Ring-Opening Aldol-Type Reaction of 2,2-Dialkoxycyclopropanecarboxylic Esters with Carbonyl Compounds. 3. The Diastereoselective Synthesis of 2,3,4-Trisubstituted γ-Lactones[1]

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The Lewis acid-promoted reaction of 3-alkyl-2,2-dialkoxycyclopropanecarboxylic esters **1d–h** with aldehydes to give 2,3,4-trisubstituted γ-lactones was investigated. The diastereoselectivity of this reaction is highly dependent on the catalyst employed. Thus while the $ZrCl_4$-promoted reaction gave (2α,3α,4β)-trisubstituted γ-lactones in good yields with excellent selectivity, the $SnBr_4$-promoted reaction was moderately selective for (2α,3α,4α)-trisubstituted γ-lactones. The present reaction was applied to the synthesis of $(+)_{589}$- and $(-)_{589}$-dihydropertusaric acid (**26**). Comparison of the spectroscopic and physical data of synthetic **26** with those of a 4-alkyl-3-carboxy-2-methyl γ-lactone isolated from the lichen *Pertusaria albescens* revealed that the relative stereochemistry of the natural γ-lactone was not (2β,3β,4α), as reported by Huneck and his co-workers, but rather (2β,3α,4α); that is, the natural γ-lactone was not $(-)_{589}$-dihydropertusaric acid (**26**), but $(-)_{589}$-pertusarinic acid (**27**).

Introduction

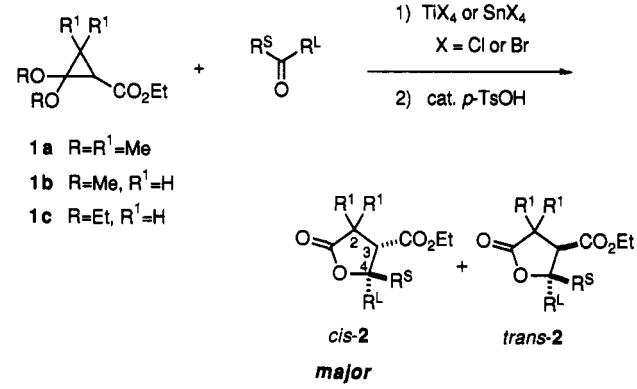
Vicinally donor–acceptor-substituted small ring compounds are useful as equivalents of 1,3- and 1,4-zwitterions.[2,3] In the course of our studies concerning the utilization of this type of compound in organic synthesis, 2,2-dialkoxycyclopropanecarboxylic esters **1** have been found to be valuable building blocks,[4] especially for the synthesis of five-membered carbo-[5] and heterocycles.[1,6] In previous papers in this series[1] we have described the highly diastereoselective syntheses of *cis*-3,4-substituted γ-lactones by the Lewis acid (LA)-promoted reaction of **1a–c** with aldehydes or unsymmetrical ketones, and of *cis*-2,3-substituted γ-lactones by the same type of reaction of **1d–h** with symmetrical ketones (Schemes I and II). On the basis of these results, it was expected that the reaction of **1d–h** with aldehydes would give 2,3,4-trisubstituted γ-lactones **4** with high diastereoselectivity (Scheme III).

Herein, we report on the LA-promoted reaction of cyclopropanes **1d–h** with aldehydes and its application to the synthesis of $(+)_{589}$- and $(-)_{589}$-dihydropertusaric acids (**26**), which has resulted in the need to correct the relative stereochemistry assigned to a γ-lactone isolated from the lichen *Pertusaria albescens*.

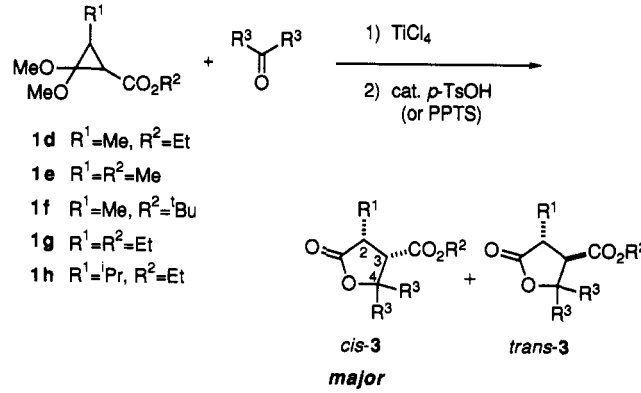
Results and Discussion

Reaction of Cyclopropanes[7] 1d–h with Aldehydes. First, the reaction of cyclopropane **1d** with cyclohexanecarbaldehyde was examined. Initially, $TiBr_4$ was selected as catalyst, as it had proved to be a highly cis-selective promoter of both the reactions shown in Schemes I and II. The reaction proceeded smoothly at −78 °C in CH_2Cl_2; the resulting product was mainly comprised of hydroxy diesters **5**, accompanied by small amounts of γ-lactones **6**. The crude product was completely converted into **6** by treatment with a catalytic amount of *p*-toluenesulfonic acid in toluene at 80 °C. A GC analysis of this product indicated that it was a mixture of the four diastereomers

Scheme I



Scheme II



(1) (a) Part 1: Shimada, S.; Hashimoto, Y.; Sudo, A.; Hasegawa, M.; Saigo, K. *J. Org. Chem.* **1992**, *57*, 7126. (b) Part 2: Shimada, S.; Hashimoto, Y.; Nagashima, T.; Hasegawa, M.; Saigo, K. *Tetrahedron*, **1993**, *49*, 1589.

(2) For a review of vicinally donor–acceptor-substituted cyclopropanes, see: Reissig, H.-U. *Top. Curr. Chem.* **1988**, *144*, 73.

(3) For examples of the use of vicinally donor–acceptor-substituted cyclobutanes for carbon–carbon bond forming reaction, see: (a) Shimada, S.; Saigo, K.; Nakamura, H.; Hasegawa, M. *Chem. Lett.* **1991**, 1149. (b) Shimada, S.; Tohno, I.; Hashimoto, Y.; Saigo, K. *Chem. Lett.* **1993**, 1117.

(4) (a) Sagio, K.; Shimada, S. *Yuki Gosei Kagaku Kyokaishi* **1991**, *49*, 928. (b) Shimada, S.; Saigo, K.; Hashimoto, Y.; Maekawa, Y.; Yamashita, T.; Yamamoto, T.; Hasegawa, M. *Chem. Lett.* **1991**, 1475.

(5) Saigo, K.; Shimada, S.; Shibasaki, T.; Hasegawa, M. *Chem. Lett.* **1990**, 1093.

