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A Simple Route to *syn* α-Amino-β-Hydroxy Esters by C-2 Regioselective Opening of α, β-Epoxy Esters with Metal Halides

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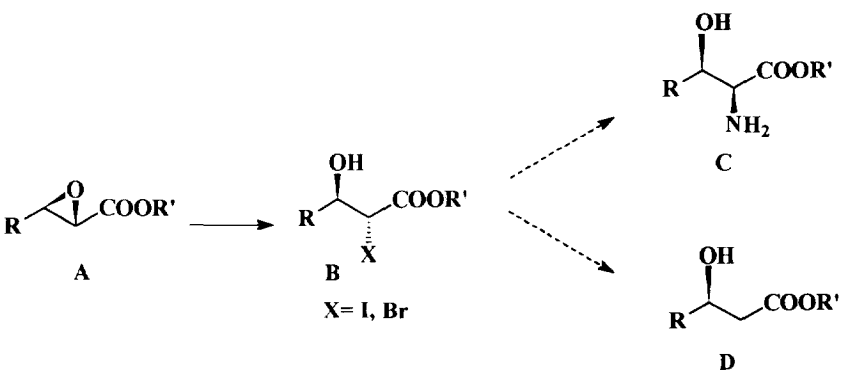
Abstract: α,β-Epoxy esters are opened by NaX (X = I, Br) in a regio and stereoselective fashion to β-hydroxy-α-halo esters, which represent suitable precursors of *syn* α-amino-β-hydroxy esters and β-hydroxy esters.

The regioselective opening of the oxirane ring of α,β-epoxy esters by halide ions appears not to have been thoroughly studied although it should represent a convenient way to prepare useful synthetic intermediates. Only a few examples, essentially concerning attack at C-3 to give the corresponding α-hydroxy-β-iodo esters, have been reported until now.[1] This paper describes a simple conversion of epoxy esters of type **A** to α-halo-β-hydroxy-esters of type **B**, which represent suitable precursors of *syn* α-amino-β-hydroxy esters of type **C** and β-hydroxy esters of type **D** (scheme 1). These latter compounds are frequently encountered in bioactive natural products and consequently in the last years many methods were developed to prepare them in an optically active form.[2] To this purpose chiral α,β-epoxy esters of type **A**, easily obtained from allylic alcohols by means of the Sharpless procedure.[3], can be considered versatile starting material.

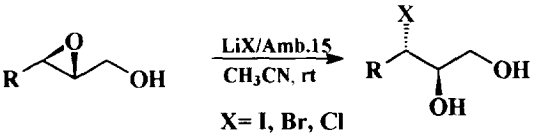
SCHEME 1



Among recent methodologies for the regioselective opening of 2,3-epoxy alcohols and derivatives with metal halide,[4] our method (LiX, X= I, Br, Cl) with Amberlyst 15 in CH_3CN at room temperature)[5,6]

demonstrated its effectiveness in obtaining 3-halo-1,2-diols in a regio, stereo and chemoselective fashion (scheme 2), and was subsequently applied to the synthesis of natural products.[6,7]

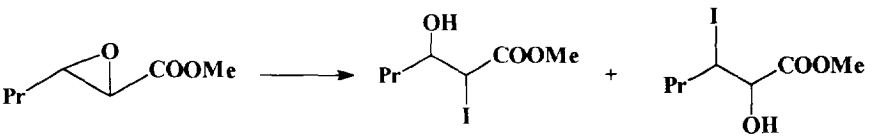
SCHEME 2



In order to extend this methodology to other substrates, we have applied the same reaction conditions to the model α,β-epoxy ester **1** in order to obtain the corresponding halohydrin (see figure 1).

As shown in Table 1, the use of the previously utilised reaction conditions (LiI / Amberlyst 15 in CH_3CN, see entry 1) was not satisfactory, especially given the low stereoselectivity observed in the oxirane opening. Modification of the reaction conditions (entries 2-4) also gave poor results.

