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Predictable close-packing similarities between *cis*- and *trans*-2-hydroxy-1-cyclooctanecarboxylic acids and *trans*-2-hydroxy-1-cyclooctanecarboxamide

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In order to extend the experimental data already available on the close packing of cyclopentanes substituted with vicinal CO*X* (*X* = OH, NH_2) and OH groups to the analogous cyclohexanes, cycloheptanes and cyclooctanes, (1*R**,2*S**)-*cis*-2-hydroxy-1-cyclooctanecarboxylic acid (8C), (1*R**,2*R**)-*trans*-2-hydroxy-1-cyclooctanecarboxylic acid (8T) and (1*R**,2*R**)-*trans*-2-hydroxy-1-cyclooctanecarboxamide (8T*) were subjected to X-ray crystal structure analysis. In 8T and 8T*, the hydrogen bonds form infinite ribbons of dimers joined by $R_2^2(12)$ rings with C_i symmetry. Two types of dimer alternate along each ribbon. The dimers differ in the donor and acceptor roles of the functional groups. This pattern was previously deduced topologically among the possible forms of association for heterochiral dimers [Kálmán *et al.* (2002). *Acta Cryst.* B**58**, 494–501]. As they have the same pattern of hydrogen bonds, 8T and 8T* are isostructural. The additional donor (*i.e.* the second hydrogen of the NH_2 group) present in 8T* links the adjacent ribbons so as to form smaller $R_2^2(8)$ rings between them. The crystals of the *cis* stereoisomer 8C are built up from antiparallel hydrogen-bonded helices. The topology and symmetry of this structure are the same as for the close packing of (1*R**,2*R**,4*S**)-4-*tert*-butyl-2-hydroxy-1-cyclopentanecarboxamide [Kálmán *et al.* (2001). *Acta Cryst.* B**57**, 539–550]; only the hydrogen-bond donors and acceptors are interchanged, in the same way as in the two dimer types of 8T and 8T* ribbons. This analogy suggests that helices may originate as homochiral dimers with C_2 symmetry and polymerize into helices during crystal formation. The conformational characteristics of the heterochiral dimers observed in the title compounds and in closely related structures are discussed.

1. Introduction

The systematic structure analyses of numerous *cis*- and *trans*-1,2-disubstituted cyclopentanes, cyclohexanes and cycloheptanes and analogous trisubstituted cyclopentanes resulted in the recognition of principal close-packing patterns (Kálmán *et al.*, 2001, 2002). As a continuation, the present paper reports on the crystal structures of analogous cyclooctane derivatives. The crystal structure of 8T comprises linear arrays of two kinds of heterochiral dimers (Fig. 1*a*) joined by $R_2^2(12)$ rings (Etter, 1990; Bernstein *et al.*, 1995). They differ in the acceptor group(s) of the hydrogen bonds. OC dimers are formed by OH···OC hydrogen bonds (hereinafter *HB*1), whereas OH dimers are formed by OH···OH hydrogen bonds (hereinafter *HB*2).

To simplify the description of these dimers, it is convenient (Kálmán *et al.*, 2002) to formulate the homologous 1,2-disubstituted alicyclic monomers (Fig. 1*a*) on paper by

omitting their saturated rings and depicting the functional groups by graphical symbols (Fig. 1*b*). A straight line represents an OH group, a circle an OC group and a triangle (in carboxamides) an NH_2 group. To distinguish between the C1-*R* and C1-*S* enantiomers, the symbols are converted into black or white triangles (Fig. 1*c*). The heterochiral dimers are joined by hydrogen bonds (Fig. 1*d*).

The parallel ribbons of 8T molecules are depicted by these symbols in Fig. 2(*a*). In these ribbons, the OC and OH dimers alternate. In other words, the heterochiral connection between two dimers of either type generates the other dimer, and this linear array is therefore unique. It can be regarded as the principal form of the close-packing patterns recognized so far (Kálmán *et al.*, 2001, 2002). This pattern is scarcely altered when the carboxyl groups of 8T are replaced by carboxamide moieties. As shown in Fig. 2(*a*), the parallel ladders (ribbons) formed by the OC and OH dimers can be cross-linked by additional $R_2^2(8)$ synthons (Desiraju, 1995). Each entering NH_2 group [small triangles in Fig. 2(*b*)] affords a new hydrogen bond with the nearest carbonyl group of a parallel ribbon. The crystal structure of 8T* confirmed this expectation.

This unique pattern (Fig. 2*a*) is basically reassembled, however, if either the heterochiral OH or the OC dimers become homochiral, *i.e.* their C_i symmetry is changed to C_2. The homochiral dimers may exist in solution, but in the crystalline state, in accordance with the close-packing rules of Zorky (1993), they polymerize into either parallel or antiparallel helices. Such antiparallel helices, formed from the homochiral OH dimers, were observed in the structure of 8C.

