# The synthesis of vicinal halohydrin phosphates *via* highly regioselective ring opening of epoxides with dialkyl halophosphate

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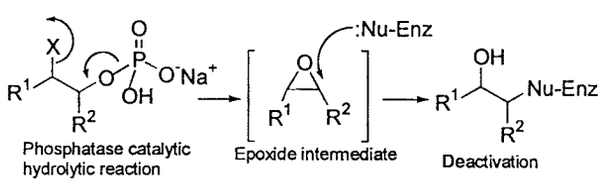
***Received (in Cambridge, UK) 6th December 1999, Accepted 1st March 2000***
***Published on the Web 19th April 2000***

Various titanium(IV) reagents catalyze the ring opening of epoxides by dialkyl halophosphates (added or formed *in situ*) under mild conditions to give the corresponding vicinal halohydrin phosphates in good yields with high regioselectivity.

## Introduction

The facile ring opening of epoxides makes them extremely versatile intermediates for organic synthesis.[1] Although a myriad reagents employed in the cleavage of epoxides have been reported, very little is known concerning the ring opening of epoxides with dialkyl halophosphates (DAHPs).[2]

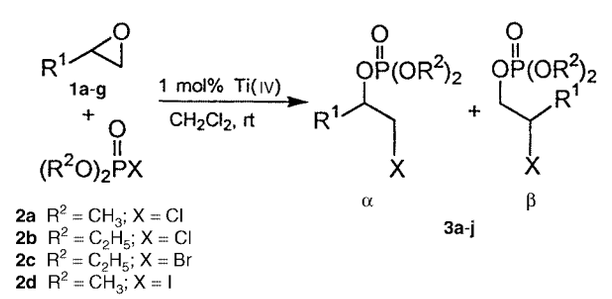
Recently, Rotella[3] suggested a mechanism-based phosphatase inhibitor model. In this hypothesis, vicinal halohydrin phosphates would undergo a phosphatase catalytic hydrolytic reaction to give a reactive intermediate epoxide that could irreversibly deactivate the phosphatase by forming a covalent bond to an active site residue (*i.e.* OH, SH and $NH_2$ groups)[4] as shown in Scheme 1.




**Scheme 1**

By taking the stereochemistry of the enzyme into consideration, the ring opening of the epoxides with DAHPs will provide the most attractive methods for the synthesis of this kind of molecule because two contiguous centers of defined stereochemistry may be generated from the readily obtained chiral epoxides.[5,6]

In this paper we wish to report the details of the ring-opening reaction of epoxides with DAHPs to provide the halohydrin phosphates in the presence of catalytic amounts of titanium(IV) compounds.




**Scheme 2** Method A.

## Results

Two models for the ring opening of epoxides with halophosphates were studied: DAHPs were used directly as the reagent in the ring opening (method A); DAHPs were formed *in situ* (methods B and C).

### Method A: chlorophosphate used directly as a reagent

The epoxide was added to a solution of $TiCl_4$ and dialkyl chlorophosphate in $CH_2Cl_2$ at room temperature (Scheme 2). After 0.5–4 h, the reaction afforded the desired product in good yield with high regioselectivity. The results of the ring opening of various representative epoxides by this process are compiled in Table 1. The presence of only one regioisomer was determined by $^1$H NMR, $^{31}$P NMR and TLC of both crude and isolated products.

Many catalysts normally used in epoxide ring-opening reactions, such as LiCl, $ZnCl_2$, $AlCl_3$, $BF_3{\cdot}Et_2O$, $NH_4Cl$, HCl and several Ti(IV) compounds,[7] were investigated. Among the catalysts examined, titanium(IV) compounds emerged as the most effective promoter; LiCl gave **3c** in very low yield (<5%), $ZnCl_2$, $AlCl_3$, $NH_4Cl$ and HCl gave only halohydrin, and $BF_3{\cdot}Et_2O$ caused decomposition of the substrate. We found that 0.5–1 mol% $TiCl_4$ was the appropriate catalyst stoichiometry. Higher concentration of $TiCl_4$ led to more by-products. There was no reaction without the catalyst.