Figure 1



1 **C-2 attack** **C-3 attack**

Table 1

entry	reaction conditions	C-2 / C-3 ratio[a]
1	LiI / Amb. 15 in CH_3CN, rt	10 / 90 diastereoisomeric mixture
2	LiI / Amb. 15 in DME, rt	70 / 30 "
3	KI / Amb. 15 in $(CH_3)_2CO$, rt	60 / 40 "
4	NaI / Amb.15 in CH_3CN, rt	65 / 35 "
5	NaI / Amb.15 in $(CH_3)_2CO$,rt	82 / 18 single diastereoisomer

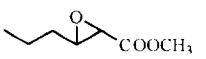
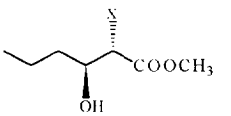
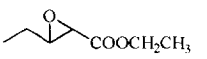
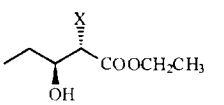
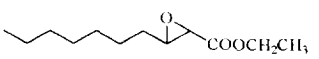
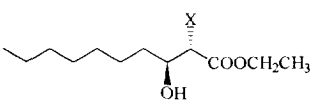
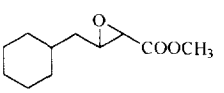
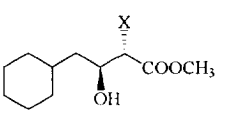
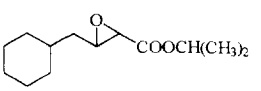
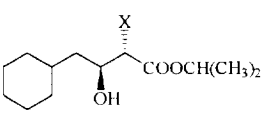
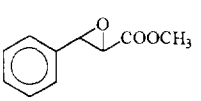
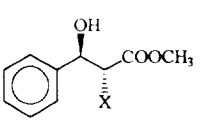
[a] The ratio has been determinated by ^{1}H-NMR (200 MHz) analysis of the peracetylated products

More interestingly with use of NaI / Amberlyst 15 in acetone at room temperature (entry 5), we observed good regioselectivity in favour of the C-2 attack and an excellent stereoselectivity, to give α-iodo-β-hydroxy ester as main product.

This use of NaI, extended also to NaBr, was therefore applied (as shown in Table 2) to some racemic α, β-epoxy esters,[8] affording the corresponding α-halo-β-hydroxy esters, with nearly quantitative yields. and a good degree of regioselectivity (which can be significantly improved when the reaction is carried out at -30°C instead of room temperature).

Only with phenylglycidic ester **6** did the reaction proceed with poor regioselectivity, as already noted for several other phenyl substituted epoxides.[4]

Table 2

Epoxy ester	Main halohydrin	X	C-2 / C-3 ratio [a, b]
 **1**		**7** I	91 / 9
		8 Br	90 / 10
 **2**		**9** I	89 / 11
		10 Br	90 / 10
 **3**		**11** I	90 / 10
		12 Br	92 / 8
 **4**		**13** I	92 / 8
		14 Br	91 / 9
 **5**		**15** I	90 / 10
		16 Br	90 / 10
 **6**		**17** I	60 / 40
		18 Br	60 / 40

[a] The ratio has been determined by ^{1}H-NMR (200 MHz) analysis of the peracetylated products

[b] Chemical yields of the isolated products are nearly quantitative

To our knowledge the observed C-2 regioselectivity in the opening of epoxy esters with metal halides, has never been reported until now. Probably in absence of any coordination between the metal and the two oxigens of α,β-epoxy ester (Na is a poor Lewis acid), the C-2 position is preferred by the halide ion because of the electronic effect of the COOR group.[9] With a good Lewis acid like LiI (see table 1, entries 1-2) the regioselectivity is reversed, or random, with lost of stereoselectivity.

