Commensurate molecules in isostructural crystals of cholesteryl *cis*- and *trans*-9-hexadecenoate[1]

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Abstract At 295 K, crystals of form I of cholesteryl *cis*-9-hexadecenoate (palmitoleate) and cholesteryl *trans*-9-hexadecenoate (palmitelaidate) are difficult to distinguish by X-ray diffraction. Both form monoclinic thin plates, space group $P2_1$ with two molecules ($C_{43}H_{74}O_2$) A and B in the asymmetric unit. Unit cell dimensions for cholesteryl palmitelaidate (I) are a = 12.827(4), b = 9.075(4), c = 35.67(1) Å, β = 93.42(3)°, very similar to those of the palmitoleate crystals. Other crystals (form II) of the palmitelaidate ester are described. The crystal structure of form I of cholesteryl palmitelaidate has been determined from 3657 reflections ($\sin\theta/\lambda < 0.46$ Å^{-1}) measured at 295 K using CuKα X-radiation and refined to give $R_w(F) = 0.095$. The molecular packing arrangement is isostructural to that of the previously determined crystal structure of cholesteryl palmitoleate. In both crystals, the fatty acid chains of the A molecules are kinked at the double bond but are nearly straight. The chains of B molecules have more complicated dislocations and are bent. It is remarkable that, neglecting their detailed conformations, corresponding fatty acid chains in the two crystal structures have similar overall shapes, although palmitoleate chains have *cis*-ethylenic groups and palmitelaidate chains have *trans* groups.—**Cho, S-I., and B. M. Craven.** Commensurate molecules in isostructural crystals of cholesteryl *cis*- and *trans*-9-hexadecenoate. *J. Lipid Res.* 1987. **28:** 80–86.

Supplementary key words X-ray crystal structure • unsaturated fatty acid • chain conformation

A series of crystal structure determinations of unsaturated long chain fatty acid esters of cholesterol is being carried out because of our interest in the conformations and packing arrangements of the unsaturated chains. The available crystal data show that all cholesteryl n-alkanoate and alkenoate esters with fatty acids of at least six C atoms belong to one of three crystal structure types. These structure types differ according to the relative importance of three kinds of molecular interaction, namely cholesteryl–cholesteryl, cholesteryl–fatty acid and fatty acid–fatty acid. Fatty acid–fatty acid interactions are predominant only in the bilayer crystal structures formed by n-alkanoate esters with chain length C_{13} or longer (1). The fatty acid chains are fully extended and pack with each other according to a regular subcell pattern. This arrangement has not yet been observed for any unsaturated long chain cholesteryl ester although such packing might well occur in modified form, since a regular subcell is present in the crystal structure of oleic acid (2) and linoleic acid (3).

The other two crystal structure types contain monolayers. So-called monolayers of type I (4) are observed for cholesteryl n-alkanoates of medium chain length (C_9 through C_{12}) and for a number of longer chain alkenoates including the crystal structure of form I of cholesteryl palmitelaidate which is presently described. In monolayers of type I, cholesteryl–cholesteryl and cholesteryl–fatty acid interactions are both important. The cholesteryl ring systems pack efficiently with each other and also surround the first eight or so C atoms of a fatty acid chain. The distal end of this chain, the cholesteryl tails, and most of a second fatty acid chain, pack irregularly and less efficiently to form the interface region between the monolayers.

Monolayers of type II are formed by the shorter chain cholesteryl n-alkanoates (C_6 through C_8) and by longer chain alkenoates, including cholesteryl oleate (5) and linolelaidate (6). Cholesteryl–cholesteryl interactions are predominant, due to an interlocking packing arrangement of cholesteryl ring systems. The fatty acid chains protrude into the interface region and pack side by side, but without a regular subcell structure.

Within the monolayers of type I or II, there is little change from one crystal structure to another. Interest centers on the interface region where the chain conformation and packing depend on the chemical nature of the fatty acid and the temperature.

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[1] See NAPS document no. 04441 for 20 pages of supplementary material, consisting of anisotropic thermal parameters, bond distances and bond angles, and observed and calculated structure factors. Order from NAPS c/o Microfiche Publications, P.O. Box 3513, Grand Central Station, New York, NY 10163. Remit in advance in U.S. funds only $7.75 for photocopies or $4.00 for microfiche. Outside the U.S. and Canada, add postage of $4.50 for photocopy and $1.50 for microfiche.