The effect of temperature on the yield and regioselectivity of the reaction was also investigated. At −78 °C, there was no reaction as monitored by TLC. The temperature was raised to room temperature, we found that the reaction took place at around −30 °C. At a reaction temperature higher than 40 °C, the products were very complex and the yields were very low (20–30%).

The success of the $TiCl_4$-catalyzed reaction encouraged us to examine the ring opening of epoxides with other DAHPs. Moreover, the reaction that is carried out directly with the pure dialkyl iodophosphate in method A seems impractical since it is impossible to isolate the dialkyl iodophosphate.[8] This prompted us to examine the possibility of developing other methods in which halophosphates are formed *in situ* as intermediates.

### Method B: chloro- and bromophosphate formed *in situ via* the Atherton–Todd reaction

*In situ* oxidation of the dialkyl phosphite *via* the Atherton–Todd reaction[9] afforded the chlorophosphate or bromophosphate **2c**. Subsequent ring opening of the epoxide in the

**Table 1** Titanium(IV) catalyzed ring opening of epoxides with DAHPs

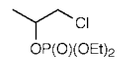
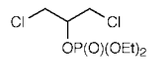
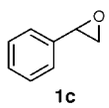
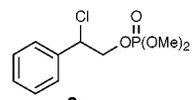
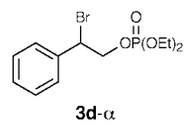
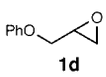
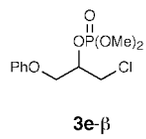
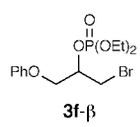
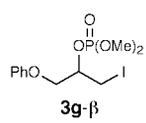
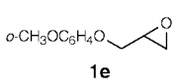
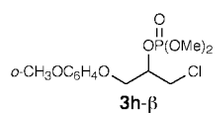
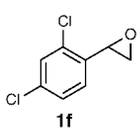
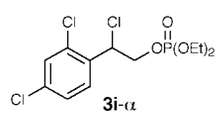
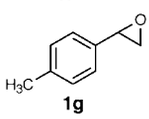
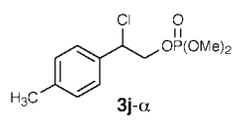
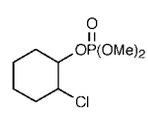
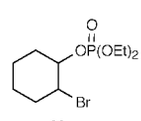
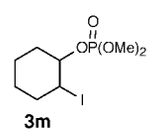
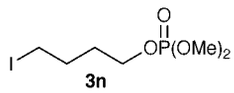
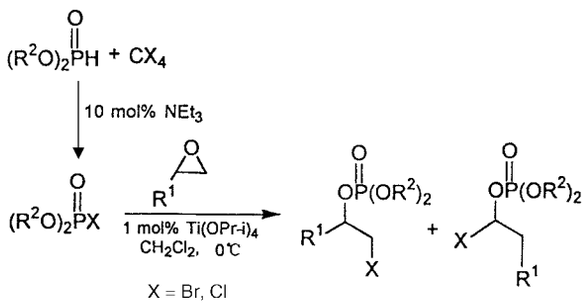
| Entry | Epoxide | Halophosphate | Time/h | Method[a] | α : β[b] | Main products | Isolated yield (%) |
|---|---|---|---|---|---|---|---|
| 1 |  **1a** | **2b** | 2 | A | <5 : 95 |  **3a**-β | 65 |
| 2 |  **1b** | **2b** | 2 | A | <5 : 95 |  **3b**-β | 71 |
| 3 |  **1c** | **2a** | 1 | A or B | >95 : 5 |  **3c**-α | 82 (A)<br>85 (B) |
| 4 | **1c** | **2c** | 1.5 | B | >95 : 5 |  **3d**-α | 80 |
| 5 |  **1d** | **2a** | 0.5 | A or B | <5 : 95 |  **3e**-β | 87 (A)<br>90 (B) |
| 6 | **1d** | **2c** | 1 | B | <5 : 95 |  **3f**-β | 92 |
| 7 | **1d** | **2d** | 1 | C | <5 : 95 |  **3g**-β | 85 |
| 8 |  **1e** | **2a** | 0.5 | A | <5 : 95 |  **3h**-β | 85 |
| 9 |  **1f** | **2a** | 1 | A | >95 : 5 |  **3i**-α | 80 |
| 10 |  **1g** | **2a** | 1 | A | >95 : 5 |  **3j**-α | 77 |
| 11 |  **1h** | **2a** | 2 | A or B | |  **3k** | 75 (A)<br>75 (B) |
| 12 | **1h** | **2c** | 2 | B | |  **3l** | 77 |
| 13 | **1h** | **2d** | 2 | C | |  **3m** | 74 |

