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The Synthesis of *cis*- and *trans*-Fused Bicyclic Sugar Amino Acids

Martijn D. P. Risseeuw,[a] Gijsbert M. Grotenbreg,[a] Martin D. Witte,[a] Adriaan W. Tuin,[a] Michiel A. Leeuwenburgh,[a] Gijsbert A. Van der Marel,[a] Herman S. Overkleeft,[a] and Mark Overhand*[a]

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Four isomeric bicyclic sugar amino acids (SAAs) were prepared from α-acetylenic-*C*-glucoside **6** by employing a Petasis olefination and a ring-closing metathesis (RCM) as key steps. The applicability of the resulting SAAs in solid-phase peptide synthesis was demonstrated by the synthesis of tetrapeptide **36**.

Introduction

In recent years sugar amino acids (SAAs) have come to the fore as versatile building blocks in organic and bio-organic chemistry. SAAs combine the wealth of functional and stereochemical information inherent to carbohydrates with the ease with which oligomers can be prepared by peptide bond formation. They are now explored in various directions: in peptide chemistry,[1] with the aim of developing peptidomimetics with an advantageous conformational bias[2] and in carbohydrate chemistry, to arrive at linear and cyclic oligosaccharide analogues (for instance as potential receptor molecules and as templates in combinatorial library synthesis).[3] SAAs have added value for several reasons, including the limited conformational freedom caused by the parent carbohydrate ring and the available functional groups (apart from the amine and carboxylate) that are appended to the carbohydrate core. A large variety of SAA building blocks differing in structural backbone (ring size), stereochemistry, and functional group pattern have been described in the literature, and the list is continuously expanding.

A recently added feature in SAA design is to introduce additional conformational strain by the attachment of a second ring onto the carbohydrate core.[4] In this context, we previously reported the synthesis of two *cis*-fused, glucopyranose-based pyranopyran SAAs **1** and **2**, which have the amine functionality masked as an azide group.[4b] We here disclose full experimental detail for the synthesis of **1** and **2** (Figure 1). Further, the synthesis of the corresponding *trans*-fused pyranopyran SAAs **3** and **4** and the application of the latter in the synthesis of a hybrid peptide-SAA tetramer is presented.

Results and Discussion

The synthesis of pyranopyrans **1** and **2** commenced (Scheme 1) with 3,4,6-tri-*O*-benzyl-D-glucal **5**, which was converted into α-*C*-glycoside **6** following a literature procedure (dimethyldioxirane-mediated epoxidation of the glucal[5] followed by treatment with lithium phenylacetylide and zinc chloride).[6] Partial reduction of the triple bond using Lindlar's catalyst yielded the known glucoside **7** in quantitative yield. Alkylation of the hydroxy moiety with methyl bromoacetate gave compound **8** (95%),[7] which was treated with Petasis reagent[8] to provide enol ether **9**. Ensuing ring-closing metathesis (RCM) under the agency of the second generation Grubbs ruthenium catalyst[9] gave pyranopyran derivative **10** (88%). Hydrolysis of the enol ether moiety afforded ketone **11**, which was treated with L-selectride to give alcohol **12** as an inseparable mixture (*endo*/*exo*, 2:1).[10]

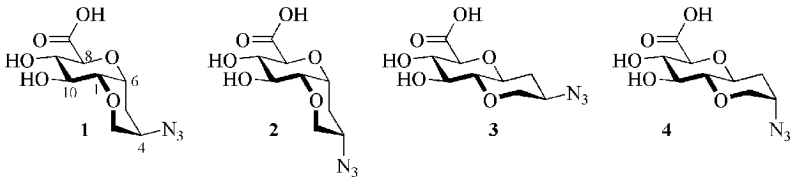


Figure 1. Four isomeric pyranopyran sugar amino acids.

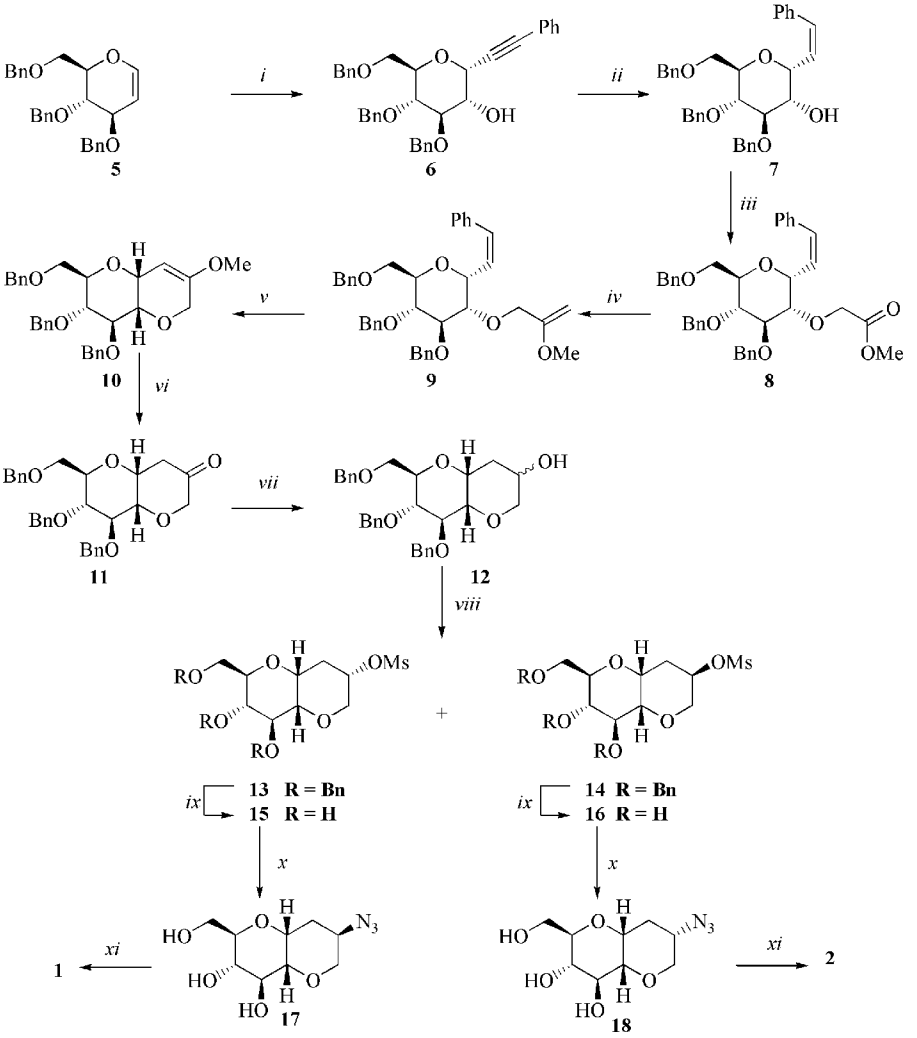
[a] Leiden Institute of Chemistry Gorlaeus Laboratories, P. O. Box 9502, 2300 RA Leiden, The Netherlands
E-mail: overhand@chem.leidenuniv.nl

The mixture of alcohols was converted into the corresponding mesylates **13** (40%) and **14** (25%), which at this stage could be separated. Mesylates **13** and **14** were converted into triols **15** and **16**, respectively. Introduction of the azide functionality was effected by treatment of the mesylates with sodium azide and 15-crown-5[11] in DMF at elevated temperature with concomitant reversal of configuration. SAAs **1** and **2** were generated from compounds **17** and **18**, respectively, through a selective TEMPO-mediated oxidation[12] of the primary hydroxy groups to their corresponding carboxylates (**1**: 53%, **2**: 52%). The configuration of the azide functionality at position 4 of compounds **1** and **2** was unambiguously assigned on the basis of NOESY NMR experiments.[4b]

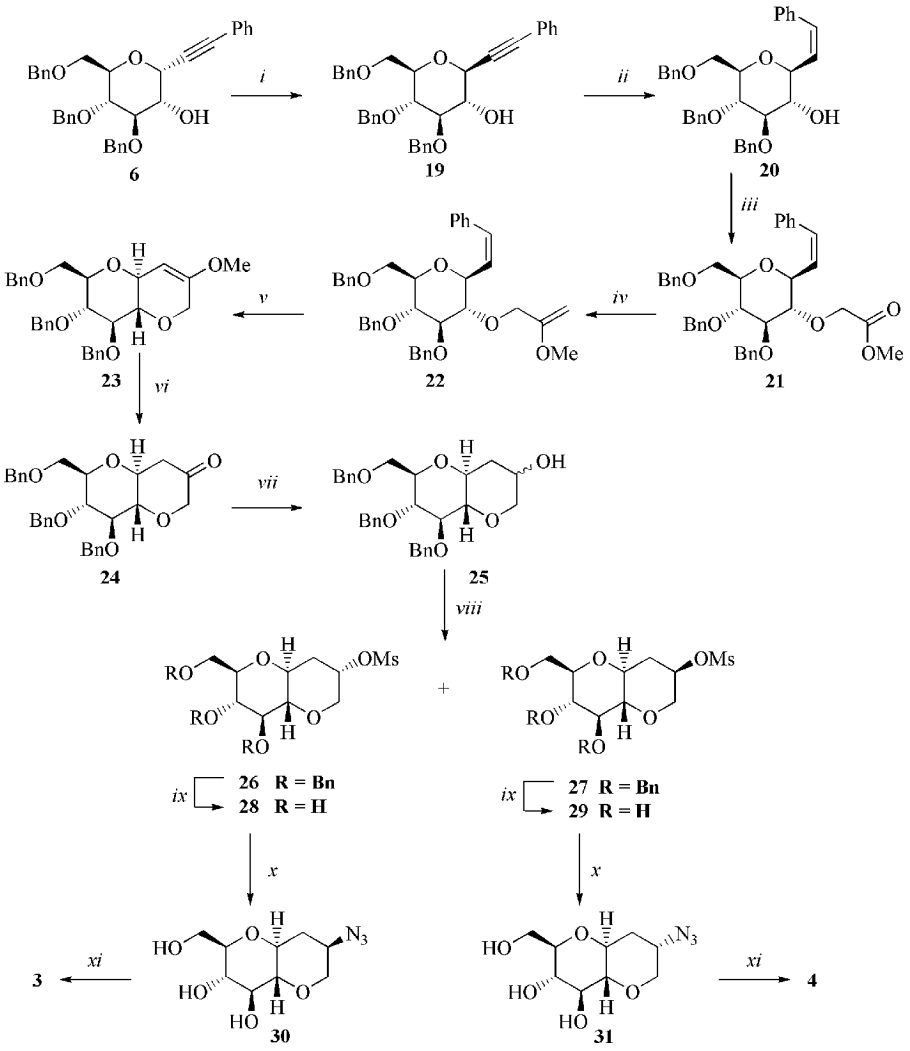
In order to access *trans*-fused pyranopyran SAAs **3** and **4** (Scheme 2) acetylenic α-glycoside **6** was epimerized into its corresponding β-glycoside **19** by using a three-step methodology originally developed by Isobe and coworkers[13] and applied by us in the synthesis of a series of fused oxacycles.[6]

Conversion of **19** into the target SAAs went uneventfully, following the same sequence of reactions as outlined for the synthesis of **1** and **2**. Thus, partial reduction of **19** followed by alkylation, Petasis olefination, and RCM gave cyclic enol ether **23**. Hydrolysis, reduction, and activation of the secondary hydroxy groups gave the corresponding mesylates **26** and **27**, which were separated on silica gel. From these, pyranopyran SAAs **3** and **4** were readily prepared by the three step procedure described above. The stereochemistry at position 4 of compounds **3** and **4** could be unmistakably assigned using the respective coupling constants of H-4 with that of its neighboring protons.

