Can the conformational flexibility of cis-decalins be modulated through intramolecular O–H⋯O hydrogen bonding? Profiling the molecular and supramolecular attributes of designer cis-fused polycyclitols

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A B S T R A C T
In order to unravel the modalities of hydrogen bonding in conformationally flexible polycyclitols vis-à-vis their conformationally locked siblings, three diastereomeric perhydro-2,3,4a,6,7,8a-naphthalenehexols, all embodying a 4a,8a-dihydroxy-cis-decalin framework, have been synthesized via sequential stereoccontrolled oxyfunctionalization of 1,4,5,8-tetrahydronaphthalene. Variable temperature NMR studies on the cis-fused polycyclitols thus obtained suggest that their inherent conformational flexibility in solution is restrained at ambient temperature owing either to the formation of a stable H-bonded molecular solvate or to the presence of strong intramolecular O⋯H⋯O H-bonding. Single crystal X-ray diffraction studies on the three hexols reveal an interesting commonality in their gross molecular packing and a ubiquitous presence of the R2\(^2\)\(^1\) dimer motif—a supramolecular synthon rarely encountered in the crystal structures of conformationally locked and axially-rich hexols.

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1. Introduction

For quite some time now, we have been actively involved in probing the modalities of O–H⋯O hydrogen bonding in specially designed polyhydroxylated trans-decalins (conformationally locked polycyclitols) and exploring the possibility of engineering their solid-state self-assemblies. These polyhydroxylated entities, fashioned from a prototypical rigid 4a,8a-dihydroxy-trans-decalin backbone, have been shown to predictably lock the hydroxyl functionalities into axial-rich conformations so that those in 1,3-syn-diaxial relationship were automatically brought into a favorable geometry to participate in intramolecular O–H⋯O hydrogen bonding. The deterministic role played by intramolecular O–H⋯O H-bonding in their supramolecular assemblies and the conformity of the intermolecular O–H⋯O H-bonding patterns, observed therein, to core concepts of hydrogen bonding in polyols were amply demonstrated in the crystal structures of several diastereomeric 4a,8a-perhydro-2,3,4a,6,7,8a-naphthalenehexols (1–6) and their acyl derivatives.

It may be pertinent to recall that the conceptualization of conformationally locked polycyclitols was, from a purely chronological perspective, largely inspired by the syntheses and intriguing yeast α-glucosidase inhibitory activity of the polycyclitols 7 and 8, in which the hydroxy functionalities were embedded in a cis-hydrindane and cis-decalin framework, respectively. Unlike their structural siblings constructed on a trans-decalin framework, polyols, such as 7 and 8, are not destined to exhibit a spatial locking of the hydroxy substituents, and present ideal molecular systems to...
study the effect of competing intra- and intermolecular $\text{O} \cdots \text{H} \cdots \text{O}$ hydrogen bonding on the chosen molecular conformation.\textsuperscript{5−7}

With the intent of developing a holistic understanding of the supramolecular chemistry of polyclycitos in general, the present endeavor is a retrospective revisitation of polyhydroxylated cis-decalins through the representative examples 9−11—all perhydro-2,3,4a,6,7,8a-naphthalenehexols, epimeric with the conformationally locked hexols 1−3. The polyols 9−11 were conceptualized to permit a direct comparison of the nuances of their solid-state self-assemblies with that observed in the crystal structures of the polyclycitos 1−6.

2. Results and discussion

2.1. Synthesis of the diastereomeric hexols 9−11

Synthesis of the hexols 9 and 10 commenced from the acetonide derivative 17\textsuperscript{22} of the diol 16, which was conveniently prepared from naphthalene following an earlier reported procedure.\textsuperscript{5b} Catalytic OsO\textsubscript{4} mediated exhaustive dihydroxylation of 17 furnished an equimolar mixture of two diastereomeric tetrols 18, which were isolated from the reaction mixture and separated from each other as their bisacetonide derivatives 19 and 20. Exposure of 19 and 20 to mild acid gave the hexols 9 and 10, respectively in quantitative yield (Scheme 1).