**Table 1** (*Contd.*)

| Entry | Epoxide | Halophosphate | Time/h | Method[a] | α : β[b] | Main products | Isolated yield (%) |
|---|---|---|---|---|---|---|---|
| 14 |  1i | **2d** | 2 | C | |  3n | 87 |

[a] A, B and C represent methods A, B, and C. [b] The ratios were determined by $^1$H and $^{31}$P NMR.

presence of a catalytic amount of Ti(IV) led to the desired halohydrin phosphates. If $TiCl_4$ was used as the catalyst there was always some trace amount of chlorohydrin phosphate as a contaminant in the reaction product of the bromophosphate because the initial chloride ion could come from $TiCl_4$.[10] We found that Ti(OPr-*i*)$_4$ readily catalyzes the ring opening reaction to give the clean products in good yields (Scheme 3).[11] The results are also shown in Table 1.

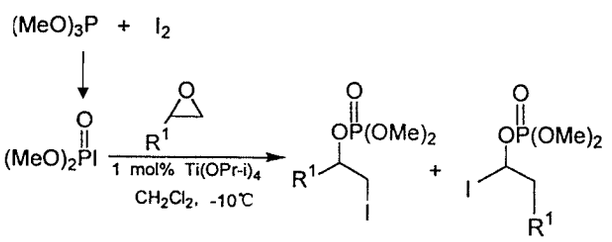



**Scheme 3** Method B.

Compared with method A, method B gave a higher yield (Table 1, entries 3, 4 and 7) and was experimentally more convenient. In method A it was essential to carry out the experiment with the freshly distilled halophosphates since acid (an obvious contaminant) is known to open epoxides with ease. However, in method B, the presence of $NEt_3$ efficiently prevented acid-catalyzed ring opening.

### Method C: iodophosphate formed *in situ* by the reaction of trimethyl phosphite with iodine

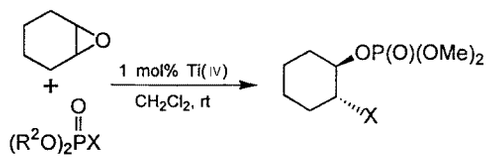
The iodohydrin phosphates were prepared in good yields by the ring opening of epoxides with iodophosphate **2d** formed *in situ* from trimethyl phosphite and elemental iodine at −10 °C as shown in Table 1 and Scheme 4. Ti(OPr-*i*)$_4$ was used as the




**Scheme 4** Method C.

catalyst for the same reasons given above. Tetrahydrofuran (THF) used as solvent can also be ring opened by iodophosphate **2d** (Table 1, entry 14).

