δ 1.31 (3H, t, *J*=7.2 Hz) and 1.34 (3H, t, *J*=7.2 Hz), 2.35 (3H, s) and 2.39 (3H, s), 3.83 (1H, d, *J*=3.9 Hz) and 3.96 (1H, d, *J*=4.8 Hz), 4.28 (2H, q, *J*=7.2 Hz) and 4.33 (2H, q, *J*=7.2 Hz), 4.36 (1H, d, *J*=4.8 Hz) and 4.47 (1H, d, *J*=5.4 Hz), 4.82–5.02 (1H, m). ^{13}C NMR δ 13.79 and 13.83, 29.2 and 31.4, 55.3 and 56.6, 62.71 and 62.75, 69.0 (dd, *J*=21.4, 27.2 Hz) and 70.1 (dd, *J*=21.1, 28.5 Hz), 165.8 and 168.9, 198.4 and 204.0. ^{19}F NMR δ −128.18 (1F, dm, *J*=284.9 Hz), −126.73 (1F, dm, *J*=280.4 Hz), −125.87 to −122.12 (8F, m), −82.05 (3F, t, *J*=10.3 Hz). IR (neat) ν 3473, 2990, 1745, 1720, 1364, 1239, 1201, 1146, 1121, 1021, 847, 811, 733 cm^{-1}. Anal. Calcd for $C_{13}H_{11}F_{13}O_4$: C, 32.65; H, 2.32. Found: C, 32.88; H, 2.42.

*3.2.6. Ethyl 2-acetyl-4,4,5,5,5-pentafluoro-3-hydroxypentanoate, **3f***. Due to difficult identification between the major and the minor isomers, NMR data were described in a set of two peaks. Yield 47%. dr=51:49. R_f=0.63 (AcOEt:hexane=1:1). ^{1}H NMR δ 1.31(3H, t, *J*=7.5 Hz) and 1.33 (3H, t, *J*=7.5 Hz), 2.35 (3H, s) and 2.39 (3H, s), 3.83 (1H, d, *J*=4.2 Hz) and 3.95 (1H, d, *J*=4.5 Hz), 4.27 (2H, q, *J*=6.9 Hz) and 4.32 (2H, q, *J*=6.9 Hz), 4.44 (1H, s) and 4.47 (1H, s), 4.72–4.91 (1H, m). ^{13}C NMR δ 13.8 and 13.9, 29.3 and 31.4, 55.1 and 56.5, 62.71 and 62.75, 68.5 (dd, *J*=21.7, 29.2 Hz) and 69.7 (dd, *J*=21.7, 29.1 Hz), 165.8 and 168.9, 198.4 and 204.1. ^{19}F NMR δ −131.94 (1F, dd, *J*=21.6, 272.6 Hz) and −130.44 (1F, dd, *J*=21.6, 272.6 Hz), −121.03 (1F, d, *J*=272.6 Hz) and −120.99 (1F, dd, *J*=272.6 Hz), −83.09 (3F, s) and −83.05 (3F, s). IR (neat) ν 3473, 2989, 1744, 1719, 1369, 1195, 1127, 1055, 1020, 862, 725 cm^{-1}. Anal. Calcd for $C_9H_{11}F_5O_4$: C, 38.86; H, 3.99. Found: C, 38.95; H, 4.14.

Because the separation of **3g** and **3h** was difficult from the excess amount of diethyl malonate present in a crude mixture, as depicted in the text, they were used for the next decarboxylation step without further purification.