Interestingly, both the $C_{2v}$ symmetric 9 and $C_{3}$ symmetric 10 displayed a five-line (consistent with the retention of the twofold symmetry, Fig. 1) and a ten-line $^{13}$C spectrum, respectively at 298 K, indicating a restraint on the conformational flexibility of the cis-decalin framework in the two hexols at ambient temperature. The observed conformational rigidity in the bowl-shaped 9 at 298 K may be ascribed to the extensive hydration of the more polar concave face (Fig. 2), wherein the intervening water bridges tie down the secondary hydroxyl groups together through an intricate network of $\text{O} \cdots \text{H} \cdots \text{O}$ hydrogen bonding.\textsuperscript{9} In case of the hexol 10, it is the formation of a persistent intramolecular $\text{O} \cdots \text{H} \cdots \text{O}$ H-bond between the 1,3-diaxial hydroxyl groups that prevents a rapid thermal flipping between the two chair conformations of 10 in solution (Fig. 3).\textsuperscript{10} Such an effect of hydrogen bonding (intra- and/or inter) on the conformational flexibility of a cis-decalin scaffold would be expected to weaken with increasing temperature. Indeed, the $^{13}$C spectra, recorded for the hexols 9 and 10 at 343 and 353 K, exhibited the expected three and five carbon resonances, respectively (See Supplementary data for details).

The syn-diol 22, obtained by regioselective bromination and subsequent Woodword cis-dihiydroxilation in 21 (the Birch reduction product of naphalene), formed the starting material for the synthesis of the hexol 11 (Scheme 2).\textsuperscript{12} Exhaustive epoxidation of the carbonate derivative 23 of 22 with mCPBA furnished a mixture of two diepoxides 24 and 25 in the ratio 7:3. The stereostructure of the major diastereomer 24 was unambiguously assigned by single crystal X-ray diffraction analysis.\textsuperscript{13} Mild acid catalyzed ring opening in the mixture of diepoxides, thus obtained, afforded the tetrol 26 as a single diastereomer. Though unexpected, the observed stereo-
in 26 yielded the hexol 11 in quantitative yield. For reasons noted for 10, a ten- and six-line $^{13}$C spectrum was also observed for the Cs symmetric hexol 11 at 298 K and 348 K, respectively (Fig. 3).

2.2. X-ray crystallographic studies on the diastereomeric hexols 9–11

Crystals of the isomeric hexols 9–11, suitable for single crystal X-ray crystallography, were grown under ambient temperature and pressure from their solutions in deionized water by slow solvent evaporation technique. Details of the packing patterns in the polycyclitols 9–11, as gleaned from an analysis of their respective crystal data, are discussed below.

2.2.1. Crystal structure of the hexol 9. Crystal structure of the hexol 9 was solved and refined in the centrosymmetric monoclinic space group $P2_1/c$ (Z=4) (Fig. 4). A pair of hydrogen bonds, involving O3⋯O5 and O6⋯O2, describes a $R_2^2(10)$ H-bonding motif and links the hexol molecules to form zigzag chains along the c-axis. These molecular chains, translated along the b-axis, are in turn connected to each other by two H-bonds [hydrogen bonding motif: $R_2^2(10)$], which engage two vicinal tertiary (O1 and O4) and two vicinal secondary (O5 and O6) hydroxy moieties. The resulting self-assembly consists of columnar architectures, which are further linked to one another along the a-axis by hydrogen bonds involving O2⋯O1 and O4⋯O5 (Fig. 5, Table 1).

2.2.2. Crystal structure of the hexol 10. The hexol 10 packed in the centrosymmetric monoclinic space group $C2/c$ (Z=8) (Fig. 6). As would have been expected from the NMR studies, the 1,3-syndial hydroxy groups participated in intramolecular O⋯H⋯O hydrogen bonding. Unlike its diastereomeric sibling 9, molecules of the hexol 10 form zigzag molecular chains along the c-axis via the agency of an intermolecular hydrogen bond involving O3⋯O5. These molecular chains, translated along the b-axis, are in turn linked by a pair of intermolecular O⋯H⋯O hydrogen bonds (O2⋯O6 and O6⋯O4). The molecular sheets, thus formed, are in turn connected to one another by two pairs of hydrogen bonds that constitute either a $R_2^2(8)$ H-bonding cycle (O5⋯O3) or a $R_2^2(10)$ motif (O4⋯O1) (Fig. 7, Table 2).