Unfortunately, the ring opening of 1,2-disubstituted epoxides failed with the exception of cyclohexene oxide (Scheme 5). 2-Halocyclohexyl phosphates can be prepared by method A, B or C. $^1$H NMR spectroscopy of the hydrolytic products proved the phosphates derived from cyclohexene oxide to be *trans* in structure by comparison with reference data.[12]




**Scheme 5**

We chose to test disodium 2-chloro-2-phenylethyl phosphate (**4a**) and disodium 2-chlorocyclohexyl phosphate (**4b**) as inhibitors of orthophosphoric monoester phosphohydrolase because they were the simplest molecules that contained this structure; they were obtained by removing the phosphoric acid protecting group $CH_3$ from compounds **3c** and **3m** with $BrSiMe_3$.[13] The $IC_{50}$ value of compound **4b** is $2.46 \times 10^{-3}$ M and with 4-nitrophenyl phosphate compound **4b** is a competitive inhibitor of the phosphohydrolase.

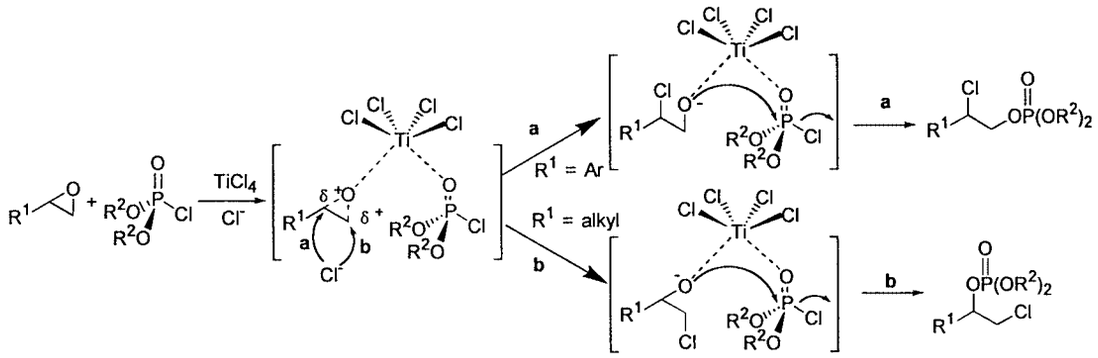
## Discussion

Two regioisomers are distinguished easily by comparing the different couplings of the methylene or methyl group to the phosphorus atom. Surprisingly, the methylene resonances of the products **3c-α**, **3d-α**, **3i-α** and **3j-α** are triplets because $J_{PH} = J_{HH}$. The methine resonances are also triplets. The compounds **3e–h-β** have two methylene groups that have a doublet signal. All the methylene groups in these compounds show deceptively simple splitting patterns (at 90 MHz) and no diastereotopicity, but these peaks are broadened in some of the compounds.

Based on experimental observations, a possible mechanism involves the precomplexation between $TiCl_4$, an epoxide and a phosphoryl group, as shown in Scheme 6.

In the reaction with $TiCl_4$ the mechanism of ring opening is thought to be a borderline $S_N2$.[10] We might expect nucleophilic attack to occur at the more highly substituted and more electrophilic carbon. In the present case, the possible precomplexation with the phosphoryl group may weaken the Lewis acidity of $TiCl_4$, and so lower the polarization of the C–O bond and decrease the positive charge on the carbon. Thus, the reaction occurs by a mechanism in which there is less $S_N1$ character in the transition state. In this case, the positive charge on the carbon atom could be efficiently stabilized by the conjugated aryl group, so that the chloride ion would attack the benzylic carbon atom. The reaction pathway **a** (Scheme 6), *via* a carbonium ion-like transition state, was favored and followed the borderline $S_N2$ mechanism with considerable $S_N1$ character. When $R^1$ is an aliphatic chain which cannot sufficiently stabilize the positive charge on the substituted carbon atom as the aryl group did, the reaction occurs by pathway **b** and follows an $S_N2$ mechanism in which the halogen atom becomes attached to the less substituted carbon atom.