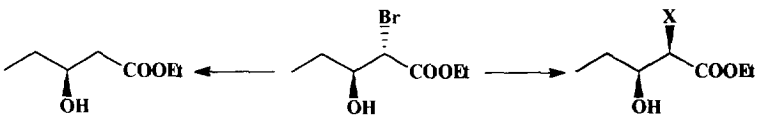
The major α-halo-β-hydroxy ester (easily separated by flash chromatography from the minor regioisomer) can be conveniently transformed into other useful compounds, as below reported.

As already shown in the case of the opening of epoxy alcohols with metal halides,[10] and also with α-bromo-β-hydroxy-esters prepared by different route, [11] the halogen can be easily removed via radical reduction.

In fact tributyltin hydride reduction of **10** (see scheme 3) afforded the desired β-hydroxy ester **19** in chemoselective fashion and with overall chemical yield superior to those reported for the direct transfomation of α,β epoxy esters in to the corresponding β-hydroxy esters, employing SmI_2.[12]

On the other hand the azide substitution of the halogen in **10**, afforded the azido alcohol **20**, with complete stereocontrol. The subsequent catalytic hydrogenation of **20** afforded the *syn* α-amino-β-hydroxy ester **21.**

SCHEME 3



19 **10** **20** X = N_3
21 X = NH_2

a: n-Bu_3SnH, AIBN, toluene, 70°C, 2 h, 90%; b: NaN_3, DMF, 48 h, rt, 90%; c: H_2, Pd/C, EtOAc, 4 h, rt, 85 %

α-Amino-β-hydroxy esters or the corresponding acids have been also prepared by direct C-2 nucleophilic amination of the corresponding epoxy acids or derivatives; in particular they can be prepared from α,β-epoxy acids using primary or secondary amines.[13] A more recent methodology[14] employs C-2 azide cleavage of α, β-epoxy esters with the use of DIPEA-HN_3, an extremely explosive and toxic reagent, as reported by the authors.

However these methodologies can conveniently afford α-amino-β-hydroxy acids or esters with relative *anti* configuration starting from optically pure *trans* α,β-epoxy acids or esters; also *syn* α-amino-β-hydroxy acids or esters could be prepared in the same way, but starting from *cis* α,β-epoxy acids or esters, which cannot be obtained in optically pure form as for the *trans* isomer.[15]

Our methodology, if applied to chiral α,β-epoxy esters prepared by Sharpless AE,[3, 16] could represent a straightforward preparation of optically active *syn* α-amino-β-hydroxy esters in good yields as well as an alternative methodology for the obtaining of β-hydroxy esters. The application of this procedure to the synthesis of chiral naturally occurring α-amino-β-hydroxy acids is currently under investigation.

Experimental section [19]

General: Flash chromatography was carried out on silica gel Merck (70-230 mesh). TLC analysis were carried out on Merck Kieselgel 60 F-254 plates. All solvent used, except CH_3CN, were distilled and dried before use. ^{1}H-NMR spectra were recorded on a Varian Gemini (200 MHz) instrument in a $CDCl_3$ solution. ^{13}C-NMR spectra were determined on the same instrument (50.3 MHz) in a $CDCl_3$ solution. IR specra were recorded on a Shimadzu IR-470. High-resolution mass spectra were measured on a VG-ZAB 2SE instrument by the Mass Spectrometer Centre of the University of Naples.

Preparation of the starting epoxy esters

Epoxy esters **1** and **6** are know compounds.[17] Epoxy esters **2**, **3**, **4**, **5** were prepared according to ref.17.

Ethyl *trans*-2,3-epoxypentanoate 2. ^{1}H-NMR: 4.03 (q, 2H, J=7.9 Hz), 3.15-2.85 (m, 2H), 1.70-1.30 (m, 2H), 1.15 (t, 3H, J=7.4 Hz), 0.90 ppm (t, 3H, J=7.8 Hz). ^{13}C-NMR: 169.3; 61.1; 59.0; 52.4; 24.1; 13.6; 9.0 ppm.