2.2.3. Crystal structure of the hexol 11. The hexol 11 underwent spontaneous resolution and crystallized in the chiral orthorhombic space group $P2_12_12_1$ (Z=8) with two molecules (A and B) of the hexol occupying the asymmetric unit (Fig. 8). Isolation of the otherwise

Fig. 3. Restriction of the conformational flexibility of the cis-decalin scaffold in the hexols 10 and 11, brought about by intramolecular O⋯H⋯O H-bonding between the 1,3-syndial hydroxy groups.

Scheme 2. Reagents and conditions. (a) triphosgene, pyridine, DMAP, DCM, –78 °C to rt, 2 h, 80%; (b) mCPBA, DCM, rt, 48 h, 75% (overall yield), 24 (53%) and 25 (22%); (c) 10% AcOH (aq), 65 °C, 68 h, quant.; (d) KOH, MeOH, rt, 3h, quant.

Scheme 3. Postulated mechanism for the observed stereo-convergence in the epoxide ring opening of the diepoxides 24 and 25.

Fig. 4. ORTEP diagram of the hexol 9, with the atom numbering scheme for the asymmetric unit. Displacement ellipsoids have been drawn at 50% probability level and H atoms are shown as small spheres of arbitrary radii.
Cs symmetric 11 as a conglomerate supplemented the results of the NMR studies and pointed toward the fact that the hexol 11 exists as an enantiomeric mixture in solution on account of the strong intramolecular O–H/ O H-bonding, which leads to a breakdown of the mirror symmetry in the molecule. Crystal structure analysis also confirmed that the 1,3-syndiaxial hydroxy groups in 11 do participate in intramolecular O–H/ O H-bonding. Each of the two crystallographically independent molecules engages two vicinal tertiary [(O1 and O4) or (O7 and O10)] and two vicinal secondary [(O5 and O6) or (O11 and O12)] hydroxy moieties to form zigzag hydrogen bonded [H-bonding motif: R2(10)] chains (alternating AAA and BBB types) growing parallel to the b-axis.15 Intermolecular O–H/ OH− bonds, involving O9–O5, O3–O11, and O2–O12, link these molecular chains to form sheets essentially perpendicular to the a-axis. The molecular sheets, translated along the a-axis, are further interconnected by hydrogen bonds, involving O8–O3, O4–O11, and O10–O6, to engender the intricate three-dimensional supramolecular assembly of the hexol 11 (Fig. 9, Table 3).

### 2.3. Comparison of the hydrogen bonded self-assemblies of the polycyclitols 9–11

Crystal structures of the three diastereomeric hexols 9–11 differ, like that observed for their conformationally locked siblings 1–3, in the number of nearest neighbors to which a hexol is hydrogen bonded and the number of H-bonds that the molecule forms (Table 4). However, as opposed to the individualistic nature of the crystal packing noted in case of 1–3,1d–f an interesting similarity can be clearly discerned in the overall packing patterns of all three polycyclitols under study. A general description for the crystal packing in the hexols 9–11 would be: molecules form zigzag H-bonded chains, the translationally related chains link with one another to form sheets and the translationally related molecular...
sheets connect via hydrogen bonds to culminate in the observed crystal structure. A putative explanation for this commonality would lie probably in the ubiquitous presence of the \( R_2^2(10) \) hydrogen bonding motif (‘synthon’) in the solid-state self-assemblies of 9–11. It is pertinent to highlight at this point that the \( R_2^2(10) \) dimer, which has been shown to be the preferred \( O-H-O \) hydrogen bonding motif in fully hydrogen bonded crystal structures of vic-diols,\(^b\) has rarely been observed in the crystal structures of conformationally locked hexols 1–6. This seems to be the key differentiator in the packing patterns of the cis- and the trans-decalin based hexols and can be reconciled in terms of the prohibitive spatial separation of the vicinal hydroxy groups in the latter.