The fact that only one regioisomer was obtained is similar to the results reported by Eisch *et al.*[10] They reported that the ring opening of epoxides became extremely regioselective by adding a stoichiometric amount of a tertiary amine as a ligand on the metal halide. Recently, Iranpoor and Zeynizadeh[14] proposed a similar mechanism for the highly regioselective conversion of epoxides into vicinal chloroesters.



**Scheme 6**

$AlCl_3$ and other catalysts lack the additional valencies required to complex with the phosphoryl group to promote substitution at the phosphorus atom, so ring opening of epoxides occurred, but halohydrin phosphates were not formed.

In conclusion, $TiCl_4$ is a versatile catalyst for the cleavage of a variety of epoxides with chlorophosphates. Using Ti(OPr-*i*)$_4$, the bromohydrin phosphates and iodohydrin phosphates were also obtained cleanly by ring opening with **2b** and **2c** formed *in situ*. The good yields, excellent regioselectivity, small amount of catalyst required and the mild experimental conditions make the procedure useful for the synthesis of the multifunctionalized synthons. The experimental observations supported the precomplexation hypothesis for the mechanism.

## Experimental section

$^1$H-NMR spectra were recorded on an FX-90Q spectrometer in carbon tetrachloride (TMS as the internal reference) or in $CDCl_3$. $^{31}$P-NMR spectra were recorded in $CDCl_3$ on a DRX-400 spectrometer (161.97 MHz, 85% $H_3PO_4$ as the external reference). Mass spectra were determined on a Finnigan 4021 instrument. IR spectra were recorded on a Y-Zoom CURSOR spectrometer. Elemental analyses were performed on a Rapid CHN-O-S instrument at Shanghai Institute of Organic Chemistry. $CH_2Cl_2$ was distilled from $CaH_2$, THF from sodium–benzophenone. All the reaction vessels were flame-dried under vacuum and back-filled with $N_2$, and all reactions were carried out under a $N_2$ atmosphere. The epoxides **1a**, **1b**, **1c**, and **1h** were obtained commercially and purified prior to use (distilled from $CaH_2$). The epoxides **1d**, **1e**, **1f** and **1g** were prepared from the literature.[15] Compounds **3a-β**, **3b-β**, and **3k** are known compounds, which were identified in agreement with the literature data and only the $^1$H-NMR data are reported here.

### General procedure for the ring opening of epoxides with 2a or 2b (method A)

A solution of $TiCl_4$ (0.05 mmol) in $CH_2Cl_2$ (2 ml) was added to the stirred solution of **2a** or **2b** (5 mmol) in $CH_2Cl_2$ (10 ml) at room temperature *via* syringe. Then, a solution of epoxide (5 mmol) in $CH_2Cl_2$ (10 ml) was added dropwise during 15 min to the above mixture. The progress of the reaction was monitored by TLC. After complete disappearance of the starting material (0.5–4 h), water (1 ml) was added to the reaction mixture, and the mixture was left to stir at room temperature, then dried, filtered and concentrated. The residue was purified by flash chromatography on silica gel.

**3-Chloropropan-2-yl diethyl phosphate 3a-β.**[2a] Colorless oil. $\delta_H$ ($CCl_4$) 4.93–4.33 (m, POCH), 4.43–3.76 (m, 4H, $POCH_2$), 3.42 (d, *J* 4 Hz, 2H, $ClCH_2$), 1.10 (m, 9H, $3CH_3$).

**1,3-Dichloropropan-2-yl diethyl phosphate 3b-β.**[2a] Colorless oil. $\delta_H$ ($CCl_4$) 4.96–4.60 (m, 1H, POCH), 4.46–4.06 (m, 4H, $POCH_2$), 3.93 (d, *J* 5 Hz, 4H, $2ClCH_2$), 1.50 (t, *J* 6 Hz, 6H, $2CH_3$).