3.3. Decarboxylation

*3.3.1. Ethyl 4,4,5,5,6,6,7,7,8,8,9,9,9-tridecafluoro-3-hydroxy-nonanoate, **4a***. To a mixture of LiCl (0.163 g, 3.84 mmol) and the crude **3a** (0.822 g, 0.768 mmol determined by ^{1}H NMR using toluene as an internal standard) in DMSO (4 mL) was added H_2O (0.31 mL, 17.2 mmol), and the whole mixture was heated at 160 °C for 6 h. After addition of water (30 mL), the usual workup and chromatographic purification by silica gel (AcOEt:hexane=1:8) furnished **4a** (0.408 g, 0.719 mmol) as a white solid. Yield 94%. R_f=0.50 (AcOEt:hexane=1:6). Mp 34–35 °C. ^{1}H NMR δ 1.31 (3H, t, J=7.2 Hz), 2.73–2.78 (2H, m), 3.52 (1H, d, J=6.3 Hz), 4.23 (2H, q, J=7.2 Hz), 4.58–4.72 (1H, m). ^{13}C NMR δ 14.0, 33.8, 61.6, 67.0 (dd, J=22.6, 28.9 Hz), 171.1. ^{19}F NMR δ −128.01 (1F, dm, J=289.7 Hz), −126.68 (1F, dm, J=285.2 Hz), −124.68 (1F, br d, J=307.8 Hz), −124.22 (1F, br d, J=202.9 Hz), −123.15 (1F, br d, J=202.9 Hz), −122.90 (2F, br s), −122.65 (1F, br d, J=310.3 Hz), −121.06 (2F, td, J=16.1, 282.9 Hz), −81.99 (3F, t, J=9.3 Hz). IR (neat) ν 3503, 1725, 1323, 1239, 1205, 1146, 1122, 1077, 1019, 744, 705, 651 cm^{-1}. Anal. Calcd for $C_{11}H_9F_{13}O_3$: C, 30.29; H, 2.08. Found: C, 30.16; H, 1.78.

*3.3.2. Ethyl 4,4,4-trifluoro-3-hydroxybutanoate, **4b**[17].* Quantitative yield. R_f=0.43 (AcOEt:hexane=1:4). ^{1}H NMR δ 1.30 (3H, t, J=7.2 Hz), 2.64–2.78 (2H, m), 3.47–3.53 (1H, m), 4.22 (2H, q, J=7.2 Hz), 4.38–4.52 (1H, m).

*3.3.3. Ethyl 4,4,5,5,5-pentafluoro-3-hydroxypentanoate, **4c**[17].* Yield 66%. R_f=0.42 (AcOEt:hexane=1:4). ^{1}H NMR 1.29 (3H, t, J=6.9 Hz), 2.72–2.75 (2H, m), 3.56 (1H, d, J=5.4 Hz), 4.23 (2H, q, J=6.9 Hz), 4.46–4.63 (1H, m). ^{19}F NMR δ −132.79 (1F, dd, J=18.1, 278.1 Hz), −123.94 (1F, d, J=278.1 Hz), −83.03 (3F, br s).

*3.3.4. Ethyl 4-chloro-4,4-difluoro-3-hydroxybutanoate, **4h**[17].* Yield 75%. R_f=0.43 (AcOEt:hexane=1:4). ^{1}H NMR δ 1.30 (3H, t, J=7.2 Hz), 2.69 (1H, dd, J=9.0, 16.5 Hz), 2.80 (1H, dd, J=3.0, 16.5 Hz), 3.50–3.63 (1H, m), 4.22 (2H, q, J=7.2 Hz), 4.40–4.56 (1H, m). ^{19}F NMR δ −67.18 (1F, dd, J=9.0, 166.5 Hz), −65.52 (1F, dd, J=9.0, 166.5 Hz).

*3.3.5. Diethyl 3-(difluoromethyl)-2-(ethoxycarbonyl)glutarate, **5g**.* The reaction of the starting material **3g** was the special case, which did not follow the usual decarboxylation but afforded a mixture of **5g** and **6g**. Yield 78%. R_f=0.44 (AcOEt:hexane=1:4). ^{1}H NMR δ 1.27 (3H, t, J=7.2 Hz), 1.28 (6H, t, J=7.2 Hz), 2.60–2.75 (2H, m), 3.11–3.27 (1H, m), 3.72 (1H, d, J=5.7 Hz), 4.16 (2H, q, J=7.2 Hz), 4.21 (2H, q, J=7.2 Hz), 4.22 (2H, q, J=7.2 Hz), 6.16 (1H, dt, J=3.9, 56.5 Hz). ^{13}C NMR δ 13.9, 14.1, 30.2 (t, J=4.7 Hz), 39.0 (t, J=21.1 Hz), 49.8 (t, J=4.3 Hz), 60.9, 61.9, 62.0, 116.1 (t, J=242.2 Hz), 167.5, 167.6, 171.2. ^{19}F NMR δ −125.35 (1F, ddd, J=16.1, 54.8, 285.2 Hz), −123.08 (1F, ddd, J=13.8, 57.1, 285.2 Hz). IR (neat) ν 3460, 2985, 2942, 2909, 2349, 1737, 1467, 1448, 1372, 1339, 1267, 1180, 1132, 1097, 1051, 961, 864 cm^{-1}. Anal. Calcd for $C_{13}H_{20}F_2O_6$: C, 50.32; H, 6.50. Found: C, 50.30; H, 6.36.

