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Synthesis of New Lipophilic Phosphonate and Phosphonamidate Analogues of *N*-Acetylmuramyl-L-alanyl-D-isoglutamine Related to LK 423

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Abstract: A syntheses of three new muramyl dipeptide (MDP) analogues related to LK 423 as potential immunomodulators are presented. The dipeptide part of the lead compound was modified by introducing a phosphonamide isostere instead of the amide bond between L-alanine and D-glutamic acid (or D-isoglutamine), yielding new MDP analogues **5** and **9**. Furthermore, the amide bond between L-Ala and D-Glu was replaced by a phosphonate isostere, giving peptidyl phosphonate **14**. The scope and limitations of the synthetic strategies employed are discussed.

Keywords: Muramyl dipeptide, analogues, phosphonamidates, phosphonates, immunomodulators.

Introduction

Bacterial cell wall components like proteoglycans, lipopolysaccharides and lipoproteins possess strong immunostimulating activities. Since 1974 *N*-acetylmuramyl-L-alanyl-D-isoglutamine (muramyl dipeptide, MDP, Figure 1) has been known as the smallest immunologically active fragment of bacterial cell wall peptidoglycan [1]. As MDP is one of the most potent immunostimulants, many of its derivatives and analogues have been synthesized and evaluated biologically in order to obtain new

molecules with improved pharmacological properties [2]. Recently the lipophilic MDP derivative *N*[2]-[*N*-(acetylmuramyl)-L-alanyl-D-isoglutaminyl]-*N*[6]-stearoyl-L-lysine (rumortide) was introduced for the treatment of radiotherapy-induced leukopenia [2,3]. While most of the MDP analogs synthesized so far possess an intact dipeptide L-Ala-D-Glu-NH$_2$ or L-Ala-D-Glu moiety, it has been generally accepted that the *N*-acetyl-D-glucosamine fragment is not essential for the immunomodulating activity of this class of compounds [4-6]. Replacement of the *N*-acetylmuramyl moiety with various acyl groups thus represents an important approach in the design and synthesis of new immunologically active MDP analogues, as demonstrated by FK-156 [7], pimelautide [8], 7-(oxoacyl)-L-alanyl-D-isoglutamines [9], some carbocyclic MDP analogues [10,11], and by the adamantyl-substituted MDP analogue LK 415 [12].

Figure 1

MDP   LK 423
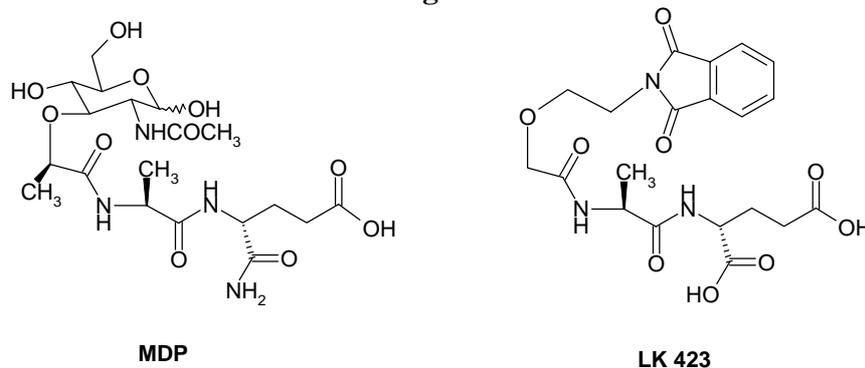
In the search for new lipophilic MDP analogues some phthalimido desmuramyl dipeptides were synthesized whose *N*-acetylmuramic acid part was replaced by different *N*-phthaloylated amino acids [13,14]. The most promising compound in this series was LK 423 (Figure 1), which exhibited some interesting immunomodulating activities. It was found to augment the capacity to produce interleukin-10 in the spleen cells of cyclophosphamide-treated mice [15], and it alleviated the dextran sulfate sodium-induced colitis in rodents [16]. LK 423 is thus a candidate substance to be developed as an anti-inflammatory pharmaceutical agent [16]. The compound was also able to stimulate the production of tumor necrosis factor in *in vitro* phorbol 12-myristate 13-acetate and ionomycin-stimulated cultures of human peripheral blood mononuclear cells [17].