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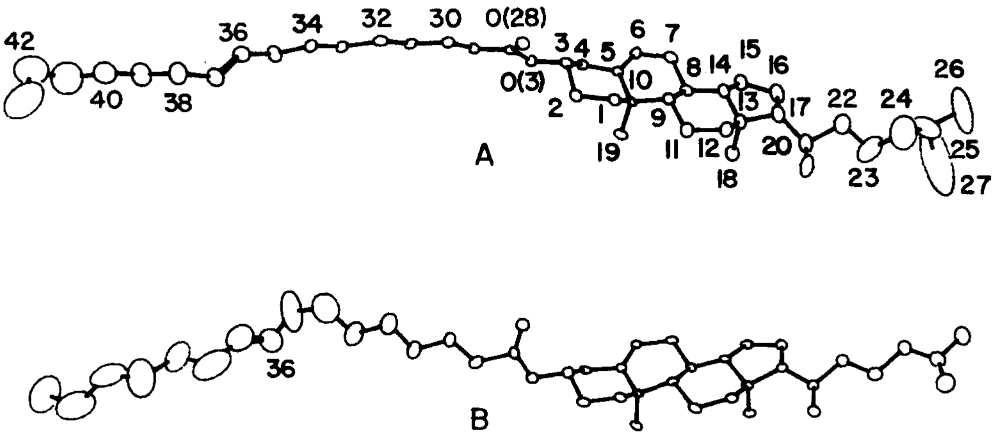

Fig. 1. Molecules A and B of cholesteryl palmitelaidate are shown with cholesteryl ring systems in a similar orientation. Atoms are shown as thermal vibration ellipsoids with 25% probability of enclosing each atom (17).

Cholesteryl palmitelaidate (9-*trans*-hexadecenoate, **Fig. 1**) is of particular interest because it is the first case in which we have observed two different crystalline forms (I and II) both giving single crystals suitable for structure determination. Form I is so called because the structure contains monolayers of type I. The crystal structure of form II has not yet been determined.[3] The unit cell constants indicate that form II may be a new structure type for cholesteryl esters. However, it is possible that the crystal structure is derived from monolayers of type II by approximate doubling of the crystal *a*-axis repeat.

The crystal structure of form I of cholesteryl palmitelaidate (**Fig. 2**) is remarkably similar to that of cholesteryl palmitoleate (7), which also contains monolayers of type I. At 295 K, the two X-ray diffraction patterns are almost indistinguishable. The molecules are geometric isomers, with ester chains that are 9-*trans*- and 9-*cis*-hexadecenoate, respectively. In molecules of this size, such a stereochemical difference would usually give rise to quite different crystal structures. The similarity in crystal structure indicates that the isomeric chains have adopted similar overall conformations. We have determined the crystal structure of form I of cholesteryl palmitelaidate in order to make detailed comparisons with the corresponding palmitoleate structure.

EXPERIMENTAL

Cholesteryl palmitelaidate, obtained from Sigma Chemical Company, St. Louis, MO, was recrystallized at 272 K from acetone in an atmosphere of nitrogen. The crystals obtained were a mixture of forms I and II which were difficult to distinguish. Both had a blade-like habit, exhibiting {001} and were elongated on *b*. X-ray diffraction data were collected using an Enraf-Nonius CAD-4 diffractometer with Ni-filtered CuKα radiation (λ = 1.5418 Å). Crystals with typical dimensions 0.3 × 0.7 × 0.1 mm were mounted with *b* close to the diffractometer ϕ-axis. Both crystal forms were found to be monoclinic, space group P2$_1$ with four molecules ($C_{43}H_{72}O_2$) per unit cell. Unit cell dimensions were obtained by least squares fitting of $\sin^2\theta$-values for 25 reflections $17 < \theta < 23°$ measured at $\pm\ \omega$. At 295 K, form I gave a = 12.827(4), b = 9.075(4), c = 35.67(1) Å, β = 93.42(3)°, V = 4145(3) Å^3 and form II gave a = 28.48(1), b = 9.027(7), c = 16.154(4) Å, β = 98.43(3)°, V = 4108(3) Å^3. Individual crystals of form I melt to an isotropic liquid at 335 K.[4]

Slow cooling (12 hr) of form I crystals was monitored by two-dimensional $\omega/2\theta$ scans of selected X-ray reflections (9). Crystal deterioration was apparent at 275 K and was unacceptable at 210 K, with reflections extending $\Delta\omega > 2°$.

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[3] Form II was the first to be studied using crystals obtained from acetone solution at 273 K by Dr. Patricia Sawzik. Much of the required X-ray intensity data have been collected at reduced temperature. However, after cooling to 123 K, the crystals have an unpredictable lifetime, due to fracture which is presumably induced by thermal stress. It became necessary to crystallize a new sample. Suitable crystals of form II were obtained, but most of the crystals selected for X-ray study turned out to be form I. The two forms have similar crystal morphology.