*3.3.6. Diethyl 3-(difluoromethyl)-2,4-bis(ethoxycarbonyl)-glutarate, **6g**.* Yield 17%. R_f=0.37 (AcOEt:hexane=1:4). ^{1}H NMR δ 1.28 (12H, t, J=7.2 Hz), 3.48 (1H, qt, J=6.0, 12.3 Hz), 3.90 (2H, d, J=5.7 Hz), 4.22 (8H, q, J=7.2 Hz), 6.44 (1H, dt, J=4.8, 55.9 Hz). ^{13}C NMR δ 13.9, 42.5 (t, J=21.7 Hz), 49.1 (t, J=4.0 Hz), 62.0, 62.1, 115.7 (t, J=243.1 Hz), 167.4, 167.5. ^{19}F NMR δ −121.24 (dd, J=13.8, 54.8 Hz). IR (neat) ν 2985, 1737, 1467, 1372, 1335, 1299, 1260, 1224, 1178, 1158, 1095, 1050, 1023, 862, 800 cm^{-1}. Anal. Calcd for $C_{16}H_{24}F_2O_8$: C, 50.26; H, 6.33. Found: C, 50.59; H, 6.30.

3.4. Formal dehydration

*3.4.1. Diethyl 2-(2,2,3,3,4,4,5,5,6,6,7,7,7-tridecafluoro-hexylidene) malonate, **8a**.* To a CH_2Cl_2 (4 mL) solution of the crude **3a** (0.794 g, 0.703 mmol by ^{1}H NMR using toluene as an internal standard) and acetyl chloride (0.11 mL, 1.55 mmol) was slowly added triethylamine (0.45 mL, 3.22 mmol) at 0 °C and after 5 min, the mixture was refluxed for 6 h. The usual workup and chromatographic purification by silica gel (AcOEt:hexane=1:8) afforded the title compound **8a** (0.306 g, 0.625 mmol). Yield 89%. R_f=0.67 (AcOEt:hexane=1:4). ^{1}H NMR δ 1.33 (3H, t, J=7.2 Hz), 1.34 (3H, t, J=7.2 Hz), 4.33 (2H, q, J=7.2 Hz), 4.35 (2H, q, J=7.2 Hz), 6.78 (1H, t, J=14.1 Hz). ^{13}C NMR δ 13.7, 13.9, 62.5, 63.1, 126.1 (t, J=23.6 Hz), 137.3 (t, J=5.0 Hz), 161.3, 162.7. ^{19}F NMR δ −127.28 (2F, m), −123.94 (4F, s), −122.87 (2F, s), −112.76 (1F, d, J=13.6 Hz), −112.61 (1F, d, J=13.8 Hz), −81.91 (3F, s). IR (neat) ν 3480, 3074, 2990, 2945, 2911, 2880, 1747, 1671, 1469, 1350, 1240, 1204, 1146, 1132, 1071, 1052, 1022, 865, 811, 744, 709, 654 cm^{-1}. Anal. Calcd for $C_{14}H_{11}F_{13}O_4$: C, 34.30; H, 2.26. Found: C, 33.84; H, 2.42.