Recently we have been interested in the synthesis of new MDP analogues related to LK 423. To obtain more information about structure-activity relationships, we modified the peptide backbone of phthalimido desmuramyl dipeptides by introducing various phosphorus-containing species. We replaced the amide bond at the end of the acyclic side chain by phosphonamidate ethyl ester [18] and by the phosphinamide moiety [19]. We have also replaced the amide bond between Ala and Glu by phosphonamidate methyl ester [19], and the γ-carboxylic group of Glu by diethyl phosphonate isostere [20]. Stimulated by the results of preliminary immunological tests of selected phosphorus MDP analogues [17], we present the syntheses of three new phosphapeptides related to LK 423, whose amide bonds between L-alanyl and D-glutamate moieties are replaced by phosphonamidate and

phosphonate bonds, respectively. In order to increase the lipophilicity of novel desmuramyl dipeptides, the target compounds are in the form of either methyl or benzyl esters.

Results and Discussion

The synthesis of the phosphonamidate MDP analogue **5** was carried out from methyl (1*R*,*S*)-1-(*N*-benzyloxycarbonyl)aminoethyl phosphonate (**1**) [21] according to Scheme 1. Methyl D-isoglutaminate hydrochloride (**2**) was prepared from D-glutamic acid as described for the corresponding benzyl ester [22]. Monomethyl phosphonate **1** was coupled with compound **2** using diphenylphosphorylazide (DPPA) as a coupling reagent, giving a protected phosphadipeptide **3** in a moderate, but satisfactory yield. We were unable to couple compounds **1** and **2** using the oxalyl chloride method, the most commonly employed method in the synthesis of phosphonamidates [23], probably due to poor solubility of hydrochloride **2** in dichloromethane. The Z protecting group was removed by catalytic hydrogenation in a Parr hydrogenator and the free amine obtained was used immediately in the coupling reaction with 2-(2-phthalimidoethoxy)acetic acid (**4**) [24], affording the target phosphonamidate **5**.
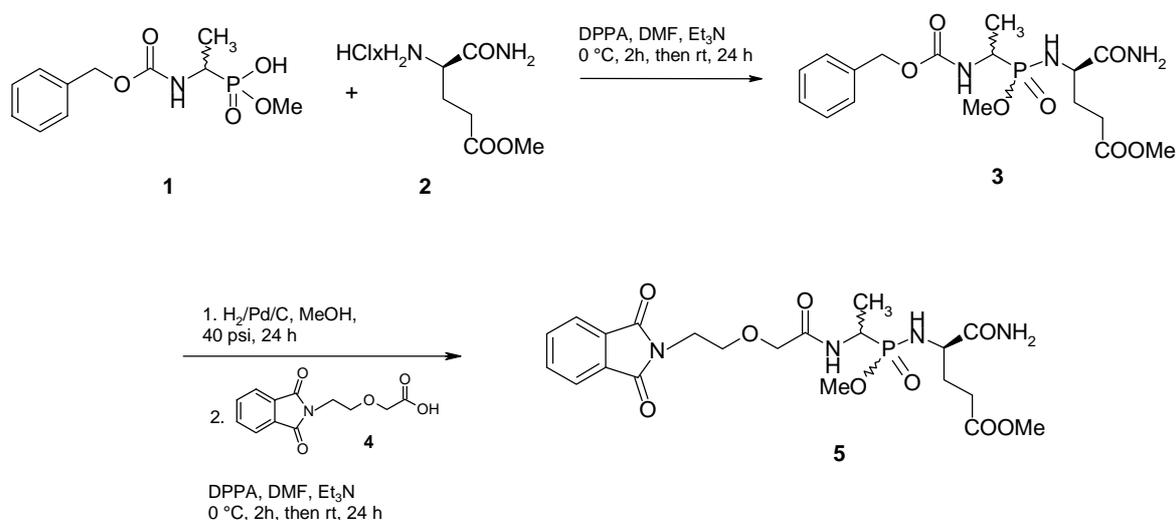
Scheme 1

The lipophilic phosphonamidate MDP analogue **9** was prepared according to Scheme 2. The starting compound **1** was hydrogenated over Pd/C to remove the Z protecting group, and the 9-fluorenylmethoxycarbonyl (Fmoc) group was introduced to give methyl (1*R*,*S*)-1-(*N*-(9-fluorenyl-methoxycarbonyl)amino)ethyl phosphonate (**6**) [25]. Monomethyl phosphonate **6** was then coupled with dibenzyl D-glutamate *p*-toluenesulfonate [26] using the acid chloride method [23] to yield the triple-protected phosphadipeptide **7**. After selectively removing the Fmoc protecting group with diethylamine the phosphonamidate **9** was obtained by coupling of the free amine with 5-phthalimido-pentanoic acid **8** [27].