(6) Saigo, K.; Shimada, S.; Hasegawa, M. *Chem. Lett.* **1990**, 905.

(7) Cyclopropanes **1d–h** consisted mainly of the trans-isomers. Trans/cis ratios were ≥95:5 for **1d–f**, ca. 90:10 for **1g** and ca. 70:30 for **1h**.

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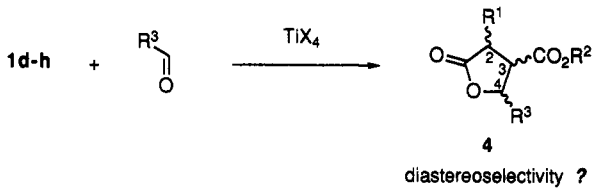
Table I. Reaction of 1d with Cyclohexanecarbaldehyde in the Presence of Various LAs[a]

entry	LA	time (h)	yield (%)[b]	TT/TC/CT/CC[c]	2,3-position[d] cis/trans	3,4-position[d,e] cis/trans
1[f]	$SnBr_4$	4	71	2:22:22:54	76:24	76:24 (99:1)
2	$TiBr_4$	1	83	2:10:61:27	88:12	37:63 (85:15)
3	$AlCl_3$	4	81	21:11:43:25	68:32	36:64 (77:23)
4	$GaCl_3$	1	78	3:8:67:22	89:11	30:70 (36:64)
5	$ZrCl_4$	15	89	4:4:81:11	92:8	15:85 (32:68)
6	$HfCl_4$	10	60	8:5:76:11	87:13	16:84

[a] The reaction was performed in CH_2Cl_2 at −78 °C. 1d/aldehyde/LA = 1.1:1:1.1. [b] Isolated yield. [c] Determined by GC. [d] See ref 9. [e] The values in parentheses are the cis/trans ratios of γ-lactones obtained by the reaction of cyclopropane 1a with 3-phenylpropanal.[1a] [f] The reaction was performed at −94 °C.

Scheme III



6a–d in a ratio of 2:10:61:27 ordered by GC retention time (t_R). The relative stereochemistries of the compounds were assigned to be TT, TC, CT, and CC[8] (Scheme IV), respectively, on the basis of ^1H NMR, GC t_R, and isomerization experiments on the diastereomers themselves, and of an X-ray crystallographic analysis of their corresponding *tert*-butyl esters 8 (vide infra). Contrary to our expectation, the major product obtained was the CT isomer.

The cis selectivity at the 2,3-position (cis/trans = 88:12)[9] was as high as that in the reaction of **1d–h** with symmetrical ketones.[1b] On the other hand, the slight trans selectivity at the 3,4-position (cis/trans = 37:63)[9] was opposite to the result observed in the reaction of **1a–c** with aldehydes or unsymmetrical ketones.[1a] Since the selectivity of the reaction of cyclopropanes **1a–c** with aldehydes or unsymmetrical ketones largely depended on the LA used,[1a] several LAs were examined in the present reaction (Table I).

All of the LAs gave cis selectivity at the 2,3-position, and, except for $SnBr_4$, trans selectivity at the 3,4-position. Comparing the selectivity of this reaction at the 3,4-position with that of the reaction of **1a** with 3-phenylpropanal (Table I), the order of selectivity of the LAs was found to be the same, even though **1d–h** have a bias toward giving the trans product as compared to **1a**. Among the LAs examined, $ZrCl_4$ exhibited the highest CT selectivity.

The reactions of cyclopropanes **1d–h** with various aldehydes were carried out using $ZrCl_4$ as a catalyst (Table II). Methyl ester **1e** showed almost the same diastereoselectivity as did ethyl ester **1d**, whereas *tert*-butyl ester **1f** exhibited decreased selectivity (Table II, entries 3 and 4). Therefore, for the reaction of 3-ethyl- and 3-isopropylcyclopropanes, ethyl esters **1g** and **1h** were used. In all cases, the CT isomers were obtained in good yields with good to excellent selectivity. As the alkyl group of the aldehyde and/or cyclopropane became larger, the selectivity increased. Moreover, a lower temperature resulted in an increase in the CT selectivity, especially for primary aldehydes (Table II, entries 2 and 6).

Table II. Reaction of 1d-h with Aldehydes Promoted by $ZrCl_4$[a]

entry	1	R^3	time (h)	product	yield (%)[b]	TT/TC/CT/CC[c]
1	1d	*c*-hex	15	6	89	4:4:81:11
2[d]			7		82	3:3:83:11
3	1e		5.5	7	90	3:4:81:12
4	1f		5.5	8	80	7:18:64:11
5	1d	*n*-hep	16	9	84	14:5:68:13
6[d]			5		83	3:5:77:15
7		*i*-Pr	15	10	61	3:3:85:9
8		*t*-Bu	5	11	84	3:1:86:10
9		Ph	5	12	87	7:4:73:16
10	1g	$PhCH_2CH_2$	7	13	83	7:2:77:14
11		*c*-hex	5	14	82	4:2:80:14
12		Ph	7	15	92	4:3:74:19
13	1h	*c*-hex	16	16	96	5:2:90:3

[a] The reaction was performed in CH_2Cl_2 at −78 °C. 1/aldehyde/LA = 1.1:1:1.1. [b] Isolated yield. [c] Determined by GC. [d] The reaction was performed at −94 °C.

Assignment of the Stereochemistry of the γ-Lactones. As described in our previous papers, the chemical shift of the proton at the 3-position of the lactone ring (H.3) is useful in assigning the stereochemistry of **2** and **3**; the H.3s of *cis*-**2** and *cis*-**3** appearing further downfield than those of *trans*-**2** and *trans*-**3**, respectively.[1] The chemical shifts of the H.3s of **6a–d** varied over a wide range. Among them, that of **6a** appeared furthest upfield (2.73 ppm) and that of **6d** appeared furthest downfield (3.32 ppm). Therefore, the relative stereochemistries of **6a** and **6d** were inferred to be TT and CC, respectively. This assignment was supported by their GC t_Rs, the t_R being shortest for **6a** and longest for **6d**, consistent with the fact that the GC t_Rs of *cis*-**2** and *cis*-**3** were longer than those of the corresponding *trans*-isomers. Moreover, isomerization of a mixture of **6a–d** by treatment with NaOEt in EtOH gave predominantly **6a** (Scheme V). This result means that **6a** is the most thermodynamically stable, i.e. the TT isomer. The reported ^1H NMR data for the TT[10,11] and CC isomers[10,12] of related γ-lactones were also in good agreement with those of **6a** and **6d**.