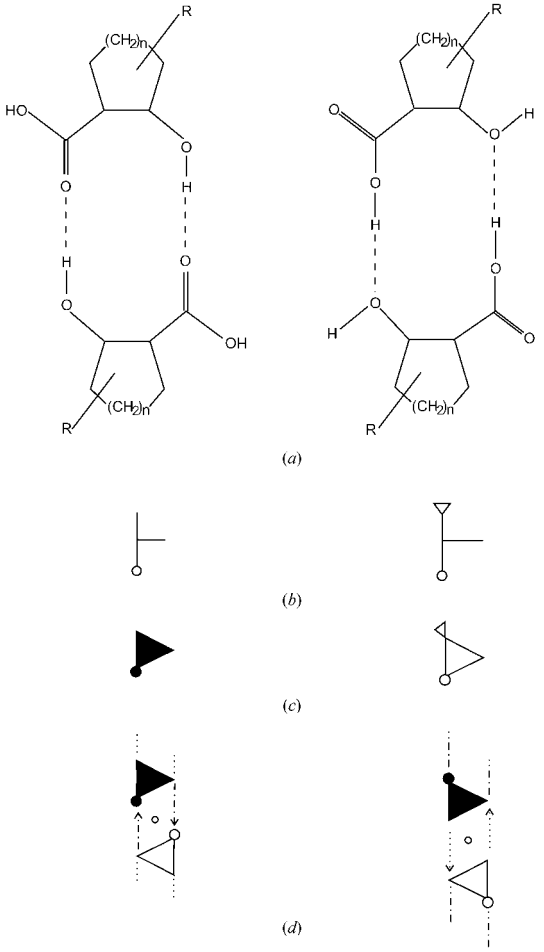

Figure 1
(*a*) The basic forms of the cyclic dimer OC (left) and OH (right), observed in 2-hydroxy-1-cyclopentane- ($n = 1$), -cyclohexane- ($n = 2$), -cycloheptane- ($n = 3$) and -cyclooctane- ($n = 4$) carboxylic acids. In general, R = H or an alkyl group. (*b*) Symbolic form: straight lines represent OH groups, small triangles (in carboxamides) represent NH_2 groups and circles represent OC groups. (*c*) To distinguish between the enantiomers, the stick symbols are converted into black or white triangles. (*d*) The symbolic dimers are held together by hydrogen bonds depicted as -·-·-> (OH···O═C) and ···> (XH···OH) (X = O in COOH or NH in $CONH_2$). In carboxamides (8T*), the third hydrogen bond (XH···O═C) is denoted by --->.

2. Experimental

2.1. Synthesis

The syntheses, characterization and chemical reactions of 8T, 8C and 8T* have been reported previously (Bernáth *et al.*, 1974, 1975).

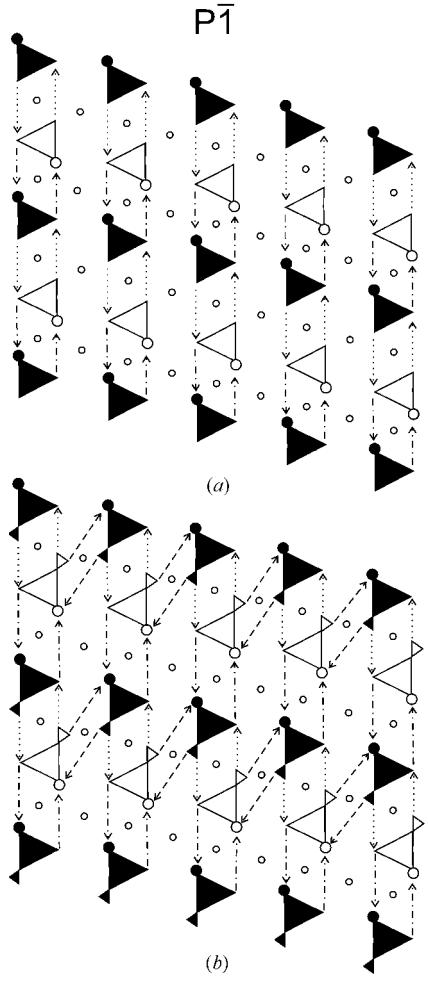

Figure 2
Symbolic (topological) presentation of the close packings of 8T (*a*) and 8T* (*b*) projected onto the *ab* plane of the common triclinic unit cell, space group $P\bar{1}$.

Table 1
Experimental details.

	8T	8T*	8C
Crystal data			
Chemical formula	$C_9H_{16}O_3$	$C_9H_{17}NO_2$	$C_9H_{16}O_3$
Chemical formula weight	172.22	171.24	172.22
Cell setting, space group	Triclinic, $P\overline{1}$	Triclinic, $P\overline{1}$	Monoclinic, $P2_1/c$
a, b, c (Å)	6.035 (1), 8.390 (1), 9.389 (2)	6.760 (1), 7.314 (1), 11.217 (1)	11.082 (1), 7.618 (1), 11.579 (1)
α, β, γ (°)	84.29 (1), 76.37 (1), 77.95 (1)	79.22 (1), 74.12 (1), 69.45 (1)	90, 105.67 (1), 90
V (Å^3)	451.20 (13)	496.93 (11)	941.20 (17)
Z	2	2	4
D_x (Mg m^{-3})	1.268	1.144	1.215
Radiation type	Mo $K\alpha$	Mo $K\alpha$	Mo $K\alpha$
No. of reflections for cell parameters	25	25	25
θ range (°)	17.0–18.91	12.04–14.35	16.23–17.84
μ (mm^{-1})	0.094	0.080	0.090
Temperature (K)	293 (2)	293 (2)	293 (2)
Crystal form, color	Prism, colorless	Prism, colorless	Prism, colorless
Crystal size (mm)	0.60 × 0.40 × 0.30	0.30 × 0.25 × 0.02	0.50 × 0.40 × 0.25
F(000)	188	188	376
Data collection			
Diffractometer	Enraf–Nonius CAD-4	Enraf–Nonius CAD-4	Enraf–Nonius CAD-4
Data collection method	ω–2θ scans	ω–2θ scans	ω–2θ scans
Absorption correction	φ-scan	φ-scan	φ-scan
T_{min}	0.9346	0.8932	0.9579
T_{max}	0.9799	0.9946	0.9876
No. of measured, independent and observed reflections	8683, 3931, 2585	4315, 1941, 989	4372, 4074, 2100
Criterion for observed reflections	$I > 2\sigma(I)$	$I > 2\sigma(I)$	$I > 2\sigma(I)$
R_{int}	0.0213	0.0257	0.0159
θ_{max} (°)	34.95	25.99	34.95
Range of h, k, l	$-9 \rightarrow h \rightarrow 9$ $-13 \rightarrow k \rightarrow 13$ $-15 \rightarrow l \rightarrow 15$	$-8 \rightarrow h \rightarrow 8$ $-9 \rightarrow k \rightarrow 9$ $-13 \rightarrow l \rightarrow 13$	$-17 \rightarrow h \rightarrow 17$ $-12 \rightarrow k \rightarrow 0$ $0 \rightarrow l \rightarrow 18$
No. and frequency of standard reflections	3 every 60 min	3 every 60 min	3 every 60 min
Intensity decay (%)	3	2	3
Completeness to 2θ	0.993	0.999	0.987
Refinement			
Refinement on	F^2	F^2	F^2
$R[F^2 > 2\sigma(F^2)]$, $wR(F^2)$, S	0.0442, 0.1417, 0.949	0.0431, 0.1464, 0.837	0.0502, 0.1543, 0.847
$wR[F^2 > 2\sigma(F^2)]$	0.1284	0.1225	0.1361
$R(F^2)$	0.0693	0.1043	0.1098
No. of reflections, restraints and parameters used in refinement	3931, 101, 111	1941, 146, 110	4074, 99, 111
H-atom treatment	Riding	Riding	Riding
Weighting scheme	$w = 1/[\sigma^2(F_o^2) + (0.1P)^2]$ where $P = (F_o^2 + 2F_c^2)/3$	$w = 1/[\sigma^2(F_o^2) + (0.1P)^2]$ where $P = (F_o^2 + 2F_c^2)/3$	$w = 1/[\sigma^2(F_o^2) + (0.1P)^2]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max}$	0.000	0.000	0.000
$\Delta\rho_{max}$, $\Delta\rho_{min}$ (e Å^{-3})	0.327, −0.195	0.163, −0.141	0.307, −0.166