Scheme 2
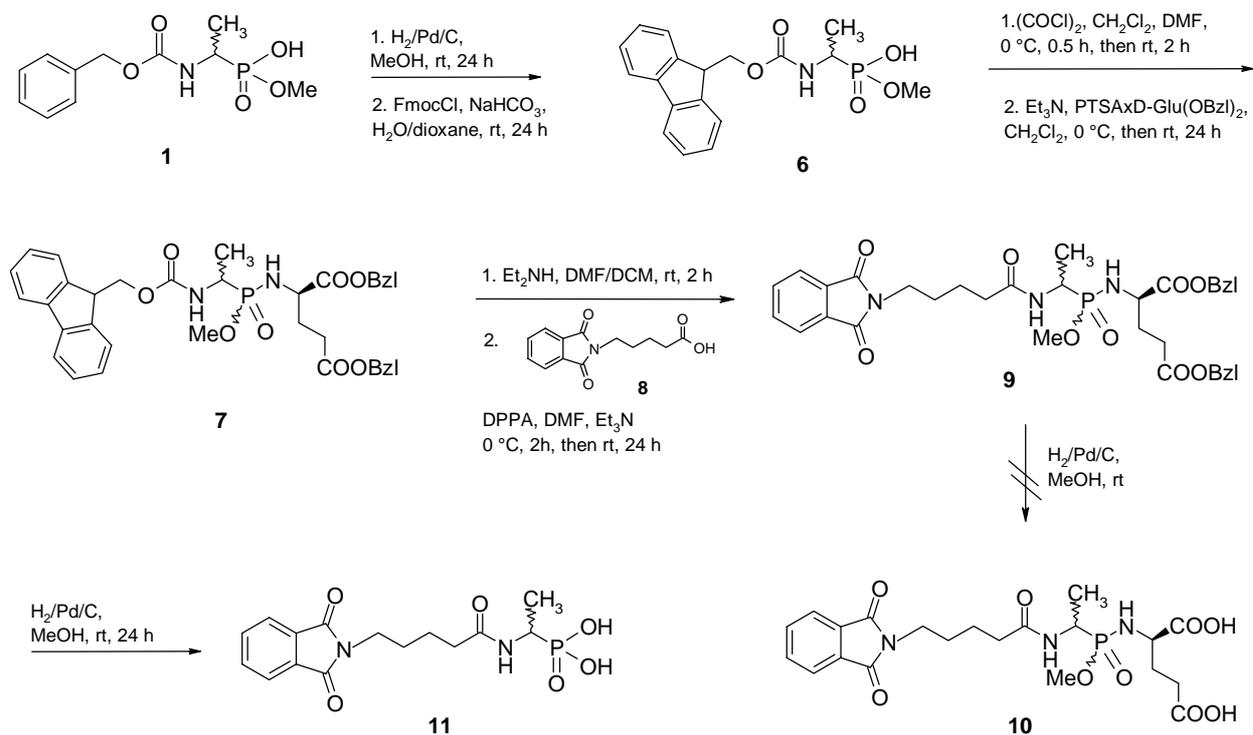
In order to prepare the phosphonamidate muramyl dipeptide analogue **10** that closely resembles LK 423, we wanted to remove the benzyl protecting groups of the D-Glu moiety. However, catalytic hydrogenation of compound **9** over Pd/C in methanol yielded a heterogeneous mixture, from which we were able to isolate only phosphonic acid **11**, recently synthesized by us from 5-phthalimidopentanoic acid and phosphonoalanine [28]. It is well known that phosphonamidates are unstable under acidic conditions [29]. To overcome this problem, the use of so called »capped« phosphonamidates (phosphonamidate esters), reported to be stable in acidic aqueous media, was suggested [30]. However, in our hands phosphonamidate methyl ester **9** decomposed even during mild catalytic hydrogenation. We could observe similar decomposition during our efforts to either hydrolytically or acidolytically deprotect closely related phosphonamidate methyl esters, bearing methyl, ethyl or *tert*-butyl protection on the C-terminal D-Glu residue [19]. Hence, we can conclude that the stability of phosphonamide bond depends strongly on the chemical structure of phosphonamidate ester pseudopeptide under investigation. The target phosphonate MDP analogue **14** was synthesized according to previously described strategies for the assembly of phosphapeptides [31].

Mixed phosphonate **13** was obtained after condensation of monomethyl phosphonate **1** with (2*S*)-2-hydroxyglutaric acid dimethyl ester (**12**) [32] in the presence of the BOP reagent [33]. Catalytic hydrogenation in a Parr apparatus furnished the free amine, which was finally acylated with 2-(2-phthalimidoethoxy)acetic acid (**4**) (Scheme 3).