Although the relative stereochemistries of **6b** and **6c** were not inferable from their ^1H NMR spectra, they could be assigned based on X-ray crystallographic analysis of the corresponding *tert*-butyl esters **8**.[13] Fortunately, three isomers of **8** gave single crystals which were satisfactory for X-ray crystallography. This analysis revealed that **8b**,

(8) In this paper, the following abbreviations are used to describe the relative stereochemistry of the γ-lactones (Scheme IV): TT for (2β,3α,4β)-isomers; TC for (2β,3α,4α)-isomers; CT for (2α,3α,4β)-isomers; CC for (2α,3α,4α)-isomers.

(9) The cis/trans ratio for the 2,3-position can be calculated from (CT + CC)/(TC + TT) and that for the 3,4-position from (TC + CC)/(TT + CT).

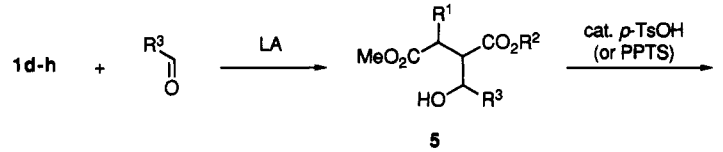
(10) Huneck, S.; Tonsberg, T.; Bohlmann, F. *Phytochemistry* **1986**, *25*, 453.

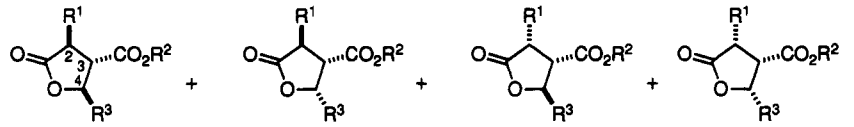
(11) Huneck, S.; Schreiber, K.; Hofle, G.; Snatzke, G. *J. Hattori Bot. Lab.* **1979**, *45*, 1.

(12) Mulzer, J.; deLasalle, P.; Chucholowski, A.; Blaschek, U.; Brüntrup, G.; Jibril, I.; Huttner, G. *Tetrahedron* **1984**, *40*, 2211.

(13) The authors have deposited atomic coordinates for the crystal structures of **8b–d** with the Cambridge Crystallographic Data Centre. The coordinates can be obtained, on request, from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Combridge, CB2 1EZ, UK.

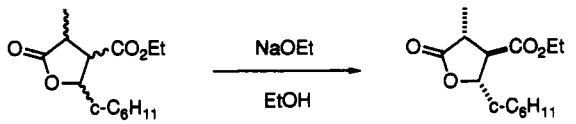
Scheme IV



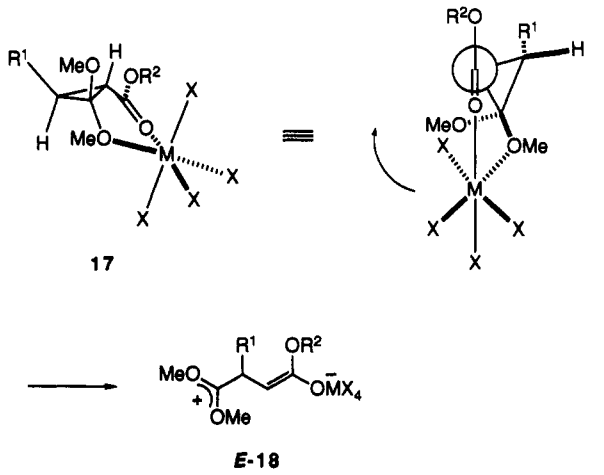


6a-16a (TT) 6b-16b (TC) 6c-16c (CT) 6d-16d (CC)

Scheme V



Scheme VI



8c, and 8d were the TC, CT, and CC isomers, respectively. Consequently, the remaining compound 8a was the TT isomer. These results are consistent with the assignment of 6a and 6d as described above.

The stereochemistry of the other γ-lactones was determined on the basis of their ^{1}H NMR and GC t_R. The characteristics for each isomer are as follows: For the TT isomers, $^3J_{2-3}$s and $^3J_{3-4}$s are 10.7–11.6 and 8.2–9.5 Hz, respectively, and H.2 appears further downfield than H.3 (for the TC, CT, and CC isomers, H.2 appears *upfield* from H.3). In all cases, the GC t_Rs of the TT compounds are the shortest of the four isomers. For the TC isomers, $^3J_{2-3}$s and $^3J_{3-4}$s are 7–10 Hz; the differences in the coupling constant between $^3J_{2-3}$s and $^3J_{3-4}$s are less than 2 Hz for all of the TC isomers. The GC t_Rs of the TC isomers are shorter than those of the CT isomers, except for 11. For the CT isomers, $^3J_{2-3}$s and $^3J_{3-4}$s are 8.9–10.2 and 5.9–6.7 Hz, respectively. For the CC isomers, $^3J_{2-3}$s and $^3J_{3-4}$s are 6.4–7.6 and 4.6–5.8 Hz, respectively; the H.4s of the CC isomers derived from secondary and tertiary aldehydes exhibit a characteristic upfield shift; in all cases, the GC t_Rs of the CC compounds are the longest of the four isomers.

Mechanistic Aspects. Although it is difficult to rationalize all the results based on a single transition state (TS) model, the selectivity observed in the bidentate LA-promoted reactions can be explained as follows.

The present reaction is considered to proceed through a ring-opened zwitterion 18. Although the low-temperature ^{1}H and ^{13}C NMR spectra of 1:1 mixtures of 1a and $TiBr_4$[1a] and of 1g and $TiCl_4$[1b] showed the major species present to be the TiX_4-chelated cyclopropanes 17 and could provide no direct information concerning the existence of zwitterion 18,[14] the color change of the mixtures to deep red or deep brown indicates that this titanium enolate 18 is indeed formed.[15] Moreover, the formation of 18 is strongly supported by a report that the Lewis acid-promoted cis–trans isomerization reaction of related vicinally donor–acceptor-substituted cyclopropanes proceeds through a similar zwitterion.[16] At the stage of ring opening of 17 to 18, the reaction is expected to proceed in a stereoselective manner to give the (*E*)-enolate, as depicted in Scheme VI.[1a]

The observed diastereoselectivity at the 2,3-position in the reaction of 1d–h with aldehydes is the same as that in their reaction with symmetrical ketones.[1b] Therefore, the same mechanism is probably responsible for this selectivity. That is, it is determined by the geometry of the chiral center adjacent to the enolate double bond.[1b] As depicted in Figure 1, the cationic substituent favors anti approach of the aldehyde because of its steric bulkiness as well as the electronic repulsion between it and the polarized carbonyl carbon. Moreover, among the four six-membered TS 19a–d leading to the four diastereomers, 19a,b are favored over 19c,d, due to the steric repulsions between the alkyl substituent at the chiral center (R^1) and the substituent at the double-bond moiety (OR^2) and between R^1 and the approaching aldehyde. Thus, 2,3-cis selectivity was achieved in the same way as the reaction of 1a–d with symmetrical ketones.

