Variable Strategy toward Carbasugars and Relatives. 1. Stereocontrolled Synthesis of Pseudo-β-D-gulopyranose, Pseudo-β-D-xylofuranose, (Pseudo-β-D-gulopyranosyl)amine, and (Pseudo-β-D-xylofuranosyl)amine

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Four novel, chiral nonracemic carbasugars have been synthesized from 1,2-*O*-isopropylidene-D-glyceraldehyde. Furan- and pyrrole-based 2-silyloxy dienes—mimics of the α,γ-dianions of γ-hydroxy- and γ-aminobutanoic acid, respectively—nicely served to complete the syntheses of two all-oxygen compounds, pseudo-β-D-gulopyranose and pseudo-β-D-xylofuranose, and two "anomeric" amino derivatives, (pseudo-β-D-gulopyranosyl)amine (1,2,4-tri-*epi*-validamine) and (pseudo-β-D-xylofuranosyl)amine. Two sequential, highly diastereoselective carbon−carbon bond-forming maneuvers, i.e., a vinylogous crossed aldol addition and an intramolecular aldolization, proved central to these constructions. The fact that readily available heterocyclic diene scaffolds can be employed in the assembly of a varied repertoire of carbasugars and analogues widens the prospects of dienoxy silane chemistry.

Introduction

Carbasugars,[1] otherwise known as pseudo-sugars, are a subclass of the largely represented family of cyclitols, of which inositols, condutirols, cyclophellitols, mannostatins, validamine, and aristeromycin are the most attractive and biologically interesting representatives.[2] Strictly speaking, the term carbasugar is restricted to the carbocyclic analogues of monosaccharides, where the ring oxygen is replaced by a methylene group. Nonetheless, in a broader sense, structurally modified carbafuranose and carbapyranose rings possessing either different heteroatom substituents, an unsaturated framework, or oxidized functionalities may also be considered to be carbasugars (Figure 1).

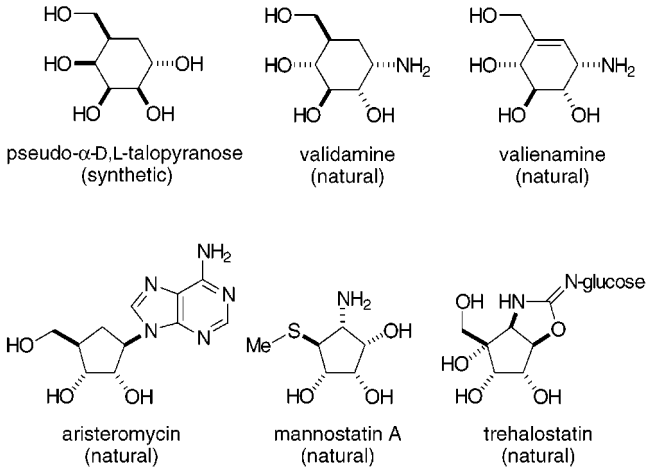

Figure 1.

After the pioneering synthesis of racemic pseudo-α-talopyranose by McCasland in 1966,[3] numerous researchers have been challenged by the chemical synthesis of furanose and pyranose carbasugars and their efforts have resulted in the assembly of a growing repertoire of constructs possessing the most diverse structural and stereochemical arrangements.[2a,4] In this paper we have developed a flexible approach to carbasugar synthesis and confirmed its viability by preparing four carbapyranose and carbafuranose representatives.

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(1) For review articles on carbasugars, see: (a) Suami, T.; Ogawa, S. *Adv. Carbohydr. Chem. Biochem.* **1990**, *48*, 21. (b) Suami, T. *Top. Curr. Chem.* **1990**, *154*, 257. (c) Suami, T. *Pure Appl. Chem.* **1987**, *59*, 1509. (d) Agrofoglio, L.; Suhas, E.; Farese, A.; Condom, R.; Challand, S. R.; Earl, R. A.; Guedj, R. *Tetrahedron* **1994**, *50*, 10611. (e) Marquez, V. E.; Lim, M. *Med. Res. Rev.* **1986**, *6*, 1. (f) Hudlicky, T.; Cebulak, M. *Cyclitols and Their Derivatives. A Handbook of Physical, Spectral, and Synthetic Data*; VCH: New York, 1993. (g) Nishimura, Y. In *Studies in Natural Products Chemistry*; Atta-ur-Rahman, Ed.; Elsevier Publishers B. V.: Amsterdam, 1992; Vol 10, p 495.

(2) For leading references, see: (a) Berecibar, A.; Grandjean, C.; Siriwardena, A. *Chem. Rev.* **1999**, *99*, 779. (b) Ogawa, S.; Washida, K. *Eur. J. Org. Chem.* **1998**, 1929. (c) Ogawa, S.; Ashiura, M.; Uchida, C.; Watanabe, S.; Yamaziki, C.; Yamagishi, K.; Inokuchi, J.-I. *Bioorg. Med. Chem. Lett.* **1996**, *6*, 929. (d) Lee, M. D.; Fantini, A. A.; Morton, G. O.; James, J. C.; Borders, D. B.; Testa, R. T. *J. Antibiot.* **1984**, *37*, 1149. (e) Marquez, V. E. *Adv. Antiviral Drug Des.* **1996**, *2*, 89. (f) Mansour, T. S.; Storer, R. *Curr. Pharm. Des.* **1997**, *3*, 227. (g) Parmely, M. J.; Hausmann, E. H.; Morrison, D. C. *Infect. Dis. Ther.* **1996**, *19*, 253. (h) Ganem, B. *Acc. Chem. Res.* **1996**, *29*, 340. (i) Humphries, M. J.; Matsumoto, K.; White, S. L.; Olden, K. *Proc. Natl. Acad. Sci. U.S.A.* **1986**, *83*, 1752. (j) Montefiori, D. C.; Robinson, W. E.; Mitchell, W. M. *Proc. Natl. Acad. Sci. U.S.A.* **1988**, *85*, 9248.

(3) McCasland, G. E.; Furuta, S.; Durham, L. J. *J. Org. Chem.* **1966**, *31*, 1516.

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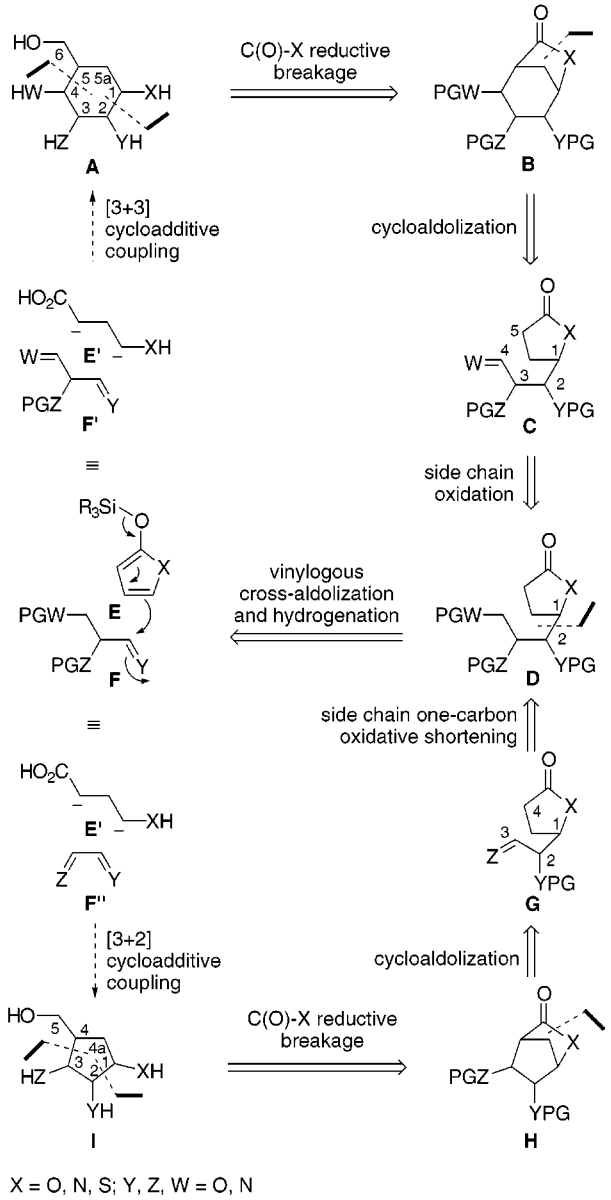
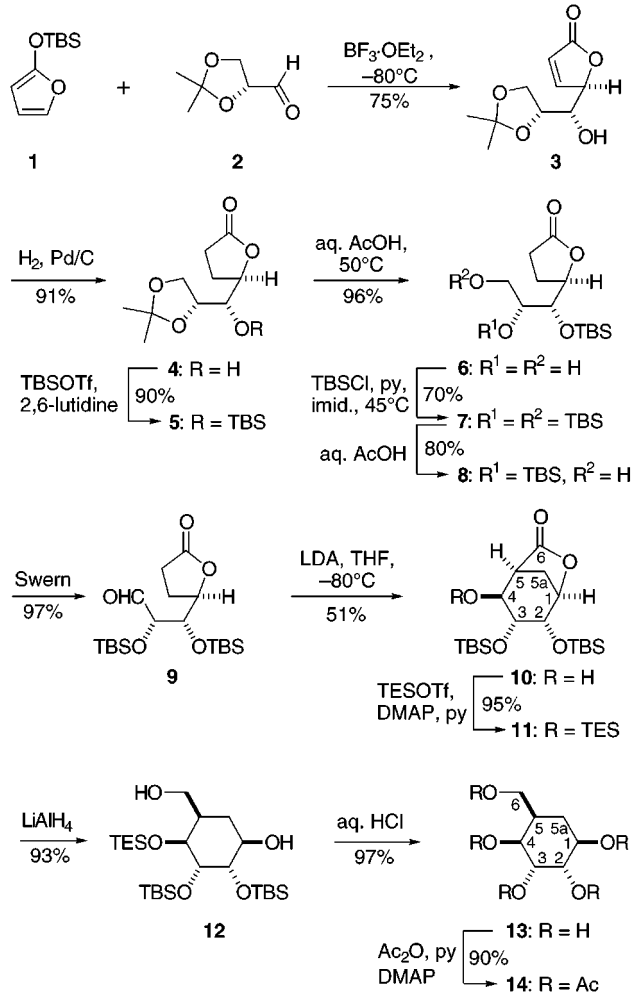
Scheme 1



Scheme 2



Results and Discussion

Planning and Strategy. For this enterprise, we opted to take advantage of the availability of a variable set of nucleophilic building blocks, the furan-, pyrrole-, and thiophene-based dienoxy silanes denoted as **E** in Scheme 1. This was an obvious choice in keeping with our long-standing familiarity with this class of reagents.[5] To arrive at the carbasugar constructs, we addressed the retrosynthetic plan contemplated in Scheme 1, where both carbapyranoses **A** and carbafuranoses **I** were assembled by conjoining two complementary subunits, the butyric acid-based α,γ-dianion **E′** and malondialdehyde **F′** or glyoxal-related fragment **F″**. Here, two common retrons, the enoxy silane **E** and the chiral glyceraldehyde-related unit **F,** are envisioned as synthetic equivalents of dianion **E′** and dialdehydes **F′** or **F″**, respectively.

The route we hoped to pursue involves formation of the divergent intermediary adduct **D** via implementation of the C1−C2 juncture before the annulation processes (**C** → **B** or **G** → **H**; C4−C5 or C3−C4 junctures), which ultimately produce pseudopyranoses **A** or pseudofuranoses **I**. Two formal [3 + 3] or [3 + 2] cycloadditive maneuvers featuring a sequential vinylogous cross aldolization-cycloaldolization protocol are central to these constructions. Worthy of note is the malleability of this scheme, which allows one to play around with a wide panel of heteroatom and chirality combinations. This project was then put into practice in the form of stereocontrolled syntheses of chiral, nonracemic pseudo-β-D-gulopyranose (**13**), pseudo-β-D-xylofuranose (**19**), (pseudo-β-D-gulopyranosyl)amine (**33**) (1,2,4-tri-*epi*-validamine), and (pseudo-β-D-xylofuranosyl)amine (**39**).

Synthesis of Pseudo-β-D-gulopyranose (13). Analysis of **13** suggested an all-oxygen option, where the X, Y, Z, and W variables expressed in our plan are oxygen functionalities. Accordingly (Scheme 2), the synthesis commenced with the vinylogous cross aldolization of furan-based silyloxy diene **1** to glyceraldehyde **2**.

Under the guidance of BF_3 etherate (CH_2Cl_2, −80 °C), coupling occurred in a strict vinylogous sense (γ-alkyla-

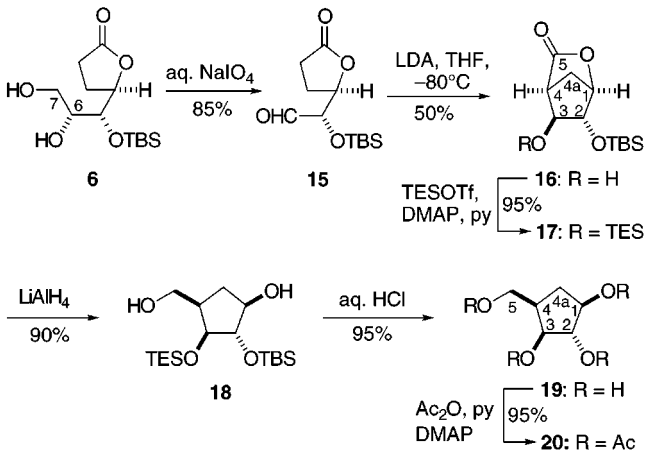
(4) For leading references, see: (a) Ferrier, R. J.; Middleton, S. *Chem. Rev.* **1993**, *93*, 2779. (b) *Carbohydrate Mimics: Concepts and Methods*; Chapleur, Y., Ed.; Wiley-VCH: Weinheim, 1998. (c) Ogawa, S. *Synth. Org. Chem. Jpn.* **1985**, *43*, 26. (d) Dalko, P. I.; Sinay, P. *Angew. Chem., Int. Ed. Engl.* **1999**, *38*, 773. (e) Hudlicky, T.; Entwistle, D. A.; Pitzer, K. K.; Thorpe, A. J. *Chem. Rev.* **1996**, *96*, 1195.