**2-Chloro-2-phenylethyl dimethyl phosphate 3c-α.** Colorless oil. $\delta_H$ ($CCl_4$) 7.20–7.50 (m, 5H, PhH), 5.07 (t, *J* 7 Hz, 1H, ClCH), 4.29 (t, $J_{HH} = J_{PH}$ 7 Hz, 2H, $POCH_2$), 3.66 (d, *J* 10 Hz, 6H, $2POCH_3$); *m/z* 267 (M + 1, 6.48%), 229 (19.66), 138 (100.00), 127 (37.08), 103 (48.63); $\delta_P$ 1.0820; IR(neat) 1282, 1037 cm$^{-1}$. Found: C, 45.50; H, 5.40; $C_{10}H_{14}O_4ClP$ requires C, 45.39; H, 5.33%.

**3-Chloro-1-phenoxypropan-2-yl dimethyl phosphate 3e-β.** Colorless oil. $\delta_H$ ($CCl_4$) 7.36–6.80 (m, 5H, Ph), 4.96–4.50 (m, 1H, POCH), 4.16 (d, *J* 5 Hz, 2H, $PhOCH_2$), 3.93–3.50 (m, 8H, $ClCH_2$ and $2POCH_3$); *m/z* 295 (M + 1, 100.00%), 201 (15.62), 105 (8.60), 133 (93.64), 127 (45.18), 77 (12.38); $\delta_P$ 0.6956; IR(neat) 1282, 1048 cm$^{-1}$. Found: C, 44.51; H, 5.50; $C_{11}H_{16}O_5ClP$ requires C, 44.84; H, 5.47%.

**3-Chloro-1-(2-methoxyphenoxy)propan-2-yl dimethyl phosphate 3h-β.** Colorless oil. $\delta_H$ ($CCl_4$) 6.80 (s, 4H, Ph), 5.03–4.50 (m, 1H, POCH), 4.13 (d, *J* 5 Hz, 2H, $ClCH_2$), 3.92–3.42 (m, 11H, $2POCH_3$, $CH_3OPh$ and $PhOCH_2$); *m/z* 325 (M + 1, 81.55%), 203 (36.03), 201 (100.00), 165 (22.25), 163 (8.32), 127 (14.81), 109 (4.66); $\delta_P$ 0.6419; IR(neat) 1257, 1046 cm$^{-1}$. Found: C, 44.41; H, 5.70; $C_{12}H_{18}O_6ClP$ requires C, 44.39; H, 5.59%.

**2-Chloro-2-(2,4-dichlorophenyl)ethyl diethyl phosphate 3i-α.** Colorless oil. $\delta_H$ ($CCl_4$) 7.60–7.32 (m, 3H, Ph), 5.63 (t, *J* 6 Hz, 1H, ClCH), 4.42 (t, $J_{HH} = J_{PH}$ 6 Hz, 2H, $POCH_2CHCl$), 4.40–3.70 (m, 4H, $2POCH_2$), 1.40 (t, *J* 6 Hz, 6H, $2CH_3$); *m/z* 360 (M, 33.21%), 327 (54.25), 325 (77.04), 208 (100.00), 206 (96.84), 193 (13.61), 171 (37.24), 155 (54.88), 137 (24.52), 109 (37.88); $\delta_P$ −1.187; IR(neat) 1276, 1031 cm$^{-1}$. Found: C, 39.78; H, 4.57; $C_{12}H_{16}Cl_{13}O_4P$ requires C, 39.86; H, 4.46%.