In the next stage, the compatibility of the *trans*-fused pyranopyran **4** with standard solid phase peptide synthesis techniques was ascertained by the synthesis of tetrapeptide **36**, as follows. The synthesis of the oligomer commenced



Scheme 1. Reagents and conditions: *i*) (a) dimethyldioxirane, acetone. (b) phenylacetylene, *n*BuLi, $ZnCl_2$, THF, –70 °C to room temp.[6] *ii*) H_2, Lindlar's catalyst, EtOAc.[6] *iii*) methyl bromoacetate, TBAI, NaH, DMF, 95%. *iv*) Cp_2TiMe_2, THF, 60 °C, 82%. *v*) dichlorido(1,3-dimesityl-2-imidazolidinylidene)(phenylmethylene)(tricyclohexylphosphane)ruthenium, CH_2Cl_2, reflux, 88%. *vi*) TFA, water, CH_2Cl_2, 92%. *vii*) L-selectride, THF, –78 °C to room temp., (*endo*/*exo* = 2:1). *viii*) MsCl, Et_3N, CH_2Cl_2, 0 °C, **13** 40%, **14** 25%, two steps. *ix*) H_2, Pd/C, EtOH, **15** quant., **16** quant. *x*) NaN_3, DMF, 70 °C, **17** 90%, **18** 94%. *xi*) TEMPO, NaOCl, $NaHCO_3$, MeCN, 0 °C, **1** 53%, **2** 52%.



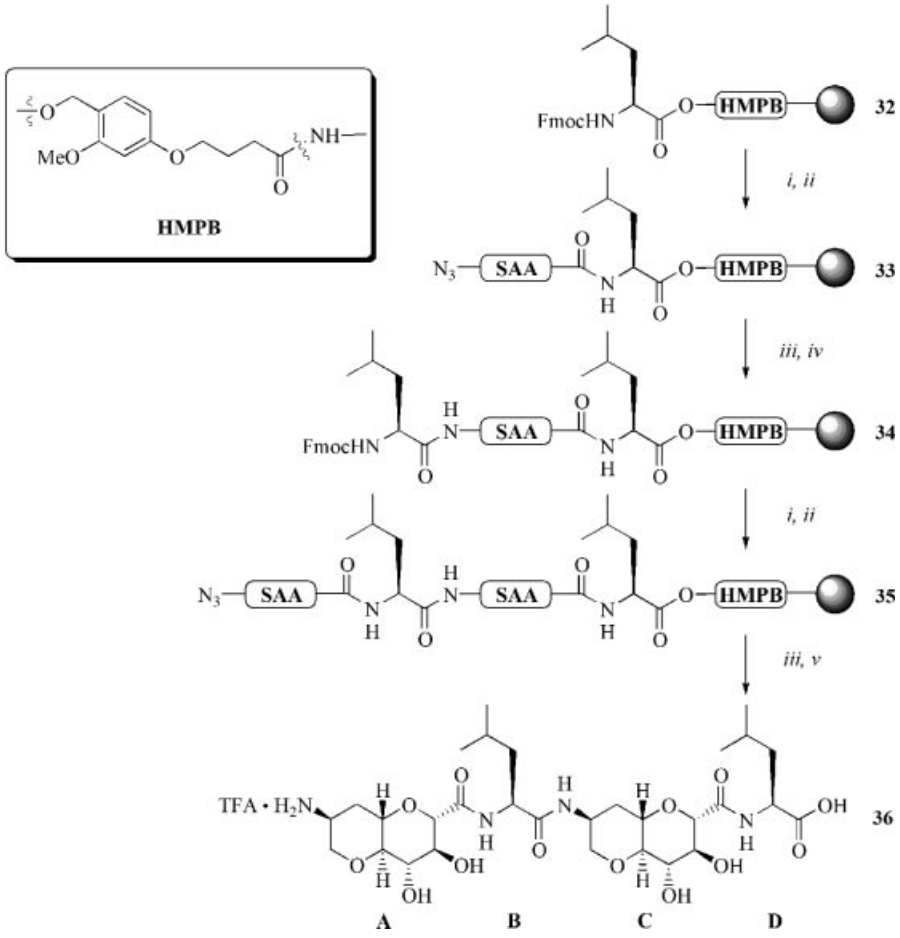
Scheme 2. Reagents and conditions: *i*) (a) $Co_2(CO)_8$, CH_2Cl_2. (b) TfOH, CH_2Cl_2. (c) I_2, THF.[6] *ii*) H_2, Lindlar's catalyst, EtOAc.[6] *iii*) methyl bromoacetate, TBAI, NaH, DMF, 87%. *iv*) Cp_2TiMe_2, THF, 60 °C, 72%. *v*) dichlorido(1,3-dimesityl-2-imidazolidinylidene)(phenylmethylene)(tricyclophosphane)ruthenium, CH_2Cl_2, reflux, 86%. *vi*) TFA, water, CH_2Cl_2, 90%. *vii*) L-selectride, THF, –78 °C to room temp. *viii*) MsCl, Et_3N, CH_2Cl_2, 0 °C, **26** 36%, **27** 43%, two steps, *ix*) H_2, Pd/C, EtOH, **28** quant, **29** 95%. *x*) NaN_3, DMF, 70 °C, **30** 70%, **31** 74%. *xi*) TEMPO, NaOCl, $NaHCO_3$, MeCN, 0 °C, **4** 49%, **3** 72%.

with Fmoc-leucine immobilized on HMPB-functionalized MBHA resin (Scheme 3). Removal of the Fmoc group under standard conditions and ensuing condensation with pyranopyran SAA **4** using PyBOP,[14] HOBt, and DIPEA as the condensation agents gave immobilized dipeptide **33**.[15] Staudinger reduction of the azide followed by condensation with Fmoc-Leu gave compound **34**. A second elongation cycle using SAA **4** led to immobilized tetrapeptide **35**. Reduction of the azide followed by acid-mediated cleavage gave the target tetrapeptide **36**, which was purified to homogeneity by reversed-phase HPLC (RP-HPLC) with an overall yield of 24% based on **32**.

In conclusion, we have demonstrated a flexible and productive synthesis of four pyranopyran SAA building blocks **1**, **2**, **3**, and **4** starting from a common intermediate, α-*C*-glucoside **6**. The conformational behavior of these SAAs when incorporated in oligomeric structures such as **36** is currently being investigated.

Experimental Section

All reactions were performed under an inert atmosphere and at ambient temperature unless stated otherwise. Reactions were monitored by TLC analysis using DC-fertigfolien (Schleicher & Schuell, F1500, LS254) with detection by spraying with H_2SO_4 in ethanol (20%) followed by charring at ≈ 150 °C or by spraying with a solution of $(NH_4)_6Mo_7O_{24}{\cdot}4H_2O$ (25 g/L) and $(NH_4)_4Ce(SO_4)_4{\cdot}2H_2O$ (10 g/L) in H_2SO_4 (10%) followed by charring at ≈ 150 °C. Column chromatography was performed on Merck silica gel (0.040–0.063 nm), and size exclusion chromatography was performed on Sephadex™ LH-20. Mass spectra were recorded with a PE/Sciex API 165 instrument with a custom-built electrospray ionization (ESI) interface and HRMS (SIM mode) were recorded with a TSQ Quantum (Thermo Finnigan) spectrometer fitted with an accurate mass option, interpolating between PEG calibration peaks. ^{1}H- and ^{13}C-APT-NMR spectra were recorded with a Bruker AV-400 (400/100 MHz) spectrometer equipped with a pulsed-field gradient accessory. Chemical shifts are given in ppm (δ) relative to tetramethylsilane as an internal standard (^{1}H NMR)



Scheme 3. Reagents and conditions: *i*) piperidine/NMP, 1:4 v/v. *ii*) **4**, PyBOP, HOBt, DIPEA, NMP. *iii*) (a) Me_3P, dioxane, (b) water, dioxane *iv*) FmocLeuOH, PyBOP, HOBt, DIPEA, NMP. *v*) TFA: CH_2Cl_2 1:99 v/v, **36** 24% (based on **32**).

or $CDCl_3$ (^{13}C NMR). Coupling constants are given in Hz. All presented ^{13}C-APT spectra are proton decoupled. The atomic numbering of bicyclic compounds was performed as described in Figure 1. Optical rotations were measured with a Propol automatic polarimeter (Sodium D line, λ = 589 nm) and attenuated total reflectance IR (ATR-IR) spectra were recorded with a Shimadzu FTIR-8300 spectrometer fitted with a single bounce DurasamplIR diamond crystal ATR-element. RP-HPLC was performed with a Gilson preparative HPLC system and a Phenomenex Gemini C18 column (150 × 21.2 mm).

General Procedure I: Alkylation of Carbohydrate Alcohols with Methyl Bromoacetate: To an anhydrous solution of the alcohol in DMF (0.1 M) were added methyl bromoacetate (3.0 equiv.) and tetrabutylammonium iodide (0.1 equiv.). After stirring for 5 min, sodium hydride (5.0 equiv.) was added in portions over a period of 4 h. Stirring was continued until TLC analysis showed no further progress of the reaction (16 h), and the mixture was partitioned between sat. aq. NH_4Cl and diethyl ether. The organic phase was washed with saturated aq. $NaHCO_3$ and brine, dried with $MgSO_4$, concentrated in vacuo, and applied to a silica column. Elution with a gradient of ethyl acetate (EtOAc) in light petroleum ether afforded the methyl ester. Recovered starting material was submitted to a second alkylation cycle as described above.

General Procedure II: Conversion of Esters into Enol Ethers Using Petasis Reagent: Cp_2TiMe_2 (1.5 equiv.) was added to a solution of the methyl ester in THF (0.15 M). The mixture was heated at reflux for 48 h with the exclusion of light. The reaction mixture was poured into light petroleum. The precipitate was removed by filtration and washed with light petroleum and ether. The filtrate was concentrated and purified by silica gel chromatography to provide the desired enol ether.

General Procedure III: RCM of Pyrans to Pyranopyrans: To an anhydrous solution of the enol ether in CH_2Cl_2 (0.07 M), dichlorido(1,3-dimesityl-2-imidazolidinylidene)(phenylmethylene)-(tricyclophosphane)ruthenium (0.05 equiv.) was added. The mixture was refluxed under a constant flow of argon until all starting material had disappeared, as determined by TLC analysis. Concentration of the crude mixture and purification by silica gel column chromatography using a gradient of light petroleum and EtOAc in toluene gave the product.

General Procedure IV: Acidic Hydrolysis of Pyranopyran Enol Ethers to Pyranopyranones: To a solution of the enol ether in CH_2Cl_2 (0.1 M) was added a mixture of TFA and water (3:7 (v/v), 0.5 mL·mmol^{-1} enol ether). After stirring for 30 min, the mixture was diluted twice with toluene and concentrated in vacuo. Chromatography of the residue on a silica column using a gradient of EtOAc in light petroleum yielded the ketone product.

General Procedure V: Conversion of Pyranopyranones to Methanesulfonyl Esters: A solution of the ketone in THF (0.15 M) was cooled to –78 °C before adding a solution of L-selectride in THF (1.0 M, 2.0 equiv.) over the period of 1 h. The solution was warmed

to ambient temperature, and stirring was continued for 16 h. The mixture was then quenched with saturated aq. NH_4Cl and extracted with EtOAc. The combined organic phase was dried with anhydrous $MgSO_4$, filtered, and concentrated to afford the intermediate product as an inseparable mixture of isomers, which was directly used without further purification. A solution of the isomeric mixture in CH_2Cl_2 (0.15 M) was made after thorough coevaporation with toluene. To this solution were added triethylamine (3.0 equiv.) and methanesulfonyl chloride (3.0 equiv.), and the reaction mixture was stirred for 4 h, until all starting material was converted into two higher-running spots as determined by TLC analysis. The solution was diluted with CH_2Cl_2, extracted with saturated aq. $NaHCO_3$ and brine. The organic layer was dried with $MgSO_4$ and concentrated in vacuo. Purification and separation of the epimeric methanesulfonyl esters could be effected by silica gel chromatography using a gradient of light petroleum and ethyl acetate.