(5) (a) Casiraghi, G.; Rassu, G. *Synthesis* **1995**, 607. (b) Casiraghi, G.; Rassu, G.; Zanardi, F.; Battistini, L. In *Advances in Asymmetric Synthesis*; Hassner, A., Ed.; JAI Press: Stamford, CT, 1998; Vol. 3, p 113. (c) Rassu, G.; Zanardi, F.; Battistini, L.; Casiraghi, G. *Synlett* **1999**, 1333. (d) Rassu, G.; Zanardi, F.; Battistini, L.; Casiraghi, G. *Chem. Soc. Rev.* **2000**, 109.

tion only) giving rise to a 94:6 mixture of two diastereoisomers. The major adduct, isolated in 75% yield, was the syn,anti butenolide **3**. Saturation of the butenolide double bond to **4** followed by silylation of the free hydroxyl gave rise to the substituted furanone **5** in 82% yield for the two steps. Exposure of **5** to 70% aqueous acetic acid ensured selective removal of the terminal isopropylidene blockage, providing a 96% yield of the partially protected triol **6**, a key divergent intermediate in our syntheses (vide infra). A two-stage protocol, consisting of full protection to **7** followed by selective desilylation of the primary hydroxyl, was then adopted in order to obtain the diprotected triol **8** which was isolated in 56% yield over two steps. Subsequently, a Swern oxidative maneuver ensured arrival at aldehyde **9** (97%), ready for the crucial intramolecular aldolization. We were delighted to observe that following brief exposure to LDA in THF at −80 °C, compound **9** was transformed into the bicyclic lactone **10**, which was isolated as the sole detectable (4*S*,5*S*)-configured stereoisomer (51% yield).[6] The rather constrained structure of the bicyclic scaffold **10** strongly facilitated its structural diagnosis, based on careful inspection of the ^{1}H NMR spectral data (vide infra). At this point, all that remained was the liberation of the carbasugar cyclohexane ring within the bicycle **10**, and this was effected via reductive breakage of the lactone C(O)−O linkage. The free C4-hydroxyl was first temporarily protected as the triethylsilyl ether **11**, whose lactone junction was cleaved upon $LiAlH_4$ treatment to give the protected pseudo-pyranose **12** in 88% yield (two steps). This was then quantitatively liberated to pseudo-*β*-D-gulopyranose (**13**) (6 N HCl, MeOH, THF), the relative (and hence absolute) configuration of which was firmly established by NMR analysis (vide infra). Remarkably, the ^{1}H NMR data in our possession nicely matched the data reported more than 30 years ago by McCasland[7] for its racemic counterpart. Exposure of the free sugar **13** to Ac_2O/pyridine finally gave the crystalline peracetate **14** in 90% isolated yield. The ^{1}H NMR is consistent with the reported data for the *β*-L-*gulo* enantiomer; apart from the sign of rotation, the $[\alpha]_D$ value of **14** matches that of the reported compound ($[\alpha]_D^{20}$ −19.3 (*c* 3.4, $CHCl_3$); lit.[8] $[\alpha]_D^{20}$ +20.5 (*c* 1.0, $CHCl_3$)). The total synthesis of pseudosugar **13** was thus completed, covering 11 individual steps with a 14% overall yield starting from aldehyde **2**.

Synthesis of Pseudo-*β*-D-Xylofuranose (19). In light of our synthesis, outlined in Scheme 1, the preparation of **19** initiated with the excision of the terminal chain carbon in the previously synthesized seven-carbon lactone **6**. Treatment of **6** with silica gel-supported $NaIO_4$ in CH_2Cl_2/water solvent mixture resulted in the breakage of the C6−C7 carbon−carbon bond, giving aldehyde **15** in 85% yield (Scheme 3). Once compound **6** was tailored to the requisite six-carbon skeleton, the key cycloaldolization could be performed. Noteworthily, the maneuver (LDA, THF, −80 °C) worked diastereoselectively, giving rise to a reasonable yield (50%) of a single 2,3-*trans*-3,4-*cis*-configured bicyclic lactone **16**.[6] Silylation of the free C3-

Scheme 3



located hydroxyl function then provided the fully protected lactone **17** the NOE experiments of which allowed us to ascertain its stereochemistry as shown (vide infra).

Having constructed the desired cyclopentane ring, we turned to the elaboration of the lactone moiety. Exposure of **17** to $LiAlH_4$ in THF cleanly gave pseudo-pentofuranose **18**, which was liberated to give pseudo-*β*-D-xylofuranose (**19**) by acidic treatment (86%, two steps). Apart from a few discrepancies, possibly due to the use of different solvents (D_2O vs CD_3OD), the ^{1}H and ^{13}C NMR characteristics of the nonracemic sugar **19** were in good accordance with the data reported by Griengl for its racemic counterpart.[9,10] Peracetylation of **19**, following the usual protocol (Ac_2O, pyridine, DMAP), ensured preparation of the peracetate **20** which was obtained as a crystalline solid in 95% yield. As a whole, the synthesis of the enantiopure carbasugar **19** was accomplished in nine steps from aldehyde **2**, with a reasonable overall yield of 20% (five steps, 34% starting from **6**).

Synthesis of (Pseudo-*β*-D-gulopyranosyl)amine (33).[11] According to our basic project in Scheme 1, a nitrogen function can be implemented into the target pseudosugar **A** or **I** by adopting either a nitrogen-containing dienoxy silane **E** or a nitrogen-containing aldehyde **F**. To obtain the anomeric title-compound **33**, the heteroatom choice was obvious; we selected the readily available *N*-(*tert*-butoxycarbonyl)-2-[(*tert*-butyldimethylsilyl)oxy]pyrrole (**21**) and aldehyde **2** as our starting materials.

As shown in Scheme 4, the synthesis started with the intermolecular vinylogous aldol addition of **21** to (*R*)-glyceraldehyde **2** ($SnCl_4$, Et_2O, −80 °C). As previously experienced,[5] the crystalline syn,anti-configured butenolide adduct **22** was obtained in a good chemical yield (80%) and with an excellent level of regio- and diastereoselectivity (≥ 95% de). From here on, apart from only modest adaptations, the synthesis paralleled the route to **13**. Catalytic hydrogenation easily provided lactam **23**, which was protected as the silyl ether **24** (85% yield for the two steps). Permutation of the isopropylidene protection to TBS was then effected via deacetonidation to **25**

(6) After this work was completed, the efficiency of the intramolecular aldolisation reaction was greatly improved (> 80% yield) by adopting a Mukaiyama aldol-type protocol (TBSOTf, DIPEA, −78 °C to room temperature). Details of this investigation will be communicated shortly.

(7) McCasland, G. E.; Furuta, S.; Durham, L. J. *J. Org. Chem.* **1968**, *33*, 2835.

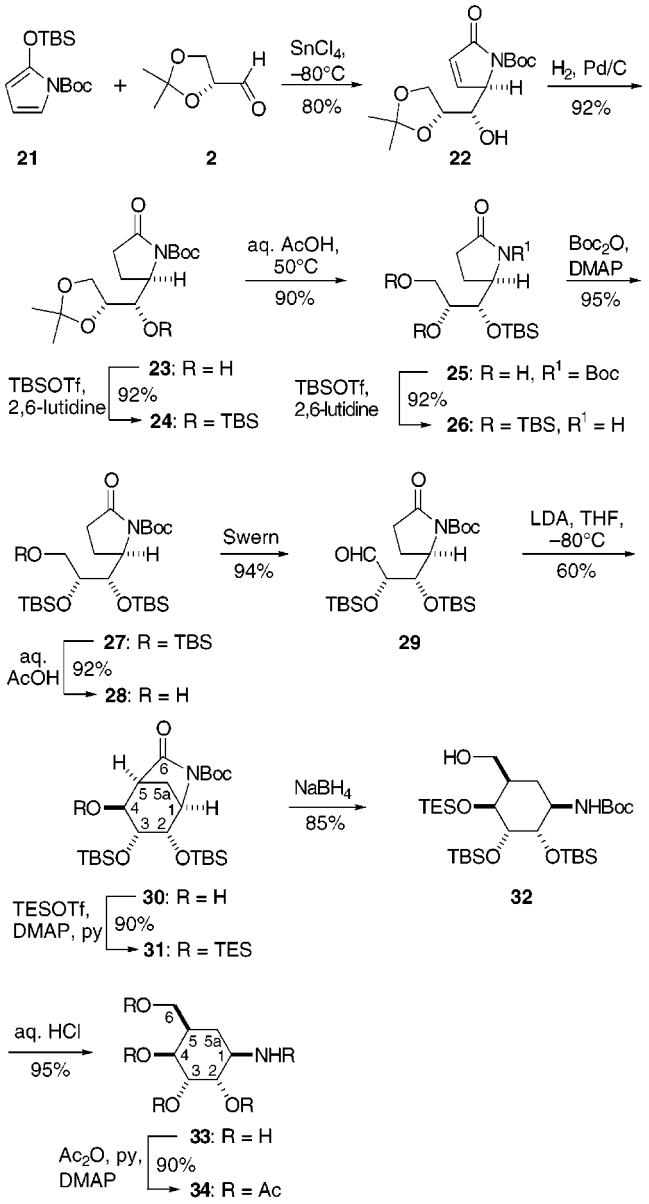
(8) Pingli, L.; Vandewalle, M. *Synlett* **1994**, 228.

(9) Marschner, C.; Baumgartner, J.; Griengl, H. *J. Org. Chem.* **1995**, *60*, 5224.

(10) Synthesis of pseudo-*β*-L-xylofuranose, see: Yoshikawa, M.; Cha, B. C.; Okaichi, Y.; Kitagawa, I. *Chem. Pharm. Bull.* **1988**, *36*, 3718.

(11) For a preliminary account of this synthesis, see: Rassu, G.; Auzzas, L.; Pinna, L.; Zanardi, F.; Battistini, L.; Casiraghi, G. *Org. Lett.* **1999**, *1*, 1213.

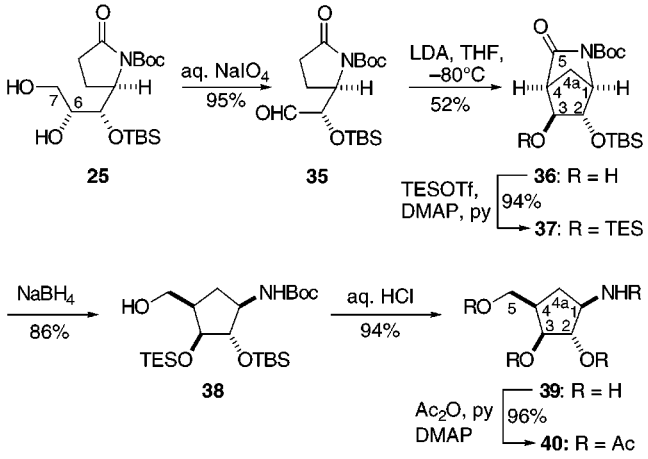
Scheme 4



followed by persilylation. Because of the sluggish nature of this protection reaction, no conditions were found that obviated concomitant unmasking of the NH group. Therefore, reintroduction of the Boc function was required. We thus arrived at **27**, through the intermediacy of protected triol **26** (79% yield for three steps). After the primary hydroxyl group was liberated (compound **28**, 92%), Swern oxidation ensured formation of the aldehyde **29** in 94% yield. Exposure of **29** to ring-closing aldol conditions (LDA, THF, −80 °C, 15 min) resulted in exclusive formation of 6-azabicyclo[3.2.1]octan-7-one **30** in 45% isolated yield and with 33% aldehyde recovery. Recycling unconverted **29** resulted in the formation of an additional quantity of **30**, and brought the overall yield up to 60% for both cycles.

The stereochemical course of this intramolecular aldol reaction (**29** → **30**) is a mirror image of the behavior of the cycloaldolization of the all-oxygen aldehyde counterpart **9** (Scheme 2, **9** → **10**), resulting in formation of the 3,4-trans-4,5-cis-configured aldol adduct **30**, as expected. Following silylaton to **31**, the lactam ring cleavage was reductively effected by exposure to $NaBH_4$ in wet THF.

Scheme 5



The protected six-membered ring intermediate **32** was thus constructed in 77% yield for two steps. Exposure of **32** to 6 N HCl in THF/MeOH finally completed the synthesis, giving (pseudo-*β*-D-gulopyranosyl)amine (**33**) (1,2,4-tri-*epi*-validamine), which was isolated as the free base in 95% yield. Crystalline penta-*N*,*O*,*O*,*O*,*O*-acetyl derivative **34** was also synthesized, by subjecting free amino sugar **33** to acetic anhydride/pyridine treatment. The diastereoselective synthesis of the targeted pyranosylamine **33** has been achieved, utilizing the vinylogous aldol−cycloaldol combination, in 20% overall yield over 12 steps.

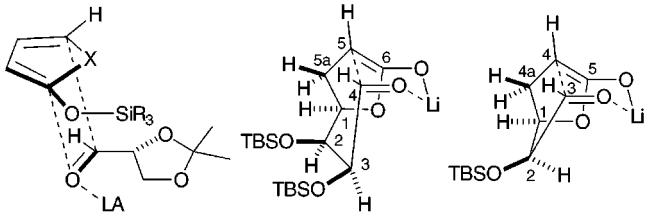
Synthesis of (Pseudo-*β*-D-xylofuranosyl)amine (39). For the synthesis of the title amino-carbasugar, we followed the reaction pathway portrayed in Scheme 5, which closely resembles the sequence used for its all-oxygen cousin **19** (vide supra). The intermediate triol **25** was thus shortened by one carbon atom via periodate fission, giving rise to aldehyde **35** (95% yield), which, in turn, was subjected to cycloaldolization (LDA, THF, −80 °C, 15 min).

The ring forming event showed a spectacular diastereocontrol, resulting exclusively in the formation of 2,3-trans-3,4-cis-disposed 5-azabicyclo[2.2.1]heptan-6-one **36** in 52% yield. To obtain the target carbasugar, the free hydroxy function was first protected giving **37**, and the lactam N−C(O) bond was then cleaved under reductive conditions ($NaBH_4$, wet THF). The functionalized cyclopentane **38** formed (81% yield from **36**) was totally deprotected by acidic treatment to give the free (pseudo-*β*-D-xylofuranosyl)amine (**39**) in 94% yield (23% overall yield for the nine-step sequence from **2**). Peracetylation of **39** proceeded smoothly, to afford the tetra-*N*,*O*,*O*,*O*-acetyl derivative **40** in 96% yield. It is worth noting that the synthesis of racemic **39** and **40** was reported in 1984 by Vince et al.;[12] however, their given characterization data were barely readable and did not prove useful for comparison with the spectroscopic data in our possession.