[4] At 295 K, crystals of form I of cholesteryl palmitoleate have a = 12.873(7), b = 9.173(4), c = 34.424(13) Å, β = 93.47(1)°, V = 4057(3) Å^3, and melt to an isotropic liquid at 325 K (7). Small (8) obtained from II reversibly from the smectic phase at 314 K. It transforms monotropically to form I on cooling. No structural relationship has been established between forms II of cholesteryl palmitoleate and palmitelaidate.

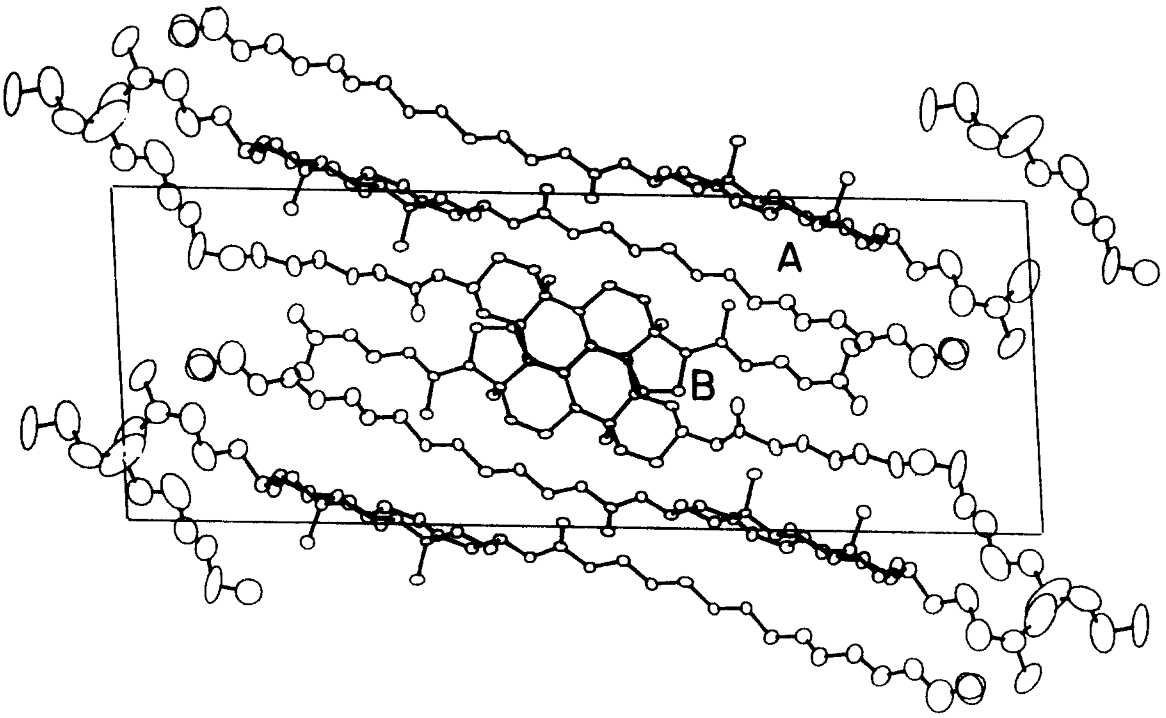

Fig. 2. The crystal structure of cholesteryl palmitelaidate at 295 K in projection down the *b*-axis. Atoms are represented as thermal ellipsoids with 25% probability of enclosing each atom (17).

Accordingly, X-ray data were collected at room temperature (295 K). For 4424 reflections with $\sin\theta/\lambda < 0.46$ Å^{-1} ($d_{min} = 1.09$ Å), each intensity profile was sampled at 96 intervals in a conventional $\omega/2\theta$ scan. Integrated intensities corrected for X-ray absorption ($\mu = 0.413$ mm^{-1}) were obtained using computer programs by Blessing and DeTitta (10). Multiple observations gave agreement with $R(F_o^2) = \Sigma|\Delta F_o^2|/\Sigma<F_o^2> = 0.016$. After averaging these, there were 3657 independent reflections, of which there were 2508 with $F_o^2 > 2\sigma$ and 487 with $F_o^2 < 0$, the most significantly negative being -3.2σ. Variances were assumed to be $\sigma^2(|F_o|) = \sigma^2(F_o^2)/4|F_o^2|$ with $\sigma^2(F_o^2) = [\sigma^2 + (0.02\ F_o^2)]^2$, except for reflections $F_o^2 < \sigma(F_o^2)$ where $\sigma^2(|F_o|) = \sigma(F_o^2)/2$ (11). Here, σ^2 is the variance in F_o^2 due to counting statistics. Values $F_o^2 < 0$ were assigned $|F_o| = 0$ so that all reflections could be included in the structure determination.