**Table 2**

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<tbody>
<tr>
<td>O1–H1O1- O2(^a)</td>
<td>0.82</td>
<td>1.95</td>
<td>2.686(3)</td>
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<td>O2–H2O2- O6(^a)</td>
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<td>O3–H3O- O5(^iii)</td>
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<td>O6–H6O- O4(^v)</td>
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<td>1.97</td>
<td>2.789(3)</td>
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</table>

\(^a\) Symmetry codes: (i) \( x, y, z \); (ii) \( -x, -y+1, z \); (iii) \( x, -y+1, z+1/2 \); (iv) \( -x, y+1, z \); (v) \( x+1/2, y-1/2, z+1 \); (vi) \( x, -y, z \).

\(^b\) Certain C-H-O hydrogen bonds, such as C3–H3A–O1 (\( d=2.54 \) Å, \( \beta=152^\circ \)), could also be discerned in the crystal structure of 10. However, these interactions resulted from the extensive O-H-O H-bonding, forcing the interacting atoms to approach nearer to each other.

**Table 3**

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<td>1.91</td>
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<td>O3–H3O- O11(^iii)</td>
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<td>O4–H4O– O11(^iv)</td>
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<td>O5–H5O– O11(^iv)</td>
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<td>1.87</td>
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<td>2.725(3)</td>
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<td>O10–H10O– O6(^v)</td>
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<td>2.757(3)</td>
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<td>1.90</td>
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<td>O12–H12O– O10(^iii)</td>
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<td>1.86</td>
<td>2.671(2)</td>
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\(^a\) Symmetry codes: (i) \( x, y, z \); (ii) \( -x+3/2, -y+1, z-1/2 \); (iii) \( x-1/2, -y+3/2, z \); (iv) \( -x+1, y+1/2, z-1/2 \); (v) \( x+1, y-1, z \); (vi) \( x-1/2, -y+3/2, z \); (vii) \( x, y-1, z \); (viii) \( -x+2, y+1/2, z+1/2 \).

\(^b\) Certain C-H-O hydrogen bonds, such as C7–H7B–O7 (\( d=2.46 \) Å, \( \beta=155^\circ \)), could also be discerned in the crystal structure of 11. However, these interactions resulted from the extensive O-H-O H-bonding, forcing the interacting atoms to approach nearer to each other.

**Table 4**

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<td>Number of nearest H-bonded neighbors</td>
<td>8</td>
<td>9</td>
<td>7</td>
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<tr>
<td>Number of intermolecular O-H-O hydrogen bonds per hexol molecule</td>
<td>12</td>
<td>10</td>
<td>10</td>
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<tr>
<td>Packing index</td>
<td>75.6%</td>
<td>71.1%</td>
<td>73.3%</td>
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**3. Conclusions**

In summary, our synthetic approach to cis-fused polycyclitols has revealed some interesting diastereoselections and stereo-convergences during the varied oxyfunctionalization protocols on a cis-
4. Experimental section

4.1. Synthesis of the acetone 17

A solution of the diol 16 (95 mg, 0.572 mmol) in dry acetone (10 mL) was stirred with Amberlyst-15 (4 Hz, 2H), 1.53 (s, 3H), 1.45 (s, 3H), 1.33 (s, 3H), 1.32 (s, 3H); 13C NMR (400 MHz, CDCl3, 298 K) δ 3.76 (s, 4H), 2.30 (br s, 2H), 1.71 (br s, 2H), 1.53 (br s, 2H), 1.35 (br s, 2H); 13C NMR (100 MHz, CDCl3, 298 K) δ 73.6 (2C), 69.1 (2C), 67.5 (2C), 40.3 (2C), 38.2 (2C); 1H NMR (400 MHz, D2O, 343 K) δ 4.46 (dd appearing as a t, J = 4 Hz, 4H), 2.61 (br s, 4H), 2.25 (d, J = 14 Hz, 4H); 13C NMR (100 MHz, D2O, 343 K) δ 73.8 (2C), 68.6 (4C), 39.7 (4C); HRMS (ES) m/z calcd for C16H32O6Na (M+Na)+: 325.2201; found: 325.2197.