The diastereoselectivity at the 3,4-position is determined by the orientation of the aldehyde in the transition state. The $TiBr_4$-promoted reaction of 1d–h with aldehydes was moderately trans-selective at the 3,4-position, whereas that

(14) Other than the major signals, minor signals were also observed, which may arise from a ring-opened species and/or the *cis*-isomer (in the case of 1g), but which could not be assigned.

(15) This color can be attributed to the formation of the titanium ester enolate. A deep red or wine-red color has been reported for titanium enolates. (a) Nakamura, E.; Shimada, J.; Horiguchi, Y.; Kuwajima, I. *Tetrahedron Lett.* **1983**, *24*, 3341. (b) Nakamura, E.; Kuwajima, I. *Tetrahedron Lett.*, **1983**, *24*, 3343. (c) Reissig, H.-U.; Holzinger, H.; Glomsda, G. *Tetrahedron* **1989**, *45*, 3139.

(16) (a) Reissig, H.-U.; Böhm, I. *Tetrahedron Lett.* **1983**, *24*, 715. (b) Komatsu, M.; Suehiro, I.; Horiguchi, Y.; Kuwajima, I. *Synlett* **1991**, 771.

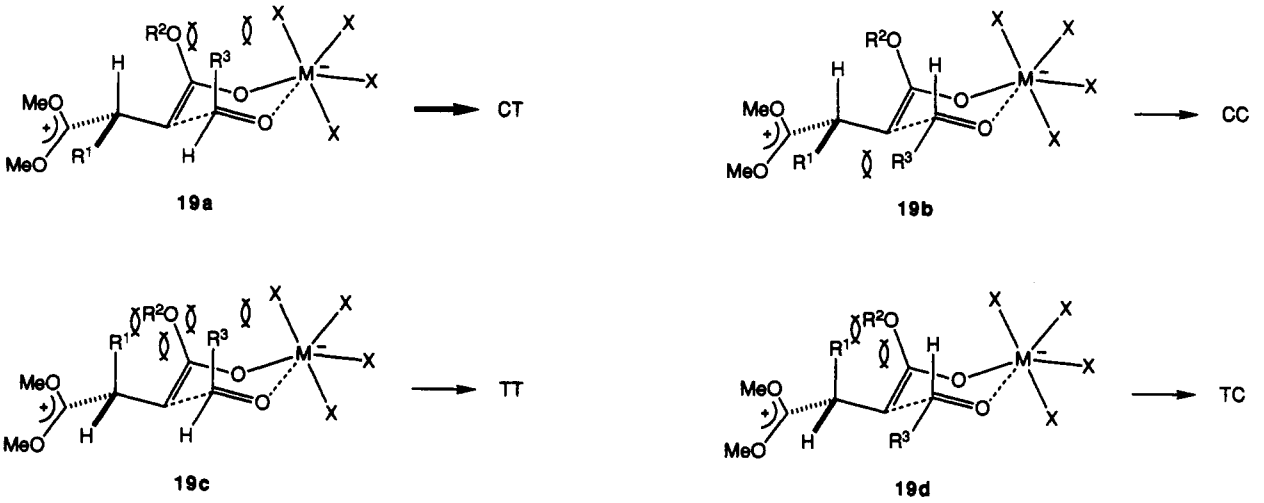


Figure 1. TS models for the $TiBr_4$- or $ZrCl_4$-promoted reaction of **1d–h** with aldehydes.

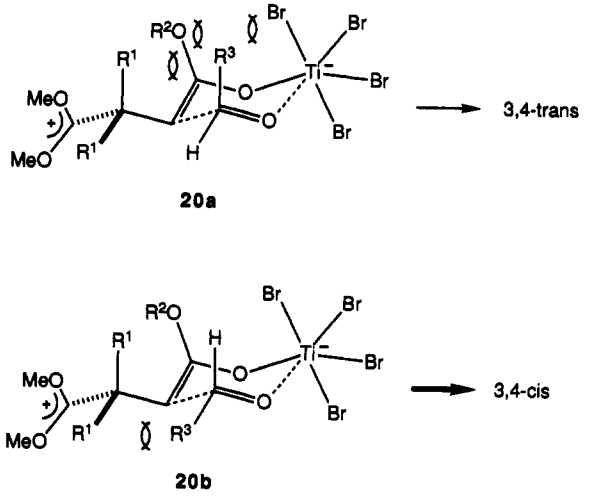
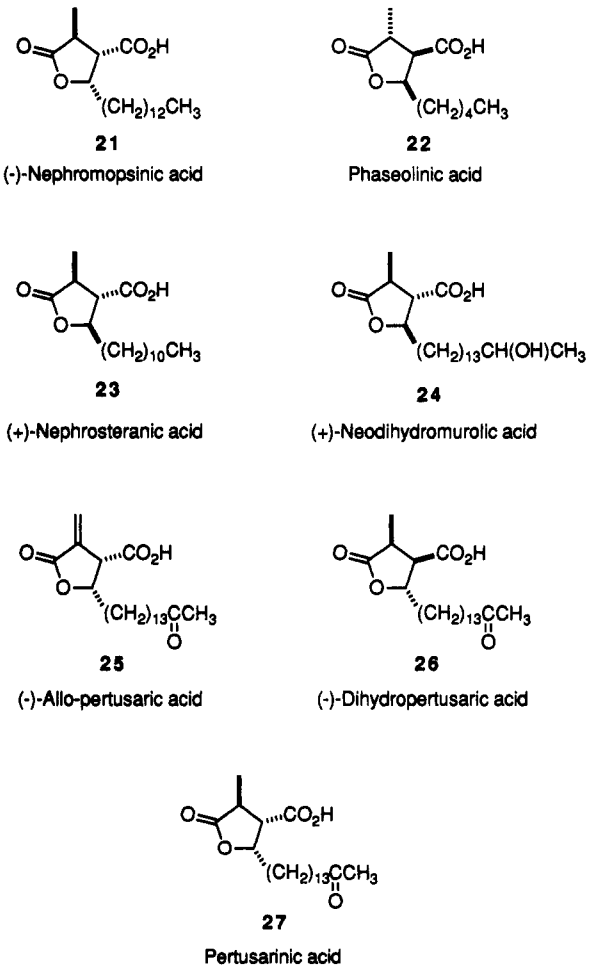