An initial Fourier synthesis of electron density was calculated using the structure amplitudes for cholesteryl palmitelaidate and the final phases from the known palmitoleate structure (7). The map showed all C and O atoms except those in the ester chains beyond C(34) and in the cholesteryl tail of molecule A. Beginning with the 70 C and O atoms found in this way, the structure was determined by an arduous procedure in which cycles of Fourier refinement alternated with block-diagonal least squares refinement. Atomic scattering factors were taken from Cromer and Waber (12) and Stewart, Davidson, and Simpson (13). In Fourier syntheses, the coefficients were $w\{2|F_o| - |F_c|\}$ with weights $w = I_1(x)/I_0(x)$, where I_0 and I_1 are zero and first order modified Bessel functions of the first kind, as proposed by Sim (14), except with $x = 2|F_o|\,|F_c|/\Delta^2$ where $\Delta = |F_o| - |F_c|$. For reflections with $|F_o| < \sigma(F)$, $w = 1$. In the least squares refinement, the residual $\Sigma w\Delta^2$ was minimized with weights $w = \sigma^{-2}(F_o)$. Damping factors 0.5 were applied to all parameter shifts. Before each run of least squares refinement, fixed H atom positions were recalculated at standard bond lengths and angles (C-H, 0.90 Å, H-C-H, 112°), and assigned fixed isotropic thermal parameters, $B = B_{eq} + 3.0$ Å^2, where B_{eq} was the thermal parameter for the appropriate bonded C atom. The electron density was diffuse and peaks were poorly resolved for much of the ester chain of molecule B, for the end of the ester chain of molecule A, and for the cholesteryl tail of molecule B. For these atoms, least squares refinement led to several unacceptable bond lengths and angles. In each of these regions, atoms were fitted to the Fourier synthesis using an MMS-X graphics system and assuming a chain constrained to have standard bond lengths (C-C, 1.50 Å) and angles (C-C-C, 112°). Thus only the C-C bond torsion angles were adjusted. There was no convincing evidence of disorder such as occurs in cholesteryl palmitoleate at 295 K (7). In subsequent least squares refinement, the fitted atoms were fixed in position with only their anisotropic thermal parameters as variables. The structure refinement gave

TABLE 1. Atomic parameters[a]