Computer programs used: CAD-4 *EXPRESS* (Enraf–Nonius, 1992), *XCAD*4 (Harms, 1996), *SHELXS*97 (Sheldrick, 1997*b*), *SHELXL*97 (Sheldrick, 1997*a*).

2.2. Data collection, structure solution and refinement

Details of the cell data, data collection and refinement are provided in Table 1.[1] Each data set was collected at room temperature on CAD-4 diffractometers equipped with graphite monochromators. Standard reflections (three for each data collection, measured every 60 min) indicated some crystal decay (2% for 8T* and 3% for 8T and 8C samples), which was corrected using the program *XCAD*4 (Harms, 1996). All reflections were corrected for Lorenz and polarization effects. The space groups were determined from unit-cell volume, symmetry (8T and 8T*) and systematic absences (8C). The crystallographic phase problems were solved by direct methods using the program *SHELXS*97 (Sheldrick, 1997*b*). The atomic positions for each structure were refined with anisotropic displacement parameters in F^2 mode using the program *SHELXL*97 (Sheldrick, 1997*a*). The positions of H atoms bound to O and N atoms were located in difference-Fourier maps, while the others were generated from assumed geometry and were refined isotropically in riding mode. The eight-membered rings exhibit the largest thermal motions at

[1] Supplementary data for this paper are available from the IUCr electronic archives (Reference: DE0017). Services for accessing these data are described at the back of the journal.

Table 2
Hydrogen bonds and their descriptors.

The symmetry codes given in rows 2, 7 and 12 refer to the acceptor atoms of hydrogen bonds.

	8T	8T*	8C
O1—H1(*xyz*)···O2	$-x+1, -y+1, -z$	$-x+1, -y+1, -z+1$	$-x, -y, -z$
D···*A* (Å)	2.739 (1)	2.732 (2)	2.788 (1)
H···*A* (Å)	1.92	1.92	1.98
D—H···*A* (°)	176.6	170.0	169.5
Symmetry	Inversion center	Inversion center	Inversion center
O3—H3(*xyz*)···O1N1—H1*c*(*xyz*)···O1	$-x, -y+1, -z$	$-x+2, -y+1, -z+1$	$-x, y-\frac{1}{2}, -z+\frac{1}{2}$
D···*A* (Å)	2.656 (1)	2.883 (2)	2.634 (1)
H···*A* (Å)	1.85	2.04	1.82
D—H···*A* (°)	165.7	165.9	170.9
Symmetry	Inversion center	Inversion center	Screw axis
N1—H1*b*(*xyz*)···O2		$-x+1, -y+2, -z+1$	
D···*A* (Å)		2.945 (2)	
H···*A* (Å)		2.09	
D—H···*A* (°)		172.3	
Symmetry		Inversion center	

C5 and C6 (Fig. 3), opposite the CO*X* (*X* = OH or NH_2) and OH moieties.

3. Results and discussion

3.1. Survey of the structures at a molecular level

The chemical and molecular structures of the three 2-hydroxycyclooctane derivatives are depicted in Fig. 3. The common feature of the saturated eight-membered rings is their similar conformation. Each of them exhibits a *boat–chair* shape (Hendrickson, 1967) with low asymmetry parameter (Duax *et al.*, 1976): $\Delta C_s(2–6) = 3.6^\circ$ in 8T, $\Delta C_s(3–7) = 3.1^\circ$ in 8T* and $\Delta C_s(3–7) = 2.5^\circ$ in 8C. The mean values of the C(sp^3)—C(sp^3) bond lengths [8T, 1.532 (11); 8C, 1.527 (12); and 8T*, 1.526 (11) Å] do not differ significantly either. What is different is the position of the substituents on the *boat–chair* rings. In 8T, the mirror plane (C_s) of the ring bisects C2 and C6 atoms, while in 8T* and 8C the pseudorotation (Altona *et al.*, 1968) turns the mirror plane onto the pair of atoms C3···C7. From this, it follows that (apart from the effect of the *cis–trans* isomerism on the relative orientation of the ring functions) the conformations of the 8T* and 8C molecules are similar. In both cases, the orientation of the CO*X* group is *equatorial* with exocyclic torsion angles −*ac* and −*ap* (Klyne & Prelog, 1960). The *cis–trans* isomerism is indicated by the different torsion angles around the *pseudoaxial* OH group: −*ap* and *sc* for 8T* and *sc* and *ap* for 8C. Consequently, the O1—C2—C1—C9 torsion angles differ significantly: 71.7 (2)° in 8T* and −43.9 (1)° in 8C. In contrast, the overall conformation of the 8T molecule with the similarly puckered cyclooctane ring displays a visible difference from the other two. In 8T, the O2 atom sits on the mirror plane of the *boat–chair* ring in *equatorial* position (the corresponding exocyclic torsion angles are *ap* and −*ap*) and forms a low O1—C2—C1—C9 torsion angle of 48.0 (1)° with the *pseudoequatorial* carboxyl group. This may be attributed to intermolecular interactions and in particular to the formation of infinite ladders of alternating OC and OH dimers. One of them, depicted in Fig. 4(*a*), reveals a linear array of planar OH and folded OC dimers.