Figure 2. TS models for the $TiBr_4$-promoted reaction of **1a** with aldehydes.

of **1a** with aldehydes was highly cis-selective.[1a] These results can be consistently explained as follows. As can be seen from the TS models for the reaction of **1a** with aldehydes (Figure 2), the 1,3-diaxial-like repulsion between R^1 and R^3 exists in both **20a** and **20b**. However, only **20a** suffers a steric repulsion between R^3 and Br and/or between R^3 and OR^2. Therefore, **20b** is highly favored over **20a**, resulting in excellent cis selectivity. On the other hand, in the TS models **19a,b** for the $TiBr_4$-promoted reaction of **1d–h** with aldehydes, the serious 1,3-diaxial-like repulsion between R^1 and R^3 exists only in **19b**, although there is steric repulsion between R^3 and Br and/or between R^3 and OR^2 in **19a**. Here, the repulsion in **19b** is expected to be larger than that in **19a**. Therefore, the alkyl group of the aldehyde prefers to be axial, resulting in some trans selectivity at the 3,4-position. When $TiBr_4$ is replaced with $ZrCl_4$, the bond lengths between the metal and the oxygens become longer, and the steric repulsion between R^3 and Cl and/or between R^3 or OR^2 becomes less serious. Consequently, **19a** becomes much preferable to **19b**, thus resulting in more selective formation of the CT isomers.[17]

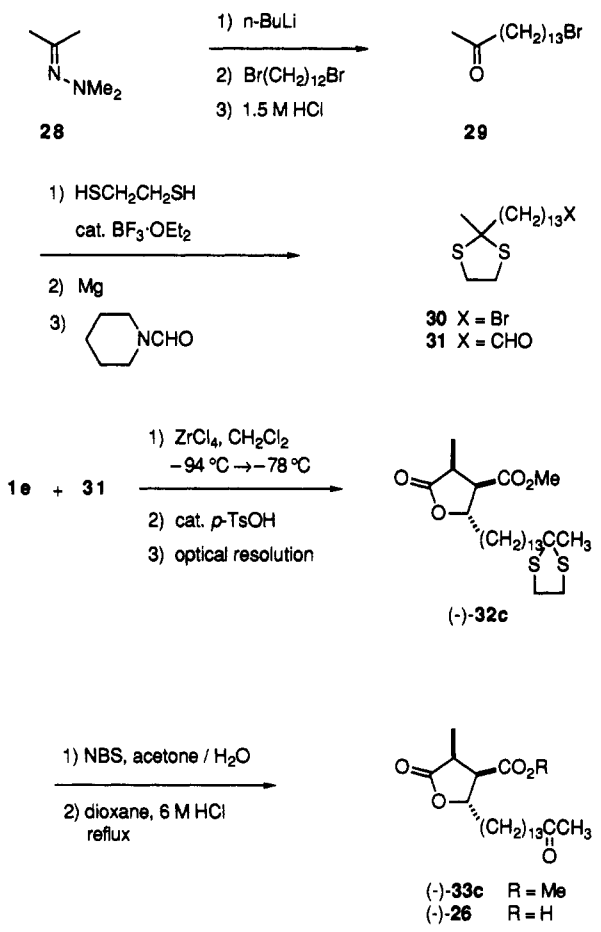
Synthesis $(+)_{589}$-Dihydropertusaric Acid (26) and Correction of the Misassigned Relative Stereochemistry of a 3-Carboxy γ-Lactone Isolated from the Lichen *Pertusaria albescens*. 4-Alkyl-3-carboxy-2-methyl γ-lactones, the products of the present reaction, are occasionally found in nature, nephromopsinic acid (**21**),[18] phaseolinic acid (**22**),[19] nephrosteranic acid (**23**),[11,20] and neodihydromurolic acid (**24**)[11] being representative of this class of natural product.



In 1983, Hanko isolated two 3-carboxy γ-lactones, "bH" and "bH1", from the lichen *Pertusaria albescens*.[21] Their structures were assigned by Huneck and his co-workers in 1986, "bH" as $(-)_{589}$-*allo*-pertusaric acid (**25**) and "bH1"

(17) The $ZrCl_4$-promoted reaction of **1a** with 3-phenylpropanal was moderately trans-selective (Table I). This result is also compatible with the proposed mechanism.

Scheme VII



as $(-)_{589}$-dihydropertusaric acid (**26**).[10] Since the purported dihydropertusaric acid **26** is a CT 2,3,4-trisubstituted γ-lactone, which should be accessible by the present reaction, we carried out its synthesis (Scheme VII).

The required aldehyde **31** was easily prepared, as shown in Scheme VII. Monoalkylation of 1,12-dibromododecane with the organolithium reagent derived from acetone dimethylhydrazone (**28**), followed by acidic hydrolysis of the resultant hydrazone, gave 15-bromo-2-pentadecanone (**29**) in 87% yield (based on the consumed dibromide). After protecting the carbonyl group of **29** by dithioacetalization, one-carbon homologation was achieved by the reaction of the corresponding Grignard reagent with *N*-formylpiperidine to give aldehyde **31** in 27% yield. The reaction of **1e** with **31** in the presence of $ZrCl_4$ at −94 °C to −78 °C, followed by lactonization of the crude product, gave the desired CT 2,3,4-trisubstituted γ-lactone **32c** (65% isolated yield), accompanied by small amounts of the TT, TC, and CC isomers. Racemic **32c** was resolved by using a chiral HPLC column (cellulose tris(4-methylbenzoate)-coated silica gel, Chiralcel OJ) to give $(+)_{589}$- and $(-)_{589}$-**32c**. Both enantiomers were converted to $(+)_{589}$- and $(-)_{589}$-**33c** by treatment with NBS[22] and then in good yield to $(+)_{589}$- and $(-)_{589}$-**26** by acidic hydrolysis.[23] However, the melting points and optical rotations of the synthetic $(-)_{589}$-**33c** (mp 78–78.5 °C, $[\alpha]^{20}_D$ −45.2° (*c* 0.84, $CHCl_3$)) and $(-)_{589}$-**26** (mp 99–101 °C, $[\alpha]^{20}_D$ −45.9° (*c* 2.15, MeOH)) were different from the values reported for "bH1" methyl ester (mp 61–63 °C, $[\alpha]^{24}_D$ −67.8, $CHCl_3$)) and "bH1" (mp 105–107 °C, $[\alpha]^{24}_D$ −74.9° (*c* 2.15, MeOH)), respectively.[10] The ^1H NMR spectrum of $(-)_{589}$-**33c** and the ^1H and ^{13}C NMR spectra of $(-)_{589}$-**26** were also different in some respects from those reported for "bH1" methyl ester and "bH1" itself, respectively. Therefore, it was suspected that the structure assigned to "bH1" by Huneck and his co-workers was incorrect.