Molecule A					Molecule B				
Atom	x/a	y/b	z/c	$<u^2>$	Atom	x/a	y/b	z/c	$<u^2>$
CA1	−5207 (7)	−2135 (13)	−1410 (3)	96 (8)	CB1	−2696 (6)	−831 (10)	426 (3)	81 (7)
CA2	−5693 (7)	−1719 (11)	−1053 (3)	96 (8)	CB2	−3049 (6)	−606 (11)	808 (3)	94 (8)
CA3	−5403 (6)	−114 (11)	−943 (3)	91 (8)	CB3	−2126 (7)	−693 (12)	1103 (3)	97 (8)
CA4	−5698 (7)	889 (10)	−1261 (3)	82 (7)	CB4	−1345 (6)	457 (10)	1007 (3)	86 (7)
CA5	−5320 (7)	458 (11)	−1625 (3)	89 (7)	CB5	−1018 (6)	355 (10)	610 (2)	72 (6)
CA6	−4868 (8)	1418 (12)	−1816 (3)	105 (9)	CB6	3 (6)	338 (10)	549 (2)	68 (6)
CA7	−4491 (8)	1142 (13)	−2188 (3)	124 (9)	CB7	397 (6)	266 (10)	162 (3)	76 (7)
CA8	−4814 (7)	−355 (14)	−2382 (3)	111 (9)	CB8	−424 (6)	469 (9)	−156 (2)	68 (6)
CA9	−4838 (7)	−1514 (12)	−2069 (3)	101 (8)	CB9	−1461 (6)	−277 (10)	−45 (2)	71 (6)
CA10	−5493 (6)	−1150 (11)	−1748 (3)	78 (7)	CB10	−1912 (6)	249 (10)	317 (2)	66 (6)
CA11	−5006 (8)	−3045 (13)	−2240 (3)	121 (9)	CB11	−2258 (6)	−221 (11)	−389 (3)	95 (8)
CA12	−4375 (9)	−3423 (15)	−2576 (3)	138 (11)	CB12	−1855 (6)	−755 (11)	−762 (3)	81 (7)
CA13	−4444 (7)	−2241 (15)	−2878 (3)	122 (9)	CB13	−859 (6)	66 (10)	−861 (2)	71 (7)
CA14	−4196 (8)	−826 (15)	−2704 (3)	133 (10)	CB14	−87 (6)	−79 (10)	−521 (2)	69 (6)
CA15	−4142 (10)	288 (17)	−3016 (3)	170 (13)	CB15	930 (6)	472 (11)	−688 (3)	88 (7)
CA16	−3667 (11)	−739 (24)	−3320 (4)	216 (16)	CB16	907 (7)	−79 (12)	−1090 (3)	96 (8)
CA17	−3686 (9)	−2380 (18)	−3189 (3)	166 (13)	CB17	−244 (6)	−599 (10)	−1188 (2)	71 (6)
CA18	−5590 (9)	−2355 (18)	−3052 (3)	159 (12)	CB18	−1116 (7)	1697 (12)	−943 (3)	93 (8)
CA19	−6658 (7)	−1352 (12)	−1873 (3)	113 (9)	CB19	−2391 (6)	1862 (11)	270 (3)	87 (7)
CA20	−3876 (11)	−3575 (23)	−3512 (4)	216 (16)	CB20	−581 (6)	−364 (12)	−1586 (2)	85 (7)
CA21	−3947 (14)	−5165 (26)	−3387 (4)	266 (20)	CB21	−1714 (7)	−688 (13)	−1682 (3)	104 (8)
CA22	−2853 (14)	−3428 (31)	−3761 (5)	303 (23)	CB22	120 (7)	−1284 (14)	−1837 (3)	122 (10)
CA23	−3060 (0)	−4180 (0)	−4130 (0)	457 (39)	CB23	−25 (8)	−1054 (17)	−2229 (3)	159 (12)
CA24	−1960 (0)	−4580 (0)	−4240 (0)	688 (76)	CB24	622 (9)	−2155 (23)	−2472 (3)	199 (14)
CA25	−1790 (0)	−3860 (0)	−4620 (0)	511 (47)	CB25	522 (10)	−1974 (22)	−2857 (4)	219 (16)
CA26	−690 (0)	−4200 (0)	−4760 (0)	159 (22)*	CB26	−494 (13)	−2282 (29)	−2997 (5)	290 (22)
CA27	−2580 (0)	−4400 (0)	−4930 (0)	173 (22)*	CB27	1253 (14)	−2621 (36)	−3058 (5)	345 (28)
CA28	−5594 (6)	−104 (11)	−286 (3)	88 (7)	CB28	−2069 (8)	−1287 (14)	1734 (3)	121 (10)
CA29	−6204 (7)	445 (12)	25 (3)	91 (8)	CB29	−2538 (10)	−957 (15)	2116 (3)	155 (11)
CA30	−5981 (7)	−260 (12)	394 (3)	95 (8)	CB30	−2405 (10)	−2001 (17)	2418 (3)	160 (12)
CA31	−6678 (7)	260 (12)	687 (3)	96 (8)	CB31	−2900 (11)	−1685 (17)	2770 (3)	190 (14)
CA32	−6595 (7)	−442 (12)	1062 (3)	107 (8)	CB32	−2687 (14)	−2867 (24)	3052 (4)	259 (20)
CA33	−7390 (7)	−17 (12)	1353 (3)	94 (8)	CB33	−3000 (0)	−2250 (0)	3430 (0)	362 (28)
CA34	−7357 (7)	−752 (13)	1711 (3)	101 (8)	CB34	−2900 (0)	−3560 (0)	3720 (0)	489 (43)
CA35	−8202 (9)	−347 (15)	1969 (3)	145 (11)	CB35	−3100 (0)	−3200 (0)	4100 (0)	119 (14)*
CA36	−8153 (10)	−1162 (15)	2324 (4)	166 (13)	CB36	−4200 (0)	−3000 (0)	4160 (0)	431 (37)
CA37	−8762 (12)	−1925 (20)	2484 (4)	208 (15)	CB37	−4710 (0)	−3840 (0)	4370 (0)	447 (39)
CA38	−8653 (12)	−2610 (21)	2872 (4)	231 (18)	CB38	−5870 (0)	−3970 (0)	4460 (0)	93 (11)*
CA39	−9310 (0)	−2110 (0)	3150 (0)	275 (20)	CB39	−5850 (0)	−4000 (0)	4850 (0)	537 (52)
CA40	−9086 (0)	−3080 (0)	3511 (0)	310 (23)	CB40	−6920 (0)	−4280 (0)	5020 (0)	132 (16)
CA41	−9880 (0)	−2550 (0)	3780 (0)	701 (74)	CB41	−6900 (0)	−3890 (0)	5420 (0)	593 (55)
CA42	−9580 (0)	−3250 (0)	4130 (0)	506 (44)	CB42	−7920 (0)	−3490 (0)	5600 (0)	763 (76)
CA43	−9650 (0)	−4900 (0)	4110 (0)	611 (57)	CB43	−7680 (0)	−3240 (0)	6020 (0)	852 (84)
OA3	−5931 (4)	326 (7)	−626 (2)	82 (4)	OB3	−2487 (5)	−462 (8)	1479 (2)	103 (5)
OA28	−4870 (4)	−1038 (9)	−243 (2)	115 (6)	OB28	−1322 (7)	−2041 (12)	1722 (2)	182 (8)

