Lithium triethylborohydride-promoted generation of $\alpha,\alpha$-difluoroenolates from 2-iodo-2,2-difluoroacetophenones: an unprecedented utilization of lithium triethylborohydride†

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Lithium triethylborohydride was found to promote the generation of $\alpha,\alpha$-difluoroenolates from 2-iodo-2,2-difluoroacetophenones, and applied to the synthesis of polyfluorinated $\beta$-hydroxy ketones via self-condensation or aldol reaction. The reaction indicates an unprecedented utilization of lithium triethylborohydride and provides novel access to the generation of $\alpha,\alpha$-difluoroenolates.

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

2-Iodo-2,2-difluoroacetophenones are one of the important building blocks to introduce $\alpha,\alpha$-difluoromethyl ketone fragment into molecules. Our group has reported several reactions with 2-iodo-2,2-difluoroacetophenones to construct structurally diverse difluoromethylene compounds. As part of our continued research, further structure modification of 2-iodo-2,2-difluoroacetophenones was investigated. Lithium triethylborohydride (LiEt$_3$BH, a superhydride, 1 M in THF) is a powerful reducing agent and can efficiently reduce a wide range of functional groups, especially halogen atoms. However, the reaction with 2-iodo-2,2-difluoroacetophenones and LiEt$_3$BH result in the generation of difluoroenolates instead of reduction products. Herein, we disclosed the LiEt$_3$BH-promoted in situ generation of difluoroenolates from 2-iodo-2,2-difluoroacetophenones and their application in aldol-type self-condensation and aldol reactions to give various $\alpha,\alpha$-difluoro-$\beta$-hydroxy ketones (Scheme 1).

Initially, we chose LiEt$_3$BH 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-1-phenylethanone 1a and LiEt$_3$BH at $-78 {^\circ}C$ did not furnish any reduction product, instead leading to a self-adduct $\alpha,\alpha,\gamma$-tetrafluoro-$\beta$-hydroxy ketone 2a with high yield (Table 1, entry 1). Raising the temperature of LiEt$_3$BH 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 LiEt$_3$BH, then the difluoroenolate 5 went through protonation process to form $\alpha,\alpha$-difluoroacetophenone 6. The aldol reaction between 5 and 6 gave the $\alpha,\alpha,\gamma$-tetrafluoro-$\beta$-hydroxy ketone 2a (Scheme 2).

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

Scheme 1 The novel utilization of LiEt$_3$BH for the generation of $\alpha,\alpha$-difluoroenolates from 2-iodo-2,2-difluoroacetophenones.
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 2,2-difluoro-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-1-phenylethanol 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 α,α,γ,γ-tetrafluoro-β-hydroxy ketones 2a–h in good yields. Few of the reduction products 4d, 4f, 4g were still observed in low yields. The results indicated that 2-iodo-2,2-difluoroacetophenone derivatives bearing different aryl or heterocyclic ring could be served as difluoroenolates precursors through the reaction with LiEt₃BH, which provided a novel and efficient access to difluoromethylation reactions.

α,α-Difluoro-β-hydroxy ketones are an important class of substructure in medicinal chemistry, which could be obtained via aldol reaction with difluoroenolates. 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 product 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 conversion 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-

| Entry | R            | Yield (%) | 2 | 4 |
|-------|--------------|-----------|---|---|
| 1     | Ph           | 2a, 86    | 4a, — |
| 2     | 4-MeC₆H₄     | 2b, 83    | 4b, — |
| 3     | 4-BrC₆H₄     | 2c, 85    | 4c, — |
| 4     | 3-FC₆H₄      | 2d, 72    | 4d, 20 |
| 5     | 4-ClC₆H₄     | 2e, 87    | 4f, 14 |
| 6     | 4-CF₃C₆H₄    | 2f, 71    | 4f, 15 |
| 7     | Thiophenyl   | 2g, 70    | 4g, 15 |
| 8     | Naphthyl     | 2h, 84    | 4h, — |

*Isolated yields.

Table 1 The influence of temperature to reaction of 2,2-difluoro-2-iodo-1-phenylethanone with LiEt₃BH

| Entry | Temp. (°C) | Yield (%) |
|-------|------------|-----------|
| 1     | −78        | 98.9      |
| 2     | 0          | 43.9      |
| 3     | rt         | 42.3      |

Yield based on GC.

Scheme 2 Proposed mechanism of LiEt₃BH-promoted aldol-type self-condensation.

Scheme 3 The reduction reactions of 2-iodo-2,2-difluoroacetophenone 1a. *Yield based on GC.
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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