General Procedure VI: Cleavage of Benzyl Ether Protecting Groups by Catalytic Reduction: To a solution of the benzylated methanesulfonyl ester in ethanol (0.1 M) was added a catalytic amount of 10% Pd/C. The reaction mixture was stirred under a constant stream of H_2(g) for 4 h, filtered through a path of diatomaceous earth, and concentrated to give the deprotected product.

General Procedure VII: Substitution of Methanesulfonyl Esters Using Sodium Azide: The mesylate was coevaporated twice with dry toluene before being dissolved in DMF (0.1 M). The solution was placed under an inert atmosphere, and sodium azide (5.0 equiv.) and 15-crown-5 (catalytic) were added. The mixture was stirred for 7 days at 70 °C. The mixture was concentrated under reduced pressure, redissolved in MeOH/CH_2Cl_2 (1:1 v/v), filtered, and concentrated before being applied to a Dowex-Na^+ column in order to remove 15-crown-5. Further purification was performed by silica gel column chromatography using a gradient of methanol in EtOAc.

General Procedure VIII: TEMPO Oxidation of the Primary Hydroxy Groups to Carboxylates: First, three solutions were prepared. Solution A: KBr in saturated aq. $NaHCO_3$ (5.0 mg·mL^{-1}). Solution B: 2,2,6,6-tetramethyl-1-piperidinyloxy free radical (TEMPO) in acetonitrile (1.0 mg·mL^{-1}). Solution C: a mixture of saturated aq. $NaHCO_3$, aq. NaOCl (15% w/w), and saturated aq. NaCl (5:8:9 v/v/v).

To a solution of the alcohol in saturated aq. $NaHCO_3$ (0.07 M) were added solution A and B (2.6 mL·mmol^{-1} each). Solution C was added dropwise, causing the color of the mixture to oscillate between yellowish and colorless. When TLC analysis revealed completion of the reaction, addition of solution C was terminated, and the reaction was quenched with MeOH, acidified to pH 7 with HCl (1.0 M) and extracted with CH_2Cl_2. Concentration of the aqueous layer yielded a crude product contaminated with inorganic salts, which were removed to a large extent by precipitation from MeOH. Removal of residual salts by HW-40 column chromatography yielded the acid.

α-D-Glucopyranosyl Derivative 8: 2-(3′,4′,6′-Tri-*O*-benzyl-α-D-glucopyranosyl)-(*Z*)-styrene **7**[6b] (12.9 g, 23 mmol) was treated according to General Procedure I to yield the title compound (13.2 g, 21.7 mmol, 95%) as a pale yellow oil. Silica gel chromatography: petroleum → petroleum/EtOAc, 1:1 v/v. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.55–7.13 (m, 20 H, $CH_{arom.}$ Bn, Ph), 6.86 (d, J = 11.9 Hz, 1 H, Ph-CH,), 6.01 (dd, J = 7.9, 11.9 Hz, 1 H, =CH–C$^{1'}$), 5.04 (ddd, J = 1.3, 7.9, 7.3 Hz, 1 H, H$^{1'}$), 4.99 (d, J = 10.9 Hz , 1 H, CH_2Bn), 4.87 (d, J = 10.9 Hz, 1 H, CH_2Bn), 4.85 (d, J = 10.7 Hz, 1 H, CH_2Bn), 4.62 (d, J = 12.2 Hz, 1 H, CH_2Bn), 4.51 (d, J = 10.7 Hz, 1 H, CH_2Bn), 4.45 (d, J = 12.2 Hz, 1 H, CH_2Bn), 4.19 (d, J = 16.3 Hz, 1 H, CH_2C=O), 4.12 (d, J = 16.3 Hz, 1 H, CH_2C=O), 3.97 (dd, $J_{3',2'} = J_{3',4'}$ = 8.9 Hz, 1 H, H$^{3'}$), 3.72 (m, 2 H, H$^{2'}$, H$^{4'}$), 3.68 (m, 2 H, H$^{5'}$, H$^{6'a}$), 3.58 (s, 3 H, OMe), 3.46 (dd, $J_{6'b,5'}$ = 3.5 Hz, $J_{6'b,6'a}$ = 12.3 Hz, 1 H, H$^{6'b}$) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 170.3 (C=O), 138.6, 138.2, 137.9 (C_q Bn), 137.4 (=CH–Ph), 135.9 (C_q Ph), 129.5, 128.4, 128.3, 128.1, 127.9, 127.7, 127.6 ($CH_{arom.}$ Bn, Ph), 124.4 (=CH–C$^{1'}$), 83.8 (C$^{3'}$), 81.3 (C$^{2'}$), 78.2 (C$^{4'}$), 75.5, 75.0, 73.4 (3×CH_2 Bn), 72.3 (C$^{5'}$), 69.8 (C$^{1'}$), 68.7 (C$^{6'}$), 68.5 (OCH_2C=O), 51.7 (OCH_3) ppm. ATR-IR (thin film): $\tilde{\nu}$ = 2862.2, 1755.1, 1496.7, 1452.3, 1436.9, 1361.7, 1211.2, 1137.9, 1095.5, 1028.0, 736.8, 698.2 cm^{-1}. $[\alpha]_D^{23}$ = +145.6 (c = 1.00, $CHCl_3$). MS (ESI): m/z = 631.4 [M + Na]$^+$. HRMS: calcd. for $C_{38}H_{40}O_7$H 609.2852, found 609.2852.

α-D-Glucopyranosyl Derivative 9: Methyl ester **8** (2.31 g, 3.8 mmol) was treated according to General Procedure II to yield the title compound (1.89 g, 3.12 mmol, 82%) as a colorless oil. Silica gel chromatography: petroleum → petroleum/EtOAc v/v, 19:1. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.53–7.14 (m, 20 H, $CH_{arom.}$ Bn, Ph), 6.86 (d, J = 11.8 Hz, 1 H, Ph-CH), 6.06 (dd, J = 11.8, 11.8 Hz, 1 H, =CH–C$^{1'}$), 5.00 (d, J = 10.8 Hz, 1 H, CH_2Bn), 4.86 (m, 1 H, H_1), 4.83 (d, J = 10.8 Hz, 1 H, CH_2Bn), 4.81 (d, J = 10.8 Hz, 1 H, CH_2Bn), 4.63 (d, J = 12.1 Hz, 1 H, CH_2Bn), 4.50 (d, J = 10.8 Hz, 1 H, CH_2Bn), 4.44 (d, J = 12.1 Hz, 1 H, CH_2Bn), 4.07 (m, 1 H, =CH_2), 4.01 (d, J = 12.5 Hz, 1 H, OCH_2C=), 3.96–3.76 (m, 3 H, H$^{3'}$, OCH_2C=, =CH_2), 3.79 (m, 1 H, H$^{2'}$), 3.75 (m, 1 H, H$^{4'}$), 3.69 (m, 2 H, H$^{5'}$, H$^{6'a}$), 3.50 (dd, $J_{6'b,5}$ = 3.5 Hz, $J_{6'b,6'a}$ = 12.3 Hz, 1 H, H$^{6'b}$), 3.30 (s, 3 H, OMe) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 159.9 (C=O), 138.8, 138.3, 137.9 (C_q Bn), 137.1 (=CH–Ph), 136.0 (C_q Ph), 129.4, 128.3, 128.2, 128.1, 128.0, 127.9, 127.8, 127.6, 127.5 ($CH_{arom.}$ Bn, Ph), 125.0 (=CH–C$^{1'}$), 84.0 (=CH_2), 82.7 (C$^{3'}$), 80.4 (C$^{2'}$), 78.1 (C$^{4'}$), 75.5, 75.0, 73.3 (3×CH_2 Bn), 72.2 (C$^{5'}$), 71.5 (OCH_2C=O), 69.7 (C$^{1'}$), 68.8 (C$^{6'}$), 54.6 (OCH_3) ppm. ATR-IR (thin film) $\tilde{\nu}$ = 2910.4, 1629.7, 1494.7, 1452.3, 1359.7, 1299.9, 1257.5, 1155.3, 1074.3, 1043.4, 1028.0, 810.0, 732.9, 694.3 cm^{-1}. $[\alpha]_D^{23}$ = +188.4 (c = 1.00, $CHCl_3$) MS (ESI): m/z = 629.6 [M + Na]$^+$. HRMS: calcd. for $C_{39}H_{42}O_6$Na 629.2879, found 629.2872.

(1*R*,6*R*,8*S*,9*S*,10*S*)-9,10-Bis(benzyloxy)-8-benzyloxymethyl-4-methoxy-2,7-dioxabicyclo[4.4.0]dec-4-ene (10): Enol ether **9** (0.66 g, 1.1 mmol) was treated according to General Procedure III to yield the title compound (0.49 g, 0.97 mmol, 88%) as a clear oil. Silica gel chromatography: petroleum/toluene, 1:1 → petroleum/EtOAc, 1:1. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.37–7.18 (m, 15 H, $CH_{arom.}$ Bn), 4.86 (d, J = 11.3 Hz, 1 H, CH_2Bn), 4.80 (d, J = 10.6 Hz, 1 H, CH_2Bn), 4.77 (d, J = 11.3 Hz, 1 H, CH_2Bn), 4.69 (m, 1 H, H^5), 4.66 (m, 1 H, H^6), 4.59 (d, J = 12.1 Hz, 1 H, CH_2Bn), 4.50 (d, J = 12.1 Hz, 2 H, 2×CH_2Bn), 3.99–3.88 (m, 3 H, H^1, H^3, H^{10}), 3.77–3.64 (m, 4 H, H^8, H^9, H^{11}), 3.55 (s, 3 H, OMe) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 156.4 (C^4), 138.5, 138.1 (C_q Bn), 128.3, 128.0, 127.8, 127.7, 127.6, ($CH_{arom.}$ Bn), 92.2 (C^5), 78.8, 76.6, 75.9, 72.6 (C^1, C^8, C^9, C^{10}) 74.6, 73.6, 73.4 (3× CH_2 Bn), 69.5 (C^{11}), 67.5 (C^6), 61.4 (C^3), 54.4 (OCH_3) ppm. ATR-IR (thin film) $\tilde{\nu}$ = 2910.6, 1672.2, 1496.7, 1452.3, 1355.9, 1224.7, 1174.6, 1093.6, 1072.3, 1026.1, 1004.8, 939.0, 846.7, 734.8, 696.3 cm^{-1}. $[\alpha]_D^{23}$ = +80.8 (c = 1.00, $CHCl_3$). MS (ESI): m/z = 526.6 [M + Na]$^+$, 541.4 [M + K]$^+$. HRMS: calcd. For $C_{31}H_{34}O_6$H 503.2434, found 503.2437.

(1*R*,6*R*,8*R*,9*S*,10*S*)-9,10-Bis(benzyloxy)-8-benzyloxymethyl-2,7-dioxabicyclo[4.4.0]decane-4-one (11): Enol ether **10** (0.97 g, 1.95 mmol) was treated according to General Procedure IV to yield the title compound (0.872 g, 1.79 mmol, 92%) as a colorless oil. Silica gel chromatography: petroleum/EtOAc, 9:1 → petroleum/

EtOAc, 3:2 v/v. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.35–7.24 (m, 15 H, $CH_{arom.}$ Bn), 4.82 (d, J = 11.2 Hz, 1 H, CH_2Bn), 4.80 (d, J = 11.6 Hz, 1 H, CH_2Bn), 4.75 (d, J = 11.6 Hz, 1 H, CH_2Bn), 4.53–4.47 (m, 3 H, H^6, 2 × CH_2Bn), 4.39 (d, J = 12.1 Hz, 1 H, CH_2Bn), 4.13 (d, J = 17.2 Hz, 1 H, H^{3a}), 3.95–3.85 (m, 3 H, H^1, H^{3b}, H^{10}), 3.84–3.78 (m, 2 H, H^8, H^9), 3.62 (dd, $J_{11a,8}$ = 3.6 Hz, $J_{11a,11b}$ = 10.5 Hz, 1 H, H^{11a}), 3.57 (dd, $J_{11b,8}$ = 2.6 Hz, $J_{11b,11a}$ = 10.5 Hz, 1 H, H^{11b}), 2.70 (d, J = 5.3 Hz, 2 H, H_5) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 207.7 (C^4), 138.0 (C_q Bn), 128.4, 128.1, 127.9, 127.8, 127.7, 127.6 ($CH_{arom.}$ Bn), 79.1, 77.7 (C^1, C^{10}), 75.4, 74.1 (C^8, C^9), 74.1, 73.5, 73.2 (3 × CH_2 Bn), 71.1 (C^3), 69.5 (C^{11}), 68.2 (C^6), 41.6 (C^5) ppm. ATR-IR (thin film) $\tilde{\nu}$ = 2866.0, 1735.8, 1496.7, 1454.2, 1363.6, 1207.4, 1089.7, 1028.0, 912.3, 736.8, 696.3 cm^{-1}. $[\alpha]_D^{23}$ = +32.2 (c = 1.00, $CHCl_3$), MS (ESI): m/z = 511.4 $[M + Na]^+$. HRMS: calcd. for $C_{30}H_{32}O_6H$ 489.2277, found 489.2276.

