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Lithium triethylborohydride-promoted generation of α, α -difluoroenolates from 2-iodo-2,2difluoroacetophenones: an unprecedented utilization of lithium triethylborohydride[†]

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Lithium triethylborohydride was found to promote the generation of α, α -difluoroenolates from 2-iodo-2,2difluoroacetophenones, and applied to the synthesis of polyfluorinated β -hydroxy ketones *via* selfcondensation or aldol reaction. The reaction indicates an unprecedented utilization of lithium triethylborohydride and provides novel access to the generation of α, α -difluoroenolates.

Difluoroenolates are useful fluorinated synthons for preparing difluoromethylene compounds,¹ with significant application in medicinal chemistry.² Accordingly, the protocols to generate difluoroenolates have attracted much attention. Colby firstly reported that compounds trifluoromethyl-α,α-difluoro-β-keto gem-diols could be used to give difluoroenolates by the release trifluoroacetate.3 Additionally, of more difluorinated compounds have been developed as valuable precursors of difluoroenolates, such as α, α -difluoroketones,⁴ α, α -difluoro- α -(trimethylsilylacet)amides,⁵ α, α -difluoro- β -ketoesters,⁶ α, α, α trifluoroketones,7 and 2,2-difluoro-1,3-diketones.8 Furthermore, difluoroenoxysilanes or difluoroenol O-Boc esters were often served as difluoroenolates in different difluoromethylenation reactions,9 as well as transition-metal difluoroenolates.10

2-Iodo-2,2-difluoroacetophenones are one of the important building blocks to introduce α, α -difluoromethyl ketone fragment into molecules.¹¹ Our group has reported several reactions with 2-iodo-2,2-difluoroacetophenones to construct structurally diverse difluoromethylene compounds.^{11d-f} As part of our continued research, further structure modification of 2-iodo-2,2-difluoroacetophenones was investigated. Lithium triethylborohydride (LiEt₃BH, a superhydride, 1 M in THF) is a powerful reducing agent and can efficiently reduce a wide range of functional groups, especially halogen atoms.¹² However, the reaction with 2-iodo-2,2-difluoroacetophenones and LiEt₃BH result in the generation of difluoroenolates instead of reduction products. Herein, we disclosed the LiEt₃BH-promoted *in situ* generation of difluoroenolates from 2iodo-2,2-difluoroacetophenones and their application in aldoltype self-condensation and aldol reactions to give various α , α difluoro- β -hydroxy ketones (Scheme 1).

Initially, we chose LiEt₃BH as one of the reducing agents to selectively reduce the carbonyl group or iodine atom of 2-iodo-2,2-difluoroacetophenones. Surprisingly, our initial attempt to perform the reaction between 2,2-difluoro-2-iodo-1phenylethanone 1a and LiEt₃BH at -78 °C did not furnish any reduction product, instead leading to a self-adduct $\alpha, \alpha, \gamma, \gamma$ tetrafluoro- β -hydroxy ketone 2a with high yield (Table 1, entry 1). Raising the temperature of LiEt₃BH only led to a little increasing of the yield of reduction product 3a and 4a (entries 2 and 3). It was speculated that a difluoroenolate 5 was generated from 2,2-difluoro-2-iodo-1-phenylethanone with LiEt₃BH, then the difluoroenolate 5 went through protonation process to form α, α -difluoroacetophenone 6. The aldol reaction between 5 and 6 gave the $\alpha, \alpha, \gamma, \gamma$ -tetrafluoro- β -hydroxy ketone 2a (Scheme 2).

We wonder that whether the fluorine atom in 2-iodo-2,2difluoroacetophenone play an important role in the fortuitous reaction. Therefore, the reaction of 2-halo-acetophenone or 2chloro(bromo, fluoro)-2,2-difluoroacetophenone or 2,2-



Scheme 1 The novel utilization of LiEt₃BH for the generation of α , α -difluoroenolates from 2-iodo-2,2-difluoroacetophenones.

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Table 1	The influence of temperature to reaction of 2,2-difluoro-2-				
iodo-1-phenylethanone with LiEt ₃ BH ^a					



^{*a*} Reaction conditions: **1a** (1 mmol), LiEt₃BH (1.2 mmol, 1.2 equiv.), THF (dry), N₂, 4 h. ^{*b*} Yield based on GC.

difluoroacetophenone with LiEt₃BH were also performed in THF at -78 °C. The results showed that all these reduction reactions proceeded well leading to the formation of different reduction products (see Scheme 1 in ESI†), which demonstrates the specific characteristic of substrate 2-iodo-2,2-difluoroacetophenone owing to the adjacent fluorine atoms of carbonyl group.

Then, other reducing agents were also investigated using 2,2difluoro-2-iodo-1-phenylethanone **1a** as substrate, only led to the formation of different reduction products (Scheme 3). It was noteworthy that the reducing agents sodium borohydride and Zn power show high selectivity, affording 2,2-difluoro-2-iodo-1phenylethan-1-ol **3a** and 2,2-difluoro-1-phenylethanone **6** as major products separately.