Ethyl *trans*-2,3-epoxydecanoate 3. ^{1}H-NMR: 4.20 (q, 2H, J=7.9 Hz), 3.20-3.00 (m, 2H), 1.70-1.00 (m, 15H), 0.84 ppm (t, 3H, J=7.9 Hz). ^{13}C-NMR: 169.5; 61.3, 58.3, 52.9; 31.5; 31.2; 28.9; 28.8; 25.4; 22.3; 13.8; 13.7 ppm.

Methyl *trans*-2,3-epoxy-4-cyclohexylbutanoate 4. ^{1}H-NMR: 3.7 (s, 3H), 3.18 (s, 2H), 1.85-0.75 ppm (m, 13H). ^{13}C-NMR: 170, 57.2, 53.0, 52.2, 39.1, 35.5, 33.3, 32.8, 26.1, 25.93, 25.9 ppm.

Isopropyl *trans*-2,3-epoxy-4-cyclohexylbutanoate 5. ^{1}H-NMR: 5.15-4.95 (m, 1H), 3.20-3.02 (m, 2H), 1.85-0.75 (m, 13 H), 1.25 ppm (d, 6H, J=6.2 Hz). ^{13}C-NMR: 169.1; 69.0; 57.0; 53.2; 39.0; 35.5; 33.2; 32.7; 26.0; 25.9; 25.8; 21.5; 21.4 ppm.

General preparation of the 2-halo-3-hydroxy esters 7-18

Representative procedure for methyl-2-iodo-3-hydroxyhexanoate 7. To a cold (-30°C), stirred solution of epoxy ester **1** (144 mg, 1 mmol) in acetone (10 mL), NaX (150 mg, 1 mmol for X = I and 206 mg, 2 mmol for X = Br) and Amberlyst 15 (217 mg, 1 mmol) were added. The mixture was stirred for 6 h (TLC monitoring) and filtered. The filtrate solution, diluted with EtOAc, was washed with saturated $Na_2S_2O_3$; the organic layer, dried over Na_2SO_4, was evaporated in vacuo, affording the crude mixture of haloderivatives, which was peracetylated and checked by ^{1}H-NMR analysis. The regioisomers can be eventually separated by flash chromatography purification.^{1}H-NMR: 4.30 (d, 1H, J=7.8 Hz), 3.92 (dt, 1H, J=8.1 and 2.9 Hz), 3.76 (s, 3H), 2.9 (bs, 1H, OH), 2.0-1.75 (m, 1H), 1.70-1.10 (m, 3H), 0.95 ppm(t, 3H, J=7.8 Hz). ^{13}C-NMR: 171.6; 72.7, 52.8, 36.1, 24.4, 18.5, 13.5 ppm. IR (neat film) ν 3550 (br), 2932, 2875, 1742, 1441, 1258, 1223, 1132, 1082, 859, 724 cm^{-1}. HRMS (FAB) for $C_7H_{14}O_3I$ (M+1) calcd 272.9989, found 272.9993.

Methyl 2-hydroxy-3-iodohexanoate (other regioisomer). ^{1}H-NMR: 4.31-4.20 (m, 2H), 3.80 (s, 3H), 3.18 (bd, 1H, OH, J=6.2 Hz), 2.02- 1.81 (m, 1H), 1.68-1.12 (m, 3H), 0.9 ppm (t, 3H, J=6.4 Hz). ^{13}C-NMR: 172.0, 75.4, 52.8, 37.0, 36.7, 22.7, 12.8 ppm. IR (neat film) ν 3565 (br), 2958, 2930, 1750, 1471, 1287, 1251, 1215,

1125, 1074, 783, 741 cm^{-1}.