(1*R*,4*S*,6*R*,8*R*,9*S*,10*S*)-9,10-Bis(benzyloxy)-8-benzyloxymethyl-2,7-dioxabicyclo[4.4.0]decane-4-yl Methanesulfonate (13) and (1*R*,4*R*,6*R*,8*R*,9*S*,10*S*)-9,10-Bis(benzyloxy)-8-benzyloxymethyl-2,7-dioxabicyclo[4.4.0]decane-4-yl Methanesulfonate (14): Pyranopyranic ketone **11** (654 mg, 1.34 mmol) was treated according to General Procedure V to yield compounds **13** (301 mg, 0.53 mmol, 40%) and **14** (191 mg, 0.34 mmol, 25%) as transparent oils. Silica gel chromatography: petroleum → petroleum/EtOAc, 2:1 v/v.

Compound 13: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.37–7.16 (m, 15 H, $CH_{arom.}$ Bn), 4.81 (d, J = 11.4 Hz, 1 H, CH_2Bn), 4.79 (d, J = 10.9 Hz, 1 H, CH_2Bn), 4.75 (d, J = 11.4 Hz, 1 H, CH_2Bn), 4.69 (m, 1 H, H^4), 4.58 (d, J = 12.1 Hz, 1 H, CH_2Bn), 4.50 (d, J = 10.9 Hz, 1 H, CH_2Bn), 4.49 (d, J = 12.1 Hz, 1 H, CH_2Bn), 4.13 (m, 1 H, H^6), 3.98 (dd, $J_{10,1}$ = $J_{10,9}$ = 7.6 Hz, 1 H, H^{10}), 3.86 (dd, $J_{1,6}$ = 5.1 Hz, $J_{1,10}$ = 7.6 Hz, 1 H, H^1), 3.78–3.74 (m, 2 H, H^{3eq}, H^8), 3.69–3.63 (m, 3 H, H^9, H^{11}), 3.54 (dd, $J_{3ax,4}$ = 7.8 Hz, $J_{3ax,3eq}$ = 12.1 Hz, 1 H, H^{3ax}), 2.98 (s, 3 H, SO_3CH_3), 2.20–2.14 (m, 2 H, H^5) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 138.0, 137.9, 137.8 (C_q Bn), 128.3, 128.1, 127.9, 127.8, 127.7, 127.6 ($CH_{arom.}$ Bn), 77.2 (C^9), 77.1 (C^{10}), 75.3 (C^1), 74.4, 73.5, 73.4 (3 × CH_2 Bn), 72.9 (C^4), 72.4 (C^8), 69.1 (C^{11}), 67.5 (C^6), 64.1 (C^3), 38.7 (SO_3CH_3), 31.0 (C^5) ppm. ATR-IR (thin film) $\tilde{\nu}$ = 2871.8, 1496.7, 1454.2, 1355.9, 1209.3, 1174.6, 1093.6, 1070.4, 1028.0, 958.6, 937.3, 889.1, 864.1, 829.3, 738.7, 698.2 cm^{-1}. $[\alpha]_D^{23}$ = +62.6 (c = 1.00, $CHCl_3$). MS (ESI): m/z = 569.2 $[M + H]^+$, 591.2 $[M + Na]^+$. HRMS: calcd. for $C_{31}H_{36}O_8SH$ 569.2209, found 569.2192.

Compound 14: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.34–7.20 (m, 15 H, $CH_{arom.}$ Bn), 4.96 (m, 1 H, H^4), 4.75 (d, J = 11.4 Hz, 1 H, CH_2Bn), 4.69 (d, J = 11.6 Hz, 1 H, CH_2Bn), 4.62 (d, J = 11.6 Hz, 1 H, CH_2Bn), 4.56 (d, J = 12.1 Hz, 1 H, CH_2Bn), 4.53 (d, J = 11.4 Hz, 1 H, CH_2Bn), 4.48 (d, J = 12.1 Hz, 1 H, CH_2Bn), 4.22 (m, 1 H, H^6), 3.90 (dd, $J_{3ax,4}$ = 3.1 Hz, $J_{3ax,3eq}$ = 11.9, 1 H, H^{3ax}), 3.80 (m, 2 H, H^8, H^{10}), 3.73–3.66 (m, 3 H, H^1, H^9, H^{11a}), 3.60 (dd, $J_{11b,8}$ = 3.2 Hz, $J_{11b,11a}$ = 10.4 Hz, 1 H, H^{11b}), 3.47 (dd, $J_{3eq,4}$ = 7.2 Hz, $J_{3eq,3ax}$ = 11.9 Hz, 1 H, H^{3eq}), 3.02 (s, 3 H, SO_3CH_3), 2.32 (m, 1 H, H^{5ax}), 1.90 (m, 1 H, H^{5eq}) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 138.0, 137.9, 137.8 (C_q Bn), 128.4, 128.3, 127.9, 127.8, 127.7, 127.6 ($CH_{arom.}$ Bn), 77.9 (C^{10}), 76.1 (C^1), 74.5 (C^9), 73.7 (CH_2 Bn), 73.5, 73.4 (C^4, C^8), 73.3, 72.7 (2 × CH_2 Bn), 68.8 (C^{11}), 66.5 (C^3), 65.9 (C^6), 38.4 (SO_3CH_3), 32.3 (C^5) ppm. ATR-IR (thin film) $\tilde{\nu}$ = 2864.1, 1496.7, 1454.2, 1355.9, 1209.3, 1174.6, 1093.6, 1028.0, 1001.0, 958.6, 935.4, 891.1, 854.4, 738.7, 698.2 cm^{-1}. $[\alpha]_D^{23}$ = +44.6 (c = 1.00, $CHCl_3$). MS (ESI): m/z = 569.2 $[M + H]^+$, 591.2 $[M + Na]^+$. HRMS: calcd. for $C_{31}H_{36}O_8S$ 569.2209, found 569.2207.

(1*R*,4*S*,6*R*,8*R*,9*S*,10*S*)-9,10-Dihydroxy-8-hydroxymethyl-2,7-dioxabicyclo[4.4.0]decane-4-yl Methanesulfonate (15): Benzylated mesylate **13** (301 mg, 0.53 mmol) was treated according to General Procedure VI to yield the title compound (158 mg, 0.53 mmol, quantitative) as a colorless oil that solidified upon standing. ^{1}H NMR (400 MHz, $CD_3OD/CDCl_3$): δ = 4.73 (m, 1 H, H^4), 4.15 (m, 1 H, H^6), 4.02 (dd, $J_{10,1}$ = $J_{10,9}$ = 8.1 Hz, 1 H, H^{10}), 3.85 (dd, $J_{3eq,4}$ = 4.3 Hz, $J_{3eq,3ax}$ = 11.9 Hz, 1 H, H^{3eq}), 3.79 (d, J = 3.9 Hz, 2 H, H^{11}), 3.72 (dd, $J_{3ax,4}$ = 8.3 Hz, $J_{3ax,3eq}$ = 11.9 Hz, 1 H, H^{3ax}), 3.65 (m, 1 H, H^1), 3.59 (m, 1 H, H^8), 3.43 (dd, $J_{9,8}$ = $J_{9,10}$ = 8.1 Hz, 1 H, H^9), 3.11 (s, 3 H, SO_3CH_3), 2.24 (m, 2 H, H^5) ppm. ^{13}C NMR (100 MHz, $CD_3OD/CDCl_3$): δ = 74.5 (C^1, C^8), 73.2 (C^4), 70.0 (C^9), 67.3 (C^{10}), 67.0 (C^6), 63.2 (C^3), 61.2 (C^{11}), 38.0 (SO_3CH_3), 30.5 (C^5) ppm. ATR-IR (thin film) $\tilde{\nu}$ = 3332.8, 2937.4, 1346.2, 1272.9, 1172.6, 1083.9, 1035.7, 960.5, 896.8, 831.3 cm^{-1}. $[\alpha]_D^{23}$ = +47.6 (c = 1.00, 1/1 v/v MeOH/$CHCl_3$). MS (ESI): m/z = 298.9 $[M + H]^+$, 320.9 $[M + Na]^+$. HRMS: calcd. For $C_{10}H_{18}O_8SNH_4$ 316.1066, found 316.1044.

(1*R*,4*R*,6*R*,8*R*,9*S*,10*S*)-9,10-Dihydroxy-8-hydroxymethyl-2,7-dioxabicyclo[4.4.0]decane-4-yl Methanesulfonate (16): Benzylated mesylate **14** (191 mg, 0.34 mmol) was treated according to General Procedure VI to yield the title compound (101 mg, 0.34 mmol, quantitative) as a colorless oil that solidified upon standing. ^{1}H NMR (400 MHz, $CD_3OD/CDCl_3$): δ = 4.90 (m, 1 H, H^4), 4.19 (m, 1 H, H^6), 3.85 (dd, $J_{3ax,4}$ = 2.8 Hz, $J_{3ax,3eq}$ = 12.4 Hz, 1 H, H^{3ax}), 3.82 (dd, $J_{10,1}$ = $J_{10,9}$ = 7.6 Hz, 1 H, H^{10}), 3.66–3.61 (m, 2 H, H^{11}), 3.53 (dd, $J_{3eq,4}$ = 4.7 Hz, $J_{3eq,3ax}$ = 12.4 Hz, 1 H, H^{3eq}), 3.51 (m, 1 H, H^1), 3.47 (m, 1 H, H^8), 3.26 (dd, $J_{9,8}$ = $J_{9,10}$ = 7.6 Hz, 1 H, H^9), 3.02 (s, 3 H, SO_3CH_3), 2.27 (m, 1 H, H^{5ax}), 1.91 (m, 1 H, H^{5eq}) ppm. ^{13}C NMR (100 MHz, $CD_3OD/CDCl_3$): δ = 77.2 (C^1), 77.0 (C^4, C^8), 71.3 (C^9), 69.3 (C^{10}), 66.8 (C^6), 65.5 (C^3), 62.4 (C^{11}), 38.4 (SO_3CH_3), 31.4 (C^5) ppm. ATR-IR (thin film) $\tilde{\nu}$ = 3271.0, 2933.5, 1326.9, 1234.4, 1170.7, 1083.9, 1029.9, 933.5, 894.9, 875.6, 813.9, 771.5 cm^{-1}. $[\alpha]_D^{23}$ = +22.0 (c = 1.00, 1:1 v/v MeOH/$CHCl_3$). MS (ESI): m/z = 298.9 $[M + H]^+$, 320.9 $[M + Na]^+$ 619.1 $[2M + Na]^+$. HRMS: calcd. for $C_{10}H_{18}O_8SNH_4$ 316.1066, found 316.1087.