Mechanistic Insights. According to the "chiron" concept,[13] all of the syntheses herein disclosed utilize >98% ee (*R*)-glyceraldehyde acetonide **2** (ex D-mannitol) as the source of chirality. Indeed, the single stereogenic element of **2** is transmitted to the various synthesis intermediates and ultimately emerges in the multichiral

(12) Vince, R.; Brownell, J.; Daluge, S. *J. Med. Chem.* **1984**, *27*, 1358.
(13) Hanessian, S. *The Total Synthesis of Natural Compounds: the Chiron Approach*; Pergamon Press: Oxford, 1983.

Scheme 6



pseudo-furanose and pyranose target structures. Common to all processes are two pivotal carbon−carbon bond constructions, namely, the opening vinylogous cross-aldolization and the conclusive ring-forming aldolization (Scheme 6).

As already discussed, the stereochemical outcome of the diastereocontrolled vinylogous cross-aldolization which favors syn,anti aldol adducts can be rationalized based on the putative transition state model **TS1**, which displays a low-energy Diels−Alder-like conformation.[5] As for the transition states associated with the extremely diastereoselective aldol cyclizations, leading to either bicyclooctanoids **10** and **30** or bicycloheptanoids **16** and **36**, a plausible explanation might reside in the structures **TS2** and **TS3**, respectively. It is worth noting that, in all instances, the newly formed C4−C5 and C3−C4 junctures cause the hydroxyl functions at C4 and C3 to emerge trans to the corresponding vicinal C3 and C2 hydroxyls. This implies that the aldehyde carbonyl is oriented so as to expose its *si* face to the incoming nucleophilic carbon. On the other hand, the geometry of the molecules, with the C1 side chains β oriented, forces the aldehyde carbonyl to enter the *re* face of the *E*-enolate carbon. The Zimmerman−Traxler-like models **TS2** and **TS3**, where the enolate lithium counterion coordinates to the aldehyde carbonyl, probably represent favorable orientations capable of delivering the aldol products with the indicated 3α,4β or 2α,3β trans stereochemistries.

Configurational and Conformational Analysis. The chirality of the starter aldehyde **2**, chosen as (*R*), and the awareness of the syn,anti selective character of the opening vinylogous aldolization (vide supra) allowed us to fix the stereochemistry of C1−C2−C3 in bicyclooctanoids **11** and **31** and C1−C2 in bicycloheptanoids **17** and **37**, as indicated (Figure 2).

Hence, the critical stereochemical events were restricted to the cycloaldolization steps, where the relationships of C3, C4, and C5 in **11** and **31** and C2, C3, and C4 in **17** and **37** were established. The strongly reduced conformational flexibility of these oxa- and azabicycles facilitated the stereochemical assignment by inspection of the respective ^{1}H NMR parameters. The most diagnostic data derived from the measurements of interproton coupling constants and detection of specific NOE contacts. The ^{1}H NMR analysis of bicyclooctanoids **11** and **31** suggested that the cyclohexane frames within the constructs adopted $^3C_{5a}$ conformations, with four equatorially disposed protons (1, 2, 5, and 5aβ) and three axial protons (3, 4, and 5aα). In particular, the large coupling constants between H−C3 and H−C4 (8.7 Hz for **11** and **31**) were indicative of the trans-antiperiplanar location of these protons, whereas the observation of two *W* long-

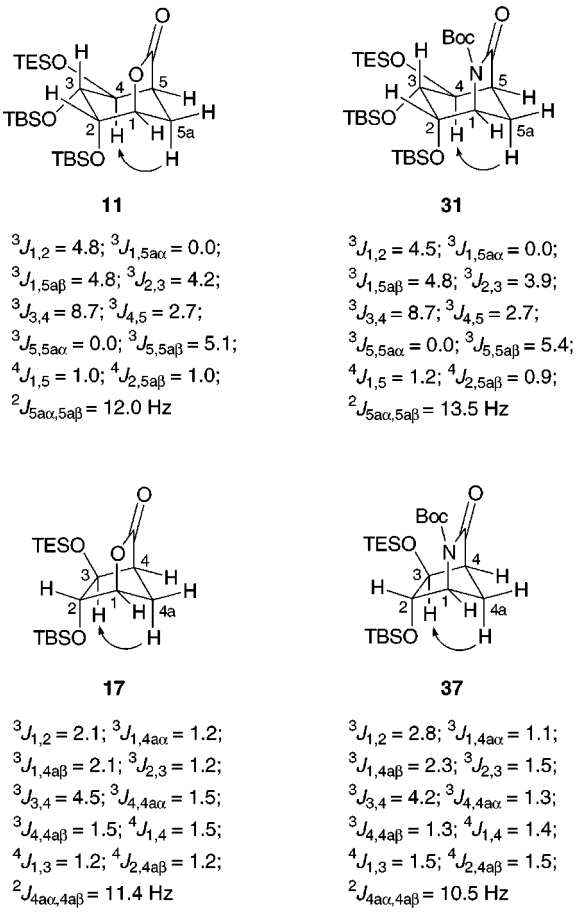
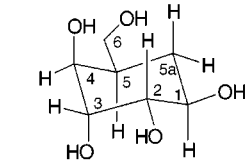


Figure 2.

range coupling constants between H−C2 and H−C5aβ and between H−C1 and H−C5 in both compounds was suggestive of an equatorial-coplanar disposition for these protons. The presence of a strong NOE contact between H−C4 and H−C5aα in both **11** and **31** further corroborated the suggested assignments.

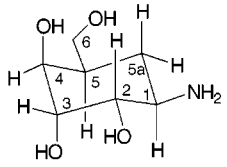
In the bicycloheptanoid couple **17** and **37**, the cyclopentane ring was blocked in an E_{4a} envelope conformation, where the dihydroxylated C2−C3 unit resides in the flattened portion of the envelope. The α-disposition of protons H−C3 in **17** and **37** was manifested by strong NOE contacts with the corresponding H−C4a protons in α-position and confirmed the (*S*) absolute configuration for the C3 stereocenters. In particular, 2D-COSY experiments revealed that the H−C1 proton in both molecules correlates with all of the remaining backbone protons, with three vicinal couplings ($^3J_{1,2}$, $^3J_{1,4a\alpha}$, $^3J_{1,4a\beta}$) and two *W* long-range couplings ($^4J_{1,4}$ and $^4J_{1,3}$). Considered together, these measurements left no doubts about the proposed configurational and conformational assignment for **17** and **37**.

The analysis of the four target pseudo-sugars of this study proved reasonably viable, based on the various ^{1}H NMR measurements. As summarized in Figure 3, for the six-membered ring compounds **13** and **33**, the coupling constants for the cyclohexane protons were suggestive of $^4C_1$ conformations, with all vicinal ^{1}H−^{1}H couplings consistently fitting the expected values. Among the most diagnostic coupling constants, we could mention the large *J* values between H−C1 and H−C2 (9.9, 10.8 Hz), H−C1 and H−C5aβ (11.4, 12.6 Hz), and H−C5 and H−C5aβ (12.6 Hz), which are disposed in a trans-diaxial relation-



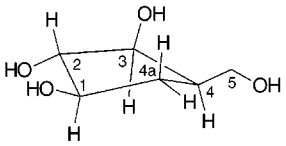
13

$^3J_{1,2}$ = 9.9; $^3J_{1,5a\alpha}$ = 4.8;
$^3J_{1,5a\beta}$ = 11.4; $^3J_{2,3}$ = 2.7;
$^3J_{3,4}$ = 3.2; $^3J_{4,5}$ = 3.2;
$^3J_{5,5a\alpha}$ = 4.5; $^3J_{5,5a\beta}$ = 12.6;
$^3J_{5,6a}$ = 8.1; $^3J_{5,6b}$ = 6.3;
$^2J_{5a\alpha,5a\beta}$ = 12.6;
$^2J_{6a,6b}$ = 11.0 Hz



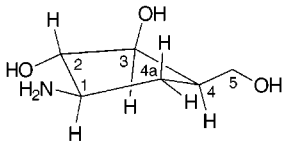
33

$^3J_{1,2}$ = 10.8; $^3J_{1,5a\alpha}$ = 4.2;
$^3J_{1,5a\beta}$ = 12.6; $^3J_{2,3}$ = 3.0;
$^3J_{3,4}$ = 3.0; $^3J_{4,5}$ = 4.8;
$^3J_{5,5a\alpha}$ = 4.5; $^3J_{5,5a\beta}$ = 12.6;
$^3J_{5,6a}$= 7.5; $^3J_{5,6b}$ = 6.6;
$^2J_{5a\alpha,5a\beta}$ = 12.6;
$^2J_{6a,6b}$ = 11.1 Hz



19

$^3J_{1,2}$ = 6.6; $^3J_{1,4a\alpha}$ = 7.8;
$^3J_{1,4a\beta}$ = 9.0; $^3J_{2,3}$ = 5.4;
$^3J_{3,4}$ = 7.5; $^3J_{4,4a\alpha}$ = 7.8;
$^3J_{4,4a\beta}$ = 9.0; $^3J_{4,5a}$ = 6.6;
$^3J_{4,5b}$ = 6.9; $^2J_{4a\alpha,4a\beta}$ = 12.9;
$^2J_{5a,5b}$ = 11.1 Hz



39

$^3J_{1,2}$ = 5.4; $^3J_{1,4a\alpha}$ = 8.4;
$^3J_{1,4a\beta}$ = 8.7; $^3J_{2,3}$ = 5.4;
$^3J_{3,4}$ = 5.1; $^3J_{4,4a\alpha}$ = 8.4;
$^3J_{4,4a\beta}$ = 8.7; $^3J_{4,5a}$ = 6.6;
$^3J_{4,5b}$ = 6.0; $^2J_{4a\alpha,4a\beta}$ = 12.6;
$^2J_{5a,5b}$ = 11.1 Hz

Figure 3.

ship. The values of the remaining coupling constants involving axial/equatorial and equatorial/equatorial proton relationships also agreed with the suggested conformations.

However, the detailed conformations of cyclopentanoid structures **19** and **39** could not be established with absolute certainty by inspection of inter-proton couplings, since five-membered ring compounds are known to be flexible and may exist as equilibrium mixtures.[14] Nonetheless, it might be plausible to assume that, in D_2O solution, the cyclopentane rings of **19** and **39** might preferentially adopt twisted $^2T_1$ conformations where the exocyclic hydroxymethyl functions lie in a pseudoequatorial orientation ($\theta_{H1-C1-C2-H2} \approx \theta_{H2-C2-C3-H3} \approx 145-150°$; $^3J_{1,2} \approx {}^3J_{2,3} \approx 5.4-6.6$ Hz).

Conclusions

We have planned an enantiospecific synthetic methodology to access six-membered and five-membered carbasugars and variants thereof, which embody large malleability. This protocol was used to synthesize a couple of novel nonracemic pseudo-pyranoses, **13** and **33**, and a couple of novel pseudo-furanoses, **19** and **39**, all belonging to the sugar D series. The component compounds of these syntheses were the readily available D-glyceraldehyde acetonide **2** (ex D-mannitol) and the furan- and pyrrole-based dienoxy silane pair **1** and **21**. The protocols employed a rather uniform chemistry, focused on two sequential, extremely diastereoselective constructions, an intermolecular vinylogous aldol coupling followed by a cycloaldolization. Future work will define the extent to which such a versatile plan can be used to construct variably substituted carbacycles of different ring sizes and stereostructures.

(14) Fuchs, B. *Top. Stereochem.* **1978**, *10*, 1.

Experimental Section[15,16]

Materials. *N*-(*tert*-Butoxycarbonyl)-2-[(*tert*-butyldimethylsilyl)oxy]pyrrole (**21**) was prepared from pyrrole (Aldrich) according to a described protocol.[17] 2-[(*tert*-Butyldimethylsilyl)oxy]furan (**1**) was obtained from 2-furaldehyde (Aldrich) following a reported method.[17] 2,3-*O*-Isopropylidene-D-glyceraldehyde (**2**) was prepared from D-mannitol (Aldrich) according to a recently optimized protocol.[18]

(1′*S*,4″*R*,5*R*)-5-[(2,2-Dimethyl-1,3-dioxolan-4-yl)hydroxymethyl]-5*H*-furan-2-one (3). To a solution of **1** (6.43 mL, 30.7 mmol) in anhydrous CH_2Cl_2 (120 mL), under argon atmosphere, was added 2,3-*O*-isopropylidene-D-glyceraldehyde (**2**) (4.0 g, 30.7 mmol), and the resulting mixture was cooled to −80 °C. $BF_3 \cdot Et_2O$ (3.78 mL, 30.7 mmol), cooled to the same temperature, was added dropwise to the stirring solution, and the reaction was allowed to proceed for 6 h at −80 °C. The reaction was then quenched at −80 °C by the addition of saturated aqueous $NaHCO_3$, and after ambient temperature was reached, the mixture was extracted with CH_2Cl_2. The combined organic layers were washed with brine, dried ($MgSO_4$), filtered, and concentrated in a vacuum to give a solid crude residue, which was subjected to flash chromatographic purification (6:4 hexanes/EtOAc). 4.93 g (75%) of pure **3** were obtained as white crystals: mp 125 °C; $[\alpha]_D^{20}$ +69.6 (*c* 1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.59 (dd, J = 5.8, 1.7 Hz, 1H), 6.17 (dd, J = 5.8, 1.9 Hz, 1H), 5.27 (m, 1H), 4.18 (m, 2H), 4.05 (m, 1H), 3.67 (m, 1H), 2.94 (d, J = 6.6 Hz, 1H), 1.42 (s, 3H), 1.37 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 176.4, 154.3, 122.1, 109.8, 84.2, 75.5, 72.9, 67.1, 26.7, 25.1. Anal. Calcd for $C_{10}H_{14}O_5$: C, 56.07; H, 6.59. Found: C, 55.94; H, 6.71.