[a] Positional parameters are functional coordinates (× 10^4) with estimated standard deviations (e.s.d.) in brackets. Parameters with zero e.s.d. were obtained by fitting to the observed electron density and were not subsequently refined. Mean square amplitudes of thermal vibration are given by $<u^2> = (U_{11} + U_{22} + U_{33} + 2U_{13}\cos\beta)/3$, where U_{ij} are listed in supplementary data. Values are Å^2 × 10^3 except for those marked (*) which are Å^2 × 10^2.

convergence with R(F) = 0.150, $R_w(F)$ = 0.095, S = 1.98.[5] The larger value for R(F) is due to the many weak or negative-intensity reflections that were included in the refinement. In a final Fourier synthesis with $|F_o|$ coefficients, the chains were readily traced, having highly significant electron density at all atomic sites. Thus for atoms C(36) and C(37) at the double bond in chain B, values for the electron density were 1.34(5) and 1.39(5) eÅ^{-3}. The smallest electron density [0.73(5) eÅ^{-3}] was observed at C(26) in molecule A. A final difference Fourier synthesis gave the maximum residual electron density 0.29(5) eÅ^{-3} occurring near C(38) in molecule B. Final atomic parameters are in **Table 1.**[1] Thermal vibration parameters are represented in Fig. 1.

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[5] $R(F) = \Sigma|\Delta|/\Sigma|F_o|$, $R_w(F) = \{\Sigma w\Delta^2/\Sigma wF_o^2\}^{1/2}$, $S = \{\Sigma w\Delta^2/(n-m)\}^{1/2}$ where $\Delta = |F_o| - |F_c|$.

RESULTS AND DISCUSSION

Bond lengths and angles[1] agree well with those of cholesteryl palmitoleate. Estimated standard deviations (e.s.d.) for cholesteryl palmitelaidate are in the range 0.01–0.03 Å for bond lengths and 0.1–0.3° for bond angles. The C–C bond lengths range from 1.35(3) Å for C(25)–C(27) in molecule B to 1.63(3) Å for C(20)–C(22) in molecule A.

The conformations are very similar for the tetracyclic ring systems in molecules A_e and B_e (subscript "e" for cholesteryl palmitelaidate) and also for molecules A_o and B_o (subscript "o" for cholesteryl palmitoleate). Thus in a best least squares superposition (15) of atoms C(1) through C(20) in molecules taken by pairs, the root mean square (r.m.s.) atomic separations were 0.09 Å, 0.10 Å, 0.09 Å, and 0.07 Å for (A_e,B_e), (A_o,B_o), (A_e,A_o), and (B_e,B_o), respectively. Selected torsion angles for cholesteryl palmitelaidate (**Table 2**) are for the cholesteryl tails and ester chains where the major differences in conformation occur. The tail C(17) through C(27) for molecule B which is incorporated in the efficiently packed layers, is almost fully extended. The A tail, which projects between layers, is more twisted. Atoms of the A tail have very large mean square amplitudes (m.s.a.) of thermal vibration (> 1 Å^2) and may well be disordered with respect to closely related conformers (see also Fig. 1).

The palmitelaidate chain in molecules A and B each contains two sections where the C atoms form nearly coplanar zigzags, and a third section around the double bond which forms a chain dislocation. For describing details of the chain dislocations in cholesteryl palmitelaidate, the six atoms C(30) through C(35) in each molecule are taken as the first almost coplanar zigzag and the five atoms C(38) through C(42) as the second. The root mean square displacements of these atoms from the respective best least squares planes are 0.07 Å and 0.05 Å for the zigzags in A, 0.08 Å and 0.18 Å for B. The dihedral angle between planar zigzags is small for molecule A (2.7°) but considerable for molecule B (67.4°). The bend in each chain, as determined by the angle between the best least squares lines through each zigzag, is small for A (171°) and large for B(149°). Furthermore, these best least squares lines are skewed so that there are perpendicular separations or kinks of 1.21 Å between the two lines in A and 1.85 Å in B. By all the above criteria, the dislocation in the B chain is the more severe. In molecule A the dislocation is primarily a kink in an almost straight chain.