Scheme 3
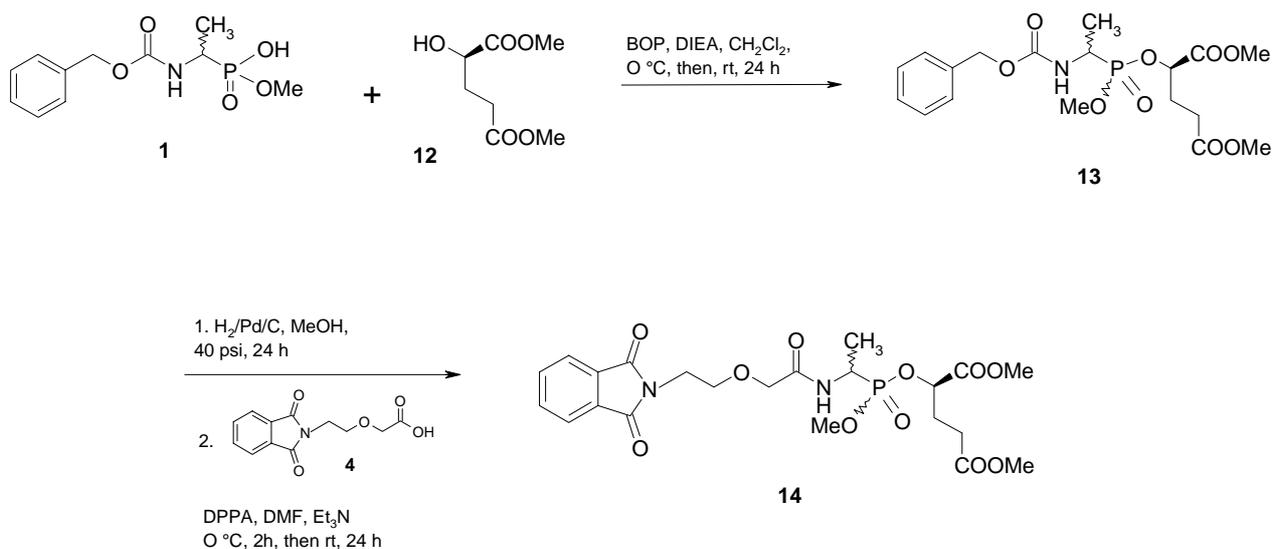
In all syntheses we used readily available racemic methyl phosphonoalaninate **1** as a starting material. It is well known that during the preparation of either phosphonamidate or phosphonate bond a racemic mixture is formed on new stereogenic centre – phosphorus atom [23]. Hence, all target compounds were syntetized as mixtures of four diastereomers. In Figure 2 all diastereomers of the target phosphonate **14** are presented.

Figure 2
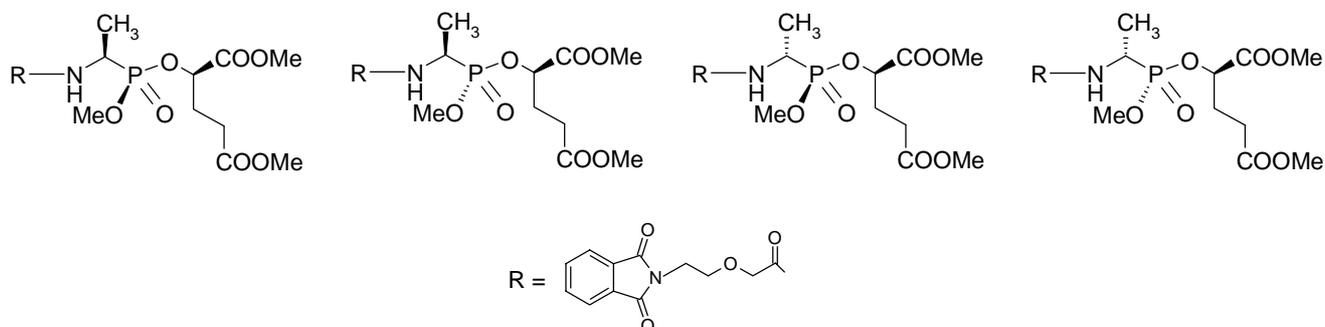
Conclusions

In summary, we present the synthesis of three new phosphorus desmuramyldipeptides related to LK 423. Efforts to separate mixtures of diastereomers and to evaluate each isomer in an *in vitro* immunological test are underway and will be published elsewhere. The immunological activities of these compounds will provide important information about the effects of the replacement of the planar peptide bond between Ala and Glu moieties with tetrahedral phosphonate and phosphonamidate esters to the activity of the series of phthalimido desmuramyldipeptides.