(1′*S*,4″*R*,5*R*)-5-[(2,2-Dimethyl-1,3-dioxolan-4-yl)hydroxymethyl]dihydrofuran-2-one (4). Palladium on carbon (10%, 0.60 g) was added to a solution of α,β-unsaturated lactone **3** (4.80 g, 22.4 mmol) in anhydrous THF (120 mL) in the presence of a small amount of NaOAc (0.18 g) at room temperature. The reaction vessel was evacuated by aspirator and thoroughly purged with hydrogen (three times), and the resulting heterogeneous mixture was stirred under a balloon of hydrogen. After 24 h, the hydrogen was evacuated, the catalyst filtered off, and the filtrate was concentrated under vacuum to give a crude residue which was subjected to flash chromatographic purification (6:4 EtOAc/hexanes) to yield 4.41 g (91%) of saturated lactone **4** as a colorless oil: $[\alpha]_D^{20}$ −13.9 (*c* 0.9, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.77 (td, J = 7.5,

(15) *General Experimental Methods.* Flash chromatography was performed on 32−63 μm silica gel ICN Biomedicals, using the indicated solvent mixtures. Analytical thin-layer chromatography was performed on Merck silica gel 60 F_{254} plates (0.25 mm). The compounds were visualized by dipping the plates in an aqueous H_2SO_4 solution of cerium sulfate/ammonium molybdate or in an ethanolic solution of ninhydrin, followed by charring with a heat gun. ^{1}H NMR spectra were obtained on a Bruker AC-300 or Varian XL-300 and are reported in parts per million (δ) relative to tetramethylsilane (0.0 ppm) as an internal reference, with coupling constants in hertz (Hz). Rotations were measured on a Perkin-Elmer 241 Polarimeter and are given in units of 10^{-1} deg cm^2 g^{-1}. Elemental analyses were performed by the Microanalytical Laboratory of University of Sassari. Melting points were determined on an Electrothermal apparatus and are recorded uncorrected. All the solvents were distilled before use: THF over Na/benzophenone, Et_2O over $LiAlH_4$, CH_2Cl_2 over CaH_2.

(16) In the Experimental Section each compound has been named according to the conventional naming rules. As a consequence, the atom numbering of the compounds throughout the text does not always correspond to that reported in the Experimental Section.

(17) Rassu, G.; Zanardi, F.; Battistini, L.; Gaetani, E.; Casiraghi, G. *J. Med. Chem.* **1997**, *40*, 168.

(18) Zanardi, F.; Battistini, L.; Rassu, G.; Pinna, L.; Marzocchi, L.; Casiraghi, G. *J. Org. Chem.* **2000**, *65*, 2048.

2.1 Hz, 1H), 4.14 (m, 2H), 4.01 (m, 1H), 3.53 (bs, 1H), 3.35 (bs, 1H), 2.5−2.7 (m, 2H), 2.31 (m, 2H), 1.41 (s, 3H), 1.35 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 178.0, 109.3, 79.9, 75.6, 73.7, 66.8, 28.5, 26.6, 25.1, 23.6. Anal. Calcd for $C_{10}H_{16}O_5$: C, 55.55; H, 7.46. Found: C, 55.33; H, 7.60.

(1′*S*,4″*R*,5*R*)-5-[(*tert*-Butyldimethylsilanyloxy)-(2,2-dimethyl-1,3-dioxolan-4-yl)methyl]dihydrofuran-2-one (5). *tert*-Butyldimethylsilyl trifluoromethanesulfonate (TBSOTf) (5.02 mL, 21.9 mmol) and 2,6-lutidine (6.95 mL, 59.7 mmol) were sequentially added to a stirred solution of the saturated lactone **4** (4.3 g, 19.9 mmol) in anhydrous CH_2Cl_2 (50 mL) under argon atmosphere at room temperature. After 6 h the reaction was concentrated under vacuum to afford a crude residue that was purified by flash chromatography (6:4 hexanes/EtOAc). Protected lactone **5** (5.90 g, 90%) was obtained as a colorless oil: $[\alpha]_D^{20}$ −9.5 (*c* 0.6, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.60 (dt, J = 6.6, 3.6 Hz, 1H), 4.13 (m, 1H), 4.06 (dd, J = 8.1, 6.3 Hz, 1H), 3.87 (dd, J = 8.1, 6.9 Hz, 1H), 3.78 (dd, J = 6.0, 3.6 Hz, 1H), 2.51 (m, 2H), 2.21 (m, 2H), 1.41 (s, 3H), 1.33 (s, 3H), 0.89 (s, 9H), 0.13 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 176.5, 109.0, 81.2, 76.3, 74.3, 66.6, 28.4, 26.5, 25.8 (3C), 27.2, 23.6, 18.1−4.0 (2C). Anal. Calcd for $C_{16}H_{30}O_5Si$: C, 58.15; H, 9.15. Found: C, 58.30; H, 9.09.

(1′*S*,2′*R*,5*R*)-5-[1-(*tert*-Butyldimethylsilanyloxy)-2,3-dihydroxypropyl]dihydrofuran-2-one (6). Protected lactone **5** (5.80 g, 17.6 mmol) was dissolved in 40 mL of 70% aqueous acetic acid, and the resulting solution was allowed to react at 50 °C. The reaction was monitored by TLC and was judged complete after 8 h. The solution was then diluted with CH_2Cl_2, the organic layer was separated and treated twice with saturated $NaHCO_3$ solution. The combined organic layers were dried ($MgSO_4$) and concentrated to give a crude residue that was purified by flash chromatography (7:3 EtOAc/THF). Pure terminal diol **6** (4.91 g, 96%) was obtained as a white solid: mp 81−83 °C; $[\alpha]_D^{20}$ −14.2 (*c* 2.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.76 (td, J = 7.2, 3.0 Hz, 1H), 3.79 (m, 3H), 3.66 (m, 1H), 3.32 (bs, 2H), 2.55 (m, 2H), 2.27 (m, 1H), 2.14 (m, 1H), 0.90 (s, 9H), 0.14 (s, 3H), 0.13 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 177.6, 80.8, 74.3, 72.3, 63.1, 28.4, 25.7 (3C), 23.5, 18.0, −4.4, −4.5. Anal. Calcd for $C_{13}H_{26}O_5Si$: C, 53.76; H, 9.02. Found: C, 53.69; H, 8.81.

(1′*S*,2′*R*,5*R*)-5-[1,2,3-Tris-(*tert*-butyldimethylsilanyloxy)-propyl]dihydrofuran-2-one (7). To a solution of compound **6** (4.80 g, 16.5 mmol) in dry pyridine (50 mL), under argon atmosphere, were added TBSCl (19.90 g, 132.0 mmol) and imidazole (8.99 g, 132.0 mmol), and the mixture was stirred at 45 °C for 5 h. One further addition of TBSCl (4.97 g, 33.0 mmol) was effected, and after 12 h, the reaction was quenched with H_2O (200 mL). The resulting slurry was extracted with CH_2Cl_2, and the extracts were dried ($MgSO_4$), filtered, and evaporated under reduced pressure to give a crude product which was flash chromatographed on silica gel (9:1 hexanes/THF) to afford **7** (5.99 g, 70%) as an oil: $[\alpha]_D^{20}$ −22.5 (*c* 1.2, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.62 (dt, J = 9.6, 6.6 Hz, 1H), 3.77 (m, 3H), 3.44 (m, 1H), 2.50 (m, 2H), 2.25 (m, 1H), 1.91 (dq, J = 12.3, 9.9 Hz, 1H), 0.90 (s, 9H), 0.89 (s, 18H), 0.12 (s, 3H), 0.10 (s, 6H), 0.08 (s, 3H), 0.06 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 176.7, 82.3, 77.9, 74.3, 63.5, 29.2, 25.9 (9C), 24.9, 18.2 (3C), −4.5, −4.6 (2C), −4.7, −5.5 (2C). Anal. Calcd for $C_{25}H_{54}O_5Si_3$: C, 57.86; H, 10.49. Found: C, 57.66; H, 10.32.

(1′*S*,2′*R*,5*R*)-5-[1,2-Bis-(*tert*-butyldimethylsilanyloxy)-3-hydroxypropyl]dihydrofuran-2-one (8). Protected lactone **7** (5.90 g, 11.4 mmol) was dissolved in 20 mL of 80% aqueous acetic acid, and the resulting solution was allowed to react at room temperature with stirring. The reaction was monitored by TLC and was judged complete after 6 h. The solution was then quenched with saturated $NaHCO_3$ solution, and the resulting mixture was extracted with CH_2Cl_2 and EtOAc. The combined organic layers were dried ($MgSO_4$), filtered and concentrated under vacuum to give a crude residue that was purified by flash chromatography (7:3 hexanes/THF). A pure terminal alcohol intermediate **8** (3.69 g, 80%) was obtained as a glassy solid: $[\alpha]_D^{20}$ −18.4 (*c* 1.1, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.69 (td, J = 7.5, 3.6 Hz, 1H), 3.80 (m, 2H), 3.68 (m, 2H), 2.53 (m, 2H), 2.25 (m, 1H), 2.08 (m, 1H), 1.88 (bs, 1H), 0.91 (s, 9H), 0.90 (s, 9H), 0.16 (s, 3H), 0.13 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 176.7, 80.3, 75.2, 73.4, 62.6, 28.7, 25.9 (3C), 24.0, 18.3, 18.0, −4.2, −4.5, −4.6, −4.7. Anal. Calcd for $C_{19}H_{40}O_5Si_2$: C, 56.39; H, 9.96. Found: C, 56.25; H, 10.09.

(2*S*,2′*R*,3*S*)-2,3-Bis-(*tert*-butyldimethylsilanyloxy)-3-(5-oxo-tetrahydrofuran-2-yl)propionaldehyde (9). To a solution of oxalyl chloride (2.33 mL, 26.7 mmol) in CH_2Cl_2 (130 mL) at −80 °C, under argon was added dropwise a solution of DMSO (2.53 mL, 35.6 mmol) in CH_2Cl_2 (16 mL). After 30 min, a solution of alcohol **8** (3.60 g, 8.9 mmol) in CH_2Cl_2 (16 mL) was added dropwise. After 30 min at −80 °C, Et_3N (12.40 mL, 88.9 mmol) was added. The reaction mixture was stirred at −80 °C for 30 min and then warmed slowly to 0 °C over 1 h. After 30 min of stirring at 0 °C, toluene (400 mL) was added to the mixture, and the solution was filtered through a Celite pad and concentrated in vacuo. The residue was dissolved in hexanes (400 mL), filtered again, and concentrated under reduced pressure to give aldehyde **9** (3.48 g, 97%) as a white solid which was used without further purification in the aldol reaction: mp 40−42 °C, $[\alpha]_D^{20}$ −3.13 (*c* 0.9, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.64 (d, J = 1.2 Hz, 1H), 4.61 (td, J = 7.5, 6.3 Hz, 1H), 4.09 (dd, J = 3.0, 1.5 Hz, 1H), 4.00 (dd, J = 6.3, 3.0 Hz, 1H), 2.55 (m, 2H), 2.26 (dq, J = 12.9, 7.5 Hz, 1H), 2.01 (m, 1H), 0.93 (s, 9H), 0.89 (s, 9H), 0.13 (s, 3H), 0.11 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 202.6, 176.3, 80.3, 79.6, 77.2, 28.5, 25.7 (6C), 23.7, 18.2, 18.1, −4.6, −4.7, −4.8, −5.0. Anal. Calcd for $C_{19}H_{38}O_5Si_2$: C, 56.67; H, 9.51. Found: C, 56.51; H, 9.26.

(1*S*,2*S*,3*R*,4*S*,5*R*)-3,4-Bis-(*tert*-butyldimethylsilanyloxy)-2-hydroxy-6-oxabicyclo[3.2.1]octan-7-one (10). A solution of diisopropylamine (1.68 mL, 12.0 mmol) in dry THF (40 mL), under argon, was treated at −20 °C with BuLi (6.45 mL of a 1.6 M solution in hexane, 10.3 mmol). The reaction was allowed to react for 20 min after which time the solution was cooled to −80 °C and treated with a solution of aldehyde **9** (3.45 g, 8.6 mmol) in dry THF (20 mL). The reaction was monitored by TLC and was judged complete after 15 min. The reaction was then quenched at −80 °C by the addition of saturated aqueous NH_4Cl (20 mL), and after ambient temperature was reached, the mixture was extracted with CH_2Cl_2. The combined extracts were dried ($MgSO_4$), filtered, and concentrated to give a crude residue that was purified by flash chromatography (85:15 hexanes/EtOAc). A pure binuclear adduct **10** (1.77 g, 51%) was obtained as a glassy solid: $[\alpha]_D^{20}$ +16.4 (*c* 0.6, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.59 (td, J = 5.1, 0.6 Hz, 1H), 4.14 (td, J = 4.5, 0.6 Hz, 1H), 3.82 (ddd, J = 9.0, 5.1, 3.0 Hz, 1H), 3.61 (dd, J = 9.0, 4.2 Hz, 1H), 2.73 (ddd, J = 5.1, 3.0, 0.6 Hz, 1H), 2.45 (d, J = 12.0 Hz, 1H), 2.20 (dtd, J = 12.0, 5.1, 0.6 Hz, 1H), 1.91 (d, J = 5.1 Hz, 1H), 0.92 (s, 9H), 0.89 (s, 9H), 0.12 (s, 3H), 0.11 (s, 3H), 0.09 (s, 3H), 0.07 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 175.8, 79.5, 74.9, 71.3, 70.0, 43.6, 29.7, 26.0 (3C), 25.7 (3C), 18.2, 18.0, −3.6, −4.4, −4.6, −4.7. Anal. Calcd for $C_{19}H_{38}O_5Si_2$: C, 56.67; H, 9.51. Found: C, 56.55; H, 9.34.