(1*R*,4*R*,6*R*,8*R*,9*S*,10*S*)-4-Azido-9,10-dihydroxy-8-hydroxymethyl-2,7-dioxabicyclo[4.4.0]decane (17): Mesylate **15** (56 mg, 0.19 mmol) was treated according to General Procedure VII to yield the title compound (42 mg, 0.17 mmol, 90%) as a pale yellow oil. Silica gel chromatography: EtOAc → EtOAc/MeOH, 4:1 v/v. ^{1}H NMR (400 MHz, $CD_3OD/CDCl_3$): δ = 4.27 (m, 1 H, H^6), 3.99 (dd, $J_{3ax,3eq}$ = 11.2 Hz, $J_{3ax,4}$ = 1.0 Hz, 1 H, H^{3ax}) 3.70–3.96 (m, 3 H, H^4, H^{11a}, H^{10}), 3.74–3.80 (m, 2 H, H^{11b}, H^8), 3.54 (dd, $J_{1,6}$ = 2.9 Hz $J_{1,10}$ = 5.5 Hz, 1 H, H^1), 3.51 (dd, $J_{9,8}$ = $J_{9,10}$ = 5.1 Hz, 1 H, H^9), 3.34 (dd, $J_{3eq,4}$ = 7.3 Hz, $J_{3ax,3eq}$ = 11.2 Hz, 1 H, H^{3eq}), 2.30 (m, 1 H, H^{5a}), 1.71 (m, 1 H, H^{5b}) ppm. ^{13}C NMR (100 MHz, $CD_3OD/CDCl_3$): δ = 77.0 (C^8), 75.8 (C^1), 69.2 (C^9), 67.6 (C^{10}), 66.9 (C^3), 64.1 (C^6), 61.4 (C^{11}), 53.8 (C^4), 31.4 (C^5) ppm. ATR-IR (thin film) $\tilde{\nu}$ = 3340.5, 2931.6, 2360.7, 2106.1, 2052.1, 1651.0, 1211.2, 1080.1, 1033.8, 879.5 cm^{-1}. $[\alpha]_D^{23}$ 66.5 (c = 1.00, $CHCl_3$) MS: m/z = 268.1 $[M + Na]^+$, 513.2 $(2M + Na)^+$ HRMS: calcd. For $C_9H_{15}N_3O_5Na$ 268.09094, found 268.09022

(1*R*,4*S*,6*R*,8*R*,9*S*,10*S*)-4-Azido-9,10-dihydroxy-8-hydroxymethyl-2,7-dioxabicyclo[4.4.0]decane (18): Mesylate **16** (171 mg, 0.57 mmol) was treated according to General Procedure VII to yield the title compound (133 mg, 0.54 mmol, 94%) as an oil. Silica gel chromatography: EtOAc → EtOAc/MeOH, 4:1 v/v. ^{1}H NMR (400 MHz, $CD_3OD/CDCl_3$): δ = 4.11 (m, 1 H, H^6), 4.00 (dd, $J_{10,1}$ = 9.2 Hz, $J_{10,9}$ = 8.5 Hz, 1 H, H^{10}) 3.70–3.80 (m, 2 H, H^{11}, H^{3eq}), 3.67 (dd, $J_{1,6}$ = 5.6 Hz $J_{1,10}$ = 9.2 Hz, 1 H, H^1) 3.57 (m, 2 H, H^4, H^8), 3.49 (dd, $J_{3ax,4}$ = 9.7 Hz, $J_{3ax,3eq}$ = 11.2 Hz, 1 H, H^{3ax}), 3.38 (dd, $J_{9,8}$ = $J_{9,10}$ = 8.5 Hz, 1 H, H^9), 2.13 (m, 1 H, H^{5eq}), 2.00 (m, 1 H, H^{5ax}) ppm. ^{13}C NMR (100 MHz, $CD_3OD/CDCl_3$): δ = 74.4

(C^1), 74.0 (C^8), 70.2 (C^9), 67.8 (C^6), 67.1 (C^{10}), 62.8 (C^3), 61.1(C^{11}), 54.7 (C^4), 29.1 (C^5) ppm. ATR-IR (thin film) $\tilde{\nu}$ = 3255.6, 2931.6, 2360.7, 1350.1, 1249.8, 1087.8, 1010.6, 925.8, 848.6 cm^{-1}. $[\alpha]_D^{23}$ = +116 (c = 1.00, MeOH) MS: m/z = 268.1 $[M+Na]^+$, 513.2 $(2M+Na)^+$

(1*R*,4*R*,6*R*,8*S*,9*S*,10*S*)-4-Azido-9,10-dihydroxy-2,7-dioxabicyclo-[4.4.0]decane-8-carboxylic Acid (1): Compound **17** (42 mg, 0.17 mmol) was treated according to General Procedure VIII to yield the title compound (23 mg, 0.09 mmol, 53%) as an oil. ^1H NMR (400 MHz, D_2O): δ = 4.49 (m, 1 H, H^6), 4.09 (d, $J_{8,9}$ = 5.3 Hz, 1 H, H^8), 4.05 (dd, $J_{10,9}$ = 5.5 Hz, $J_{10,1}$ = 5.9 Hz, 1 H, H^{10}), 4.02 (m, 2 H, H^{3ax}, H_4), 3.89 (dd, $J_{9,8}$ = 5.3 Hz, $J_{9,10}$ = 5.5 Hz, 1 H, H^9), 3.65 (dd, $J_{1,6}$ = 3.5 Hz, $J_{1,10}$ = 5.9 Hz, 1 H, H^1), 3.45 (ddd, $J_{3eq,5eq}$ = 1.7 Hz, $J_{3eq,4}$ = 7.8 Hz, $J_{3eq,3ax}$ = 12.4 Hz, 1 H, H^{3eq}), 2.37 (m, 1 H, H^{5ax}), 1.86 (m, 1 H, H^{5eq}) ppm. ^{13}C NMR (100 MHz, D_2O): δ = 177.3 (C=O), 76.8 (C^8) 75.2 (C^1), 70.9 (C^9), 67.6 (C^{10}), 66.7 (C^3), 66.0 (C^6), 54.9 (C^4), 30.7 (C^5) ppm. ATR-IR (thin film): $\tilde{\nu}$ = 3398.1, 2920.0, 2120.1, 1605.6, 1454.5, 1385.0, 1315.5, 1247.7, 1096.9, 1076.7, 1062.2, 1001.4, 947.7, 923.1, 879.9, 811.4 cm^{-1}. $[\alpha]_D^{23}$ = +39.0 (c = 1.00, $CHCl_3$) MS (ESI): m/z = 260.0 $[M+H]^+$, 282.1 $[M+Na]^+$, 541.1 $[2M+Na]^+$. HRMS: calcd. For $C_9H_{13}N_3O_6Na$ 282.07020, found 282.06943

(1*R*,4*S*,6*R*,8*S*,9*S*,10*S*)-4-Azido-9,10-dihydroxy-2,7-dioxabicyclo-[4.4.0]decane-8-carboxylic Acid (2): Compound **18** (133 mg, 0.54 mmol) was treated according to General Procedure VIII to yield the title compound (73 mg, 0.28 mmol, 52%) as an oil. ^1H NMR (400 MHz, D_2O): δ = 4.31 (m, 1 H, H^6), 4.10 (d, $J_{8,9}$ = 5.8 Hz, 1 H, H^8), 4.07 (dd, $J_{10,9}$ = 6.1 Hz, $J_{10,1}$ = 6.3 Hz, 1 H, H^{10}), 3.83 (dd, $J_{9,8}$ = 5.8 Hz, $J_{9,10}$ = 6.1 Hz, 1 H, H^9), 3.78 (m, 3 H, H^3, H^4), 3.70 (dd, $J_{1,6}$ = 3.8 Hz, $J_{1,10}$ = 6.3 Hz, 1 H, H^1), 2.15 (m, 2 H, H^5) ppm. ^{13}C NMR (100 MHz, D_2O): δ = 177.4 (C=O), 76.7 (C^8) 75.6 (C^1), 71.5 (C^9), 68.2 (C^{10}), 66.8 (C^3, C^6), 55.2 (C^4), 30.3 (C^5) ppm. ATR-IR (thin film): $\tilde{\nu}$ = 3353.3, 2955.6, 2955.6, 2924.6, 2853.7, 2102.1, 1606.7, 1370.7, 1271.5, 1246.9, 1116.3, 1077.8, 1008.8. 967.4, 941.3 cm^{-1} $[\alpha]_D^{23}$ = +68.0 (c = 1.00, $CHCl_3$). MS (ESI): m/z = 260.0 $[M+H]^+$, 282.1 $[M+Na]^+$.

β-D-Glucopyranosyl Derivative 21: 2-(3′,4′,6′-Tri-*O*-benzyl-β-D-glucopyranosyl)-Z-styrene (**20**)[6b] (6.40 g, 11.9 mmol) was treated according to General Procedure I to yield the title compound (6.34 g, 10.4 mmol, 87%) as a colorless oil. Silica gel chromatography: petroleum → petroleum/EtOAc, 1:1 v/v ^1H NMR (400 MHz, $CDCl_3$): δ = 7.33–7.13 (m, 20 H, $H_{arom.}$), 6.83–6.80 (d,J = 11.6 Hz, 1 H, PhCH), 5.79–5.74 (dd, J = 11.6 Hz, J = 9.1 Hz, 1 H, =CHC$^{1'}$), 4.96–4.93(d, J = 11.1 Hz, 1 H, CH_2Bn), 4.89–4.86 (d, J = 11.1 Hz, 1 H, CH_2Bn), 4.82–4.79 (d, J = 11.0 Hz, 1 H, CH_2Bn), 4.62–4.59 (d, J = 12.1 Hz, 1 H, CH_2Bn), 4.55–4.52 (d, J = 11.0 Hz, 1 H, CH_2Bn), 4.52–4.49 (d, J = 12.1 Hz, 1 H, CH_2Bn), 4.43–4.38 (d, J = 15.6 Hz, 1 H, CH_2C=O), 4.31–4.27 (d, J = 15.6 Hz, 1 H, CH_2C=O), 4.22 (dd, $J_{1',2'}$ = 9.3 Hz, $J_{1',CHC}{}^1$ = 9.1 Hz, 1 H, H$^{1'}$), 3.73–3.65 (m, 2 H, OCH, 2 H, H$^{6'}$), 3.64 (s, 3 H, OMe), 3.45 (m, $J_{2',1'}$ = 9.3 Hz, 1 H, OCH, t, $J_{2',3'}$ = 8.9 Hz, 1 H, H$^{2'}$) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 170.0 (C=O), 138.7, 138.1 (C_qBn), 136.2 (C_qPh), 135.4 (=CH–C$^{1'}$), 129.0–127.6 (CH_{arom} = CH–Ph), 86.3 (C$^{2'}$), 83.7, 78.3, 77.9 (3×OCH), 75.5, 75.3 (2× CH_2Bn), 74.9 (C$^{1'}$), 73.5 (CH_2Bn), 69.9 (CH_2C=O), 69.1 (C$^{6'}$) 51.7 (OMe) ppm. ATR-IR (thin film): $\tilde{\nu}$ = 3030.0, 2860.2, 1760.9, 1739.7, 1496.7, 1454.2, 1436.9, 1361.7, 1209.3, 1099.3, 1056.9, 1028.0, 985.6, 912.3, 736.8, 698.2, 648.0, 621.0 cm^{-1}. $[\alpha]_D^{23}$ = +67.2 (c = 1.00, $CHCl_3$). MS (ESI): m/z = 631.5 $[M+Na]^+$. HRMS: calcd. for $C_{38}H_{40}O_7Na$ 631.2666, found 631.2673 $[M+Na]^+$.