The relative and absolute stereochemistries of "bH1" were originally determined mainly by comparing the ORD spectrum of "bH1" methyl ester with those of three diastereomers (TT, CT, and CC isomers) of nephromopsinic acid (**21**) methyl ester. However, no comparison was made with **21** methyl ester (the TC isomer) itself. Huneck and his co-workers attributed the downfield shift in the ^1H NMR spectrum of H.4 (δ 4.67) of "bH1", compared with that (δ 4.39) of the CC isomer of **26**, to a deshielding effect of the *cis*-oriented ester group. However, this downfield shift of H.4 was observed not only for the CT isomers but also for the TC isomers of almost all the 2,3,4-trisubstituted γ-lactones prepared in this study and is therefore not evidence for a trans arrangement of the 3- and 4-substituents. Moreover, the reported ^1H NMR data for "bH1" [10] are in good agreement with those for the TC isomers of primary aldehyde-derived γ-lactones **9** and **13**, rather than those of the CT isomers. Especially, the signal of H.4, which was reported as a double double doublet with coupling constants of 3, 8, and 10 Hz, was in good agreement with those of H.4 of the TC isomers of **9** and **13**, while H.4 of the CT isomers of **9** and **13** appeared as a quartet with a coupling constant of 6.5 Hz or a double triplet with coupling constants of 6.0 and 7.3 Hz, respectively. The ^1H and ^{13}C NMR data of "bH1" also resemble those of **21**.[18c] Furthermore, when TC isomer **32b**, that produced in the smallest amount by the present reaction, was isolated by repeated chromatography and dedithioacetalized, the ^1H NMR of the racemic **33b** formed was essentially identical with that reported for "bH1". It is therefore concluded that the natural product "bH1" isolated from *Pertusaria albescens* is not $(-)_{589}$-dihydropertusaric acid **26**, but pertusarinic acid **27**.[24]

Conclusion

The LA-promoted ring opening aldol-type reaction of 3-alkyl-2,2-dialkoxycyclopropanecarboxylic esters **1d–h** with aldehydes to give 2,3,4-trisubstituted γ-lactones was investigated in detail. Although the level of diastereoselectivity of the present reaction depended on the LA, the diastereoselectivity at the 2,3-position was invariably *cis*, the same as that of the reaction of **1d–h** with symmetric ketones, while the diastereoselectivity at the 3,4-position was *trans*, opposite to that of the reaction of **1a–c** with aldehydes. As a result, the $ZrCl_4$-promoted reaction gave (2α,3α,4β)-trisubstituted γ-lactones in good yields with excellent selectivity. The diastereoselectivities of the

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(24) According, to Huneck, "dihydropertusaric acid" and "pertusarinic acid" are the names given to the CT and TC isomers, respectively; see ref 10.

reaction of **1d-h** with aldehydes, of **1a-c** with aldehydes or unsymmetrical ketones, and of **1d-h** with symmetric ketones could be explained in a self-consistent manner by considering (i) the *E*-geometry of the enolate part of the 1,3-zwitterionic intermediate, (ii) the electronic and steric effects of the cationic substituent, and (iii) a six-membered chair transition state. The present reaction was applied to the syntheses of $(+)_{589}$- and $(-)_{589}$-dihydropertusaric acids **26**, which resulted in a correction to the misassigned relative stereochemistry of a 3-carboxy γ-lactone isolated from the lichen *Pertusaria albescens*. On the basis of its ^{1}H NMR data, the relative stereochemistry of the natural γ-lactone was shown to be (2β,3α,4α).

Experimental Section

General Methods. The boiling points given for γ-lactones refer to the oven temperature (ot) on bulb-to-bulb distillation. The melting points are not corrected. ^{1}H NMR (400 or 270 MHz) and ^{13}C NMR (68 MHz) spectra were recorded in $CDCl_3$ with Me_4Si as an internal standard; *J* values are given in hertz. GC analysis was performed with a 25-m OV-1701 fused silica capillary column. Optical resolution was performed by using a cellulose tris(4-methylbenzoate)-coated silica gel HPLC column (Chiralcel OJ, Daicel).

All moisture-sensitive reactions were carried out under Ar. All aldehydes except for **31** were purchased from commercial suppliers and distilled from CaH_2. CH_2Cl_2 was distilled from P_2O_5 and then from CaH_2 and stored over molecular sieves (4 Å). THF was distilled from Na and stored over Na. Column chromatography was performed with E. Merck silica gel 60 (70–230 or 230–400 mesh). Preparative TLC (PTLC) was carried out with Wakogel B-5F.

Reaction of Cyclopropanes 1d-h with Aldehydes. The general procedure is exemplified by the reaction of **1d** with cyclohexanecarbaldehyde. A suspension of $ZrCl_4$ (255 mg, 1.1 mmol) in CH_2Cl_2 (2 mL) was stirred and cooled to −78 °C while a mixture of **1d** (232 mg, purity of **1d** was ca. 90%, corrected amount of **1d** is ca. 1.1 mmol)[25] and cyclohexanecarbaldehyde (112 mg, 1.00 mmol) in CH_2Cl_2 (2.2 mL) was added drop by drop. After being stirred for 15 h, the reaction was quenched at the same temperature by adding a 1:1 mixture of H_2O/THF (1 mL). After the cooling bath was removed, H_2O (2 mL) was added, and the mixture was allowed to warm to rt. After CH_2Cl_2 (15 mL) and H_2O (10 mL) were added to the mixture, the organic layer was separated. Then, the aqueous layer was extracted with CH_2Cl_2 (3 × 8 mL), and the combined organic layers were dried over Na_2SO_4. The organic solution was filtered through a short pad of silica gel and then concentrated under reduced pressure to give the crude product, which consisted mainly of hydroxy diesters. The crude product was dissolved in dry toluene (10 mL), and a catalytic amount of *p*-toluenesulfonic acid (TsOH) was added to this solution. After being stirred for 1 h at 80 °C, the solvent was removed under reduced pressure. The residue was dissolved in a 1:1 mixture of hexane/EtOAc and filtered through a short pad of aluminum oxide in order to remove TsOH. After evaporation of the solvent, the crude product was subjected to GC analysis to determine the diastereomer ratio (TT/TC/CT/CC = 4:4:81:11). The crude product was purified by bulb-to-bulb distillation to give 226 mg (89%) of **6**: ot 150–165 °C (0.3 Torr).