3.2. Hydrogen-bond networks

3.2.1. Dimers and their conformational characteristics. Since each of the structures 8T, 8T* and 8C is self-assembled by OC and OH dimers, their conformational similarities and differences may shed light on the predicted architecture (Kálmán *et al.*, 2002) afforded by similar hydrogen bonds (Table 2). In the course of crystallization, the homochiral OH dimers of 8C are polymerized into antiparallel helices (Zorky, 1993). Thus, the OC dimers (Fig. 5) remain the common building blocks of the three structures. Surprisingly, the OC dimers of the *trans* and *cis* isomers are rather similar (Figs. 5*a*

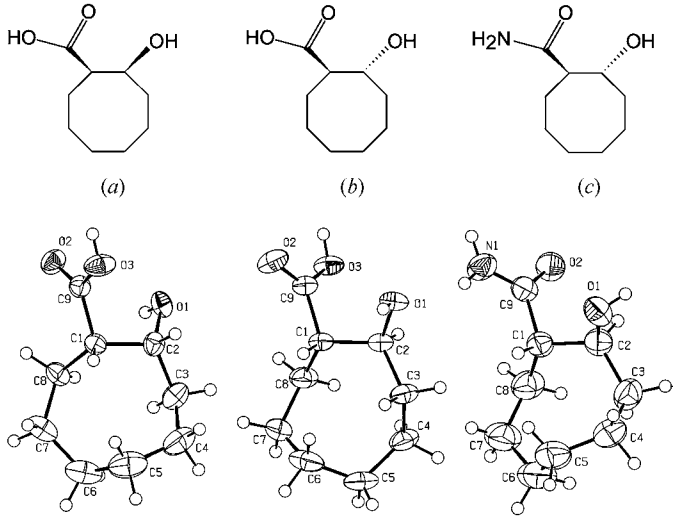

Figure 3
Chemical and molecular structures of (*a*) (1*R**,2*S**)-*cis*-2-hydroxy-1-cyclooctanecarboxylic acid (8C), (*b*) (1*R**,2*R**)-*trans*-2-hydroxy-1-cyclooctanecarboxylic acid (8T) and (*c*) (1*R**,2*R**)-*trans*-2-hydroxy-1-cyclooctanecarboxamide (8T*) labeled with common atomic numbering. The pairs have opposite chirality.

and 5*b*). Both of them are folded along the *HB*1 hydrogen-bond pairs. In contrast, the OC dimers in 8T* are planar (Fig. 5*c*). In this structure, the OH dimers (Fig. 6*a*) assume a folded conformation, with endocyclic torsion angles similar to those of the OC dimers in 8T and 8C (Table 3). The folded conformations of these dimers (numbers 1–3 in Table 3) are characterized by the same sequence of torsion-angle amplitudes as described by the abbreviations of Klyne & Prelog (1960): *sc*, −*ac*, *sp*, *ac*, −*sc*. The planar dimers [Figs. 6(*b*) and 6(*c*) and Table 3], irrespective of the hydrogen bonds that hold them together and of the *cis–trans* stereoisomerism of the molecules, are hallmarked by a different sequence of the torsion-angle amplitudes: *sc*, *sc*, −*ap*, *sc*, *sc*. The OC dimers of 8T* (number 10 in Table 3) exhibit slightly different torsion angles. Their sequence is shifted on the cyclooctane ring by three bonds with respect to the puckering of the planar dimers in the structures of 8T, (1*R**,2*S**)-*cis*-2-hydroxy-1-cycloheptanecarboxylic acid (7C), (1*R**,2*S**)-*cis*-2-hydroxy-1-cyclohexanecarboxylic acid (6C), (1*R**,2*R**)-*trans*-2-hydroxy-1-cyclopentanecarboxylic acid (5T) (Kálmán *et al.*, 2002) and (1*R**,2*S**,4*R**)-*cis*-4-*tert*-butyl-2-hydroxy-1-cyclopentanecarboxylic acid (IV) (Kálmán *et al.*, 2001). This can be attributed to the presence of additional $R_2^2(8)$ synthons (Desiraju, 1995) joined by the NH_2 groups between the adjacent molecular ribbons (Fig. 2*b*). Accordingly, from Table 3 it follows that the hydrogen-bonded twelve-membered OC and OH rings of C_i symmetry can equally assume either a folded or a planar conformation, and this freedom of choice is independent of stereoisomerism.