β-D-Glucopyranosyl Derivative 22: Compound **21** (6.34 g, 10.4 mmol) was treated according to General Procedure II to yield the title compound (4.57 g, 7.5 mmol, 72%). Silica gel chromatography: petroleum → petroleum/EtOAc v/v, 19:1. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.47–7.13 (m, 20 H, H_{arom}), 6.80–6.77 (d, J = 11.6 Hz, 1 H, =CH–C$^{1'}$), 5.75–5.70 (dd, J = 11.6 Hz, J = 9.2 Hz, 1 H, =CH–Ph), 5.02–5.00 (d, J = 10.8 Hz, 1 H, CH_2Bn), 4.84–4.83 (d, J = 3.9 Hz, 1 H, CH_2Bn), 4.81–4.80 (d, J = 3.9 Hz, 1 H, CH_2Bn), 4.60–4.57 (d, J = 12.5 Hz, 1 H, CH_2Bn), 4.54–4.51(d, J = 10.8 Hz, 1 H, CH_2Bn), 4.50–4.47 (d, J = 12.5 Hz, 1 H, CH_2Bn), 4.23–4.18 (dd, $J_{1,\ =CH-C}{}^{1'}$ = $J_{1',2'}$ = 9.2 Hz, 1 H, H$^{1'}$), 4.18 (s, 2 H, CH_2C=), 4.15–4.14 (dd, J = 2.2 Hz, 1 H, =CH_2), 4.01–4.00 (dd, J = 2.2 Hz, 1 H, =CH_2), 3.71–3.64 (m, 4 H, H$^{3'}$, H$^{4'}$, H$^{6'}$), 3.45 (s, 3 H, OMe), 3.50–3.39 (m, 2 H, H$^{2'}$, H$^{5'}$) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 160.1 [=C(OMe)], 138.8, 138.2, 138.1 (C_qBn), 136.2 (C_qPh), 134. (=CH–C$^{1'}$), 129.0–127.3 (CH_{arom} = CH–Ph), 86.4 (C$^{3'}$), 83.8 (=CH_2),82.8, (C$^{2'}$), 78.3, 78.0 (C$^{4'}$,C$^{5'}$), 75.4, 74.8 (2×CH_2Bn), 74.8 (C$^{1''}$), 73.4 (CH_2 Bn), 73.1 (C$^{1''}$), 69.1 (C^6) 54.6 (OMe) ppm. ATR-IR (thin film): $\tilde{\nu}$ = 1496.7, 1452.3, 1361.7, 1299.9, 1257.5, 1207.4, 1056.9, 1028.0, 1001.0, 950.8, 910.3, 810.0, 775.3, 732.9, 694.3, 650.0, 619.1 cm^{-1}. $[\alpha]_D^{23}$ = +73.6 (c = 1.00, $CHCl_3$). HRMS: calcd. For $C_{39}H_{46}O_6N_1$ 624.33251, found 624.33869.

(1*R*,6*S*,8*R*,9*S*,10*S*)-9,10-Bis(benzyloxy)-8-benzyloxymethyl-4-methoxy-2,7-dioxabicyclo[4.4.0]dec-4-ene (23): Compound **22** (172 mg, 0.28 mmol) was treated according to General Procedure III to yield the title compound (121 mg, 0.24 mmol, 86%) as an oil. Silica gel chromatography: petroleum/toluene, 1:1 → petroleum/EtOAc, 1:1. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.39–7.10 (m, 15 H, H_{arom}), 5.00–4.97 (d, J = 11.5 Hz, 1 H, CH_2Bn), 4.87 (m, 1 H, H^5), 4.87–4.85 (d, J = 10.8 Hz, 1 H, CH_2Bn), 4.78–4.75 (d, J = 11.5 Hz, 1 H, CH_2Bn), 4.61–4.58 (d, J = 12.3 Hz, 1 H, CH_2Bn), 4.54–4.51 (d, J = 12.3 Hz, 1 H, CH_2Bn), 4.48–4.45 (d, J = 10.8 Hz, 1 H, CH_2Bn), 4.16–4.13 (dt, J = 15.1 Hz, J = 2.1 Hz, 1 H, H^3), 4.07–4.03 (dt, J = 15.1 Hz, 1 H, H^3), 3.92–3.90 (dd, J = 8.7 Hz, J = 2.1 Hz, 1 H, H^6), 3.74–3.58 (m, H^8, H^9, H^{10}, H^{11}), 3.56 (s, 3 H, OMe), 3.31–3.26 (t, J = 9.1 Hz, 1 H, H_1) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 155.6 (C^4), 138.8, 138.1, 138.0 (C_q Bn), 128.3–127.5 ($CH_{arom}Bn$), 93.6 (C^5), 83.6 (OCH), 80.1 (C^1), 79.3, 78.1 (2× OCH), 75.1, 74.7 (2× CH_2 Bn), 73.4 (CH_2 Bn), 72.8 (C^6), 69.2 (C^{11}), 65.7(C^3) 54.5 (OMe) ppm. ATR-IR (thin film): $\tilde{\nu}$ = 3030.0, 2862.2, 1728.1, 1703.0, 1668.3, 1618.2, 1496.7, 1452.3, 1357.8, 1315.4, 1271.0, 1228.6, 1207.4, 1091.6, 1076.2, 1056.9, 1026.1, 908.4, 792.7, 729.0, 696.3, 669.3, 648.0 cm^{-1}. $[\alpha]_D^{23}$ = +20.2 (c = 1.00, $CHCl_3$). MS (ESI): m/z = 525.2 $[M+Na]^+$. HRMS: calcd. for $C_{31}H_{34}O_6Na$ 525.2247, found 525.2255.

(1*R*,6*S*,8*R*,9*S*,10*S*)-9,10-Bis(benzyloxy)-8-benzyloxymethyl-2,7-dioxabicyclo[4.4.0]decane-4-one (24): Enol ether **23** (3.24 g, 6.45 mmol) was treated according to General Procedure IV to yield the title compound (2.84 g, 5.8 mmol, 90%) as an oil. Silica gel chromatography: petroleum/EtOAc, 9:1 → petroleum/EtOAc, 3:2 v/v. ^1H NMR (400 MHz, $CDCl_3$): δ = 7.35–7.13 (m, 15 H, H_{arom}), 4.96–4.93 (d, J = 11.5 Hz, 1 H, CH_2Bn), 4.88–4.85 (d, J = 10.8 Hz, 1 H, CH_2Bn), 4.80–4.77 (d, J = 11.5 Hz, 1 H, CH_2Bn), 4.60–4.57 (d, J = 12.2 Hz, 1 H, CH_2Bn), 4.53–4.50 (d, J = 12.2 Hz, 1 H, CH_2Bn), 4.53–4.50 (d, J = 10.8 Hz, 1 H, CH_2Bn), 4.17–4.11 (dd, $J_{3eq,3ax}$ = 16.2, $J_{3eq,5eq}$ = 1.8 Hz, 1 H, H^{3eq}), 3.94–3.90 (d, $J_{3ax,3eq}$ = 16.2 Hz, 1 H, H^{3ax}), 3.72–3.65 (m, 4 H, 2×OCH, H^{11}), 3.56–3.51 (m, 2 H, H^6, OCH), 3.44–3.41 (t, 1 H, H^1), 3.03–2.98 (m, $J_{5eq,5ax}$ = 16.6 Hz, $J_{5eq,6}$ = 5.7 Hz, $J_{5eq,3eq}$ = 1.8 Hz, 1 H, H^{5eq}), 2.55–2.48 (dd, $J_{5ax,5eq}$ = 16.6 Hz, $J_{5ax,6}$ = 11.2 Hz, 1 H, H^{5ax}) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 204.4 (C^4), 138.5, 138.0, 137.8 (C_qBn), 128.5–127.6 ($CH_{arom}Bn$), 83.9 (OCH), 81.0 (C^1), 79.1, 77.28 (2×OCH), 75.2, 75.0 (2× CH_2Bn), 73.9 (C^3), 73.5 (CH_2Bn), 73.3 (C^6), 68.8 (C^{11}), 44.7 (C^5) ppm. ATR-IR (thin film): $\tilde{\nu}$ =

3030.0, 2866.0, 1730.0, 1496.7, 1452.3, 1363.6, 1315.4, 1272.9, 1234.4, 1207.4, 1139.9, 1095.5, 1074.3, 1058.8, 1028.0, 966.3, 935.4, 910.3, 881.4, 819.7, 734.8, 696.3, 638.4 cm^{-1}. $[\alpha]_D^{23}$ = +15.4 (*c* = 1.00, $CHCl_3$). MS (ESI): *m/z* = 511.3 $[M+Na]^+$. HRMS: calcd. for $C_{30}H_{32}O_6Na$ 511.2091, found 511.2122.

(1*R*,4*S*,6*S*,8*R*,9*S*,10*S*)-9,10-Bis(benzyloxy)-8-benzyloxymethyl-2,7-dioxabicyclo[4.4.0]decane-4-yl Methanesulfonate (26) and (1*R*,4*R*,6*S*,8*R*,9*S*,10*S*)-9,10-Bis(benzyloxy)-8-benzyloxymethyl-2,7-dioxa-bicyclo[4.4.0]decane-4-yl Methanesulfonate (27): Compound **24** (2.84 g, 5.8 mmol) was treated according to General Procedure V to yield compounds **26** (1.18 g, 2.1 mmol,36%) and **27** (1.44 g, 2.52 mmol, 43%) as transparent oils. Silica gel chromatography: petroleum → petroleum/EtOAc, 2:1 v/v.

Compound 26: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.35–7.13(m, 15 H, CH Bn), 4.99 (m, 1 H, H_4), 4.97–4.95 (d, *J* = 11.2 Hz, 1 H, CH_2Bn), 4.86–4.84(d, *J* = 10.7 Hz, 1 H, CH_2Bn), 4.78–4.75 (d, *J* = 10.7 Hz, 1 H, CH_2Bn), 4.61–4.58 (d, *J* = 12.2 Hz, 1 H, CH_2Bn), 4.50–4.47 (d, *J* = 11.2 Hz, 1 H, CH_2Bn), 4.53–4.50 (d, *J* = 12.2 Hz, 1 H, CH_2Bn), 4.20–4.16 (ddd, $J_{3eq,3ax}$ = 13.3 Hz, $J_{3eq,4}$ = $J_{3eq,5eq}$ = 2.5 Hz, 1 H, H^{3eq}), 3.72–3.66 (m, 2 H, H^{11}, 1 H, OCH), 3.63–3.58 (m, 1 H, H^{3ax}, 1 H, OCH), 3.54–3.49 (ddd, $J_{6,5ax}$ = 11.6 Hz, $J_{6,1}$ = 9.2 Hz, $J_{6,5eq}$ = 4.8 Hz, 1 H, H^6, m, 1 H, OCH), 3.20–3.15 (dd, $J_{1,6}$ = $J_{1,10}$ = 9.2 Hz, 1 H, H^1), 3.07 (s, 3 H, OMs), 2.54–2.51 (m, $J_{5eq,5ax}$ = 14.1 Hz, $J_{5eq,6}$ = 4.6 Hz, $J_{5eq,4}$ = $J_{5eq,3eq}$ = 2.5 Hz, 1 H, H^{5eq}), 1.87–1.80 (ddd, $J_{5ax,5eq}$ = 14.1 Hz, $J_{5ax,6}$ = 11.4 Hz, $J_{5ax,4}$ = 3.2 Hz, 1 H, H^{5ax}) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 138.7, 138.0, 137.9 (C_q Bn), 128.3–127.5 (CH Bn), 83.8 (OCH), 82.6 (C^1), 79.3 (OCH), 77.6 (OCH), 75.9(C^4), 75.2, 75.1, 73.6 (3×CH_2 Bn), 70.4 (C^6) 69.6 (C^3), 68.9 (C^{11}), 38.9 (OMs), 364.3 (C^5) ppm. ATR-IR (thin film): $\tilde{\nu}$ = 3031.9, 2869.9, 1450.4, 1357.8, 1172.6, 1095.5, 925.8, 864.1, 740.6, 702.0 cm^{-1}. $[\alpha]_D^{23}$ = +9 (*c* = 1.00, $CHCl_3$). MS (ESI): *m/z* = 591.6 $[M+Na]^+$. HRMS: calcd. for $C_{31}H_{36}O_8SNa$ 591.2023, found 591.1975.