**2-Chloro-2-(4-methylphenyl)ethyl dimethyl phosphate 3j-α.** Colorless oil. $\delta_H$ ($CDCl_3$) 7.20 (m, 4H, Ph), 5.05 (t, *J* 7.0 Hz, 1H, ClCH), 4.40–4.20 (t, 2H, $J_{HH} = J_{PH}$ 7 Hz, $POCH_2$), 3.66 (d, $J_{PH}$ 11 Hz, $2CH_3$), 2.31 (s, 3H, $CH_3Ph$); *m/z* 279 (M + 1, 15.68%), 243 (100.00), 152 (69.63), 139 (32.18), 127 (37.54), 117 (53.24), 91 (15.30), 77 (10.69); $\delta_P$ 1.0611; IR(neat) 1282, 1037 cm$^{-1}$. Found: C, 47.41; H, 5.91; $C_{11}H_{16}O_4ClP$ requires C, 47.41; H, 5.79%.

**2-Chlorocyclohexyl dimethyl phosphate 3k.**[2b] Colorless oil. $\delta_H$ ($CDCl_3$) 4.32–4.23 (m, 1H), 3.90–3.78 (m, 1H), 3.80, 3.76 (2d, 6H, $J_{PH}$ 11.20 Hz, $2POCH_3$), 2.38–1.20 (m, 8H).

### General procedure for the ring opening of epoxides with 2a–c formed *in situ* (method B)

To a stirred solution of dimethyl or diethyl phosphonate (5.1 mmol) and $CCl_4$ or $CBr_4$ (5.1 mmol) in $CH_2Cl_2$ was added dropwise $NEt_3$ (0.5 mmol) in $CH_2Cl_2$ (2 ml) at 0 °C. After 10

min, Ti(OPr-*i*)$_4$ (0.05 mmol) in $CH_2Cl_2$ (1 ml) was added. Then, the epoxide (5 mmol) in $CH_2Cl_2$ (10 ml) was added dropwise to the above mixture. The work up procedure was the same as for method A.

**2-Bromo-2-phenylethyl diethyl phosphate 3d-α.** Colorless oil. $\delta_H$ ($CCl_4$) 7.43 (s, 5H, Ph), 5.16 (t, *J* 8 Hz, 1H, BrCH), 4.50 (t, $J_{HH} = J_{PH}$ 8 Hz, 2H, $POCH_2CHBr$), 4.32–3.83 (m, 4H, $2POCH_2$), 1.32 (t, *J* 6 Hz, 6H, $2CH_3$); *m*/*z* 257 (M, 35.65%), 229 (23.58), 201 (55.60), 184 (61.35), 182 (56.39), 155 (20.91), 103 (100.00), 99 (24.65); $\delta_P$ −1.311; IR(neat) 1273, 1028 cm$^{-1}$. Found: C, 42.42; H, 5.30; $C_{12}H_{18}BrO_4P$ requires C, 42.75; H, 5.38%.

**3-Bromo-1-phenoxypropan-2-yl diethyl phosphate 3f-β.** Colorless oil. $\delta_H$ ($CDCl_3$) 7.36–6.72 (m, 5H, Ph), 4.90–4.62 (m, 1H, POCH), 4.20 (d, 2H, *J* 5 Hz, $PhOCH_2$), 4.30–3.82 (m, 4H, $2POCH_2$), 3.66 (d, *J* 5 Hz, 2H, $BrCH_2$), 1.30, 1.25 (2t, *J* 5 Hz, 6H, $2CH_3$); *m*/*z* 369 (M + 1, 37.20%), 367 (35.85), 155 (47.84), 133 (100.00), 105 (19.35), 77 (13.10); $\delta_P$ −1.586; IR(neat) 1246, 1032 cm$^{-1}$. Found: C, 42.48; H, 5.49; $C_{13}H_{20}O_5BrP$ requires C, 42.53; H, 5.49%.

**2-Bromocyclohexyl diethyl phosphate 3l.** Colorless oil. $\delta_H$ ($CCl_4$) 4.50–3.86 (m, 6H, $2POCH_2$ and POCH, BrCH), 2.53–1.40 (m, 8H, $4CH_2$), 1.36 (t, 6H, *J* 8 Hz, $2CH_3$); *m*/*z* 317 (M + 1, 7.93%), 315 (7.79), 155 (100.00), 127 (45.80), 99 (45.70), 81 (24.77); $\delta_P$ 1.994; IR(neat) 1269, 1031 cm$^{-1}$. Found: C, 38.00; H, 6.54; $C_{10}H_{20}O_4BrP$ requires C, 38.11; H, 6.40%.