Experimental

General

All reagents and solvents were of commercial grade and used as such. Melting points were determined on a Reichert hot stage microscope and are uncorrected. Optical rotations were measured on a Perkin-Elmer 1241 MC polarimeter using a 1 dm cell. Elemental C, H, N analyses were performed at the Faculty of Chemistry and Chemical Engineering, University of Ljubljana, on a Perkin-Elmer elemental analyzer 240 C. IR spectra were obtained using a Perkin-Elmer FTIR 1600 instrument from KBr peletted samples. Mass spectra were obtained with a Micromass AutospecQ mass spectrometer using FAB ionization. NMR spectra were obtained on a Bruker Avance DPX 300 instrument. ^{1}H-NMR spectra were obtained at 300.13 MHz with tetramethylsilane as an internal standard and ^{31}P-NMR spectra at 121 MHz using H_3PO_4 as an external standard.

Methyl N-[[(1R,S)-1-(N-(benzyloxycarbonyl)amino)ethyl]methoxyphosphinyl]-D-isoglutaminate (**3**). To a stirred solution of methyl (1*R,S*)-1-(*N*-benzyloxycarbonyl)aminoethyl phosphonate (**1**) (3.50 g, 12.8 mmol) and methyl D-isoglutaminate hydrochloride (**2**) (2.52 g, 12.8 mmol) in dry DMF (40 mL), diphenylphosphorylazide (DPPA) (3.3 mL, 15.4 mmol) and triethylamine (Et$_3$N) (3.92 mL, 28.2 mmol) were added at 0 °C. Stirring was continued for 2 h at 0 °C and overnight at room temperature (r.t.). EtOAc (200 mL) was added and the solution extracted successively with 10% citric acid, H$_2$O, saturated NaHCO$_3$ solution, H$_2$O, and saturated NaCl solution (50 mL each). The organic phase was dried (anh. MgSO$_4$) and evaporated in vacuo. The oily residue was purified by column chromatography on silica gel, eluting with 5:1 CHCl$_3$ – MeOH to give the desired product **3** as a white powder. Yield: 25 %; m.p.: 171-172.5 °C; IR (KBr, cm^{-1}) 3412.1, 2947.7, 1740.1, 1692.0, 1665.6, 1537.7, 1440.2, 1324.9, 1253.9, 1212.8, 1106.4, 1045.0, 923.5, 798.6, 668.1; ^{1}H-NMR (DMSO-d$_6$) δ (ppm) = 1.2 (dd, J=7.3 Hz, J=16 Hz, 3H, CH$_3$), 1.70-1.88 (m, 2H, CH$_2$-β-Glu-NH$_2$), 2.28-2.39 (m, 2H, CH$_2$-γ-Glu-NH$_2$), 3.4-3.58 (m, 6H, 2OCH$_3$), 3.60-3.75 (m, 1H, CH), 3.75-3.92 (m, 1H, CH), 4.55-4.85 (m, 1H, PNH), 5.03 (s, 2H, PhC<u>H$_2$</u>), 7.06 (s, 1H, CONH$_2$), 7.30-7.50 (m, 7H, C$_6$H$_5$ + CONH$_2$ + NH); ^{31}P-NMR (DMSO-d$_6$) δ(ppm) = 31.62, 32.35; [α]$_D^{20}$=+16.58 (c=0.41, MeOH); FAB-MS m/z 416 (M+H)$^+$; Anal. Calc. For C$_{17}$H$_{25}$N$_3$O$_7$P: C, 49.16; H, 6.31; N, 10.12. Found: C, 48.93; H, 6.39; N, 10.09%.

Methyl N-[[(1R,S)-1-[N-(2-(2-phthalimidoethoxy)acetyl)amino]ethyl]methoxyphosphinyl]-D-isogluta-minate (**5**). To a solution of phosphonamidate **3** (0.415 g, 1 mmol) in dry methanol (20 mL) cooled to 0 °C was added 10% Pd/C (80 mg) and a balloon of hydrogen gas. The reaction was warmed to r.t. and stirred overnight. After filtration through a sintered glass funnel, the solvent was removed in vacuo. The colorless oil obtained was pure enough to be used in the next reaction step. To some of this free amine (0.270 g, 0.96 mmol) was added DMF (5 mL), (2-phthalimidoethoxy)acetic acid (**4**) (0.237 g, 0.96 mmol), DPPA (0.25 mL, 1.15 mmol) and Et$_3$N (0.29 mL, 2.11 mmol) at 0 °C while stirring. The