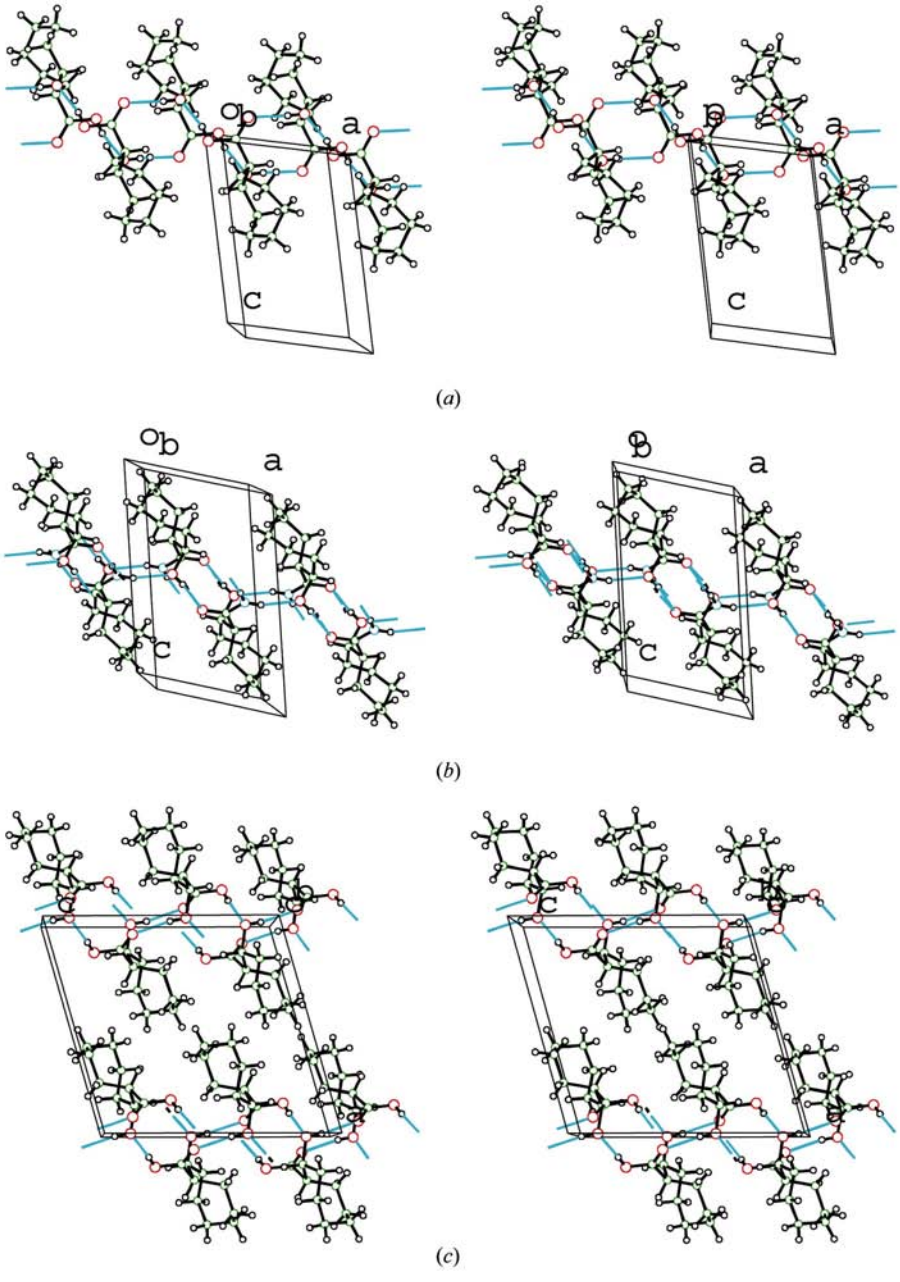

Figure 4
Stereoviews of the three-dimensional molecular packing of 8T (*a*), 8T* (*b*) and 8C (*c*).

3.2.2. Close packing and isostructurality of 8T and 8T*. In a previous paper (Kálmán *et al.*, 2002), we pointed out that the hydrogen-bond pattern of 8T (Fig. 2*a*) could be deduced from that of IV [*cf.* Fig. 10(*a*) in Kálmán *et al.* (2002)] if all *HB*1 bonds turn simultaneously from the respective homochiral chains to their neighboring enantiomers. Correspondingly, the close packing in 8T* could also be predicted (see above). Although the symbolic two-dimensional presentations of the crystal structures of 8T and 8T* (Fig. 2) do have advantages and power in making predictions, they conceal relevant three-dimensional information, *e.g.* the planar and folded conformations of the dimers cannot be seen. The crystal structure of 8T (Fig. 4*a*) shows an infinite row of planar OH dimers fixed to their inversion centers at $y = 0.5$. They are parallel to the $(a + c)/2$ diagonal and held together by folded OC dimers. The deterministic relationship of these connections is confirmed by the similar close packing of 8T* (Fig. 4*b*). However, direct replacement of the OH functions by NH_2 groups in the COOH moieties (Fig. 4*a*) is hindered by the vicinity of the cyclooctane rings. First, this steric hindrance is minimized by the rotation of the $CONH_2$ groups (by *ca.* 180°) and by an increase of 0.725 Å in the *a* axis (Fig. 4*b*). The result is an exchange between the OC and OH dimers followed by a turn in the direction of

Table 3
The five independent endocyclic ($A-B-C-D$) torsion angles of the $R_2^2(12)$ rings of C_i symmetry for 8T, 8C and 8T* and related cyclopentane, cyclohexane and cycloheptane derivatives (III†, IV†, 5T‡, 6C‡ and 7C‡).

They are calculated only for non-H atoms. The mean conformation of the similarly puckered rings is also characterized by the abbreviations introduced by Klyne & Prelog (1960).

Folded dimers							
No.	Dimer	Compound	C2—C1	C1—C*X*§	C*X*═O2	O···O1*	O1*—C2*
1	OC	8T	48	−121	15	119	−73
2	OC	8C	44	−104	3	133	−70
					C*X*—N3	···O1*	
3	OH	8T*	72	−127	11	113	−62
4	OH	III	73	−137	14	99	−69
	Klyne & Prelog¶	*sc*	*−ac*	*sp*	*ac*	*−sc*	
Planar dimers							
No.	Dimer	Compound	C2—C1	C1—C*X*§	C*X*—O3	O3···O1*	O1*—C2*
5	OH	8T	48	59	−166	53	68
6	OH	7C	53	55	−166	56	67
7	OH††	6C	61	53	−163	52	75
8	OH	IV	48	54	−167	62	59
					C*X*═O2	O2···O1*	
9	OC	5T	80	38	−150	56	79
			C*X**═O2*	O2*···O1	O1—C2	C2—C1	C1—C*X*
10	OC	8T*	83	38	−151	72	55
	Klyne & Prelog¶	*sc*	*sc*	*−ap*	*sc*	*sc*	

† Kálmán *et al.* (2001). ‡ Kálmán *et al.* (2002). § $X = 9$ in 8C, 8T and 8T*; $X = 8$ in 7C; $X = 7$ in 6C;†† and $X = 6$ in III, IV and 5T. ¶ Klyne & Prelog (1960). †† 60% OH and 40% OC dimers.

both *HB*1 and *HB*2 bonds. This is why the OH dimers become folded in 8T* (Fig. 6*a*), with the torsion angles listed in Table 3 (number 3), while the planar dimers are held together by the *HB*1 bonds (Fig. 5*c*). Simultaneously, planar $R_2^2(8)$ rings (Fig. 2*b*) are produced between the ribbons. These $R_2^2(8)$ rings diminish the separation between the parallel ladders in the direction of the *b* axis by −1.076 Å (Fig. 7) and form a second ladder between the folded OH dimers (Fig. 8), which seems to account for an increase in the *c* axis by 1.828 Å. These changes increase the unit-cell volume by 45.7 (1) Å^3. In spite of these changes, the close packings of 8T and its carboxamide derivative 8T* display a relaxed form of isostructurality (Kálmán & Párkányi, 1997), *i.e.* the parallel ladders of OC and OH dimers exhibit an inversion of the planar and folded conformations. The volumetric index of their isostructurality (Fábián & Kálmán, 1999) is $I_v = 60\%$.