(1*S*,2*S*,3*R*,4*S*,5*R*)-3,4-Bis-(*tert*-butyldimethylsilanyloxy)-2-(triethylsilanyloxy)-6-oxabicyclo[3.2.1]octan-7-one (11). To a solution of **10** (1.70 g, 4.2 mmol) in dry pyridine (15 mL), under argon atmosphere, were sequentially added triethylsilyltriflate (1.41 mL, 8.4 mmol) and a catalytic amount of DMAP (50 mg). After being stirred at room temperature for 5 h, further addition of pyridine (7.5 mL) and triethylsilyltriflate (705 μL, 4.2 mmol) was effected, and the mixture was allowed to stir overnight, quenched with H_2O (100 mL), and extracted with CH_2Cl_2. The combined organic layers were dried over $MgSO_4$, filtered, and concentrated in a vacuum to provide a crude oily residue that was purified by flash chromatography (95:5 hexanes/EtOAc) to yield 2.06 g (95%) of a binuclear adduct **11** as an oil: $[\alpha]_D^{20}$ +52.1 (*c* 2.8, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.52 (td, J = 4.8, 1.0 Hz, 1H), 4.11 (td, J = 4.8, 1.0 Hz, 1H), 3.86 (dd, J = 8.7, 2.7 Hz, 1H), 3.62 (dd, J = 8.7, 4.2 Hz, 1H), 2.57 (ddd, J = 5.1, 2.7, 1.0 Hz, 1H), 2.40 (d, J = 12.0 Hz, 1H), 2.12 (dtd, J = 12.0, 5.0, 1.0 Hz, 1H), 1.00 (t, J = 7.8 Hz, 9H), 0.91 (s, 9H), 0.90 (s, 9H), 0.66 (q, J = 7.8 Hz, 6H), 0.12 (s, 3H), 0.08 (s, 3H), 0.06 (s, 3H), 0.05 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 175.2, 78.9, 74.4, 72.0, 70.6, 44.5, 29.9, 26.3 (3C), 25.8 (3C), 18.2, 18.0, 6.8 (3C), 5.1 (3C), −3.9,

−4.1, −4.3, −4.6. Anal. Calcd for $C_{25}H_{52}O_5Si_3$: C, 58.09; H, 10.14. Found: C, 58.12; H, 10.31.

(1*R*,2*S*,3*R*,4*S*,5*R*)-2,3-Di-*O*-(*tert*-butyldimethylsilanyl)-4-*O*-(triethylsilanyl)-5-hydroxymethylcyclohexane-1,2,3,4-tetrol (12). To a reaction vessel containing lactone **11** (2.0 g, 3.9 mmol) cooled to 0 °C, under argon atmosphere, were sequentially added 30 mL of dry THF and $LiAlH_4$ (7.80 mL of a 1 M solution in THF). After being stirred for 15 min, the reaction mixture was quenched by addition of saturated aqueous NH_4Cl and with 5% aqueous citric acid solution until neutral pH was reached. The reaction mixture was extracted thoroughly with CH_2Cl_2 and EtOAc, and the extracts were dried ($MgSO_4$), filtered, and concentrated under reduced pressure to give a residue which was purified by flash chromatography (7:3 hexanes/EtOAc) to give partially protected carbasugar **12** (1.89 g, 93%) as an oil: $[\alpha]_D^{20}$ −33.9 (*c* 1.2, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.90 (t, J = 3.0 Hz, 1H), 3.83 (m, 1H), 3.79 (dd, J = 3.5, 2.7 Hz, 1H), 3.73 (dd, J = 9.0, 2.4 Hz, 1H), 3.59 (m, 2H), 2.08 (m, 1H), 1.71 (dt, J = 12.3, 4.2 Hz, 1H), 1.60 (bs, 2H), 1.45 (q, J = 12.3 Hz, 1H), 0.99 (t, J = 7.8 Hz, 9H), 0.93 (s, 9H), 0.88 (s, 9H), 0.63 (q, J = 7.8 Hz, 6H), 0.13 (s, 3H), 0.11 (s, 3H), 0.09 (s, 3H), 0.06 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 75.6, 75.4, 72.8, 69.5, 64.3, 37.6, 28.8, 26.0 (3C), 25.8 (3C), 18.1, 18.0, 6.9 (3C), 4.9 (3C), −4.3, −4.4, −4.7, −4.8. Anal. Calcd for $C_{25}H_{56}O_5Si_3$: C, 57.64; H, 10.83. Found: C, 57.78; H, 10.68.

(1*R*,2*S*,3*R*,4*S*,5*R*)-5-(Hydroxymethyl)cyclohexane-1,2,3,4-tetrol [Pseudo-*β*-D-gulopyranose] (13). The partially protected carbasugar **12** (1.85 g, 3.6 mmol) was treated, at room temperature, with a solution mixture of 6 N HCl−THF−MeOH (1:2:2) (30 mL). The reaction was allowed to react for 1 h and then concentrated to dryness under vacuum to leave an oily crude residue which was flash chromatographed on silica gel (1:1 EtOAc/MeOH) to afford fully deprotected carbasugar **13** (622 mg, 97%) as a glassy solid: $[\alpha]_D^{20}$ −60.9 (*c* 2.3, MeOH); ^{1}H NMR (300 MHz, D_2O) δ 3.94 (dd, J = 3.2, 2.7 Hz, 1H), 3.92 (t, J = 3.2 Hz, 1H), 3.74 (ddd, J = 11.4, 9.9, 4.8 Hz, 1H), 3.61 (dd, J = 11.0, 8.1 Hz, 1H), 3.60 (dd, J = 9.9, 2.7 Hz, 1H), 3.50 (dd, J = 11.0, 6.3 Hz, 1H), 1.99 (ddddd, J = 12.6, 8.1, 6.3, 4.5, 3.2 Hz, 1H), 1.76 (dt, J = 12.6, 4.5 Hz, 1H), 1.28 (dt, J = 12.6, 11.4 Hz, 1H); ^{13}C NMR (75 MHz, D_2O) δ 73.1, 72.6, 69.9, 69.2, 62.5, 36.6, 29.4. Anal. Calcd for $C_7H_{14}O_5$: C, 47.19; H, 7.92. Found: C, 47.05; H, 7.99.

(1*R*,2*S*,3*R*,4*S*,5*R*)-1,2,3,4-Tetra-*O*-acetyl-5-(acetyloxymethyl)cyclohexane-1,2,3,4-tetrol (14). Acetic anhydride (4.82 mL, 51.0 mmol) and a catalytic amount of DMAP (10 mg) were added under argon to a solution of deprotected carbasugar **13** (610 mg, 3.4 mmol) in dry pyridine (10 mL). The reaction was stirred for 5 h at room temperature. The solution was then quenched with H_2O, and the resulting mixture was extracted with CH_2Cl_2 and EtOAc. The combined organic layers were dried ($MgSO_4$), filtered, and concentrated to give a crude residue that was flash chromatographed on silica gel eluting with EtOAc to afford 1.19 g (90%) of pure protected carbasugar **14** as a white solid: mp 95−96 °C; $[\alpha]_D^{20}$ −19.3 (*c* 3.4, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.38 (dd, J = 3.9, 2.7 Hz, 1H), 5.17 (m, 2H), 5.10 (t, J = 3.5 Hz, 1H), 4.05 (dd, J = 11.0, 8.4 Hz, 1H), 3.87 (dd, J = 11.0, 6.6 Hz, 1H), 2.46 (m, 1H), 2.13 (s, 3H), 2.12 (s, 3H), 2.09 (m, 1H), 2.05 (s, 6H), 1.99 (s, 3H), 1.58 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 170.7, 170.3, 170.0, 169.2, 169.1, 70.3, 68.9, 68.3, 68.1, 63.1, 33.5, 27.5, 20.9, 20.7, 20.6 (3C). Anal. Calcd for $C_{17}H_{24}O_{10}$: C, 52.58; H, 6.23. Found: C, 52.69; H, 6.09.

(2*S*,2′*R*)-2-(*tert*-Butyldimethylsilanyloxy)-(5-oxotetrahydrofuran-2-yl)acetaldehyde (15). The partially deprotected lactone **6** (3.75 g, 12.9 mmol) was dissolved in CH_2Cl_2 (270 mL) and treated with a 0.65 M aqueous $NaIO_4$ solution (26 mL) and chromatography grade SiO_2 (29 g). The resulting heterogeneous mixture was vigorously stirred at room temperature until complete consumption of the starting material (about 20 min, monitoring by TLC). The slurry was filtered under suction, and the silica gel was thoroughly washed with CH_2Cl_2 and EtOAc. The filtrates were evaporated to afford aldehyde **15** (2.83 g, 85%) as colorless crystals: mp 60−61 °C; $[\alpha]_D^{20}$ −97.8 (*c* 2.7, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.67 (d, J = 1.3 Hz, 1H), 4.88 (ddd, J = 8.1, 5.4, 2.6 Hz, 1H), 4.04 (dd, J = 2.6, 1.3 Hz, 1H), 2.57 (m, 2H), 2.37 (m, 1H), 2.19 (m, 1H), 0.95 (s, 9H), 0.12 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 201.9, 176.5, 79.6, 79.2, 27.7, 25.5 (3 C), 23.2, 18.0, −4.7, −5.2. Anal. Calcd for $C_{12}H_{22}O_4Si$: C, 55.78; H, 8.58. Found: C, 55.58; H, 8.63.

(1*R*,4*S*,5*S*,6*S*)-6-(*tert*-Butyldimethylsilanyloxy)-5-hydroxy-2-oxabicyclo[2.2.1]heptan-3-one (16). A solution of diisopropylamine (2.12 mL, 15.1 mmol) in dry THF (56 mL), under argon, was treated at −20 °C with BuLi (8.13 mL of a 1.6 M solution in hexane, 13.0 mmol). The reaction was allowed to react for 20 min after which time the solution was cooled to −80 °C and treated with a solution of aldehyde **15** (2.80 g, 10.8 mmol) in dry THF (30 mL). The reaction was monitored by TLC and was judged complete after 15 min. The reaction was then quenched at −80 °C by the addition of saturated aqueous NH_4Cl (25 mL), and after ambient temperature was reached, the mixture was extracted with CH_2Cl_2 and EtOAc. The combined extracts were dried ($MgSO_4$), filtered, and concentrated to give a crude residue that was purified by flash chromatography (6:4 hexanes/EtOAc). A pure binuclear adduct **16** (1.40 g, 50%) was obtained as a white solid: mp 83−85 °C; $[\alpha]_D^{20}$ −32.3 (*c* 1.3, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.48 (m, 1H), 4.17 (dt, J = 4.2, 1.2 Hz, 1H), 3.90 (dt, J = 2.1, 1.2 Hz, 1H), 2.96 (dq, J = 4.5, 1.2 Hz, 1H), 2.28 (dq, J = 11.1, 2.1 Hz, 1H), 2.18 (dd, J = 11.1, 1.2 Hz, 1H), 1.68 (bs, 1H), 0.90 (s, 9H), 0.15 (s, 3H), 0.12 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 175.2, 82.1, 78.7, 78.1, 47.3, 35.9, 25.7 (3C), 17.9, −4.8, −4.9. Anal. Calcd for $C_{12}H_{22}O_4Si$: C, 55.78; H, 8.58. Found: C, 55.89; H, 8.40.

(1*R*,4*S*,5*S*,6*S*)-6-(*tert*-Butyldimethylsilanyloxy)-5-(triethylsilanyloxy)-2-oxabicyclo[2.2.1]heptan-3-one (17). To a solution of **16** (1.38 g, 5.3 mmol) in dry pyridine (15 mL), under argon atmosphere, were sequentially added triethylsilyltriflate (1.78 mL, 10.6 mmol) and a catalytic amount of DMAP (60 mg). After being stirred at room temperature for 5 h, further addition of pyridine (7.5 mL) and triethylsilyltriflate (910 μL, 5.42 mmol) was effected, the mixture was allowed to stir overnight, and the reaction was quenched with H_2O (100 mL) and extracted with CH_2Cl_2. The combined organic layers were dried over $MgSO_4$, filtered, and concentrated in a vacuum to provide a crude oily residue that was purified by flash chromatography (95:5 hexanes/EtOAc) to yield 1.88 g (95%) of protected binuclear adduct **17** were obtained as an oil: $[\alpha]_D^{20}$ +12.9 (*c* 1.4, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.42 (m, 1H), 4.08 (dt, J = 4.5, 1.2 Hz, 1H), 3.84 (dt, J = 2.1, 1.2 Hz, 1H), 2.80 (dq, J = 4.5, 1.5 Hz, 1H), 2.23 (dq, J = 11.4, 2.1 Hz, 1H), 2.12 (dt, J = 11.4, 1.2 Hz, 1H), 0.97 (t, J = 8.1 Hz, 9H), 0.89 (s, 9H), 0.63 (q, J = 8.1 Hz, 6H), 0.12 (s, 3H), 0.10 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 174.4, 81.5, 79.2, 79.0, 47.4, 35.5, 25.6 (3C), 17.8, 6.7 (3C), 4.6 (3C), −4.6, −5.0. Anal. Calcd for $C_{18}H_{36}O_4Si_2$: C, 58.02; H, 9.74. Found: C, 58.18; H, 9.84.

(1*R*,2*S*,3*S*,4*R*)-2-*O*-(*tert*-Butyldimethylsilanyl)-3-*O*-(triethylsilanyl)-4-(hydroxymethyl)cyclopentane-1,2,3-triol (18). To a reaction vessel containing lactone **17** (1.85 g, 5.0 mmol) cooled to 0 °C, under argon atmosphere, were sequentially added 30 mL of dry THF and $LiAlH_4$ (10 mL of a 1 M solution in THF). After being stirring for 1 h, the reaction was quenched by addition of saturated aqueous NH_4Cl and with 5% aqueous citric acid solution until neutral pH was reached. The reaction mixture was extracted thoroughly with CH_2Cl_2 and EtOAc, dried ($MgSO_4$), filtered, and concentrated under reduced pressure to give a residue which was purified by flash chromatography (6:4 hexanes/EtOAc) to give partially protected carbasugar **18** (1.70 g, 90%) as an oil: $[\alpha]_D^{20}$ −1.9 (*c* 1.2, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.07 (dt, J = 5.1, 1.8 Hz, 1H), 3.89 (m, 2H), 3.84 (dd, J = 11.0, 4.2 Hz, 1H), 3.73 (dd, J = 11.0, 6.0 Hz, 1H), 2.73 (bs, 2H), 2.35 (m, 2H), 1.60 (m, 1H), 0.99 (t, J = 8.1 Hz, 9H), 0.87 (s, 9H), 0.67 (q, J = 8.1 Hz, 6H), 0.10 (s, 3H), 0.08 (s, 3H);^{13}C NMR (75 MHz, $CDCl_3$) δ 83.5, 80.6, 78.3, 62.6, 43.3, 34.9, 25.7 (3C), 17.9, 6.8 (3C), 4.7 (3C), −4.6, −4.7. Anal. Calcd for $C_{18}H_{40}O_4Si_2$: C, 57.40; H, 10.70. Found: C, 57.47; H, 10.66.