Next, the scope of 2,2-difluoro-2-iodo-1-phenylethanone 1 was explored through the LiEt₃BH promoted self-condensation (Table 2). The 2-iodo-2,2-difluoroacetophenones 1b-f bearing electron-donating groups, electron-withdrawing group or halogen atoms, 2,2-difluoro-2-iodo-1-(thiophen-2-yl)ethanone 1g and 2,2-difluoro-2-iodo-1-(naphthalen-2-yl)ethanone 1h were subjected to the self-condensation reaction and all were found applicable to the reaction, giving the corresponding $\alpha, \alpha, \gamma, \gamma$ -tetrafluoro- β -hydroxy ketones 2**a**-**h** in good yields. Few of the reduction products 4d, 4f, 4g were still observed in low vields. The results indicated that 2-iodo-2.2difluoroacetophenone derivatives bearing different aryl or heterocyclic ring could be served as difluoroenolates precursors



Scheme 2 Proposed mechanism of $LiEt_3BH$ -promotd aldol-type self-condensation.



through the reaction with LiEt₃BH, which provided a novel and efficient access to difluoromethylenation reactions.

α,α-Difluoro-β-hydroxy ketones are an important class of substructure in medicinal chemistry,¹³ which could be obtained *via* aldol reaction with difluoroenolates.¹⁴ Accordingly, to further demonstrate the utility of LiEt₃BH, aldol reaction of 2-iodo-2,2-difluoroacetophenones with aldehydes promoted by LiEt₃BH were conducted. 2-Iodo-2,2-difluoro-1-phenylethanone **1a** and benzaldehyde 7 was selected as model reaction substrates to optimize the reaction condition (Table 3). The corresponding aldol produce **8** was produced in the presence of LiEt₃BH (1.2 equiv. to compound **1a**) at -78 °C in THF (entry 1). The results showed that raising the temperature led to an increased yield of reduction product **4a** (entries 2–4) and the conversation decreased with the decreasing of the amount of LiEt₃BH (entry 5).

Hence, more aldol reactions were carried out under the optimized condition (Scheme 4). To our delight, the aldol products polyfluorinated β -hydroxy ketones were obtained in high yields by employing the fluorinated aldehydes such as 2,2-



		Yield ^a (%)	
Entry	R	2	4
1	Ph	2a , 86	4a, —
2	$4 - MeC_6H_4$	2b , 83	4b, —
3	$4-BrC_6H_4$	2c , 85	4c, —
4	$3-FC_6H_4$	2d, 72	4d , 20
5	$4-ClC_6H_4$	2e, 87	4e, —
6	$4-CF_3C_6H_4$	2f , 71	4f , 14
7	Thienyl	2g, 70	4g , 15
8	Naphthyl	2h , 84	4h, —

^{*a*} Isolated yields.

Table 3 The optimization of aldol reaction of 2-iodo-2,2-difluor-oacetophenone 1a and benzaldehyde 7 a



Entry	LiEt ₃ BH (equiv.)		$\operatorname{Conv.}(\mathbf{1a})^{b}(\%)$	Yield ^{b} (%)	
		Temp.		8	4a
1	1.2	−78 °C	100	95.2	4.8
2	1.2	$-40~^\circ\mathrm{C}$	100	85.2	14.8
3	1.2	0 °C	100	79.6	20.4
4	1.2	rt	100	74.7	25.3
5	1.0	-78 °C	91.6	90.1	9.9

 a Reaction conditions: 1a (1.0 mmol), 7 (1.0 mmol), THF (dry), N₂, 4 h. b Yield based on GC.

difluoro-1-phenylethanone or 2,2,2-trifluoro-1-phenylethanone (Scheme 4a and b). The substrate 1-(4-bromophenyl)-2,2-difluoro-2-iodoethan-1-one **1c** was also suitable for the aldol reaction (Scheme 4c). Furthermore, 2,2,4,4,4-pentafluoro-3,3-dihydroxy-1-phenylbutan-1-one **12** was also used to react with benzaldehyde in the present of LiEt₃BH. The reaction gave the aldol product 2,2-difluoro-3-hydroxy-1,3-diphenylpropan-1-one **8** and self-condensation product 2,2,4,4-tetrafluoro-3-hydroxy-1,3-diphenylbutan-1-one **2a** with 4 : 1 ratio (Scheme 4d), which indicated that difluoroenolate can be generated from 2,2,4,4,4-pentafluoro-3,3-dihydroxy-1-phenylbutan-1-one with LiEt₃BH either.

In summary, we have demonstrated an unprecedented utilization of LiEt₃BH for the generation of α , α -diffuoroenolates from 2-iodo-2,2-diffuoroacetophenones in THF. Applications of the protocol led to the synthesis of polyfluorinated β -hydroxy ketones *via* self-condensation reaction and aldol reaction. The effectiveness of LiEt₃BH was discussed by the variation of α -halogen acetophenones and reducing agents in the reduction reaction. It turned out that LiEt₃BH was served as a reducing agent with most α -halogen acetophenones, resulting in the formation of different reduction products. The result disclosed



Scheme 4 The aldol reactions promoted by LiEt₃BH.

the specific property of 2-iodo-2,2-difluoroacetophenones, which might due to that the fluorine atoms of 2-iodo-2,2-difluoroacetophenones have significant impact and change the property of the adjacent C–I bond. Further study to apply the protocol for the preparation of diverse difluoromethylene compounds are in progress in our laboratory.

Conflicts of interest

There are no conflicts to declare.

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