*3.4.2. Diethyl 2-(2,2,2-trifluoroethylidene)malonate, **8b**[13c].* Yield 69%. R_f=0.70 (AcOEt:hexane=1:2). ^{1}H NMR δ 1.33 (3H, t, J=7.2 Hz), 1.34 (3H, t, J=7.2 Hz), 4.32 (2H, q, J=7.2 Hz), 4.36 (2H, q, J=7.2 Hz), 6.77 (1H, q, J=7.2 Hz). ^{19}F NMR δ −63.49 (d, J=7.3 Hz).

*3.4.3. Diethyl 2-(2,2,3,3,3-pentafluoropropylidene)malonate, **8c**.* Yield 61%. R_f=0.59 (AcOEt:hexane=1:4). ^{1}H NMR δ 1.34 (6H, t, J=7.2 Hz), 4.33 (2H, q, J=7.2 Hz), 4.35 (2H, q, J=7.2 Hz), 6.74 (1H, t, J=13.8 Hz). ^{13}C NMR δ 13.7, 13.8, 62.5, 63.0, 111.3 (qt, J=39.5, 251.6 Hz), 118.2 (tq, J=35.6, 283.7 Hz), 125.9 (t, J=23.9 Hz), 137.5 (t, J=5.3 Hz), 161.2, 162.6. ^{19}F NMR δ −116.61 (2F, d, J=14.4 Hz), −85.71 (3F, s). IR (neat) ν 3471, 3071, 2989, 2945, 2911, 2879, 1746, 1672, 1377, 1338, 1254, 1206, 1134, 1059, 1042, 1019, 866, 761, 728, 695, 607 cm^{-1}. Anal. Calcd for $C_{10}H_{11}F_5O_4$: C, 41.39; H, 3.82. Found: C, 40.91; H, 3.68.

3.5. Preparation of glutarate

*3.5.1. Diethyl 2,4-bis(ethoxycarbonyl)-3-(1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluorohexyl)glutarate, **6a**.* To a THF (2.0 mL) solution of NaH (0.014 g, 0.57 mmol) was added diethyl malonate (84 μL, 0.56 mmol) at 0 °C and stirring was continued for 30 min at that temperature. To the resultant mixture was added diethyl 2-(2,2,3,3,4,4,5,5,6,6,7,7,7-tridecafluoro-hexylidene)malonate **8a** (0.242 g, 0.494 mmol) in 1 mL of THF, and stirring was further continued for 1 h at 0 °C. After usual workup and chromatographic purification by silica gel (AcOEt:hexane=1:8) afforded the title compound **6a** (0.257 g, 0.395 mmol). Yield 80%. R_f=0.32 (AcOEt:hexane=1:4). ^{1}H NMR 1.27 (6H, t, J=7.1 Hz), 1.29 (6H, t, J=7.1 Hz), 4.03 (2H, d, J=4.8 Hz), 4.16–4.45 (9H, m). ^{13}C NMR δ 13.7, 41.0 (t, J=20.1 Hz), 48.8, 62.0, 62.2, 166.9, 166.9. ^{19}F NMR δ −127.34 (2F, m), −123.94 (2F, br s), −122.98 (2F, br s), −121.88 (2F, br s), −111.01 (2F, m), −82.03 (3F, t, J=10.3 Hz). IR (neat) ν 2987, 2943, 2910, 2878, 1761, 1467, 1448, 1378, 1348, 1334, 1239, 1209, 1147, 1116,1029, 863, 809, 735, 700, 651 cm^{-1}. Anal. Calcd for $C_{21}H_{23}F_{13}O_8$: C, 38.78; H, 3.56. Found: C, 38.90; H, 3.60.