### General procedure for the ring opening of epoxides with 2d formed *in situ* (method C)

To a stirred suspension of $I_2$ (5.0 mmol) in $CH_2Cl_2$ (10 ml) was added dropwise trimethyl phosphite (5 mmol) in $CH_2Cl_2$ (5 ml) at −10 °C. After 10 min, Ti(OPr-*i*)$_4$ (0.05 mmol) in $CH_2Cl_2$ (1 ml) was added. Then, the epoxide (5 mmol) in $CH_2Cl_2$ (10 ml) was added dropwise to the above mixture. The workup procedure was the same as for method A.

**3-Iodo-1-phenoxypropan-2-yl dimethyl phosphate 3g-β.** Colorless oil. $\delta_H$ ($CCl_4$) 7.43–6.80 (m, 5H, Ph), 4.70–4.32 (m, 1H, POCH), 4.28–4.13 (m, 2H, $PhOCH_2$), 3.72, 3.78 (2d, $J_{PH}$ 11 Hz, 6H, $2POCH_3$), 3.50 (d, *J* 5 Hz, 2H, $ICH_2$); *m*/*z* 386 (M, 10.55%), 292 (3.14), 133 (100.00), 127 (19.59), 109 (18.72), 105 (26.16), 77 (18.11); $\delta_P$ 0.4542; IR(neat) 1280, 1048 cm$^{-1}$. Found: C, 34.20; H, 4.20; $C_{11}H_{16}IO_4P$ requires C, 34.22; H, 4.18%.

**2-Iodocyclohexyl diethyl phosphate 3m.** Colorless oil. $\delta_H$ ($CCl_4$) 4.50–3.96 (m, 2H, POCHCHI), 3.82, 3.77 (2d, 6H, $J_{PH}$ 11 Hz, $2POCH_3$), 2.53–1.10 (m, 8H, $4CH_2$); *m*/*z* 335 (M + 1, 27.61%), 243 (7.64), 207 (7.24), 127 (100.00), 109 (10.50), 81 (13.90), 79 (8.50); $\delta_P$ −0.006; IR(neat) 1280, 1028 cm$^{-1}$. Found: C, 29.00; 4.69; $C_8H_{16}IO_4P$ requires C, 28.76; H, 4.83%.

**4-Iodobutyl dimethyl phosphate 3n.** Pale yellow oil. $\delta_H$ ($CCl_4$) 4.13–4.80 (m, 2H, $POCH_2$), 3.66 (d, *J* 12 Hz, 6H, $2POCH_3$), 3.36–3.20 (t, 2H, $ICH_2$), 2.03–1.53 (m, 4H, $CH_2CH_2$); *m*/*z* 309 (M + 1, 7.45%), 235 (5.37), 183 (100.00), 127 (56.35), 109 (22.70), 55 (16.04); $\delta_P$ 1.9111; IR(neat) 1278, 1045 cm$^{-1}$. Found: C, 23.66; H, 4.25; $C_6H_{14}IO_4P$ requires C, 23.40; H, 4.58%.

## Acknowledgements

The project was supported by the National Nature Science Foundation of China. We thank Professor Q. Q. Zhuang, Mr W. J. Xie and Mr F. Qin of Shanghai Medical University for their preliminary biochemical evaluation.

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$$(RO)_2P(=O)X + Ti(O\textit{i}\text{-}Pr)_4 \longrightarrow Ti(O\textit{i}\text{-}Pr)_{4-n}X_n + (RO)_2P(=O)(O\textit{i}\text{-}Pr)$$
$$X = Cl, Br, I$$

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