4-Cyclohexyl-3-(ethoxycarbonyl)-2-methyl-4-butanolide (6): ot 150–155 °C (0.3 Torr). A mixture of four isomers was submitted for elemental analysis. Anal. Calcd for $C_{14}H_{22}O_4$: C, 66.12; H, 8.72. Found: C, 66.20; H, 8.75. The isomeric mixture of **6** was separated by column chromatograpny (7.5–14% EtOAc–hexane). ***TT*-6**: oil; IR (neat) 1785, 1740; ^{1}H NMR δ 0.80–0.92 (1, m), 1.00–1.30 (4, m), 1.30 (3, t, *J* = 7.2), 1.32 (3, d, *J* = 7.0), 1.52–1.81 (5, m), 1.90 (1, br d, *J* = 13), 2.73 (1, dd, *J* = 9.3, 11.1), 2.90 (1, qd, *J* = 7.0, 11.1), 4.23 (2, q, *J* = 7.2), 4.34 (1, dd, *J* = 7.0, 9.3); EI-MS *m/z* 236 ($M^+ - H_2O$, 0.4), 143 (76), 115 (100), 97 (43), 69 (72), 55 (47), 41 (64). ***TC*-6**: mp 96.5–97 °C; IR (KBr) 1770, 1725; ^{1}H NMR δ 0.82–0.94 (1, m), 0.99–1.30 (4, m), 1.30 (3, t, *J* = 7.2), 1.31 (3, d, *J* = 7.3), 1.55–1.80 (5, m), 1.85 (1, br d, *J* = 13), 2.99 (1, quint, *J* = 7.3), 3.11 (1, t, *J* = 7.3), 4.17–4.30 (2, m), 4.40 (1, t, *J* = 7.0); EI-MS *m/z* 236 ($M^+ - H_2O$, 3), 163 (33), 143 (51), 115 (38), 99 (46), 97 (48), 87 (33), 83 (31), 69 (96), 55 (72), 41 (100). ***CT*-6**: oil; IR (neat) 1780, 1740; ^{1}H NMR δ 1.00–1.33 (5, m), 1.22 (3, d, *J* = 7.6), 1.29 (3, t, *J* = 7.2), 1.48–1.82 (5, m), 1.89 (1, br d, *J* = 12), 2.95 (1, qd, *J* = 7.6, 9.6), 3.21 (1, dd, *J* = 6.4, 9.8), 4.21 (2, dq, *J* = 2.0, 7.2), 4.50 (1, t, *J* = 6.7); EI-MS *m/z* 236 ($M^+ - H_2O$, 0.8), 143 (58), 115 (100), 97 (32), 69 (68), 55 (47), 41 (63). ***CC*-6**: mp 87.5–88 °C; IR (KBr) 1770, 1725; ^{1}H NMR δ 0.85–1.10 (2, m), 1.10–1.30 (3, m), 1.23 (3, d, *J* = 7.3), 1.29 (3, t, *J* = 7.2), 1.58–1.80 (5, m), 2.14 (1, br d, *J* = 13), 2.88 (1, quint, *J* = 7.2), 3.32 (1, dd, *J* = 4.9, 7.3), 4.04 (1, dd, *J* = 4.9), 4.15–4.39 (2, m); EI-MS *m/z* 236 ($M^+ - H_2O$, 5), 143 (35), 115 (42), 87 (34), 83 (30), 69 (100), 55 (83), 41 (99).

4-Cyclohexyl-3-(methoxycarbonyl)-2-methyl-4-butanolide (7): ot 140–145 °C (0.4 Torr). A mixture of four isomers was submitted for elemental analysis. Anal. Calcd for $C_{13}H_{20}O_4$: C, 64.98; H, 8.39. Found: C, 64.71; H, 8.30. The isomeric mixture of **7** was separated by column chromatography (7.5–13% EtOAc–hexane). The TC isomer could not be separated from the major (CT) isomer and was characterized by only GC-MS analysis. ***TT*-7**: mp 107–108 °C; IR (KBr) 1780, 1740; ^{1}H NMR δ 1.00–1.33 (5, m), 1.32 (3, d, *J* = 7.0), 1.50–1.81 (5, m), 1.89 (1, br d, *J* = 13), 2.75 (1, dd, *J* = 9.5, 11.3), 2.91 (1, qd, *J* = 7.0, 11.3), 3.77 (3, s), 4.34 (1, dd, *J* = 6.4, 9.2); EI-MS *m/z* 212 (7), 129 (98), 101 (100), 97 (52), 69 (92), 59 (41), 55 (60), 41 (84). ***TC*-7**: EI-MS *m/z* 222 ($M^+ - H_2O$, 3), 163 (33), 129 (68), 101 (36), 99 (46), 97 (47), 83 (38), 69 (92), 59 (44), 55 (79), 41 (100). ***CT*-7**: oil; IR (neat) 1780, 1740; ^{1}H NMR δ 1.00–1.33 (5, m), 1.21 (3, d, *J* = 7.6), 1.48–1.82 (5, m), 1.88 (1, br d, *J* = 13), 2.95 (1, qd, *J* = 7.6, 9.6), 3.24 (1, dd, *J* = 6.3, 9.6), 3.75 (3, s), 4.50 (1, t, *J* = 6.7); EI-MS *m/z* 212 (6), 157 (37), 129 (71), 101 (100), 97 (37), 69 (75), 59 (45), 55 (51), 41 (72). ***CC*-7**: mp 82–83 °C; IR (KBr) 1770, 1725; ^{1}H NMR δ 0.85–1.32 (5, m), 1.22 (3, d, *J* = 7.0), 1.54–1.78 (5, m), 2.13 (1, br d, *J* = 13), 2.90 (1, quint, *J* = 7.2), 3.36 (1, dd, *J* = 4.9, 7.3), 3.75 (3, s), 4.04 (1, dd, *J* = 4.9, 10.4); EI-MS *m/z* 222 ($M^+ - H_2O$, 5), 129 (38), 101 (37), 83 (34), 69 (95), 59 (39), 55 (83), 41 (100).