(1*R*,2*S*,3*S*,4*R*)-4-(Hydroxymethyl)cyclopentane-1,2,3-triol [Pseudo-*β*-D-xylofuranose] (19). The partially pro-

tected carbasugar **18** (1.68 g, 4.5 mmol) was treated, at room temperature, with a solution mixture of 6 N HCl−THF−MeOH (1:2:2) (30 mL). The reaction was allowed to react for 30 min and then concentrated to dryness under vacuum to leave an oily crude residue which was flash chromatographed on silica gel (1:1 EtOAc/MeOH) to afford fully deprotected carbasugar **19** (633 mg, 95%) as a glassy solid: $[\alpha]_D^{20}$ +34.7 (*c* 0.2, MeOH); ^{1}H NMR (300 MHz, D_2O) δ 3.95 (dd, J = 7.5, 5.4 Hz, 1H), 3.88 (ddd, J = 8.4, 7.2, 6.6 Hz, 1H), 3.73 (bt, J = 6.0 Hz, 1H), 3.72 (dd, J = 11.1, 6.6 Hz, 1H), 3.53 (dd, J = 11.1, 6.9 Hz, 1H), 2.24 (dquint, J = 9.3, 6.9 Hz, 1H), 2.12 (dt, J = 12.9, 7.8 Hz, 1H), 1.38 (dt, J = 12.9, 9.0 Hz, 1H); ^{13}C NMR (75 MHz, D_2O) δ 83.7, 75.9, 75.1, 61.7, 39.7, 32.6. Anal. Calcd for $C_6H_{12}O_4$: C, 48.64; H, 8.16. Found: C, 48.51; H, 8.26

(1*R*,2*S*,3*S*,4*R*)-1,2,3-Tri-*O*-acetyl-4-((acetyloxy)methyl)-cyclopentane-1,2,3-triol (20). Acetic anhydride (5.96 mL, 63.0 mmol) and a catalytic amount of DMAP (10 mg) were added under argon to a solution of deprotected carbasugar **19** (620 mg, 4.2 mmol) in dry pyridine (12 mL). The reaction was stirred for 30 min at room temperature. The reaction was then quenched with H_2O, and the resulting mixture was extracted with CH_2Cl_2 and EtOAc. The combined organic layers were dried ($MgSO_4$), filtered, and concentrated to give a crude residue that was flash chromatographed on silica (2:8 hexanes/EtOAc) to afford 1.26 g (95%) of pure protected carbasugar **20** as an oil: $[\alpha]_D^{20}$ −27.5 (*c* 0.4, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.17 (t, J = 7.0 Hz, 1H), 5.16 (dd, J = 8.4, 4.0 Hz, 1H), 5.06 (td, J = 7.8, 4.5 Hz, 1H), 4.14 (dd, J = 11.1, 7.5 Hz, 1H), 4.08 (dd, J = 11.4, 6.3 Hz, 1H), 2.62 (dtt, J = 10.5, 7.5, 6.3 Hz, 1H), 2.42 (dt, J = 13.5, 7.5 Hz, 1H), 2.09 (s, 3H), 2.08 (s, 3H), 2.07 (s, 3H), 2.05 (s, 3H), 1.67 (ddd, J = 13.5, 10.8, 7.8 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 170.8, 170.3, 169.8, 169.7, 81.2, 76.4, 75.6, 62.3, 38.4, 32.0, 20.9, 20.8 (2C), 20.7. Anal. Calcd for $C_{14}H_{20}O_8$: C, 53.16; H, 6.37. Found: C, 53.24; H, 6.48.

(1′*S*,4″*R*,5*R*)-1-(*tert*-Butyloxycarbonyl)-5-[(2,2-dimethyl-1,3-dioxolan-4-yl)hydroxymethyl]-1,5-dihydropyrrol-2-one (22). To a solution of 2,3-*O*-isopropylidene-D-glyceraldehyde **2** (2.15 g, 16.5 mmol) in anhydrous Et_2O (120 mL) were added silyl enol ether **21** (4.91 g, 16.5 mmol) and $SnCl_4$ (1.93 mL, 16.5 mmol) under argon at −80 °C. The mixture was stirred at this temperature for 3 h, and then a saturated aqueous $NaHCO_3$ solution was added at −80 °C. After ambient temperature was reached, the resulting mixture was extracted with Et_2O. After the extracts were dried ($MgSO_4$), the solution was evaporated under reduced pressure, and the crude product was crystallized from CH_2Cl_2/hexane to give 4.14 g (80%) of α,β-unsaturated lactam **22** as a white solid: mp 138−140 °C; $[\alpha]_D^{20}$ +197.6 (*c* 0.83, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.43 (dd, J = 6.3, 2.1 Hz, 1H), 6.13 (dd, J = 6.3, 1.5 Hz, 1H), 4.81 (dt, J = 5.7, 2.4 Hz, 1H), 4.09 (ddd, J = 6.0, 5.7, 3.9 Hz, 1H), 4.01 (q, J = 6.0 Hz, 1H), 3.94 (dd, J = 8.1, 6.0 Hz, 1H), 3.86 (dd, J = 8.1, 6.0 Hz, 1H), 3.63 (d, J = 3.9 Hz, 1H), 1.57 (s, 9H), 1.37 (s, 3H), 1.32 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 168.9, 150.9, 148.2, 126.9, 109.2, 83.8, 75.6, 72.6, 66.4, 65.6, 28.0 (3 C), 26.4, 25.1. Anal. Calcd for $C_{15}H_{23}NO_6$: C, 57.50; H, 7.40; N, 4.47. Found: C, 57.31; H, 7.35; N, 4.32.

(1′*S*,4″*R*,5*R*)-1-(*tert*-Butyloxycarbonyl)-5-[(2,2-dimethyl-1,3-dioxolan-4-yl)hydroxymethyl]pyrrolidin-2-one (23). Palladium on carbon (10%, 420 mg) was added to a solution of α,β-unsaturated lactam **22** (4.0 g, 12.8 mmol) in anhydrous THF (60 mL) in the presence of a small amount of NaOAc (176 mg) at room temperature. The reaction vessel was evacuated by aspirator and thoroughly purged with hydrogen (three times), and the resulting heterogeneous mixture was stirred under a balloon of hydrogen. After 24 h, the hydrogen was evacuated, the catalyst filtered off, and the filtrate was concentrated under vacuum to give a crude residue which was subjected to flash chromatographic purification (6:4 hexanes/EtOAc) to yield 3.71 g (92%) of saturated lactam **23** as a white solid: mp 102−105 °C; $[\alpha]_D^{20}$ −60.1 (*c* 1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.31 (ddd, J = 7.7, 5.9, 1.9 Hz, 1H), 4.09 (m, 2H), 3.98 (m, 1H), 3.75 (t, J = 6.0 Hz, 1H), 2.70 (ddd, J = 17.7, 12.1, 9.1 Hz, 1H), 2.39 (ddd, J = 17.7, 8.7, 2.2 Hz, 1H), 2.16 (m, 2H), 1.75 (bs, 1H), 1.54 (s, 9H), 1.40 (s, 3H), 1.34 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 174.5, 151.7, 109.4, 83.6, 77.7, 74.5, 66.8, 60.4, 32.0, 28.0 (3C), 26.6, 25.1, 21.7. Anal. Calcd for $C_{15}H_{25}NO_6$: C, 57.13; H, 7.99; N, 4.44. Found: C, 57.26; H, 8.10; N, 4.37.

(1′*S*,4″*R*,5*R*)-5-[(*tert*-Butyldimethylsilanyloxy)-(2,2-dimethyl-1,3-dioxolan-4-yl)methyl]-1-(*tert*-butyloxycarbonyl)pyrrolidin-2-one (24). *tert*-Butyldimethylsilyl trifluoromethanesulfonate (TBSOTf) (2.96 mL, 12.9 mmol) and 2,6-lutidine (4.50 mL, 38.6 mmol) were sequentially added to a stirred solution of the saturated lactam **23** (3.68 g, 11.7 mmol) in anhydrous CH_2Cl_2 (30 mL) under argon atmosphere at room temperature. After 6 h the reaction was concentrated under vacuum to afford a crude residue that was purified by flash chromatography (4:6 hexanes/EtOAc). Protected lactam **24** (4.62 g, 92%) was obtained as a pale yellow oil: $[\alpha]_D^{20}$ +21.3 (*c* 0.8, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.14 (ddd, J = 8.1, 3.6, 1.2 Hz, 1H), 4.04 (dd, J = 8.4, 3.3 Hz, 1H), 4.02 (dd, J = 8.4, 6.3 Hz, 1H), 3.90 (m, 1H), 3.66 (dd, J = 8.1, 6.3 Hz, 1H), 2.51 (m, 1H), 2.33 (m, 1H), 2.11 (m, 1H), 1.93 (m, 1H), 1.46 (s, 9H), 1.24 (s, 3H), 1.20 (s, 3H), 0.80 (s, 9H), 0.07 (s, 3H), 0.05 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 174.4, 149.8, 109.8, 82.3, 75.2, 71.1, 68.6, 60.2, 31.8, 29.4, 28.0 (3C), 26.2, 25.4 (3C), 24.9, 17.6, −4.2, −5.0. Anal. Calcd for $C_{21}H_{39}NO_6Si$: C, 58.71; H, 9.15; N, 3.26. Found: C, 58.79; H, 9.20; N, 3.12.

(1′*S*,2′*R*,5*R*)-5-[1-(*tert*-Butyldimethylsilanyloxy)-2,3-dihydroxypropyl]-1-(*tert*-butyloxycarbonyl)pyrrolidin-2-one (25). Protected lactam **24** (4.6 g, 10.7 mmol) was dissolved in 30 mL of 70% aqueous acetic acid, and the resulting solution was allowed to react at 50 °C. The reaction was monitored by TLC and was judged complete after 8 h. The solution was then diluted with CH_2Cl_2, and the organic layer was separated and treated twice with saturated $NaHCO_3$ solution. The combined organic layers were dried ($MgSO_4$) and concentrated to give a crude residue that was purified by flash chromatography (3:7 hexanes/EtOAc). Pure terminal diol **25** (3.75 g, 90%) was obtained as a white solid: mp 118−120 °C; $[\alpha]_D^{20}$ +45.4 (*c* 1.8, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.28 (ddd, J = 9.0, 4.0, 2.1 Hz, 1H), 4.05 (dd, J = 8.0, 4.0 Hz, 1H), 3.75 (dd, J = 10.7, 3.0 Hz, 1H), 3.62 (m, 1H), 3.52 (dd, J = 10.7, 6.3 Hz, 1H), 3.24 (bs, 2H), 2.64 (dt, J = 18.2, 10.3 Hz, 1H), 2.38 (ddd, J = 18.1, 10.3, 2.9 Hz, 1H), 1.9−2.2 (m, 2H), 1.51 (s, 9H), 0.86 (s, 9H), 0.10 (s, 3H), 0.09 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 176.3, 150.2, 82.9, 71.8, 70.2, 64.3, 60.0, 31.8, 28.0 (3C), 25.6 (3C), 17.7, 17.4, −4.3, −5.1. Anal. Calcd for $C_{18}H_{35}NO_6Si$: C, 55.50; H, 9.06; N, 3.60. Found: C, 55.37; H, 9.16; N, 3.74.

(1′*S*,2′*R*,5*R*)-5-[1,2,3-Tris-(*tert*-butyldimethylsilanyloxy)-propyl]pyrrolidin-2-one (26). A stirring solution of compound **25** (3.70 g, 9.5 mmol) in anhydrous CH_2Cl_2 (100 mL), under argon atmosphere, was sequentially treated with *tert*-butyldimethylsilyl trifluoromethanesulfonate (TBSOTf) (8.73 mL, 38.0 mmol), 2,6-lutidine (8.85 mL, 76.0 mL), and Et_3N (2.65 mL, 19.0 mmol). The resulting mixture was warmed to 50 °C and allowed to stir for 2 h. The temperature was allowed to raise to room temperature, and the reaction was left to stirring for 12 h before being sequentially quenched with a saturated aqueous NH_4Cl solution and 5% aqueous citric acid solution until neutral pH was reached. The reaction mixture was extracted with CH_2Cl_2, and the combined organic layers were dried over $MgSO_4$, filtered, and concentrated under reduced pressure. Purification of the oily residue through flash chromatography on silica gel (8:2 hexanes/EtOAc) furnished pure Boc-deprotected lactam intermediate **26** (4.53 g, 92%) as an oil: $[\alpha]_D^{20}$ −22.5 (*c* 2.8, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.82 (bs, 1H), 3.82 (q, J = 7.0 Hz, 1H), 3.71 (dd, J = 8.4, 5.1 Hz, 1H), 3.65 (d, J = 5.1 Hz, 1H), 3.52 (t, J = 9.9 Hz, 1H), 3.42 (dd, J = 10.2, 5.1 Hz, 1H), 2.24 (m, 2H), 2.10 (m, 1H), 1.78 (m, 1H), 0.85 (s, 9H), 0.84 (s, 9H), 0.83 (s, 9H), 0.06 (s, 3H), 0.05 (s, 3H), 0.03 (s, 6H), 0.01 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 177.2, 76.3, 76.2, 63.6, 54.8, 29.9, 25.9 (3C), 25.8 (3C), 25.7 (3C), 24.4, 18.0 (3C), −3.7, −4.6, −4.8, −5.3, −5.6, −5.7. Anal. Calcd for: $C_{25}H_{55}NO_4Si_3$: C, 57.37; H, 10.70; N, 2.70. Found: C, 57.21; H, 10.86; N, 2.59.

(1′*S*,2′*R*,5*R*)-5-[1,2,3-Tris-(*tert*-butyldimethylsilanyloxy)-propyl]-1-(*tert*-butyloxycarbonyl)pyrrolidin-2-one (27).