4.2. Synthesis of the bisacetonides 19 and 20

To a solution of the acetonide 17 (89 mg, 0.432 mmol) in 2 mL of dry acetone (10 mL) was stirred with Amberlyst-15 (4 Hz, 2H), 1.53 (s, 3H), 1.45 (s, 3H), 1.33 (s, 3H), 1.32 (s, 3H); 13C NMR (400 MHz, CDCl3, 298 K) δ 3.76 (s, 4H), 2.30 (br s, 2H), 1.71 (br s, 2H), 1.53 (br s, 2H), 1.35 (br s, 2H); 13C NMR (100 MHz, CDCl3, 298 K) δ 73.6 (2C), 69.1 (2C), 67.5 (2C), 40.3 (2C), 38.2 (2C); 1H NMR (400 MHz, D2O, 343 K) δ 4.46 (dd appearing as a t, J = 4 Hz, 4H), 2.61 (br s, 4H), 2.25 (d, J = 14 Hz, 4H); 13C NMR (100 MHz, D2O, 343 K) δ 73.8 (2C), 68.6 (4C), 39.7 (4C); HRMS (ES) m/z calcd for C16H32O6Na (M+Na)+: 325.2201; found: 325.2197.

4.3. Synthesis of the hexols 9 and 10

The bisacetonide 19 (13 mg, 0.041 mmol) was warmed at 60 °C for 1 h with 10% w/v aqueous acetic acid (2 mL). The volatiles were removed completely under vacuum to obtain the pure hexol 9 (10 mg) as colorless solid in quantitative yield. Mp 246–247 °C (decomp.); IR (KBr) v_max = 3390, 3270, 2910, 1451, 1078, 1060, 1041, 1023, 877, 731 cm⁻¹; 1H NMR (400 MHz, D2O, 298 K) δ 3.76 (s, 4H), 2.30 (br s, 2H), 1.71 (br s, 2H), 1.53 (br s, 2H), 1.35 (br s, 2H); 13C NMR (100 MHz, D2O, 298 K) δ 73.6 (2C), 69.1 (2C), 67.5 (2C), 40.3 (2C), 38.2 (2C); 1H NMR (400 MHz, D2O, 343 K) δ 4.46 (dd appearing as a t, J = 4 Hz, 4H), 2.61 (br s, 4H), 2.25 (d, J = 14 Hz, 4H); 13C NMR (100 MHz, D2O, 343 K) δ 73.8 (2C), 68.6 (4C), 39.7 (4C); HRMS (ES) m/z calcd for C16H32O6Na (M+Na)+: 325.2201; found: 325.2197.

Acetone deprotection in 20 was carried out in an identical manner and afforded quantitatively the hexol 10. Mp 272–274 °C (decomp.); IR (KBr) v_max = 3057, 2890, 1461, 1288, 1155, 1064, 1021, 1008, 741 cm⁻¹; 1H NMR (400 MHz, D2O, 298 K) δ 3.82–3.74 (m, 3H), 3.59 (d, J = 12 Hz, 1H), 2.19 (d, J = 16 Hz, 1H), 1.80 (dd appearing as a t, J = 13 Hz, 1H), 1.74 (dd appearing as a t, J = 13 Hz, 1H), 1.68–1.62 (m, 2H), 1.53 (d, J = 15 Hz, 1H), 1.40 (m, 2H); 13C NMR (100 MHz, D2O, 298 K) δ 74.9, 73.0, 70.1, 68.9, 67.1, 67.1, 38.6, 38.1, 35.8; 1H NMR (400 MHz, D2O, 353 K) δ 4.53 (dd appearing as a t, J = 4 Hz, 2H); 4.39 (br s, 2H), 2.49–2.27 (series of m, 8H); 13C NMR (100 MHz, D2O, 353 K) δ 74.4 (2C), 70.0 (2C), 68.9 (2C), 38.9 (2C), 36.7 (2C); HRMS (ES) m/z calcd for C16H32O6Na (M+Na)+: 325.2201; found: 325.2197.