3.2.3. Close packing of 8C and its one-dimensional similarity to 8T and 8T*. As shown by Figs. 4(*a*) and 4(*b*), the folded OC (8T) and OH (8T*) dimers hold together their complementary dimers (OH and OC), which assume a planar conformation. In the monoclinic unit cell of 8C (Fig. 4*c*), each folded dimer joins two antiparallel helices. The folded OC dimers exhibit similar conformations in the $R_2^2(12)$ rings of 8T and 8C (Figs. 5*a* and 5*b*), but differ in the orientation of the bulky cyclooctane rings. Because of the *cis–trans* isomerism, the relative position of the vicinal substituents differs. While the C8 methylene group in 8T is well separated from the 2OH group of the other monomer forming the ring, in 8C the pseudorotation of the cyclooctane ring brings the C8 methylene group quite close to the respective 2OH group. This vicinity hinders the parallelism of the *HB*2-bond pairs, which is the condition of dimer formation with C_i symmetry. Instead, the almost perpendicular incoming [*equatorial* with the $R_2^2(12)$ ring] and outgoing [*pseudoaxial* with the $R_2^2(12)$ ring] *HB*2 bonds (Fig. 5*b*) form the helical assembly of the respective OH donors and OC acceptors. The phenomenon may be regarded as a sterically controlled polymorphism of diastereomers. The conformational similarities (Fig. 4) of the infinite ribbons in the triclinic 8T and 8T* and the monoclinic 8C can be regarded as an example of one-dimensional isostructurality (Anthony *et al.*, 1998).

3.2.4. Linear associations of $R_2^2(12)$ dimers. Both OC and OH dimers may associate to form ribbons either parallel with or perpendicular to the principal dimer axis. The latter is termed lateral association of the heterochiral dimers. Two patterns of such an association were deduced from the structures 5T, 6C, 7C and IV (Kálmán *et al.*, 2002) and were denoted hoa1 and hea2 with subgroups hoa1$_H$, hoa1$_C$, hea2$_H$ and hea2$_C$,[2] respectively.

If OC and/or OH dimers are arranged parallel to the principal dimer axis in a row (hereinafter termed linear association), there are only three possible forms. With identical orientation, the heterochiral dimers, irrespective of their type, give rise to the pattern exemplified by 8T (Fig. 2*a*) and denoted hed1. However, when a linear arrangement of the monomers is built up from dimeric units with alternating orientation, the generated 'cementing' dimers are homochiral. This linear assembly again has two alternatives: either the OH or the OC dimers are homochiral (Figs. 9*a* and 9*b*). These homochiral dimers may exist in solution, but in the crystalline state (Zorky, 1993) they prefer to polymerize into infinite antiparallel or parallel helices. In the antiparallel arrays

[2] The notations refer to homochiral and heterochiral chains of hydrogen-bonded molecules in antiparallel array cross-linked by either OH (index H) or OC (index C) dimers.

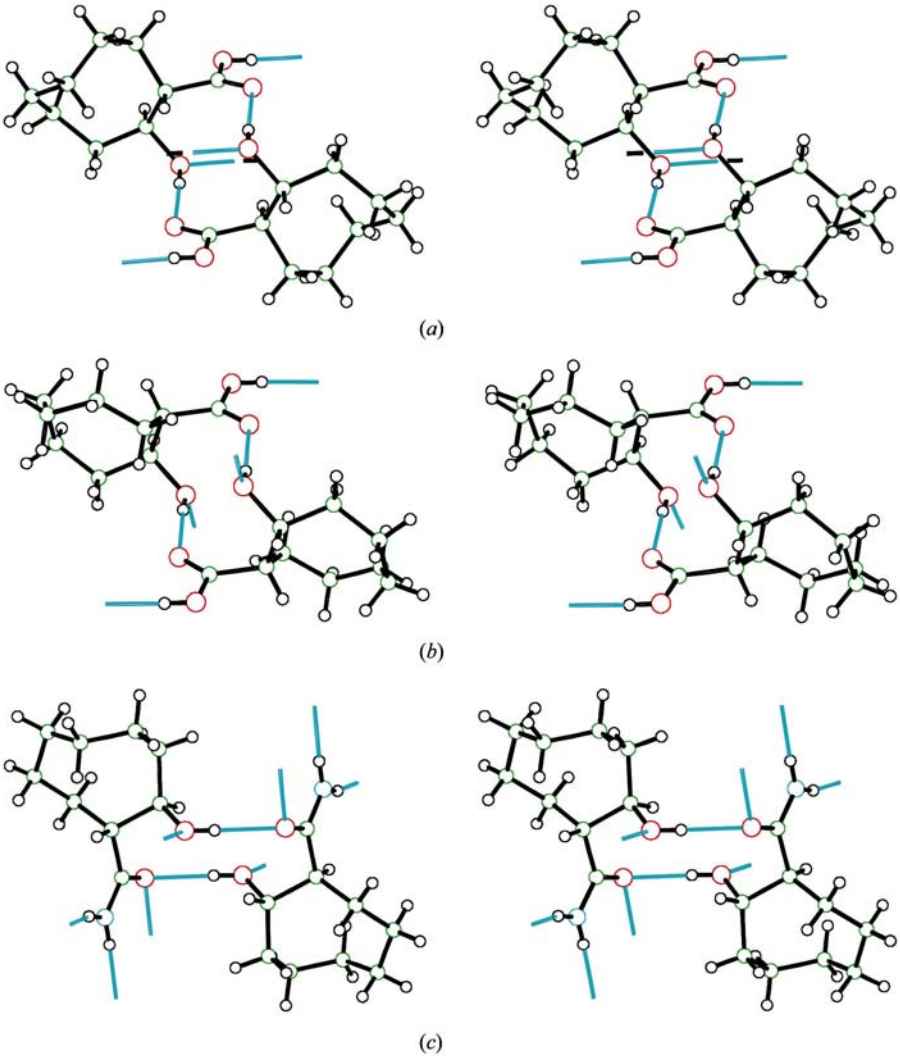

Figure 5
Stereoviews of the OC dimers observed in the compounds 8T (*a*), 8C (*b*) and 8T* (*c*). Dimers (*a*) and (*b*) are folded, whereas dimer (*c*) is planar.

(Figs. 9*c* and 9*d*), the enantiomeric helices are joined by heterochiral OC or OH dimers, respectively. They correspond to two subgroups of the pattern denoted hoa2 (Kálmán *et al.*, 2002).