TABLE 2. Selected bond torsion angles[a]

Atoms	Molecule A	Molecule B
C(10)-C(5)=C(6)-C(7)	3(2)°	2(1)°
C(4)-C(5)=C(6)-C(7)	−178(1)	−179(1)
C(16)-C(17)-C(20)-C(22)	64(2)	62(1)
C(17)-C(20)-C(22)-C(23)	−164(1)	−173(1)
C(20)-C(22)-C(23)-C(24)	−155(1)	−173(1)
C(22)-C(23)-C(24)-C(25)	−122(1)	−179(1)
C(23)-C(24)-C(25)-C(26)	−180	−65(2)
C(23)-C(24)-C(25)-C(27)	−60	163(2)
C(2)-C(3)-O(3)-C(28)	78(1)	140(1)
C(3)-O(3)-C(28)=O(28)	−8(1)	13(2)
C(3)-O(3)-C(28)-C(29)	179(1)	−179(1)
O(3)-C(28)-C(29)-C(30)	168(1)	163(1)
C(28)-C(29)-C(30)-C(31)	−176(1)	−177(1)
C(29)-C(30)-C(31)-C(32)	175(1)	180(1)
C(30)-C(31)-C(32)-C(33)	−174(1)	166(1)
C(31)-C(32)-C(33)-C(34)	176(1)	173(1)
C(32)-C(33)-C(34)-C(35)	−176(1)	177(1)
C(33)-C(34)-C(35)-C(36)	178(1)	75
C(34)-C(35)-C(36)=C(37)	−124(2)	115
C(35)-C(36)=C(37)-C(38)	−174(2)	−174
C(36)=C(37)-C(38)-C(39)	113(2)	−130
C(37)-C(38)-C(39)-C(40)	176(1)	−174
C(38)-C(39)-C(40)-C(41)	−176(1)	−164
C(39)-C(40)-C(41)-C(42)	−171	156
C(40)-C(41)-C(42)-C(43)	−63	176

[a] In the view along the central bond, a positive torsion angle is a clockwise twist of the rear bond with respect to the position where it eclipses the front bond. Values without e.s.d.'s (in brackets) were obtained by model fitting to the observed electron density map using computer graphics.

Chain dislocations occur in all crystal structures of cholesteryl esters involving unsaturated fatty acids, regardless of whether the double bonds are *cis* or *trans*. The dislocations appear to arise because the preferred conformations are (+)– or (–)–*skew* for C–C bonds adjacent to a C=C bond, except in conjugated systems (16). Gao and Craven (5) give examples showing that in chains with a *cis*-double bond, bond torsion angles in the sequences ..tsCst.. and ..ts̄Cst.. both correspond to bent chains.[6] A twist about an additional C–C bond is needed to make the chain straight, as in the palmitoleate A chain, where the sequence is ..tgsCstt.. (7). When the chain has a *trans*-double bond, the sequence ..tsTst.. would also lead to a bent chain, although such a sequence has not yet been observed. The sequence ..ts̄Tst... gives a straight chain, as occurs in the A chain of cholesteryl palmitelaidate (Table 2). In the palmitelaidate B-chain, the bend of 149° is achieved by the sequence ..tgsTs̄t.. which is the reverse of the A-chain sequence accompanied by twisting about an additional C–C bond.

The similarity between the form I crystal structures of cholesteryl palmitelaidate and palmitoleate at 295 K is remarkable in that the available packing space requires a close superposition of *cis* and *trans* geometrical isomers under *two* conditions that are quite distinct. Thus both A chains must be nearly straight while both B chains are bent (**Fig. 3**). It is a strong indication of the overall flexibil-

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[6] C = *cis*-double bond; T = *trans*-double bond; t = *trans* single bond; s = *skew* single bond; g = *gauche* single bond.