ice bath was removed after two hours and the reaction was stirred at r.t. overnight. EtOAc (70 mL) was added and the solution was extracted successively with 10% citric acid, H_2O, saturated $NaHCO_3$ solution, H_2O, and saturated NaCl solution (20 mL each), dried (anhydrous $MgSO_4$) and finnaly evaporated in vacuo. The oily residue was purified by column chromatography on silica gel, eluting with 7:1 $CHCl_3$ – MeOH to give the desired product **5** as a white solid. Yield: 81% (two steps); m.p.: 123-127 °C; IR (KBr, cm^{-1}) 3442.4, 1711.8, 1651.9, 1541.4, 1398.9, 1208.0, 1033.2, 797.1, 722.5; ^{1}H-NMR (DMSO-d_6) δ (ppm) = 1.10-1.25 (m, 3H, CH_3), 1.65-1.95 (m, 2H, CH_2-β-Glu-NH_2), 2.23-2.40 (m, 2H, CH_2-γ-iGln), 3.44-3.60 (m, 6H, $2OCH_3$), 3.68 (t, J=6 Hz, CH_2O), 3.80 (t, J=6 Hz, NCH_2), 4.08-4.25 (m, 2H, 2CH), 4.64-4.90 (m, 1H, PNH), 7.05 (s, 1H, $CONH_2$), 7.35 (s, 1H, $CONH_2$), 7.40-7.60 (m, 1H, NH), 7.80-7.88 (m, 4H, phthaloyl); ^{31}P-NMR (DMSO-d_6) δ(ppm) = 31.20, 31.35, 32.35; $[α]_D^{20}$=+15.40 (c=0.37, MeOH); FAB-MS m/z 513 $(M+H)^{+}$; Anal. Calc. For $C_{21}H_{29}N_4O_9P$: C, 49.22; H, 5.70; N, 10.93. Found: C, 48.95; H, 5.80; N, 10.64%.

Methyl (1R,S)-1-(N-(9-fluorenylmethoxycarbonyl)amino)ethyl phosphonate (**6**). Methyl (1*R*,*S*)-1-(*N*-benzyloxycarbonyl)aminoethyl phosphonate (**1**) (5.0 g, 18.0 mmol) was dissolved in dry MeOH (100 mL) and cooled to 0 °C. 10% Pd/C (0.5 g) and a balloon of hydrogen gas were added and the reaction mixture was stirred overnight at r.t. After filtration the solvent was removed on a rotary evaporator to give a white solid. Dioxane (70 mL), saturated $NaHCO_3$ (70 mL) and a solution of 9-fluorenylmethoxycarbonyl chloroformate (6 g, 23.4 mmol) in 50 mL of dioxane were then added and the solution was stirred overnight. The reaction mixture was diluted with water (50 mL) and acidified to pH 1. The precipitate was filtered off and dried in vacuo. Yield: 35% (two steps); lit [27]: 30%.

Dibenzyl N-[[(1R,S)-1-(N-(9-fluorenylmethoxycarbonyl)amino)ethyl]methoxyphosphinyl]-D-glutamate (**7**). To a solution of methyl (1*R*,*S*)-1-(*N*-(9-fluorenylmethoxycarbonyl)amino)ethyl phosphonate (**6**) (3.0 g, 8.31 mmol) in 30 mL CH_2Cl_2 at 0 °C, DMF (64 µL, 0.83 mmol) and oxalyl chloride (1.43 mL, 16.62 mmol) were added. The solution was stirred at 0 °C for 0.5 h and at r.t. for 1.5 h and the solvent was evaporated in vacuo. The residue was taken up in dry toluene and re-evaporated to remove volatile byproducts. The resulting crude phosphochloridate was dissolved in CH_2Cl_2 (50 mL), cooled to 0 °C and treated with Et_3N (2.89 mL, 20.77 mmol) followed by a solution of dibenzyl D-glutamate *p*-toluensulfonate (4.16 g, 8.31 mmol) in CH_2Cl_2. The reaction mixture was stirred overnight at r.t., the solvent was removed in vacuo and the residue was purified by column chromatography on silica gel, using 2:1 EtOAc – hexane as the eluent, giving pure **7** as a white solid. Yield: 86%; m.p.: 78.5-82 °C; IR (KBr, cm^{-1}) 3308.9, 2946.1, 1734.0, 168.8, 1540.1, 1450.7, 1316.4, 1252.7, 1211.6, 1046.1, 797.1, 739.8, 695.4; ^{1}H-NMR (DMSO-d_6) δ (ppm) = 1.20 (dd, 3H, J=7.3 Hz, J=16 Hz, CH_3), 1.75-1.90 (m, 2H, CH_2-β-Glu), 2.30-2.45 (m, 2H, CH_2-γ-Glu), 3.48 (d, 3H, J=11 Hz, $POCH_3$), 3.78-3.98 (m, 2H, 2CH), 4.15-4.35 (m, 3H, CH-fluorenyl + CO_2CH_2), 4.90-5.35 (m, 5H, 2<u>CH</u>$_2$Ph + PNH), 7.20-7.45 (m, 14H, $2C_6H_5$ + 4H-fluorenyl), 7.73 (t, 2H-fluorenyl, J=7.2 Hz), 7.88 (d, 2H-fluorenyl, J=7.5 Hz); ^{31}P-NMR (DMSO-d_6) δ(ppm) = 31.43, 31.47, 31.71, 31.76; $[α]_D^{20}$=+13.27 (c=0.446, MeOH); FAB-MS