4.4. Synthesis of the carbonate 23

Pyridine (142 mg, 1.46 mL, 1800 mmol) and DMAP (4 mg, 10 mol %) were added to a solution of the diol 22 (50 mg, 0.301 mmol) in dry dichloromethane (1 mL) at ambient temperature. The resulting mixture was then cooled to ~78 °C and a solution of triphosgene (45 mg, 0.150 mmol) in dry dichloromethane (1 mL) was added slowly for about 20 min with stirring. The reaction was subsequently allowed to proceed at ambient temperature for 2 h, after which it was quenched with saturated ammonium chloride solution and the product extracted with dichloromethane (3 × 30 mL). The combined extracts were washed successively with 1 N HCl, saturated sodium bicarbonate solution and brine, and finally dried over anhydrous sodium sulfate. Removal of the solvent and subsequent column chromatography over silica gel with 20% ethyl acetate/petroleum ether afforded the carbonate 23 (46 mg, 80%) as a colorless, crystalline solid. Mp 218–219 °C; IR (KBr) v_max = 3059, 2961, 2954, 1778, 1748, 1435, 1321, 1042, 703 cm⁻¹; 1H NMR (400 MHz, CDCl3, 298 K) δ 5.97 (dd appearing as a t, J = 3 Hz, 4H), 2.63 (ddd, J = 14, 4, 2 Hz, 4H), 2.21 (d, J = 15 Hz, 4H); 13C NMR (100 MHz, CDCl3, 298 K) δ 154.5, 1270 (4C), 87.0 (2C), 34.1 (4C); HRMS (ES) m/z calcd for C16H22O6Na (M+Na)+: 215.2042; found: 215.2039.

4.5. Synthesis of the diepoxides 24 and 25

mCPBA (70% purity, 256 mg, 1.040 mmol) was added to a solution of the carbonate 23 (100 mg, 0.520 mmol) in dichloromethane (5 mL) at ambient temperature. The reaction was allowed to stir at room temperature for 2 days and then quenched by addition of a saturated solution of sodium sulfate in water. The product was extracted with dichloromethane (5 × 30 mL); the combined extracts were washed successively with saturated sodium bicarbonate solution and brine, followed by drying over anhydrous sodium sulfate. Removal of the solvent and subsequent purification of the resultant residue by column chromatography with ethyl acetate afforded a diastereomeric mixture of the diepoxides 24 and 25 (85 mg, 75% combined yield) as a colorless solid. Though

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dispensable for the next step, chromatographic separation of this
diepoxide mixture (product ratio=7:3) allows isolation of the major
24 with 40% ethyl acetate/petroleum ether and subsequently, the
minor 25 with ethyl acetate alone.

Diepoxide 24: mp 198–199 °C; IR (KBr) vmax=2361, 2339, 1780,
1485, 1186, 1146 cm−1; 1H NMR (400 MHz, CDCl3, 298 K) δ 3.25 (dd
appearing as a t, J=1–2 Hz, 4H), 2.50 (dd, J=16, 4 Hz, 4H), 1.99 (ddd,
J=15, 3, 1 Hz, ppm); 13C NMR (100 MHz, CDCl3, 298 K) δ 152.1,
83.5 (2C), 47.7 (4C), 35.6 (4C); HRMS (ES) m/z calcd for C11H12O5Na
(M+Na)=: 247.04582; found: 247.0616.

Diepoxide 25: mp 243–244 °C; IR (KBr) vmax=2955, 1786, 1768,
1324, 1078, 1041, 764 cm−1; 1H NMR (400 MHz, CDCl3, 298 K)
δ 2.02 (d, J=15, 3 Hz, 2H), 2.34 (dd appearing as a td, J=16, 2 Hz, 2H),
2.14 (d, J=16 Hz, 2H), 1.71 (dd, J=15, 4 Hz, 2H); 13C NMR (100 MHz,
DMSO-d6, 298 K) δ 151.9, 81.4 (2C), 48.5 (2C), 46.5 (2C), 34.5 (2C),
31.8 (2C); HRMS (ES) m/z calcd for C11H12O5Na (M+Na)=: 247.0682;
found: 247.0855.

4.6. Synthesis of the tetrol 26

The mixture of diepoxides (18 mg, 0.080 mmol), obtained in the
previous step, was suspended in acetic acid (10% solution in water,
2 mL) and stirred vigorously at 60 °C for 68 h. The reaction mixture
was then dried under vacuum to obtain the tetrol 26 (20 mg) in
near quantitative yield. Mp 239–240 °C; IR (KBr) vmax=2928, 2454,
1782, 1214, 1064, 1030 cm−1; 1H NMR (400 MHz, D2O, 298 K)
δ 3.77–3.75 (m, 2H), 3.65–3.63 (m, 2H), 2.23–2.16 (m, 4H),
2.02–1.94 (m, 4H); 13C NMR (100 MHz, D2O, 298 K) δ 155.7, 85.7,
84.4, 68.7 (2C), 68.3 (2C), 36.6 (2C), 36.4 (2C); HRMS (ES) m/z calcd for
C11H16O7Na+ (M+Na)=: 283.0794; found:283.0805.