To a room-temperature solution of the Boc-deprotected compound **26** (4.50 g, 8.7 mmol) in CH_3CN (40 mL) were added di-*tert*-butyl dicarbonate (1.90 g, 8.7 mmol) and DMAP (50 mg) with stirring. The mixture was stirred at ambient temperature for 8 h, and the solvent then was evaporated in vacuo. The crude mixture was purified by flash chromatography on SiO_2 (8:2 hexanes/EtOAc) to furnish 5.11 g (95%) of fully protected lactam **27** as an oil: $[\alpha]_D^{20}$ +36.7 (*c* 3.7, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.25 (dd, J = 8.1, 6.0 Hz, 1H), 4.10 (dd, J = 6.0, 1.2 Hz, 1H), 3.77 (ddd, J = 6.8, 3.9, 1.2 Hz, 1H), 3.64 (dd, J = 11.1, 3.9 Hz, 1H), 3.54 (dd, J = 11.0, 6.9 Hz, 1H), 2.71 (ddd, J = 18.0, 11.4, 9.6 Hz, 1H), 2.38 (ddd, J = 18.0, 9.0, 1.0 Hz, 1H), 2.26 (m, 1H), 1.99 (m, 1H), 1.54 (s, 9H), 0.91 (s, 9H), 0.89 (s, 18H), 0.12 (s, 3H), 0.10 (s, 3H), 0.09 (s, 6H), 0.04 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 175.0, 150.0, 82.7, 77.4, 73.8, 65.6, 59.5, 31.7, 28.1 (3C), 26.0 (3C), 25.9 (3C), 25.8 (3C), 19.4, 18.3, 18.1, 18.0, −4.5 (2C), −4.6, −4.8, −5.3, −5.4. Anal. Calcd for: $C_{30}H_{63}NO_6Si_3$: C, 58.30; H, 10.27; N, 2.27. Found: C, 58.44; H, 10.13; N, 2.09.

(1′*S*,2′*R*,5*R*)-5-[1,2-Bis-(*tert*-butyldimethylsilanyloxy)-3-hydroxypropyl]-1-(*tert*-butyloxycarbonyl)pyrrolidin-2-one (28). Protected lactam **27** (5.0 g, 8.1 mmol) was dissolved in 20 mL of 80% aqueous acetic acid, and the resulting solution was allowed to react at room temperature under stirring. The reaction was monitored by TLC and was judged complete after 8 h. The reaction was then quenched with saturated $NaHCO_3$ solution, and the resulting mixture was extracted with CH_2Cl_2 and EtOAc. The combined organic layers were dried ($MgSO_4$), filtered, and concentrated under vacuum to give a crude residue that was purified by flash chromatography (7:3 hexanes/EtOAc). Pure terminal alcohol **28** (3.75 g, 92%) was obtained as a glassy solid: $[\alpha]_D^{20}$ +45.4 (*c* 3.8, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.38 (td, J = 6.9, 1.8 Hz, 1H), 4.00 (dd, J = 7.2, 1.8 Hz, 1H), 3.77 (td, J = 6.0, 2.1 Hz, 1H), 3.68 (m, 3H), 2.62 (ddd, J = 18.0, 11.1, 9.3 Hz, 1H), 2.44 (ddd, J = 18.0, 9.3, 2.7 Hz, 1H), 2.05 (m, 2H), 1.53 (s, 9H), 0.91 (s, 9H), 0.90 (s, 9H), 0.14 (s, 3H), 0.10 (s, 3H), 0.09 (s, 3H), 0.08 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 174.1, 150.8, 83.5, 75.7, 74.5, 63.9, 58.9, 31.6, 28.2 (3C), 25.9 (6C), 20.8, 18.1 (2C), −4.4, −4.5, −4.6 (2C). Anal. Calcd for: $C_{24}H_{49}NO_6Si_2$: C, 57.22; H, 9.80; N, 2.78. Found: C, 57.36; H, 9.68; N, 2.81.

(2*S*,2′*R*,3*S*)-2,3-Bis-(*tert*-butyldimethylsilanyloxy)-3-[1-(*tert*-butyloxycarbonyl)-(5-oxopyrrolidin-2-yl)]propionaldehyde (29). To a solution of oxalyl chloride (1.91 mL, 21.9 mmol) in CH_2Cl_2 (130 mL) at −80 °C, under argon, was added dropwise a solution of DMSO (2.07 mL, 29.2 mmol) in CH_2Cl_2 (16 mL). After 30 min, a solution of alcohol **28** (3.70 g, 7.3 mmol) in CH_2Cl_2 (16 mL) was added dropwise. After 30 min at −80 °C, Et_3N (10.17 mL, 73.8 mmol) was added. The reaction mixture was stirred at −80 °C for 30 min and then warmed slowly to 0 °C over 1 h. After 30 min of stirring at 0 °C, toluene (300 mL) was added to the mixture, filtered through a Celite pad, and concentrated in vacuo. The residue was dissolved in hexanes (300 mL), filtered again, and concentrated under reduced pressure to give crude aldehyde **29** (3.44 g, 94%) as a colorless oil which was used without further purification in the aldol reaction: $[\alpha]_D^{20}$ +46.7 (*c* 0.6, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.52 (d, J = 2.1 Hz, 1H), 4.48 (dd, J = 5.4, 1.8 Hz, 1H), 4.25 (ddd, J = 7.8, 5.7, 2.1 Hz, 1H), 4.04 (t, J = 2.1 Hz, 1H), 2.84 (dt, J = 18.0, 10.5 Hz, 1H), 2.42 (ddd, J = 18.0, 10.8, 2.7 Hz, 1H), 2.37 (ddt, J = 13.5, 10.5, 2.5 Hz, 1H), 1.93 (dq, J = 13.5, 10.8 Hz, 1H), 1.53 (s, 9H), 0.92 (s, 9H), 0.91 (s, 9H), 0.15 (s, 3H), 0.14 (s, 3H), 0.09 (s, 3H), 0.08 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 202.0, 175.1, 149.8, 83.5, 80.7, 74.2, 58.9, 31.4, 28.1 (3C), 25.7 (6C), 18.1, 18.0, 16.9, −4.6, −4.9 (3C). Anal. Calcd for: $C_{24}H_{47}NO_6Si_2$: C, 57.45; H, 9.44; N, 2.79. Found: C, 57.31; H, 9.57; N, 2.88.

(1*S*,2*S*,3*R*,4*S*,5*R*)-3,4-Bis-(*tert*-butyldimethylsilanyloxy)-6-(*tert*-butyloxycarbonyl)-2-hydroxy-6-azabicyclo[3.2.1]-octan-7-one (30). A solution of diisopropylamine (1.33 mL, 9.5 mmol) in dry THF (30 mL), under argon, was treated at −20 °C with BuLi (5.12 mL of a 1.6 M solution in hexane, 8.2 mmol). The reaction was allowed to react for 20 min after which time the solution was cooled to −80 °C and treated with a solution of aldehyde **29** (3.41 g, 6.8 mmol) in dry THF (20 mL). The reaction was monitored by TLC and was judged complete after 15 min. The reaction was then quenched at −80 °C by the addition of saturated aqueous NH_4Cl (20 mL), and after ambient temperature was reached, the mixture was extracted with CH_2Cl_2. The combined extracts were dried ($MgSO_4$), filtered, and concentrated to give a crude residue that was purified by flash chromatography (7:3 hexanes/EtOAc). A pure binuclear adduct **30** (2.04 g, 60%) was obtained as an oil: $[\alpha]_D^{20}$ +23.3 (*c* 0.3, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.27 (td, J = 3.9, 0.5 Hz, 1H), 4.17 (td, J = 3.9, 0.6 Hz, 1H), 3.82 (dt, J = 9.0, 3.0 Hz, 1H), 3.53 (dd, J = 8.7, 3.9 Hz, 1H), 2.70 (ddd, J = 5.1, 3.6, 0.6 Hz, 1H), 2.30 (d, J = 12.0 Hz, 1H), 1.95 (dtd, J = 12.0, 4.0, 0.5 Hz, 1H), 1.89 (d, J = 2.4 Hz, 1H), 1.54 (s, 9H), 0.92 (s, 9H), 0.91 (s, 9H), 0.13 (s, 3H), 0.10 (s, 6H), 0.07 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 176.3, 149.1, 83.1, 75.0, 71.4, 69.6, 59.9, 47.9, 28.0 (3C), 26.9, 26.1 (3C), 25.8 (3C), 18.3, 18.0, −3.8, −4.4, −4.5, −4.6. Anal. Calcd for: $C_{24}H_{47}NO_6Si_2$: C, 57.45; H, 9.44; N, 2.79. Found: C, 57.36; H, 9.31; N, 2.90.

(1*S*,2*S*,3*R*,4*S*,5*R*)-3,4-Bis-(*tert*-butyldimethylsilanyloxy)-6-(*tert*-butyloxycarbonyl)-2-(triethylsilanyloxy)-6-azabicyclo[3.2.1]octan-7-one (31). To a solution of **30** (2.0 g, 4.0 mmol) in dry pyridine (15 mL), under argon atmosphere, were sequentially added triethylsilyltriflate (1.34 mL, 8.0 mmol) and a catalytic amount of DMAP (50 mg). After being stirred at room temperature for 5 h, further addition of pyridine (7.5 mL) and triethylsilyltriflate (671 μL, 4.0 mmol) was effected, and the reaction was allowed to stir overnight, quenched with H_2O (100 mL), and extracted with CH_2Cl_2 and EtOAc. The combined organic layers were dried over $MgSO_4$, filtered, and concentrated in a vacuum to provide a crude oily residue that was purified by flash chromatography (9:1 hexanes/EtOAc) to yield 2.21 g (90%) of protected binuclear adduct **31** as an oil: $[\alpha]_D^{20}$ +43.3 (*c* 1.5, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.26 (td, J = 3.6, 0.9 Hz, 1H), 4.11 (td, J = 4.8, 1.2 Hz, 1H), 3.87 (dd, J = 8.7, 2.7 Hz, 1H), 3.57 (dd, J = 8.7, 3.9 Hz, 1H), 2.52 (ddd, J = 5.4, 2.7, 1.2 Hz, 1H), 2.24 (d, J = 13.5 Hz, 1H), 1.87 (dtd, J = 13.5, 5.4, 0.9 Hz, 1H), 1.52 (s, 9H), 0.99 (t, J = 8.1 Hz, 9H), 0.91 (s, 18H), 0.65 (q, J = 8.1 Hz, 6H), 0.12 (s, 3H), 0.09 (s, 3H), 0.06 (s, 3H), 0.04 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 176.2, 145.1, 82.6, 74.2, 72.2, 70.2, 59.4, 48.9, 28.1 (3C), 27.1, 26.3 (3C), 25.8 (3C), 18.0 (2C), 6.8 (3C), 5.1 (3C), −4.0, −4.2 (2C), −4.7. Anal. Calcd for: $C_{30}H_{61}NO_6Si_3$: C, 58.49; H, 9.98; N, 2.27. Found: C, 58.31; H, 9.75; N, 2.39.

(1*S*,2*R*,3*S*,4*R*,6*R*)-2,3-Di-*O*-(*tert*-butyldimethylsilanyl)-4-(*tert*-butyloxycarbonylamino)-1-*O*-(triethylsilanyl)-6-(hydroxymethyl)cyclohexane-1,2,3-triol (32). To a reaction vessel containing protected cyclohexanoid lactam **31** (2.15 g, 3.5 mmol) cooled to 0 °C, under argon atmosphere, were sequentially added 30 mL of wet THF and 264 mg (7.0 mmol) of $NaBH_4$. After being stirred for 3 h, a further addition of $NaBH_4$ (264 mg, 7.0 mmol) was effected. The reaction mixture was stirred for 2 h, and the reaction then was quenched by addition of saturated aqueous NH_4Cl until neutral pH was reached. The reaction mixture was extracted thoroughly with CH_2Cl_2 and EtOAc, and the extracts were dried ($MgSO_4$), filtered, and concentrated under reduced pressure to give a residue which was purified by flash chromatography (8:2 hexanes/EtOAc) to give partially protected carbasugar **32** (1.84 g, 85%) as a glassy solid: $[\alpha]_D^{20}$ −42.4 (*c* 1.2, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.24 (bs, 1H), 3.91 (m, 1H), 3.83 (m, 1H), 3.78 (dd, J = 3.9, 2.4 Hz, 1H), 3.67 (dd, J = 10.2, 2.4 Hz, 1H), 3.54 (d, J = 6.3 Hz, 2H), 2.11 (m, 1H), 1.76 (m, 1H), 1.70 (bs, 1H), 1.42 (s, 9H), 1.27 (q, J = 12.7 Hz, 1H), 0.98 (t, J = 8.1 Hz, 9H), 0.91 (s, 9H), 0.89 (s, 9H), 0.62 (q, J = 8.1 Hz, 6H), 0.12 (s, 3H), 0.10 (s, 3H), 0.08 (s, 3H), 0.06 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 155.5, 78.8, 75.5, 72.7, 72.5, 64.2, 49.8, 37.5, 29.4, 28.5 (3C), 26.0 (3C), 25.8 (3C), 18.1 (2C), 6.9 (3C), 4.9 (3C), −3.5, −4.4, −4.7 (2C). Anal. Calcd for: $C_{30}H_{65}NO_6Si_3$: C, 58.11; H, 10.57; N, 2.26. Found: C,58.23; H, 10.44; N, 2.18.

(1*S*,2*R*,3*S*,4*R*,6*R*)-4-Amino-6-(hydroxymethyl)cyclohexane-1,2,3-triol [Pseudo-β-D-gulopyranosyl)amine] (33). The partially protected carbasugar **32** (1.8 g, 2.9 mmol) was treated, at room temperature, with a solution mixture of 6 N

HCl−THF-MeOH (1:2:2) (30 mL). The reaction was allowed to react for 5 h and then concentrated to dryness under vacuum to leave an oily crude residue which was flash chromatographed on silica gel (5:5:3 EtOAc/MeOH/25% aqueous NH_4OH) to afford fully deprotected carbasugar **33** (488 mg, 95%) as a glassy solid: $[\alpha]_D^{20}$ −82.0 (*c* 0.5, D_2O); ^1H NMR (300 MHz, D_2O) δ 3.99 (dd, J = 4.8, 3.0 Hz, 1H), 3.97 (t, J = 3.0 Hz, 1H), 3.82 (dd, J = 10.8, 3.0 Hz, 1H), 3.63 (dd, J = 11.1, 7.5 Hz, 1H), 3.52 (dd, J = 11.1, 6.6 Hz, 1H), 3.32 (td, J = 12.3, 4.2 Hz, 1H), 2.05 (m, 1H), 1.87 (dt, J = 12.3, 4.2 Hz, 1H), 1.44 (q, J = 12.6 Hz, 1H); ^{13}C NMR (75 MHz, D_2O) δ 72.2, 69.6, 69.4, 62.3, 50.5, 36.5, 25.7. Anal. Calcd for: $C_7H_{15}NO_4$: C, 47.45; H, 8.53; N, 7.90. Found: C, 47.58; H, 8.71; N, 8.04.