The title compound 8C demonstrates subgroup hoa2$_C$, in which the helices are linked together by OC dimers. The second subgroup hoa2$_H$ was exemplified by (1*R**,2*R**,4*S**)-4-*tert*-butyl-2-hydroxy-1-cyclopentanecarboxamide [III in Kálmán *et al.* (2001)], in which the helices are held together by OH dimers. In both structures, the antiparallel helices are held together by folded dimers (numbers 2 and 4 in Table 3) with similar overall conformation. Another common feature of these two structures is the presence of large homodromic (Jeffrey & Saenger, 1991) $R_6^6(24)$ rings, formed by the same sequence of six molecular fragments [*cf.* the 'partitioned' graph-set notations in Table 4 of Kálmán *et al.* (2001)]. In 8C the sequence of the six fragments with four *HB*2 and two *HB*1 bonds is $\leftarrow_1 6^1 \leftarrow_1 4^1 \leftarrow_1 2^1 \leftarrow_1 6^1 \leftarrow_1 4^1 \leftarrow_1 2^1 \leftarrow$, whereas in III the number and direction of the *HB*1 and *HB*2 bonds are the opposite. These facts and the similarity between the monoclinic unit-cell parameters ($\Pi = 0.085$) suggest the relaxed but visible isostructurality (Kálmán & Párkányi, 1997) of 8C and III, even though their molecular structures differ.

Of course, the homochiral dimers may also polymerize into parallel helices, which are exemplified by (1*R**,2*R**)-2-hydroxy-1-cyclopentanecarboxamide (II) crystallized with polar orthorhombic space group $Pca2_1$ (Kálmán *et al.*, 2001). In this structure, the helices are no longer linked by either $R_2^2(12)$ dimers of C_i symmetry or $R_4^4(12)$ tetramers of C_2 symmetry. Instead, the close packings of the helices with opposite chirality are controlled by glide planes.

4. Conclusions

The supramolecular similarities exhibited by six cyclopentane derivatives have resulted in the recognition of five patterns (hoa1, hoa2, hea1, hop2 and hep1) of molecular close packing (Kálmán *et al.*, 2001). The sixth pattern, hea2, deduced from the others, is found in the crystals of 5T, 6C and 7C (Kálmán *et al.*, 2002). The similar close packing of 5T, 6C and 7C reveals that

(i) the $R_2^2(12)$ rings are held together by either *HB*1 or *HB*2 bonds and they can therefore be distinguished in terms of the acceptor groups, either OC (5T) or OH (7C);

(ii) each structure possesses a tetramer arranged in an $R_4^4(12)$ ring with C_2 symmetry and is hallmarked by the common space group *C*2/*c*.

It has also been concluded (Kálmán *et al.*, 2002) that $R_4^4(12)$ tetramers, irrespective of their symmetry (either C_2 or C_i), are formed whenever two $R_2^2(12)$ dimers are joined laterally. These lateral associations may be formed with identical or alternating orientation of the dimers. With identical orientation, the OH dimers form tetramers arranged in rings, compatible with the pattern subgroup hea1$_H$ found in IV (Kálmán *et al.*, 2001).

The present paper reports on the linear associations of heterochiral OH and OC dimers. If the OH or OC dimers are assembled in ribbons with identical orientation, the same pattern (hed1) is generated in both cases. It is exemplified by the structure of 8T (Figs. 2*a* and 4*a*). COOH $\rightarrow$ CONH$_2$ replacement in 8T leads to 8T*. In crystals of 8T* additional $R_4^4(8)$ synthons (Desiraju, 1995) are developed, while within the parallel ribbons inherited from 8T only the conformations

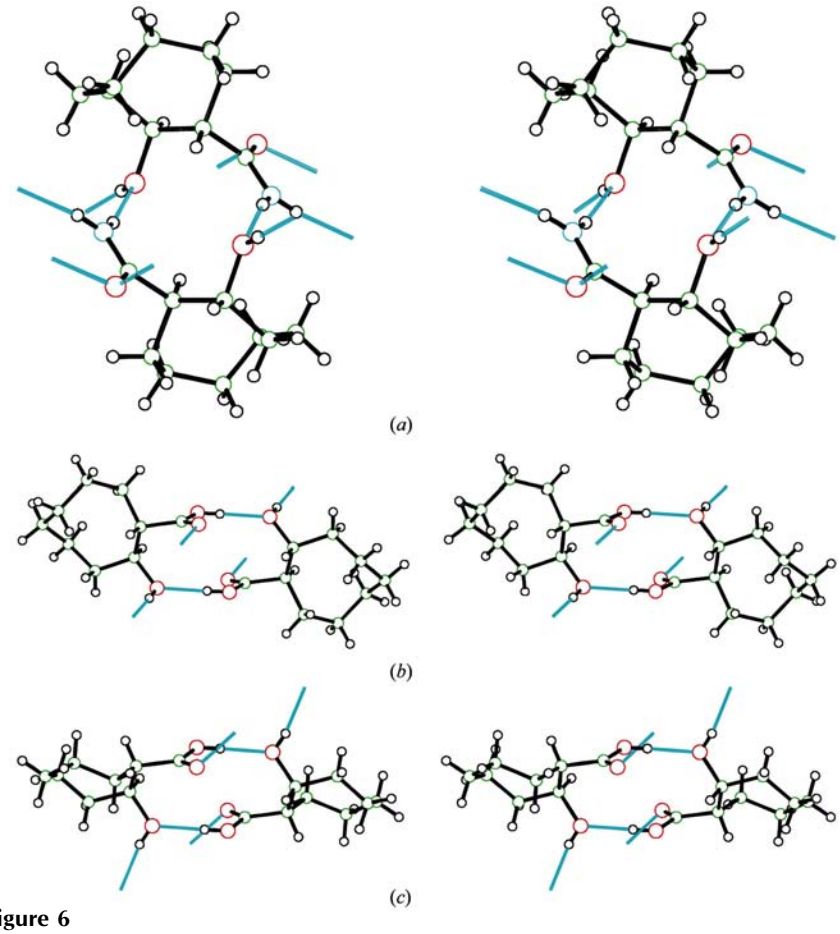

Figure 6
Stereoviews of the OH dimers observed in the compounds 8T* (*a*), 8T (*b*) and 7C (*c*). Dimer (*a*) is folded, whereas dimers (*b*) and (*c*) are planar.