Methyl 2-bromo-3-hydroxyhexanoate 8. ^{1}H-NMR: 4.12 (d, 1H, J=7.7 Hz), 3.96 (dt, 1H, J=7.7 and 2.7 Hz), 3.77 (s, 3H), 2.70 (bs, 1H, OH), 2.00-1.05 (m, 4H), 0.90 ppm (t, 3H, J=6.8 Hz). ^{13}C-NMR: 170.1, 72.0, 52.9, 47.8, 35.3, 18.3, 13.5 ppm. IR (neat film) ν 3565 (br), 2930, 1751, 1453, 1397, 1292, 1190, 1144, 1016, 950, 852, 719, 647 cm^{-1}. HRMS (FAB) for $C_7H_{14}O_3Br$ (M+1) calcd 225.0127, found 225.0121.

Methyl 2-hydroxy-3-bromohexanoate (other regioisomer). ^{1}H-NMR: 4.39 (dd, 1H, J=3.2 and 6.8 Hz), 4.25-4.13 (m, 1H), 3.81 (s, 3H), 3.20 (bd, 1H, OH, J=6.8 Hz), 2.02- 1.26 (m, 4H), 0.90 ppm (t, 3H, J=7.2 Hz). IR (neat film) ν 3565, 2933, 1751, 1474, 1291, 1251, 1217, 1129, 1082, 808, 749, 689, 647 cm^{-1}.

Ethyl 2-iodo-3-hydroxypentanoate 9. ^{1}H-NMR: 4.38-4.05 (m, 3H), 3.87 (dt, 1H, J=8.2 Hz) 3.35 (bs, 1H, OH), 2.07-1.77 (m, 1H), 1.77-1.38 (m, 1H), 1.25 (t, 3H, J=8.2 Hz), 0.96 ppm(t, 3 H, J=7.8 Hz). ^{13}C-NMR: 171.5; 74.2; 61.9; 27.0; 24.5; 13.4; 9.52 ppm. IR (neat film) ν 3565 (br), 2930, 2871, 1745, 1435, 1258, 1221, 1135, 1088, 852, 719 cm^{-1}. HRMS (FAB) for $C_7H_{14}O_3I$ (M+1) calcd 272.9989, found 272.9996.

Ethyl 2-bromo-3-hydroxypentanoate 10. ^{1}H-NMR: 4.24 (q, 2H, J=7.5 Hz), 4.10 (d, 1H, J=7.9 Hz), 3.92 (dt, 1H, J=7.9 and 3.7 Hz), 2.93 (bs, 1H, OH), 2.06-1.70 (m, 1H) 1.70-1.37 (m, 1H), 1.27 (t, 3H, J=7.9 Hz), 1.00 ppm(t, 3H, J=8.3 Hz). ^{13}C-NMR: 169.6; 73.5; 62.1; 47.6; 26.3; 13.6; 9.3 ppm. IR (neat film) ν 3565 (br), 2935, 1751, 1450, 1396, 1298, 1193, 1145, 1016, 953, 852, 720, 647 cm^{-1}. HRMS (FAB) for $C_7H_{14}O_3Br$ (M+1) calcd 225.0127, found 225.0131.

Ethyl 2-iodo-3-hydroxydecanoate 11. ^{1}H-NMR 4.40-4.15 (m, 3H), 4.02-3.86 (m, 1H), 2.92 (d, 1H, OH, J=6.1 Hz), 2.08-1.78 (m, 1H), 1.65-1.07 (m, 14H), 0.85 ppm (t, 3H, J=8.2 Hz). ^{13}C-NMR: 171.6; 73.2; 61.9; 34.1; 31.6; 31.5; 29.1; 28.9; 25.3; 22.4; 13.8; 13.5 ppm. IR (neat film) ν 3570 (br), 2934, 2867, 1744, 1477, 1410, 1315, 1293, 1250, 1179, 1119, 1088, 1026, 859, 724 cm^{-1}. HRMS (FAB) for $C_{12}H_{24}O_3I$ (M+1) calcd 343.0772, found 343.0778.