m/z 671 (M+H)$^+$; Anal. Calc. For $C_{37}H_{39}N_2O_8P$: C, 66.24; H, 5.86; N, 4.18. Found: C, 66.41; H, 6.02; N, 4.02%.

Dibenzyl N-[[(1R,S)-1-(N-(5-phthalimidopentanoyl)amino)ethyl]methoxyphosphinyl]-D-glutamate (**9**). Phosphonamidate **7** (1.50 g, 2.24 mmol) was dissolved in DMF/CH_2Cl_2 (30:70, 15 mL) and diethyl-amine (3.49 mL, 33.6 mmol) was added. The reaction was stirred at r.t. for 2 h, the solvent was removed in vacuo and the residue suspended in Et_2O (40 mL). A solution of anhydrous oxalic acid (0.202 g, 2.24 mmol) in Et_2O (20 mL) was slowly poured into the stirred suspension and the mixture was chilled in a refrigerator overnight. The solvent was decanted and the resulting oil dissolved in $CHCl_3$ (80 mL). The solution was washed with 1M NaOH (20 mL) and brine (20 mL), dried (anh. $MgSO_4$) and evaporated to give the free amine as a brown oil, which was immediately used in the next reaction step. It was dissolved in dry DMF (7 mL) and 5-phthalimidopentanoic acid **8** (0.549 g, 2.24 mmol), and DPPA (0.6 mL, 2.69 mmol) and Et_3N (0.69 mL, 4.93 mmol) were added at 0 °C while stirring. The stirring was continued at 0 °C for 2 h and at r.t. overnight. EtOAc (100 mL) was added and the solution was extracted successively with 10% citric acid, water, saturated $NaHCO_3$ solution, water and saturated NaCl solution (20 mL each). The organic phase was dried (anh. Na_2SO_4), the solvent removed under reduced pressure and the residue was purified on a silica gel column using 30:1 EtOAc – MeOH as an eluent, to give pure compound **9** as a white wax. Yield: 48% (two steps); IR (KBr, cm^{-1}) 3303.9, 2941.5, 1710.3, 1642.6, 1532.2, 1532.2, 1398.4, 1209.0, 1039.4, 797.7, 719.4; ^{1}H-NMR (CDCl$_3$) δ (ppm) = 1.18-1.39 (m, 3H, CH$_3$), 1.60-1.80 (m, 4H, CH$_2$CH$_2$), 1.95-2.30 (m, 4H, CH$_2$CO + CH$_2$-β-Glu), 2.35-2.55 (m, 2H, CH$_2$-γ-Glu), 3.60-3.75 (m, 5H, NCH$_2$ + POCH$_3$), 4.00-4.15 (m, 1H, CH), 4.30-4.55 (m, 1H, CH), 5.05-5.20 (m, 5H, 2CH$_2$Ph + PNH), 7.20-7.40 (m, 11H, 2C$_6$H$_5$ + NH), 7.65-7.72 (m, 2H, phthaloyl), 7.78-7.84 (m, 2H, phthaloyl); ^{31}P-NMR (CDCl$_3$) δ (ppm) = 31.16, 32.44, 32.77; [α]$_D^{20}$=+2.95 (c=0.43, MeOH); FAB-MS m/z 678 (M+H)$^+$; Anal. Calc. For $C_{35}H_{40}N_3O_9P\times0.5H_2O$: C, 61.22; H, 6.02; N, 6.12. Found: C, 60.98; H, 5.96; N, 6.21%.