*3.5.2. Diethyl 3-(1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluorohexyl)-glutarate, **7a**.* A DMSO (4 mL) solution containing lithium chloride (0.024 g, 0.566 mmol), water (27 μL, 1.5 mmol), and crude diethyl 2,4-bis(ethoxycarbonyl)-3-(1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluorohexyl)-glutarate **6a** (0.322 g, 0.491 mmol by ^{1}H NMR) was heated to 160 °C for 30 min. After usual workup and chromatographic purification by silica gel (AcOEt:hexane=1:8) afforded the title compound **7a** (0.105 g, 0.207 mmol). Yield 42%. R_f=0.44 (AcOEt:hexane=1:6). ^{1}H NMR δ 1.27 (6H, t, J=7.2 Hz), 2.52 (2H, dd, J=7.5, 16.8 Hz), 2.77 (2H, dd, J=5.1, 16.8 Hz), 3.41–3.60 (1H, m), 4.17 (4H, q, J=7.2 Hz). ^{13}C NMR δ 14.0, 32.8, 35.3 (t, J=21.0 Hz), 61.2, 170.2. ^{19}F NMR δ −127.42 (2F, m), −124.07 (2F, m), −123.22 (2F, m), −121.80 (2F, m), −116.48 (2F, m), −82.06 (3F, t, J=10.3 Hz). IR (neat) ν 2987, 2943, 2911, 1745, 1448, 1428, 1378, 1301, 1240, 1205, 1146, 1095, 1025, 960, 809, 735, 701, 651 cm^{-1}. Anal. Calcd for $C_{15}H_{15}F_{13}O_4$: C, 35.59; H, 2.99. Found: C, 36.06; H, 3.37.

3.6. Michael addition of hydrazines and ethanol

*3.6.1. 4-(Ethoxycarbonyl)-5-(1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluorohexyl)pyrazolidin-3-one, **9a**.* To a CH_2Cl_2 (3 mL) solution of **8a** (0.493 g, 1.01 mmol) was added hydrazine monohydrate (54 μL, 1.11 mmol) at −80 °C and stirring was continued for 1 h at that temperature. Addition of anhydrous Na_2SO_4, filtration at room temperature, and evaporation of the volatiles were carried out in this order. The obtained crude material was recrystallized from a mixture of AcOEt:hexane=1:5 to furnish a white solid (0.383 g, 0.804 mmol). Yield 80%. R_f=0.75 (AcOEt). Mp 129–130 °C. ^{1}H NMR (acetone-d_6) δ 1.28 (3H, t, J=7.2 Hz), 3.62 (1H, d, J=3.9 Hz), 4.25 (2H, q, J=7.2 Hz), 4.84 (1H, m), 5.91 (1H, d, J=8.1 Hz), 8.97 (1H, s). ^{13}C NMR (acetone-d_6) δ 14.3, 49.0, 60.5 (dd, J=20.2, 27.6 Hz), 62.8, 167.8, 168.9. ^{19}F NMR (acetone-d_6) δ −125.50 to −115.45 (10F, m), −80.05 (3F, t, J=10.1 Hz). IR (KBr) ν 3290, 3199, 3082, 2997, 1740, 1711, 1369, 1319, 1231, 1197, 1151, 1121, 646 cm^{-1}. Anal. Calcd for $C_{12}H_9F_{13}N_2O_3$: C, 30.27; H, 1.46; N, 5.88. Found: C, 30.04; H, 1.46; N, 5.76.

3.6.2. 4-(Ethoxycarbonyl)-5-(1,1,2,2,3,3,4,4,5,5,6,6,6-trideca-fluorohexyl)-1-methylpyrazolidin-3-one, ***10a***. Yield 61%. R_f=0.42 (AcOEt:hexane=1:4). Mp 102–104 °C. ^{1}H NMR (DMSO-d_6) δ 1.22 (3H, t, J=7.2 Hz), 2.64 (3H, s), 3.30–3.36 (1H, m), 4.20 (2H, q, J=6.9 Hz), 4.45 (1H, dd, J=7.7, 20.0 Hz), 10.4 (1H, s). ^{13}C NMR (DMSO-d_6) δ 13.8, 47.6, 47.8, 62.2, 64.9 (dd, J=17.3, 28.6 Hz), 165.0, 167.3. ^{19}F NMR (acetone-d_6) δ −126.30 to −119.05 (9F, m), −117.36 to −115.29 (1F, m), −79.97 (3F, t, J=10.1 Hz). IR (KBr) ν 3191, 3178, 3083, 2997, 1735, 1711, 1370, 1319, 1344, 1322, 1064, 1016, 699, 665 cm^{-1}. Anal. Calcd for $C_{13}H_{11}F_{13}N_2O_3$: C, 31.85; H, 2.26; N, 5.71. Found: C, 31.68; H, 1.86; N, 5.57.