Ethyl 2-bromo-3-hydroxydecanoate 12. ^{1}H-NMR: 4.23 (q, 2H, J=7.2 Hz), 4.11 (d, 1H, J=7.7 Hz), 3.96 (dt, 1H, J=7.7 and 2.9 Hz), 2.65 (bs, 1H, OH), 2.05-1.70 (m, 1H), 1.71-1.05 (m, 14H), 0.85 ppm (t, 3H, J=7.9 Hz). ^{13}C-NMR: 167.2; 72.4; 62.1; 48.2; 33.3, 31.3; 29.1; 28.9; 25.1; 22.4; 13.8; 13.7 ppm. IR (neat film) ν 3570 (br), 2998, 1751, 1477, 1409, 1290, 1183, 1149, 1018, 952, 853, 722, 650 cm^{-1}. HRMS (FAB) for $C_{12}H_{24}O_3Br$ (M+1) calcd 295.0909, found 295.0916.

Methyl 2-iodo-3-hydroxy-4-cyclohexylbutanoate 13. ^{1}H-NMR: 4.23 (d, 1H, J=7.5 Hz), 4.10-3.40 (m, 1H), 3.75 (s, 3H); 2.89 (bs, 1H, OH), 1.90-0.70 ppm (m, 13H). ^{13}C-NMR: 171.9; 71.0; 52.7; 41.8; 34.0; 32.0; 26.2; 26.0; 25.9; 25.8; 25.7 ppm. IR (neat film) ν 3515 (br), 2948, 2930, 1743, 1462, 1283, 1255, 1228, 1207, 1106, 1078, 1046, 860, 802 cm^{-1}. HRMS (FAB) for $C_{11}H_{20}O_3I$ (M+1) calcd 327.0459, found 327.0464.

Methyl 2-bromo-3-hydroxy-4-cyclohexylbutanoate 14. ^{1}H-NMR: 4.10-3.95 (m, 2H), 3.72 (s, 3H), 2.70 (bs, 1H, OH), 1.90-0.80 ppm (m, 13H). IR (neat film) ν 3520 (br), 2945, 2918, 1752, 1460, 1381, 1139, 1080, 1047, 980, 893, 843, 667 cm^{-1}. HRMS (FAB) for $C_{11}H_{20}O_3Br$ (M+1) calcd 279.0596, found 279.0590.

Isopropyl 2-iodo-3-hydroxy-4-cyclohexylbutanoate 15. ^{1}H-NMR: 5.07-5.15 (m, 1H), 4.20 (d, 1H, J=7.3 Hz), 4.15-3.50 (m, 1H), 2.50 (bs, 1H, OH), 2.00-0.63 (m, 13 H), 1.25 ppm (d, 6 H, J=6.4 Hz).

Isopropyl 2-bromo-3-hydroxy-4-cyclohexylbutanoate 16. ^{1}H-NMR: 5.07-5.20 (m, 1H), 4.10-4.00 (m, 2H), 2.65 (bd, 1H, OH, J=4.8 Hz), 2.00-0.63 (m, 13H), 1.25 ppm (d, 6H, J=6.4 Hz).

Methyl 2-iodo-3-phenyl-3-hydroxypropanoate 17. (mixture of regioisomers). ^{1}H-NMR: 7.50-7.15 (m, 5H), 5.54 (d, J=2.4 Hz), 5.40 (d, J=4.5 Hz), 4.61 (dd, J=4.5 and 6.07 Hz), 4.03 (dd, J=2.4 and 7.2 Hz), 3.82 (s), 3.67 (s), 3.38 (d, OH, J=7.2 Hz), 3.12 ppm (d, OH, J=6.07 Hz).

Methyl 2-bromo-3-hydroxy-3-phenylpropanoate 18. (mixture of regioisomers). ^{1}H-NMR: 7.70-7.25 (m, 5H), 5.37 (d, 0.5H, J=2.5 Hz), 5.25 (d, 0.5H, J=4.8 Hz), 4.68 (dd, 0.5H, J=4.8 and 6.7 Hz), 4.48 (dd, 0.5H, J=2.5 and 8.05 Hz), 3.83 (s, 1.5H), 3.71 (s,1.5H), 3.42 (d, 0.5H, OH, J=8.05 Hz), 3.15 ppm (d, 1H, OH, J=6.7 Hz).