Compound 27: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.35–7.11 (m, 15 H, H_{arom}), 4.93–4.91(d, *J* = 11.3 Hz, 1 H, CH_2Bn), 4.86–4.83 (d, *J* = 10.6 Hz, 1 H, CH_2Bn), 4.75–4.72 (d, *J* = 11.3 Hz, 1 H, CH_2Bn), 4.72–4.65 (m, 1 H, H^4), 4.61–4.58 (d, *J* = 12.2 Hz, 1 H, CH_2Bn), 4.53–4.50 (d, *J* = 12.2 Hz, 1 H, CH_2Bn), 4.49–4.47 (d, *J* = 10.6 Hz, 1 H, CH_2Bn), 4.24–4.20 (ddd, $J_{3eq,3ax}$ = 10.8 Hz, $J_{3eq,4}$ = 5.3 Hz, $J_{3eq,5eq}$ = 1.7 Hz, 1 H, H^{3eq}), 3.77–3.57 (m, 4 H, H^{11}, H^{10}, H^8), 3.49–3.44 (m, 1 H, H^9), 3.35–3.29 (t, $J_{3ax,3eq}$ = $J_{3ax,4}$ = 10.8 Hz, 1 H, H^{3ax}), 3.21–3.09 (ddd, 1 H, H^6, m, 1 H, H^1), 3.03 (s, 3 H, OMs), 2.66–2.63 (m, $J_{5eq,5ax}$ = 11.2 Hz, $J_{5eq,4}$ = $J_{5eq,6}$ = 4.3 Hz, $J_{5eq,3}$ = 1.7 Hz, 1 H, H^{5eq}), 1.80–1.77 (dd, $J_{5ax,5eq}$ = $J_{5ax,4}$ = $J_{5ax,6}$ = 11.2 Hz, 1 H, H^{5ax}) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 138.6, 138.0, 137.9 (C_q Bn), 129.0–127.6 (CH Bn), 83.7 (C^8/C^{10}), 82.1 (C^1), 79.4 (C^9), 77.4 (C^8/C^{10}), 75.2, 75.0, 73.6 (3×CH_2 Bn), 73.1 (C^6) 72.6(C^4), 69.0 (C^3), 68.8 (C^{11}), 38.6 (OMs), 36.0 (C^5) ppm. ATR-IR (thin film): $\tilde{\nu}$ = 1357.8, 1172.6, 1080.1, 956.6, 840.9, 740.6, 702.2 cm^{-1}. $[\alpha]_D^{23}$ = +8.2 (*c* = 1.00, $CHCl_3$). MS (ESI): *m/z* = 591.3 $[M+Na]^+$. HRMS: calcd. for $C_{31}H_{36}O_8SNa$ 591.2023, found 591.1977.

(1*R*,4*S*,6*S*,8*R*,9*S*,10*S*)-9,10-Dihydroxy-8-hydroxymethyl-2,7-dioxabicyclo[4.4.0]decane-4-yl Methanesulfonate (28): Compound **26** (1.18 g, 2.1 mmol) was treated according to General Procedure VI to yield the title compound (0.63 g, 2.1 mmol, quantitative) as an oil. ^{1}H NMR (400 MHz, CD_3OD): δ = 4.91 (m, 1 H, H^4), 4.06–4.03 (ddd, $J_{3eq,3ax}$ = 13.3 Hz, $J_{3eq,4}$ = $J_{3eq,5eq}$ = 2.3 Hz, 1 H, H^{3eq}), 3.79–3.76 (dd, 1 H, H^{11a}), 3.60–3.57 (m, 2 H, H_{11b}, H^{3ax}), 3.48–3.39 (t, $J_{10,1}$ = $J_{10,9}$ = 9.1 Hz, 1 H, H^{10}, ddd, $J_{6,5ax}$ = 11.9 Hz, $J_{6,1}$ = 9.3 Hz, $J_{6,5eq}$ = 4.7 Hz, 1 H, H^6), 3.28–3.24 (m, 2 H, H^8, H^9), 3.07 (s, 3 H, OMs), 2.90–2.85 (dd, $J_{1,6}$ = 9.3 Hz, $J_{1,10}$ = 9.1 Hz, 1 H, H^1), 2.39–2.35 (m, $J_{5eq,5ax}$ = 14.0 Hz, $J_{5eq,6}$ = 5.0 Hz, $J_{5eq,4}$ = $J_{5eq,3eq}$ = 2.3 Hz, 1 H, H^{5eq}), 1.83–1.75 (ddd, $J_{5ax,5eq}$ = 14.0 Hz, $J_{5ax,6}$ = 11.9 Hz, $J_{5ax,4}$ = 3.1 Hz, 1 H, H^{5ax}) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 82.4 (C^1), 82.2(OCH), 78.3(C^4), 76.5 (C^{10}), 72.1(OCH), 71.6(C^6), 70.6 (C^3), 62.8 (C^{11}), 38.4 (OMs), 35.1 (C^5) ppm. ATR-IR (thin film): $\tilde{\nu}$ = 3327.0, 2875.7, 1340.4, 1170.7, 1132.1, 1091.6, 1045.3, 999.1, 962.4, 920.0, 894.9, 866.0, 839.0, 779.2, 630.7, 611.4 cm^{-1}. $[\alpha]_D^{23}$ = +6.2 (*c* = 1.00, MeOH). MS (ESI): *m/z* = 320.8 $[M+Na]^+$. HRMS: calcd. for $C_{10}O_8SNH_{22}$ 316.10661, found 316.10567.

(1*R*,4*R*,6*S*,8*R*,9*S*,10*S*)-9,10-Dihydroxy-8-hydroxymethyl-2,7-dioxa-bicyclo[4.4.0]decane-4-yl Methanesulfonate (29): Compound **27** (1.18 g, 2.1 mmol) was treated according to General Procedure VI to yield the title compound (0.68 g, 2.31 mmol, 95%) as a transparent oil. ^{1}H NMR [400 MHz, CD_3OD/[D_6]DMSO (10%)]: δ = 4.71–4.64 (m, 1 H, H^4), 4.17–4.14 (ddd, $J_{3eq,3ax}$ = 10.9 Hz, $J_{3eq,4}$ = 5.2 Hz, $J_{3eq,5eq}$ = 1.7 Hz, 1 H, H^{3eq}), 3.83–3.80 (dd, 1 H, H^{11a}), 3.64–3.61 (ddd, 1 H, H^{11b}), 3.43–3.39(dd, $J_{10,1}$ = 9.0 Hz, $J_{10,9}$ = 8.8 Hz, 1 H, H^{10}), 3.33–3.25 (m, 1 H, H^{3ax}, 2 H, $H^{8/9}$), 3.24–3.20 (ddd, $J_{6,5ax}$ = 11.5 Hz, $J_{6,1}$ = 9.3 Hz, $J_{6,5eq}$ = 4.5 Hz, 1 H, H^6), 3.13 (s, 3 H, OMs), 2.88–2.84 (dd, $J_{1,6}$ = 9.3 Hz, $J_{1,10}$ = 9.0 Hz, 1 H, H^1), 2.62–2.57 (m, 1 H, H^{5eq}), 1.74–1.65 (ddd, $J_{5ax,5eq}$ = $J_{5ax,4}$ = $J_{5ax,6}$ = 11.3 Hz, 1 H, H^{5ax}) ppm. ^{13}C NMR [100 MHz, CD_3OD/[D_6]DMSO (10%)]: δ = 82.2 (C^1), 82.1(OCH), 76.3 (C^{10}), 74.3(C^4), 73.8(C^6), 71.9(OCH), 69.9 (C^3), 62.7 (C^{11}), 38.3 (OMs), 36.9 (C^5) ppm. ATR-IR (thin film): $\tilde{\nu}$ = 1350.1, 1319.2, 1272.9, 1174.6, 1122.5, 1058.8, 1041.5, 1028.0, 979.8, 956.6, 908.4, 883.3, 854.4, 759.9, 705.9 cm^{-1}. $[\alpha]_D^{23}$ = +12.2 (*c* = 1.00, DMF). MS (ESI): *m/z* = 320.9 $[M+Na]^+$. HRMS: calcd. for $C_{10}O_8SNH_{22}$ 316.10661, found 316.10567.

(1*R*,4*R*,6*S*,8*R*,9*S*,10*S*)-4-Azido-9,10-dihydroxy-8-hydroxymethyl-2,7-dioxabicyclo[4.4.0]decane (30): Mesylate **28** (149 mg, 0.50 mmol) was treated according to General Procedure VII to yield the title compound (85 mg, 0.35 mmol 70%) as a colorless oil. Silica gel chromatography: EtOAc → EtOAc/MeOH, 4:1 v/v. ^{1}H NMR (400 MHz, CD_3OD): δ = 3.95–3.91 (ddd, $J_{3eq,3ax}$ = 10.9 Hz, $J_{3eq,4}$ = 5.1 Hz, $J_{3eq,5eq}$ = 1.9 Hz, 1 H, H^{3eq}), 3.78–3.74 (dd, 1 H, H^{11a}), 3.60–3.53 (m, 2 H, H^{11b}, H_4), 3.35–3.33 (dd, $J_{10,1}$ = $J_{10,9}$ = 9.0 Hz, 1 H, H^{10}), 3.24–3.21 (m, 2 H, H^8, H^9), 3.16–3.10 (ddd, $J_{6,5ax}$ = 11.4 Hz, $J_{6,1}$ = 9.3 Hz, $J_{6,5eq}$ = 4.3 Hz, 1 H, H^6), 3.07–3.02(dd, $J_{3ax,3eq}$ = $J_{3ax,4}$ = 10.9 Hz, 1 H, H^{3ax}), 2.78–2.74(dd, $J_{1,6}$ = 9.3 Hz, $J_{1,10}$ = 9.0 Hz, 1 H, H^1), 2.39–2.35 (m, $J_{5eq,5as}$ = 11.4 Hz, $J_{5eq,4}$ = $J_{5eq,6}$ = 4.3 Hz, $J_{5eq,3eq}$ = 1.9 Hz, 1 H, H^{5eq}), 1.44–1.36 (ddd, $J_{5ax,5eq}$ = $J_{5ax,6}$ = $J_{5ax,4}$ = 11.4 Hz, 1 H, H^{5ax}) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 82.3 (C^1), 82.2(OCH), 76.6 (C^{10}), 74.4(C^6), 72.2(OCH), 70.6 (C^3), 62.8 (C^{11}), 56.5(C^4), 35.8 (C^5) ppm. ATR-IR (thin film): $\tilde{\nu}$ = 3440.6, 2924.8, 2857.5, 2098.1, 1736.0, 1459.1, 1379.3, 1311.0, 1242.6, 1125.7, 1036.1, 965.2, 904.0, 873.8 cm^{-1}. $[\alpha]_D^{23}$ = +10.4 (*c* = 1.00, MeOH). MS (ESI): *m/z* = 267.9 $[M+Na]^+$, 284.1 $[M+K^+]$, 513.1 $[M-M+Na^+]$, 529.2 $[M-M+K^+]$. HRMS: calcd. for $C_9O_5N_4H_{13}$ 263.13554, found 263.13968.