3.6.3. Diethyl 2-[2,2,3,3,4,4,5,5,6,6,7,7,7-tridecafluoro-1-(2-phenylhydrazino)heptyl]malonate, ***11a***. Yield 71%. R_f=0.48 (AcOEt:hexane=1:4). ^{1}H NMR δ 1.24 (3H, t, J=7.2 Hz), 1.31 (3H, t, J=7.2 Hz), 3.83 (1H, d, J=3.0 Hz), 4.15–4.35 (4H, m), 4.44 (1H, td, J=10.0, 18.6 Hz), 4.91 (1H, dd, J=2.4, 10.2 Hz), 5.68 (1H, d, J=2.4 Hz), 6.82 (3H, m), 7.19 (2H, m). ^{13}C NMR δ 13.9, 49.4, 61.7 (d, J=20.4 Hz), 62.1, 62.7, 113.1, 119.9, 129.0, 148.4, 167.3, 167.4. ^{19}F NMR δ −128.11 (1F, br d, J=273.6 Hz), −126.65 (1F, br d, J=275.9 Hz), −124.61 (1F, br d, J=296.5 Hz), −124.09 (1F, br d, J=146.1 Hz), −123.04 (1F, br d, J=152.9 Hz), −122.43 (1F, br d, J=303.3 Hz), −122.89 (1F, dm, J=303.3 Hz), −121.67 (1F, dm, J=303.3 Hz), −119.41 (1F, dm, J=285.2 Hz), −114.58 (1F, dm, J=289.7 Hz), −82.02 (3F, t, J=9.0 Hz). IR (neat) ν 3337, 2986, 1747, 1605, 1497, 1474, 1375, 1348, 1239, 1207, 1147, 1122, 1070, 1027, 906, 866, 809, 752, 734, 696, 658 cm^{-1}. Anal. Calcd for $C_{20}H_{19}F_{13}N_2O_4$: C, 40.15; H, 3.20; N, 4.68. Found: C, 39.97; H, 3.23; N, 4.51.

3.6.4. Diethyl 2-(1-ethoxy-2,2,3,3,4,4,5,5,6,6,7,7,7-trideca-fluoroheptyl) malonate, ***12a***. To an EtOH (3 mL) solution of **8a** (0.489 g, 1.00 mmol) was added NaOEt (0.035 g, 0.51 mmol) and the whole solution was stirred for 3 h at room temperature. After usual workup and purification by silica gel column chromatography (AcOEt:hexane=1:4) afforded 0.439 g (0.819 mmol) of the title compound **12a**. Yield 82%. R_f=0.49 (AcOEt:hexane=1:4). ^{1}H NMR δ 1.14 (3H, t, J=6.9 Hz), 1.28 (3H, t, J=7.2 Hz), 1.31 (3H, t, J=7.2 Hz), 3.77 (2H, dq, J=2.4, 6.9 Hz), 3.91 (1H, d, J=8.4 Hz), 4.17–4.40 (4H, m), 4.75 (1H, dddd, J=1.8, 4.2, 8.1, 17.1 Hz). ^{13}C NMR δ 13.8, 14.0, 15.1, 52.7, 62.2, 62.3, 69.9, 76.0 (dd, J=21.1, 27.9 Hz), 165.6, 165.9. ^{19}F NMR δ −128.16 (1F, br d, J=287.2 Hz), −126.79 (1F, br d, J=289.7 Hz), −125.17 to −123.20 (6F, m), −121.43 (1F, br d, J=268.4 Hz), −116.95 (1F, dm, J=285.2 Hz), −82.09 (3F, t, J=9.2 Hz). IR (neat) ν 2987, 2941, 2909, 1759, 1747, 1449, 1373, 1316, 1240, 1204, 1147, 1027, 699, 658 cm^{-1}. Anal. Calcd for $C_{16}H_{17}F_{13}O_5$: C, 35.83; H, 3.20. Found: C, 35.84; H, 3.20.

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