Ethyl 3-hydroxypentanoate 19. To a solution of **10** (340 mg, 1.5 mmol) in benzene (10 mL) n-Bu_3SnH (460 mg, 1.1 mmol) and AIBN (cat.) were added. The mixture was heated at 70°C for 2 h (TLC monitoring), then the solvent was removed in vacuo; the tin residues were removed according to Curran's procedure [18] and the crude mixture, purified by silica gel chromatography (hexanes/ ether 6:4), afforded pure compound **19** (257 mg, 90%). ^{1}H-NMR: 4.25 (q, 2H, J= 7.4 Hz); 4.05 -3.92 (m, 1H), 2.92 (bs, OH); 2.49 (dd, 1H, J= 17.1 and 4.0 Hz), 2.35 (dd, 1H, J= 17.1 and 8.0 Hz), 1.68-1 1 (m, 5H); 0.9 ppm (t, 3 H, J=6.4 Hz). IR (neat film) ν 3555 (br), 2965, 1731, 1475, 1394, 1278, 1180, 1071, 1020, 875 cm^{-1}. HRMS for $C_7H_{14}O_3$ calcd 146.0943, found 146.0950.

Ethyl 2-azido-3-hydroxypentanoate 20. A mixture of **10** (340 mg, 1.5 mmol), NaN_3 (380 mg, 6.03 mmol) in DMF (7 mL) was stirred at room temperature for 48 h. The mixture was then diluted with EtOAc, washed with water, dried over Na_2SO_4 and concentrated in vacuo. Flash chromatography (hexanes/ ether 7:3) afforded 253 mg of pure compound **20** (90%). ^{1}H-NMR: 4.23 (q, 2H, J= 7.5 Hz); 4.00 -3.8 (m, 2H), 2.8 (bs, OH); 1.68-1.47 (m, 2H), 1.3 (t, 3H, J= 7.8 Hz); 0.95 ppm (t, 3H, J=7.0 Hz).^{13}C-NMR: 171.9, 73.6; 65.5, 62.0, 26.7, 13.9, 9.7 ppm. IR (neat film) ν 3555 (br), 2985, 2235, 1735, 1475, 1454, 1279, 1248, 1199, 1118, 1005, 964, 854, 752, 705 cm^{-1}. HRMS (FAB) for $C_7H_{14}N_3O_3$ (M+1) calcd 188.1035, found 188.1030.

Ethyl 2-amino-3-hydroxypentanoate 21. A mixture of **20** (253 mg,, 1.4 mmol), was hydrogenated with 10% Pd/C (25 mg) in EtOAc (2.5 mL) under H_2 for 4 h at room temperature. The solution was filtered and concentrated in vacuo; flash chromatography (hexanes/ EtOAc 1:1) afforded pure compound **21** (192 mg, 85%). ^{1}H-NMR: 4.25 (q, 2H, J= 7.5 Hz), 3.80-3.68 (m, 1H), 3.30 (d, 1H, J= 4.4 Hz), 2.18 (bs, 3H), 1.62-1.33 (m, 2H), 1.28 (t, 3H, J= 7.5 Hz), 0.95 ppm (t, 3H, J= 7.05 Hz). ^{13}C-NMR: 174.5, 71.6, 61.2, 58.0, 35.7, 13.9, 13.7 ppm. IR (neat film) ν 3440 (br), 2983, 2615, 1748, 1472, 1431, 1394, 1283, 1251, 1203, 1174, 1126, 1013 cm^{-1}. HRMS (FAB) for $C_7H_{16}NO_3$ (M+1) calcd 162.1130, found 162.1138.

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