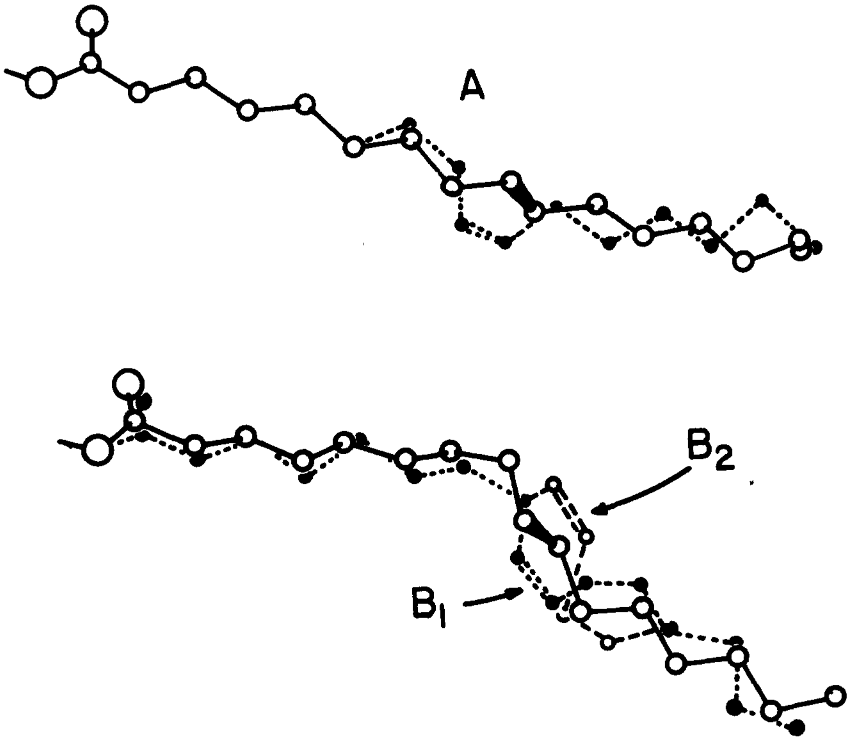

Fig. 3. Superposition of unsaturated fatty acid chains from the crystal structures of cholesteryl palmitelaidate (atoms with large open circles) and palmitoleate (atoms with small circles) at 295 K. The chains are viewed in projection along the crystal *b*-axis as in Fig. 2. Chains B1 (small solid circles) and B2 (open circles) are the disordered conformers which occur in cholesteryl palmitoleate (7).

ity of unsaturated fatty acids that these conditions can be met although the isomeric chains contain rigid *cis* and *trans* ethylenic groups of markedly different shape.

Dislocation parameters in cholesteryl palmitoleate at 295 K (7) have values similar to those given above for cholesteryl palmitelaidate. Thus the A chain has a bend of 173°, the dihedral angle betwen zigzag sections is 33°, and the kink separation is 0.5 Å. The B chain is disordered with respect to conformers which lie on either side of the corresponding chain in the palmitelaidate structure (Fig. 3). For conformer B1, the bend is 133°, the dihedral angle is 42°, and the kink is 1.5 Å. Corresponding values for B2 are 129°, 47°, and 1.9 Å.

The most significant differences in the two crystal structures are those that directly involve the fatty acid chains. Efforts were made to determine whether these differences might also have some effect on the packing together of the cholesteryl ring systems. The centers of mass and moments of inertia were calculated for atoms C(1) through C(20) for molecules A and B as given in Table 1 both here and in Sawzik and Craven (7). When centers of mass of the A ring systems in the two crystal structures are superposed, the centers of mass for the B ring systems are displaced by 0.19 Å. The long axes of the A and B ring systems, which correspond to the directions of their smallest principal moments of inertia, make an angle 9.5° in cholesteryl palmitoleate and 12.8° in cholesteryl palmitelaidate. The best least squares planes through the A and B ring systems, which are normal to the directions of the largest principal moments of inertia, make a dihedral angle of 86.8° in cholesteryl palmitoleate and 88.2° in cholesteryl palmitelaidate. A separate comparison shows that most of these differences are associated with the A-ring systems, where there is a change of 3.3° in the long axis direction and 2.4° in the tilt of the best least squares plane. For the B-ring systems, these angles are 0.4° and 0.8°.

All these effects are considered to be very small. Accordingly, in these crystal structures, it is expected that random substitution of isomeric cholesteryl palmitoleate and palmitelaidate molecules should occur readily so as to form solid solutions in all proportions at 295 K. ■

This work was supported by a grant HL-20350 from the National Institutes of Health. S-I. C. is grateful for a Research Fellowship from the Korean Science and Engineering Foundation. We are grateful to Mrs. Joan Klinger and Dr. John Ruble for technical assistance, to Dr. R. Shiono who wrote or modified many computer programs that were used, and to Dr. Patricia Sawzik who was involved in early stages of this work.

Manuscript received 8 August 1986.

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