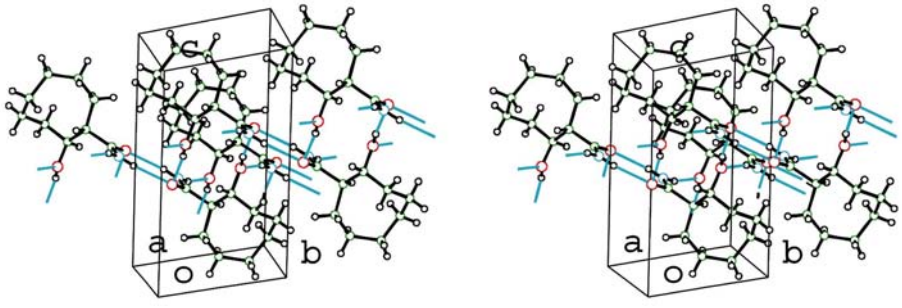

Figure 7
Stereoview of a row of planar OC dimers of 8T*, held together by $R_2^2(8)$ synthons in the direction of the *b* axis. In the direction of the *a* axis, a folded OH dimer can also be seen.

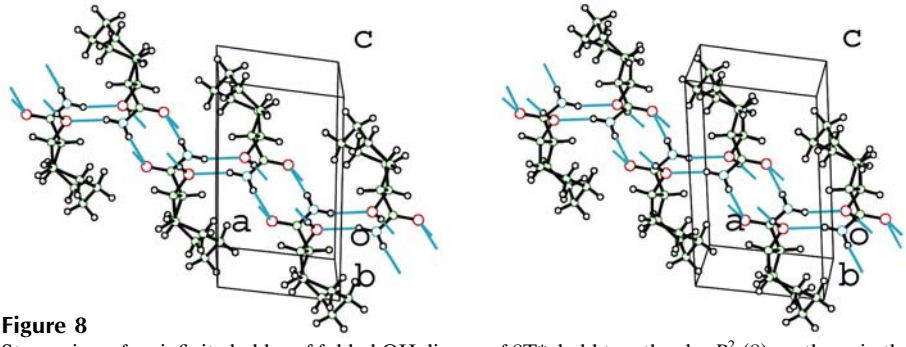

Figure 8
Stereoview of an infinite ladder of folded OH dimers of 8T*, held together by R_2^2 (8) synthons in the direction of the *b* axis.

of the OC and OH dimers are interchanged. Consequently, 8T* remains isostructural with 8T. This is the first observation of $R_4^4(8)$ rings among the homologous 1,2-disubstituted alicyclic derivatives.

If the heterochiral dimers form a linear array with *alternating* orientation, then two transitional subgroups of close-packing pattern can again be obtained: either the OC or the OH dimers become homochiral in the resulting ribbons. Since homochiral dimers generally exist only in solution, in the crystalline state they polymerize into either antiparallel or parallel helices. Thus, two independent patterns with two subgroups in each can be obtained.

To summarize, the topological combination of hetero- and homochiral OH/OC dimers results in six patterns with two subgroups in each (with the exception of hed1). So far, eight of these possibilities, involving all of the patterns, have been demonstrated experimentally. The patterns, compound(s) and the respective space groups are listed in Table 4.

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Table 4
Patterns (and their subgroups denoted by indices C and H) of supramolecular self-assembly, deduced either from experimental data or topologically from the possible forms of OC and OH dimer associations.

Structures belonging to the patterns hea1 and hed1, respectively, are isostructural. Similar relationships can be seen between the subgroups of patterns hoa2 and hea2. Structures with space groups $P2_1/c$ (III, 8C) or $C2/c$ (5T, 6C, 7C), irrespective of their *cis–trans* isomerism, are also related by some degree of isostructurality.

Patterns and subgroups	Crystal structures	Space groups
$hoa1_H$	IV†	$P\bar{1}$
$hoa1_C$	–	$P\bar{1}$
$hoa2_H$	III†	$P2_1/c$
$hoa2_C$	8C‡	$P2_1/c$
$hop2_H$	II†	$Pca2_1$
$hop2_C$	–	$Pca2_1$
hed1	8T‡, 8T*‡	$P\bar{1}$
$hea1_H$	I†, V†	$P2_1/c$
$hea1_C$	–	$P2_1/c$
$hea2_H$	6C§(60%), 7C§	$C2/c$
$hea2_C$	6C‡(40%), 5T§	$C2/c$

† Kálmán *et al.* (2001). ‡ Present work. § Kálmán *et al.* (2002).

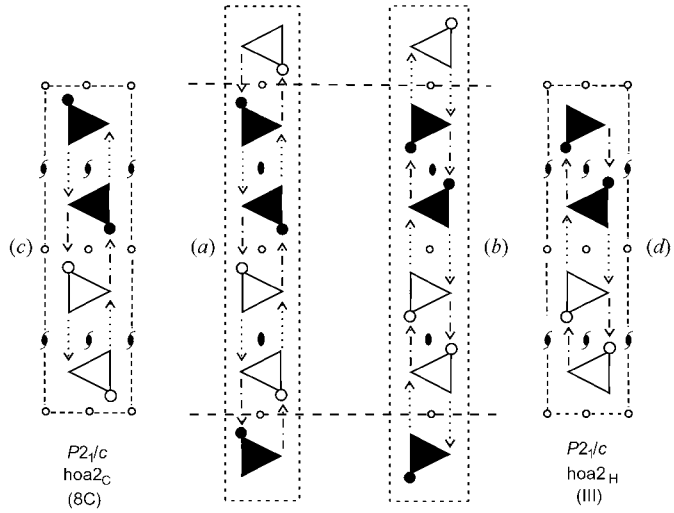

Figure 9
Linear arrays of alternating heterochiral OC (*a*) and OH (*b*) dimers. In each ribbon, three heterochiral dimers are joined by two homochiral dimers of opposite type. In the crystalline state they polymerize into antiparallel or parallel helices. The antiparallel helices with opposite chirality [observed in 8C and III (Kálmán *et al.*, 2001)] are linked by heterochiral dimers (*c*) and (*d*).

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