(1*S*,2*R*,3*S*,4*R*,6*R*)-4-Acetamido-1,2,3-tri-*O*-acetyl-6-(acetyloxymethyl)cyclohexane-1,2,3-triol (34). Acetic anhydride (3.83 mL, 40.5 mmol) and a catalytic amount of DMAP (10 mg) were added under argon to a solution of deprotected carbasugar **33** (480 mg, 2.7 mmol) in dry pyridine (10 mL). The reaction was stirred for 10 h at room temperature. The solution was then quenched with H_2O, and the resulting mixture was extracted with CH_2Cl_2 and EtOAc. The combined organic layers were dried ($MgSO_4$), filtered, and concentrated to give a crude residue that was flash chromatographed on silica gel (9:1 EtOAc/MeOH) to afford 941 mg (90%) of pure protected carbasugar **34** as a white solid: mp 194−195 °C; $[\alpha]_D^{20}$ +5.0 (*c* 0.6, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 5.65 (d, J = 8.7 Hz, 1H), 5.31 (t, J = 3.6 Hz, 1H), 5.11 (m, 1H), 5.02 (dd, J = 11.1, 3.3 Hz, 1H), 4.35 (tdd, J = 12.0, 8.1, 4.5 Hz, 1H), 4.02 (dd, J = 11.1, 8.4 Hz, 1H), 3.84 (dd, J = 11.1, 6.6 Hz, 1H), 2.43 (m, 1H), 2.15 (s, 3H), 2.11 (s, 3H), 2.05 (s, 3H), 2.04 (s, 3H), 1.95 (s, 3H), 1.67 (m, 1H), 1.37 (q, J = 12.9 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 171.7, 170.8, 169.9, 169.1 (2C), 70.7, 68.4, 68.3, 63.2, 47.4, 33.9, 29.1, 23.4, 20.9 (2C), 20.7 (2C). Anal. Calcd for: $C_{17}H_{25}NO_9$: C, 52.71; H, 6.51; N, 3.62. Found: C, 52.85; H, 6.44; N, 3.69.

(2*S*,2′*R*)-(*tert*-Butyldimethylsilanyloxy)-[1-(*tert*-butyloxycarbonyl)-5-oxopyrrolidin-2-yl]acetaldehyde (35). The partially deprotected lactam **25** (3.50 g, 9.0 mmol) was dissolved in CH_2Cl_2 (190 mL) and treated with a 0.65 M aqueous $NaIO_4$ solution (18 mL) and chromatography grade SiO_2 (20 g). The resulting heterogeneous mixture was vigorously stirred at room temperature until complete consumption of the starting material (about 20 min, monitored by TLC). The slurry was filtered under suction, and the silica gel was thoroughly washed with CH_2Cl_2 and EtOAc. The filtrates were evaporated to afford aldehyde **35** (3.06 g, 95%) as a white solid: mp 93−95 °C; $[\alpha]_D^{20}$ +34.3 (*c* 1.9, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 9.54 (d, J = 1.2 Hz, 1H), 4.43 (dt, J = 8.7, 2.4 Hz, 1H), 4.14 (dd, J = 2.1, 1.2 Hz, 1H), 2.61 (dt, J = 17.4, 10.2 Hz, 1H), 2.43 (ddd, J = 17.4, 10.2, 2.7 Hz, 1H), 2.28 (dtd, J = 12.9, 10.2, 9.0 Hz, 1H), 1.95 (ddt, J = 13.2, 9.3, 2.1 Hz, 1H), 1.52 (s, 9H), 0.92 (s, 9H), 0.09 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 200.7, 173.7, 150.5, 83.8, 79.9, 58.9, 31.8, 27.9 (3C), 25.6 (3C), 22.3, 17.9, −4.5, −5.2. Anal. Calcd for $C_{17}H_{31}NO_5Si$: C, 57.11; H, 8.74; N, 3.92. Found: C, 57.26; H, 8.60; N, 3.96.

(1*R*,4*S*,5*S*,6*S*)-6-(*tert*-Butyldimethylsilanyloxy)-2-(*tert*-butyloxycarbonyl)-5-hydroxy-2-azabicyclo[2.2.1]heptan-3-one (36). A solution of diisopropylamine (1.65 mL, 11.8 mmol) in dry THF (56 mL), under argon, was treated at −20 °C with BuLi (6.31 mL of a 1.6 M solution in hexane, 10.1 mmol). The reaction was allowed to react for 20 min after which time the solution was cooled to −80 °C and treated with a solution of aldehyde **35** (3.0 g, 8.4 mmol) in dry THF (30 mL). The reaction was monitored by TLC and was judged complete after 15 min. The reaction was then quenched at −80 °C by the addition of saturated aqueous NH_4Cl and EtOAc. The combined extracts were dried ($MgSO_4$), filtered, and concentrated to give a crude residue that was purified by flash chromatography (6:4 hexanes/EtOAc). Pure binuclear adduct **36** (1.56 g, 52%) was obtained as an oil: $[\alpha]_D^{20}$ +15.0 (*c* 0.4, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 4.19 (bd, J = 4.5 Hz, 1H), 4.15 (m, 1H), 3.86 (m, 1H), 2.89 (dq, J = 4.5, 1.8 Hz, 1H), 1.66 (bs, 1H), 1.53 (s, 9H), 1.50 (m, 2H), 0.91 (s, 9H), 0.15 (s, 3H), 0.14 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 172.9, 148.9, 83.1, 80.0, 79.1, 62.6, 52.1, 33.7, 28.1 (3C), 25.7 (3C), 17.9, −4.8, − 4.9. Anal. Calcd for $C_{17}H_{31}NO_5Si$: C, 57.11; H, 8.74; N, 3.92. Found: C, 57.02; H, 8.80; N, 3.77.

(1*R*,4*S*,5*S*,6*S*)-6-(*tert*-Butyldimethylsilanyloxy)-2-(*tert*-butyloxycarbonyl)-5-(triethylsilanyloxy)-2-azabicyclo-[2.2.1]heptan-3-one (37). To a solution of **36** (1.5 g, 4.2 mmol) in dry pyridine (15 mL), under argon atmosphere, were sequentially added triethylsilyltriflate (1.41 mL, 8.4 mmol) and a catalytic amount of DMAP (50 mg). After being stirred at room temperature for 3 h, further addition of pyridine (7.5 mL) and triethylsilyltriflate (705 μL, 4.19 mmol) was effected, and the reaction was allowed to stir overnight, quenched with H_2O (100 mL), and extracted with CH_2Cl_2. The combined organic layers were dried over $MgSO_4$, filtered, and concentrated in a vacuum to provide a crude oily residue that was purified by flash chromatography (8:2 hexanes/EtOAc) to yield 1.86 g (94%) of binuclear adduct **37** as an oil: $[\alpha]_D^{20}$ +23.9 (*c* 1.8, $CHCl_3$); ^1H NMR (300 MHz, benzene-d_6) δ 4.15 (m, 1H), 4.04 (dt, J = 2.8, 1.5 Hz, 1H), 4.01 (dt, J = 4.2, 1.5 Hz, 1H), 2.48 (dq, J = 4.2, 1.3 Hz, 1H), 1.61 (dt, J = 10.5, 1.3 Hz, 1H), 1.42 (s, 9H), 1.37 (ddt, J = 10.5, 2.3, 1.5 Hz, 1H), 1.01 (t, J = 8.1 Hz, 9H), 0.93 (s, 9H), 0.60 (q, J = 8.1 Hz, 6H), 0.18 (s, 3H), 0.17 (s, 3H); ^{13}C NMR (75 MHz, benzene-d_6) δ 172.1, 149.3, 82.0, 81.1, 80.7, 61.9, 52.6, 32.6, 28.1 (3C), 25.9 (3C), 17.8, 6.9 (3C), 5.1 (3C), −4.4, −4.9. Anal. Calcd for $C_{23}H_{45}NO_5Si$: C, 58.56; H, 9.61; N, 2.97. Found: C, 58.66; H, 9.48; N, 2.75.

(1*S*,2*S*,3*R*,5*R*)-2-*O*-(*tert*-Butyldimethylsilanyl)-3-(*tert*-butyloxycarbonylamino)-1-*O*-(triethylsilanyl)-5-(hydroxymethyl)cyclopentane-1,2-diol (38). To a reaction vessel containing protected cyclohexanoid lactam **37** (1.8 g, 3.8 mmol) cooled to 0 °C, under argon atmosphere, were sequentially added 30 mL of wet THF and 288 mg (7.6 mmol) of $NaBH_4$. After being stirred for 3 h, a further addition of $NaBH_4$ (288 mg, 7.6 mmol) was effected. The reaction mixture was stirred for 2 h, and the reaction then was quenched by addition of saturated aqueous NH_4Cl until neutral pH was reached. The reaction mixture was extracted thoroughly with CH_2Cl_2 and EtOAc, and the combined extracts were dried ($MgSO_4$), filtered, and concentrated under reduced pressure to give a residue which was purified by flash chromatography (8:2 hexanes/EtOAc) to give partially protected carbasugar **38** (1.55 g, 86%) as an oil: $[\alpha]_D^{20}$ +4.3 (c 0.7, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$) δ 4.93 (d, J = 9.0 Hz, 1H), 4.00 (m, 1H), 3.89 (m, 1H), 3.83 (dd, J = 11.1, 3.6 Hz, 1H), 3.75 (m, 1H), 3.70 (dd, J = 11.1, 6.3 Hz, 1H), 2.35 (m, 2H), 1.80 (bs, 1H), 1.46 (m, 1H), 1.41 (s, 9H), 0.99 (t, J = 7.6 Hz, 9H), 0.87 (s, 9H), 0.66 (q, J = 7.6 Hz, 6H), 0.13 (s, 3H), 0.08 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 154.9, 82.9, 80.6, 78.7, 62.4, 57.0, 43.3, 31.9, 28.3 (3C), 25.7 (3C), 17.8, 6.7 (3C), 4.7 (3C), −4.6, −4.8. Anal. Calcd for $C_{23}H_{49}NO_5Si_2$: C, 58.06; H, 10.38; N, 2.94. Found: C, 58.24; H, 10.23; N, 3.00.

(1*S*,2*S*,3*R*,5*R*)-3-Amino-5-(hydroxymethyl)cyclopentane-1,2-diol [Pseudo-β-D-xylofuranosyl)amine] (39). The partially protected carbasugar **38** (1.5 g, 3.2 mmol) was treated, at room temperature, with a solution mixture of 6 N HCl−THF−MeOH (1:2:2) (20 mL). The reaction was allowed to react for 30 min and then concentrated to dryness under vacuum to leave an oily crude residue which was flash chromatographed on silica gel (5:5:3 EtOAc/MeOH/25% aqueous NH_4OH) to afford fully deprotected carbasugar **39** (433 mg, 94%) as an oil: $[\alpha]_D^{20}$ −22.5 (*c* 0.4, MeOH); ^1H NMR (300 MHz, D_2O) δ 4.03 (dd, J = 5.4, 5.1 Hz, 1H), 3.95 (t, J = 5.4 Hz, 1H), 3.68 (dd, J = 11.1, 6.6 Hz, 1H), 3.57 (dd, J = 11.1, 6.0 Hz, 1H), 3.37 (td, J = 8.4, 5.4 Hz, 1H), 2.33 (tq, J = 8.7, 6.0 Hz, 1H), 2.28 (dt, J = 12.6, 8.4 Hz, 1H), 1.51 (dt, J = 12.6, 8.7 Hz, 1H); ^{13}C NMR (75 MHz, D_2O) δ 80.4, 76.1, 60.8, 55.1, 40.7, 29.3. Anal. Calcd for $C_6H_{13}NO_3$: C, 48.97; H, 8.90; N, 9.52. Found: C, 48.85; H, 8.67; N, 9.57.

(1*S*,2*S*,3*R*,5*R*)-3-Acetamido-1,2-di-*O*-acetyl-5-(acetyloxymethyl)cyclopentane-1,2-diol (40). Acetic anhydride (4.14 mL, 43.8 mmol) and a catalytic amount of DMAP (10 mg) were added under argon to a solution of deprotected carbasugar **39** (440 mg, 3.0 mmol) in dry pyridine (10 mL). The reaction was stirred for 30 min at room temperature. The reaction was then quenched with H_2O, and the resulting

mixture was extracted with CH_2Cl_2 and EtOAc. The combined organic layers were dried ($MgSO_4$), filtered, and concentrated to give a crude residue that was flash chromatographed on silica eluting with EtOAc to afford 908 mg (96%) of pure protected carbasugar **40** as an oil: $[\alpha]_D^{20}$ −7.1 (*c* 0.7, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.00 (d, J = 6.9 Hz, 1H), 5.23 (dd, J = 7.2, 4.5 Hz, 1H), 5.04 (dd, J = 7.8, 4.8 Hz, 1H), 4.18 (dq, J = 10.2, 7.5 Hz, 1H), 4.10 (dd, J = 11.1, 6.6 Hz, 1H), 4.04 (dd, J = 11.1, 6.9 Hz, 1H), 2.64 (dquint, J = 10.5, 7.0 Hz, 1H), 2.51 (dt, J = 12.6, 7.5 Hz, 1H), 2.10 (s, 3H), 2.08 (s, 3H), 2.05 (s, 3H), 1.97 (s, 3H), 1.45 (dt, J = 12.6, 10.5 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 171.1, 170.8, 170.2, 169.8, 81.3, 75.3, 62.4, 53.6, 37.3, 32.5, 23.2, 20.9, 20.8, 20.7. Anal. Calcd for $C_{14}H_{21}NO_7$: C, 53.33; H, 6.71; N, 4.44. Found: C, 53.21; H, 6.88; N, 4.27.

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Supporting Information Available: Copies of ^{1}H NMR and ^{13}C NMR spectra of compounds **11**, **13**, **17**, **19**, **31**, **33**, **37,** and **39**. This material is available free of charge via the Internet at http://pubs.acs.org.

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