Dimethyl (2S)-2-[[(1R,S)-1-(N-(benzyloxycarbonyl)amino)ethyl]methoxyphosphinyloxy]glutarate (**13**). To a solution of monophosphonate **1** (0.88 g, 3.22 mmol), dimethyl (*S*)-2-hydroxyglutarate (**12**) (0.85 g, 4.83 mmol) and BOP reagent (2.04 g, 4.83 mmol) in DMF (7 mL), diisopropylethylamine (2.30 mL, 12.88 mmol) was added at r.t. under stirring. After 2h, DMF was evaporated under reduced pressure, the residue was dissolved in EtOAc (100 mL) and the solution was washed with a saturated $NaHCO_3$ solution. (3 x 10 mL) and brine (3 x 10 mL), dried (anh. Na_2SO_4), and the solvent removed under reduced pressure. The crude product was purified on a silica gel column using 2:1 EtOAc – hexane as an eluent, giving **13** as a colourless oil. Yield: 84 %; IR (KBr, cm^{-1}) 3258.1, 2955.7, 1736.2, 1533.9, 1440.7, 1232.3, 1044.8, 845.0; ^{1}H-NMR (CDCl$_3$) δ (ppm) = 1.36-1.48 (m, 3H, CH$_3$), 2.15-2.30 (m, 2H, CH$_2$-β-glutarate), 2.35-2.55 (m, 2H, CH$_2$-γ-glut.), 3.66-3.90 (m, 9H, 3OCH$_3$), 4.18-4.42 (m, 1H, CH), 4.90-5.05 (m, 1H, OCH), 5.15 (s, 2H, CH$_2$Ph), 5.36-5.72 (m, 1H, NH), 7.30-7.45 (m, 5H, C$_6$H$_5$); ^{31}P-NMR (CDCl$_3$) δ (ppm) = 27.19, 27.48, 27.88, 28.64; [α]$_D^{20}$=+26.01 (c=0.48, MeOH); FAB-MS

m/z 432 (M+H)$^+$; Anal. Calc. For $C_{18}H_{26}NO_9P$: C, 50.12; H, 6.08; N, 3.25. Found: C, 49.82; H, 6.22; N, 3.19%.

Dimethyl (2S)-2-[[(1R,S)-1-[N-(2-(2-phthalimidoethoxy)acetyl)amino]ethyl] methoxyphosphinyloxy]-glutarate (**14**). Mixed phosphonate **13** (0.64 g, 1.48 mmol) was dissolved in dry MeOH and hydrogenated over 10 % Pd/C at 40 psi for 18 h in a Parr hydrogenator. The catalyst was filtered off, the solvent was evaporated and the resulting free amine was immediately used in the next reaction step. It was dissolved in dry DMF, and 2-(2-phthalimdoethoxy)acetic acid (**4**) (1.48 mmol) was added followed by DPPA (0.38 mL, 1.78 mmol) and Et$_3$N (0.45 mL, 3.26 mmol) at 0 °C. After stirring for 2 h at this temperature, stirring was continued for 48 h at r.t. EtOAc (80 mL) was added and the solution was extracted successively with 10% citric acid, water, saturated NaHCO$_3$ solution, water and saturated NaCl solution (15 mL each). The organic phase was dried (anh. Na$_2$SO$_4$), the solvent removed under reduced pressure and the residue purified by column chromatography on silica gel using 15:1 CHCl$_3$ – MeOH as an eluent, yielding compound **14** as a white wax. Yield: 68 % (two steps); IR (KBr, cm^{-1}) 3484.5, 1713.9, 1649.3, 1541.3, 1394.2, 1152.0, 1014.4, 951.6, 722.3; ^{1}H-NMR (CDCl$_3$) δ (ppm) = 1.44 (dd, 3H, J=7.3, J=16 Hz, CH$_3$), 2.10-2.30 (m, 2H, CH$_2$-β-glut.), 2.35-2.52 (m, 2H, CH$_2$-γ-glut.), 3.66-3.88 (m, 11H, 3OCH$_3$ + NCH$_2$), 3.95-4.04 (m, 4H, CH$_2$O + OCH$_2$CO), 7.10-7.25 (m, 1H, NH), 7.80-7.90 (m, 2H, phthaloyl), 7.85-7.95 (m, 2H, phthaloyl); ^{31}P-NMR (CDCl$_3$) δ (ppm) = 27.78, 28.07, 28.98; $[\alpha]_D^{20}$ =+1.71 (c=0.41, MeOH); FAB-MS m/z 529 (M+H)$^+$; Anal. Calc. For $C_{22}H_{29}N_2O_{11}P$: C, 50.00; H, 5.53; N, 5.30. Found: C, 50.35; H, 5.42; N, 5.49%.

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Sample availability: Samples of compounds **5**, **7**, **9** and **14** are available from the authors.