4.7. Synthesis of the hexol 11

The tetrol 26 (10 mg, 0.038 mmol) was taken up in 2 mL of dry
methanol and stirred at ambient temperature with solid potassium
diiodide (0.8 mg, 0.079 mmol) for 3 h. The solvent was then re-
moved completely under vacuum and the residue dissolved in
minimum volume (0.8–1.0 mL) of deionized water. The aqueous
solution was passed through a short column of pre-treated DOW-
EX-50 W ion-exchange resin (~1.5 g, 8–200 mesh, acrylic bead)
and washed with deionized water. The aqueous solution of the
product thus obtained was concentrated under vacuum to obtain
the hexol 11 (9 mg) in quantitative yield. Mp 251–252 °C
de(compd.); IR (KBr) vmax=3706, 3151, 2925, 1456, 1275, 1093, 1052,
1011, 877, 822 cm−1; 1H NMR (400 MHz, D2O, 298 K) δ 4.49–4.46
(m, 2H), 4.32 (m, 2H), 2.64–2.48 (m, 5H), 2.46–2.34 (m, 3H); 13C
NMR (100 MHz, D2O, 298 K) δ 74.7, 73.9, 73.1, 71.2, 71.0, 70.4, 41.2,
40.9, 39.6, 36.3; 1H NMR (400 MHz, D2O, 348 K) δ 4.36 (dd, J=12,
6 Hz, 2H), 2.40 (dd, J=11, 7 Hz, 2H), 2.53–2.44 (m, 6H), 2.32 (dd,
J=14, 7 Hz, 2H); 13C NMR (100 MHz, D2O, 343 K) δ 75.2, 73.7, 71.4
(2C), 71.2 (2C), 39.3 (2C), 38.1 (2C); HRMS (ES) m/z calcd for
C11H16O7Na+ (M+Na)=: 283.0794; found:283.0805.

4.8. Crystal structure analysis

Single crystal X-ray diffraction data (Table 5) was collected at
291 K on a Bruker AXS SMART APEX CCD diffractometer using
graphite monochromated Mo Kz radiation (λ=0.71073 Å). The X-ray
generator was operated at 50 kV and 40 mA. The data was collected
with a ω scan width of 0.3°. A total of 606 frames per set were collected
using SMART19 in three different settings of o (0°, 90°, and 180°). During data
collection, the sample to detector distance and the 2θ value was kept at fixed 6.026 cm and −25°, respectively. The data were reduced by SAINTPLUS,20 an empirical absorption correction
was applied using the package SADABS,20 and XPREP20 was used to
determine the space group. The crystal structures were solved by
direct methods using SIR9221 and refined by full-matrix least-squares
methods on F2 using SHELXL22 Molecular and packing diagrams
were generated using ORTEP-323 and CAMERON,24 respectively. The
geometrical calculations were done by PARSE25 and PLATON26 All hy-
drogen atoms, including those of hydroxy groups, were placed in
gerometrically idealized positions and constrained to ride on their
parent atoms with C–H distances in the range 0.97–0.98 Å and
Ueq(CH)=1.2Ueq(C), and O–H distances fixed at 0.82 Å and Ueq(O)=1.5Ueq(O) (Ok), CCDC 796419 (hexol 9), CCDC 796420 (hexol 10), CCDC
796421 (diepoxide 24) contain the supplementary crystallographic data for this paper. These data can be
obtained free of charge from The Cambridge Crystallographic Data Center www.ccdc.cam.ac.uk/data_request/cif.

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Supplementary data

Supplementary data scanned copies of 1H and 13C NMR spectra
of all new compounds have been provided. Supplementary data
related to this article can be found online at doi:10.1016/j.
tet.2011.03.042. These data include MOL files and InChIKeys of the
most important compounds described in this article.

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