(1*R*,4*S*,6*S*,8*R*,9*S*,10*S*)-4-Azido-9,10-dihydroxy-8-hydroxymethyl-2,7-dioxabicyclo[4.4.0]decane (31): Mesylate **29** (684 mg, 2.31 mmol) was treated according to General Procedure VII to yield the title compound (417 mg, 1.7 mmol 70%) as a colorless oil. Silica gel chromatography: EtOAc → EtOAc/MeOH, 4:1 v/v. ^{1}H NMR (400 MHz, CD_3OD): δ = 3.89–3.86 (ddd, $J_{3eq,3ax}$ = 12.6 Hz, $J_{3eq,4}$ = 1.8, $J_{3eq,5eq}$ = 2.5 Hz, 1 H, H^{3eq}), 3.82 (m, 1 H, H^4), 3.76–3.73 (dd, 1 H, H^{11a}), 3.56–3.52 (m, 1 H, H^{11b}), 3.52–3.40(dd, $J_{3ax,3eq}$ = 12.6 Hz, $J_{3ax,4}$ = 1.8 Hz, 1 H, H^{3ax}), 3.38–3.36(dd, $J_{10,1}$ = 9.1 Hz, $J_{10,9}$ = 8.8 Hz, 1 H, H^{10}), 3.33–3.26 (ddd,

$J_{6,5ax}$ = 11.6 Hz, $J_{6,1}$ = 9.2 Hz, $J_{6,5eq}$ = 4.5 Hz, 1 H, H^6), 3.22–3.21 (m, 2 H, H^8, H^9), 2.83–2.78 (dd, $J_{1,6}$ = 9.2 Hz, $J_{1,10}$ = 9.1 Hz, 1 H, H^1), 2.15–2.11 (m, $J_{5eq,5ax}$ = 13.4 Hz, $J_{5eq,6}$ = 4.5 Hz, $J_{5eq,4}$ = 2.4 Hz, $J_{5eq,3eq}$ = 2.5 Hz, 1 H, H^{5eq}), 1.70–1.63 (ddd, $J_{5ax,5eq}$ = 13.4 Hz, $J_{5ax,6}$ = 11.6 Hz, 1 H, H^{5ax}) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 82.9 (C^1), 82.3(OCH), 76.7 (C^{10}), 72.2(OCH), 72.1(C^6), 69.7 (C^3), 62.9 (C^{11}), 58.5(C^4), 34.0 (C^5) ppm. ATR-IR (thin film): $\tilde{\nu}$ = 3369.0, 2926.1, 2870.7, 2095.7, 1726.6, 1446.5, 1312.5, 1283.7, 1239.7, 1174.9, 1128.8, 1036.5, 995.7, 961.9, 948.6, 888.3, 843.9 cm^{-1}. $[\alpha]_D^{23}$ = +1.6 (c = 1.00, MeOH). MS (ESI): m/z = 268.0 $[M+Na]^+$, 284.0 $[M+K]^+$, 513.2 $[M-M+Na]^+$, 529.1 $[M-M+K]^+$ HRMS: calcd. for $C_9O_5N_4H_{13}$ 263.13554, found 263.13895.

(1*R*,4*R*,6*S*,8*S*,9*S*,10*S*)-4-Azido-9,10-dihydroxy-2,7-dioxabicyclo-[4.4.0]decane-8-carboxylic Acid (3): Compound **30** (85 mg, 0.35 mmol) was treated according to General Procedure VIII to yield the title compound (65 mg, 0.25 mmol, 72%) as an oil. ^{1}H NMR ($CDCl_3$): δ = 4.13–4.01 (ddd, $J_{3eq,3ax}$ = 11.1 Hz, $J_{3eq,4}$ = 5.1 Hz, $J_{3eq,5eq}$ = 1.7 Hz, 1 H, H^{3eq}), 3.80–3.71 (m, 1 H, H^4), 3.78–3.76 (d, $J_{8,9}$ = 9.6 Hz, 1 H, H^8), 3.63–3.58 (dd, $J_{10,1}$ = $J_{10,9}$ = 9.2 Hz, 1 H, H^{10}), 3.55–3.50 (dd, $J_{9,8}$ = 9.6 Hz, $J_{9,10}$ = 9.2 Hz, 1 H, H^9), 3.45–3.39 (ddd, $J_{6,5ax}$ = 11.6 Hz, $J_{6,1}$ = 9.3 Hz, $J_{6,5eq}$ = 4.3 Hz, 1 H, H^6), 3.35–3.25 (dd, $J_{3ax,3eq}$ = $J_{3ax,4}$ = 11.1 Hz, 1 H, H^{3ax}), 3.11–3.07 (dd, $J_{1,6}$ = 9.3 Hz, $J_{1,10}$ = 9.2 Hz, 1 H, H^1), 2.54–2.49 (m, $J_{5eq,5ax}$ = 11.6 Hz, $J_{5eq,6}$ = $J_{5eq,4}$ = 4.3 Hz, $J_{5eq,3eq}$ = 1.7 Hz, 1 H, H^{5eq}), 1.65–1.57 (ddd, $J_{5ax,5eq}$ = $J_{5ax,6}$ = $J_{5ax,4}$ = 11.6 Hz, 1 H, H^{5ax}) ppm. ^{13}C NMR (D_2O): δ = 177.1 (C^{11}) 81.1 (C^1), 80.7 (C^8), 75.3 (C^{10}), 73.5(C^6), 73.4(C^9), 69.9 (C^3), 55.5 (C^4), 34.7 (C^5) ppm. ATR-IR (thin film): $\tilde{\nu}$ = 3409.2, 2914.1, 2868.8, 2105.4, 1734.1, 1604.5, 1425.4, 1346.0, 1309.4, 1246.9, 1129.0, 1088.1, 1042.9, 992.8, 967.4, 878.5. $[\alpha]_D^{23}$ = $^-$33 (c = 1.00, MeOH). MS (ESI): m/z = 282.1 $[M+Na]^+$, 541.1 $[M-M+Na]^+$. HRMS: calcd. for $C_9H_{13}N_3O_6Na$ 282.07020, found 282.06943.

(1*R*,4*S*,6*S*,8*S*,9*S*,10*S*)-4-Azido-9,10-dihydroxy-2,7-dioxabicyclo-[4.4.0]decane-8-carboxylic Acid (4): Compound **31** (113 mg, 0.46 mmol) was treated according to General Procedure VIII to yield the title compound (58 mg, 0.23 mmol, 49%) as an oil. ^{1}H NMR ($CDCl_3$): δ = 4.15 (m, 1 H, H^4), 4.02–3.99 (ddd, $J_{3eq,3ax}$ = 12.8 Hz, $J_{3eq,4}$ = $J_{3eq,5eq}$ = 1.8 Hz, 1 H, H^{3eq}), 3.79–3.77 (d, J = 9.7 Hz, 1*H*. H^8), 3.73–3.69(dd, $J_{3ax,3eq}$ = 12.8 Hz, $J_{3ax,4}$ = 1.8 Hz, 1 H, H^{3ax}), 3.66–3.61 (dd, $J_{10,9}$ = 9.0 Hz, $J_{10,1}$ = 9.2 Hz, 1 H, H^{10}), 3.61–3.56 (ddd, $J_{6,5ax}$ = 11.7 Hz, $J_{6,1}$ = 9.4 Hz, $J_{6,5eq}$ = 4.4 Hz, 1 H, H^6), 3.53–3.47 (dd, $J_{9,8}$ = 9.7 Hz, $J_{9,10}$ = 9.0 Hz, 1 H, H^9), 3.18–3.13 (dd, $J_{1,6}$ = 9.4 Hz, $J_{1,10}$ = 9.2 Hz, 1 H, H^1), 2.34–2.31 (m, $J_{5eq,5ax}$ = 13.3 Hz, $J_{5eq,6}$ = 4.4 Hz, $J_{5eq,4}$ = 0.9, $J_{5eq,3eq}$ = 1.8 Hz, 1 H, H^{5eq}), 1.91–1.84 (ddd, $J_{5ax,5eq}$ = 13.3 Hz, $J_{5ax,6}$ = 11.7 Hz, $J_{5ax,4}$ = 3.6 Hz, 1 H, H^{5ax}) ppm. ^{13}C NMR (D_2O): δ = 177.1 (C^{11}) 81.8 (C^1), 81.1 (C^8), 75.2 (C^{10}), 73.4(C^9), 71.5(C^6), 69.8 (C^3), 57.8 (C^4), 32.7 (C^5) ppm. ATR-IR (thin film): $\tilde{\nu}$ = 3353.3, 2880.5, 2105.0, 1609.2, 1421.0, 1299.5, 1241.3, 1127.3, 1083.3, 1037.2, 963.6. $[\alpha]_D^{23}$ = –33 (c = 1.00, MeOH). MS (ESI): m/z = 282.2 $[M+Na]^+$, 541.1 $[M-M+Na]^+$.

Oligopeptide 36: Fmoc-Leu-HMPB-MBHA resin **32** (12 μmol) was taken up in NMP (2 mL) and allowed to swell. After 20 min the liquid was drained, and the resin was taken up in NMP: piperidine (2 mL, 4:1 v/v). After 20 min, the liquid was drained, and the resin was rinsed with NMP (5×2 mL). In an Eppendorf tube SAA **4** (7.3 mg, 28 μmol, 2.3 equiv.), PyBOP (15 mg, 28 μmol, 2.3 equiv.), and HOBt (5.0 mg, 37 μmol, 3 equiv.) were taken up in NMP (0.3 mL). Upon the addition of DIPEA (6 μL, 34 μmol, 3 equiv.) to this solution, the color turned yellow. The liquid was transferred to the resin, and the resin was shaken overnight. After draining the liquid, the resin was washed 5 times with NMP (5×2 mL), the material was taken up in dioxane (2 mL) and trimethylphosphane (≈ 1 M in toluene, 200 μmol, 13 equiv.) was added. The material was shaken mildly for 2 h during which gas evolved. After two h the liquid was drained, and the resin was taken up in dioxane/water (9:1 v/v, 2 mL). Shaking was continued for 30 min, and the resin was washed 10 times with dichloromethane (2 mL). FmocLeuOH (22 mg, 60 μmol, 5 equiv.) was condensed to the resin and deprotected under standard SPPS conditions [PyBOP (1.0 equiv.), HOBt (1.0 equiv.), DIPEA (2 equiv.), and NMP then piperidine/NMP, 1:4 v/v]. A second monomer of SAA **4** (7.3 mg, 28 μmol, 2.3 equiv.) was coupled, followed by subsequent Staudinger reduction under the conditions stated above. The material was cleaved from the resin using TFA in CH_2Cl_2 (1%) and purified by RP-HPLC to yield the title compound (2.3 mg, 2.9 μmol, 24% based on **32**). ^{1}H NMR 500 MHz (H_2O/D_2O, 9:1, v/v): δ = 8.30 (d, J = 7.0 Hz, 1 H, $CONH_{LeuB}$), 8.13 (d, J = 7.5 Hz, 1 H, $CONH_{SaaC}$), 8.00 (d, J = 8.0 Hz, 1 H, $CONH_{LeuD}$), 4.37–4.31 (m, 1 H, $H_{\alpha LeuB}$), 4.17–4.23 (m, 1 H, $H_{\alpha LeuD}$), 4.02 (m, 1 H, H_{4SaaC}), 3.93 (d, J = 13.5 Hz, 1 H, H_{3SaaA}), 3.86 (d, J = 10 Hz, 1 H, H_{8SaaD}), 3.83 (d, J = 9.5 Hz, 1 H, H_{8SaaA}), 3.80 (d, J = 16.0 Hz, 1 H, H_{3SaaC}), 3.70 (m, 2 H, H_{4SaaA}, H_{3SaaA}), 3.59–3.53 (m, 4 H, H_{3SaaC}, H_{6SaaA}, H_{10SaaA}, H_{10SaaC}), 3.52–3.43 (m, 3 H, H_{6SaaC}, H_{9SaaA}, H_{9SaaC}), 3.08 (t, J = 9.5 Hz, 1 H, H_{1SaaA}), 3.02 (t, J = 9.5 Hz, 1 H, H_{1SaaC}), 2.26–2.22 (m, 1 H, $H_{5eqSaaA}$), 2.11–2.08 (m, 1 H, $H_{5eqSaaC}$), 1.97–1.89 (m, 1 H, $H_{5axSaaA}$), 1.75–1.70 (m, 1 H, $H_{5axSaaC}$); 1.60–1.45 (6 H 2×CH_{2Leu}, 2×CH_{Leu}), 0.84–0.87 m (6 H 6×CH_{3Leu}) ppm. ^{13}C NMR 125 MHz (H_2O/D_2O, 9:1, v/v): δ = 80.0, 81.0, 75.0, 73.0, 72.0, 70, 69.0 68, 53, 52, 48, 47, 40, 32, 30, 25, 22, 21 ppm. MS (ESI): m/z = 675.4 $[M+Na]^+$, 697.4 $[M-M+Na]^+$.

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