4-Cyclohexyl-3-[(1,1-dimethylethoxy)carbonyl]-2-methyl-4-butanolide (8): ot 170 °C (0.5–0.6 Torr). A mixture of four isomers was submitted for elemental analysis. Anal. Calcd for $C_{16}H_{26}O_4$: C, 68.06; H, 9.28. Found: C, 67.88; H, 9.09. The isomeric mixture of **8** was separated by column chromatography (6–11% EtOAc–hexane). ***TT*-8**: oil; IR (neat) 1785; 1735; ^{1}H NMR δ 1.00–1.30 (5, m), 1.31 (3, d, *J* = 7.0), 1.48 (9, s), 1.49–1.81 (5, m), 1.91 (1, br d, *J* = 11), 2.62 (1, dd, *J* = 9.5, 11.3), 2.86 (1, qd, *J* = 7.0, 11.3), 4.29 (1, dd, *J* = 7.2, 9.3); EI-MS *m/z* 226 ($M^+ - CH_2{=}C(CH_3)_2$, 4), 225 (9), 207 (9), 69 (27), 57 (100), 41 (57). ***TC*-8**: mp 90–91 °C; IR (KBr) 1775, 1720; ^{1}H NMR δ 0.99–1.33 (5, m), 1.30 (3, d, *J* = 7.3), 1.49 (9, s), 1.61–1.81 (5, m), 1.88 (1, br d, *J* = 12), 2.92 (1, quint, *J* = 7.1), 3.00 (1, dd, *J* = 6.4, 7.3), 4.37 (1, t, *J* = 7.0); EI-MS *m/z* 226 ($M^+ - CH_2{=}C(CH_3)_2$, 4), 209 (5), 208 (7), 69 (28), 57 (100), 41 (57). ***CT*-8**: mp 71–72 °C; IR (KBr) 1790, 1720; ^{1}H NMR δ 1.00–1.32 (5, m), 1.25 (3, d, *J* = 7.3), 1.47 (9, s), 1.44–1.82 (5, m), 1.89 (1, br d, *J* = 12), 2.92 (1, qd, *J* = 7.5, 9.6), 3.09 (1, dd, *J* = 6.6, 9.6), 4.44 (1, t, *J* = 6.9); EI-MS *m/z* 226 ($M^+ - CH_2{=}C(CH_3)_2$, 3), 225 (9), 209 (5), 111 (10), 83 (14), 69 (23), 57 (100). ***CC*-8**: mp 140–140.5 °C; IR (KBr) 1770, 1720; ^{1}H NMR δ 0.85–1.08 (2, m), 1.15–1.28 (3, m), 1.26 (3, d, *J* = 7.0), 1.48 (9, s), 1.65–1.82 (5, m), 2.15 (1, br d, *J* = 13), 2.82 (1, quint, *J* = 7.0), 3.18 (1, dd, *J* = 4.9, 7.3), 4.00 (1, dd, *J* = 4.9, 10.4); EI-MS *m/z* 226 ($M^+ - CH_2{=}C(CH_3)_2$, 8), 209 (8), 109 (17), 69 (31), 57 (100).

3-(Ethoxycarbonyl)-2-methyl-4-undecanolide (9): ot 150–165 °C (0.3 Torr). A mixture of four isomers was submitted for elemental analysis. Anal. Calcd for $C_{15}H_{26}O_4$: C, 66.64; H, 9.69. Found: C, 66.48; H, 9.44. The isomeric mixture of **9** was separated by column chromatography (4-17% EtOAc–hexane) to give the TT, CT, and CC isomers in high purity. The TC isomer was separated from the mixture of the three isomers (TT, TC, and CT) by repeated column chromatography (2–3% acetone–

(25) Cyclopropanes **1d-h** were obtained contaminated with a small amount of ketene acetal $(MeO)_2C{=}CR^1CH_2CO_2R^2$. A small amount of the ketene acetal, however, did not affect the reaction, and we therefore use **1d-h** without further purification.

hexane). *TT*-9: oil; IR (neat) 1790, 1740; ^{1}H NMR δ 0.88 (3, t, J = 6.9), 1.20–1.55 (10, m), 1.30 (3, t, J = 7.2), 1.33 (3, d, J = 7.3), 1.65–1.82 (2, m), 2.63 (1, dd, J = 9.5, 11.6), 2.95 (1, qd, J = 7.0, 11.3), 4.23 (2, q, J = 7.2), 4.45 (1, ddd, J = 4.6, 8.1, 9.5); EI-MS m/z 242 ($M^+ - CH_2{=}CH_2$, 2), 171 (28), 143 (44), 115 (73), 69 (100), 55 (52). *TC*-9: oil; IR (neat) 1780, 1740; ^{1}H NMR δ 0.88 (3, t, J = 6.9), 1.20–1.70 (12, m), 1.29 (3, d, J = 7.0), 1.30 (3, t, J = 7.2), 3.05 (1, qd, J = 7.0, 10.0), 3.15 (1, dd, J = 8.2, 10.0), 4.23 (2, quasi dq, J = 1.0, 7.0), 4.65 (1, ddd, J = 3.3, 8.1, 10.0); EI-MS m/z 225 ($M^+ - OC_2H_5$, 6), 171 (31), 143 (57), 115 (31), 97 (41), 69 (100). *CT*-9: oil; IR (neat) 1785, 1740; ^{1}H NMR δ 0.88 (3, t, J = 6.9), 1.23 (3, d, J = 7.3), 1.23–1.55 (10, m), 1.30 (3, t, J = 7.2), 1.60–1.72 (2, m), 2.98 (1, qd, J = 7.4, 9.5), 3.08 (1, dd, J = 6.4, 9.5), 4.16–4.27 (2, m), 4.70 (1, q, J = 6.5); EI-MS m/z 242 ($M^+ - CH_2{=}CH_2$, 1), 171 (32), 143 (42), 115 (72), 69 (100). *CC*-9: oil; IR (neat) 1790, 1740; ^{1}H NMR: δ 0.88 (3, t, J = 6.9 Hz), 1.20–1.65 (11, m), 1.25 (3, d, J = 7.0), 1.29 (3, t, J = 7.0), 1.73–1.83 (1, m), 2.89 (1, quint, J = 7.2), 3.28 (1, dd, J = 5.2, 7.6), 4.16–4.28 (2, m), 4.40 (1, td, J = 5.2, 8.4); EI-MS m/z 225 ($M^+ - OC_2H_5$, 4), 211 (15), 171 (10), 143 (18), 115 (24), 69 (100), 55 (39).

3-(Ethoxycarbonyl)-2,5-dimethyl-4-hexanolide (10): ot 115 °C (0.8 Torr). A mixture of four isomers was submitted for elemental analysis. Anal. Calcd for $C_{11}H_{18}O_4$: C, 61.66; H, 8.47. Found: C, 61.46; H, 8.40. The isomeric mixture of **10** was separated by column chromatography (7.5–22% EtOAc–hexane). *TT*-10: oil; IR (neat) 1780, 1735; ^{1}H NMR δ 0.96 (3, d, J = 7.0), 1.02 (3, d, J = 6.7), 1.30 (3, t, J = 7.0), 1.32 (3, d, J = 7.0), 1.91 (1, m), 2.70 (1, dd, J = 9.3, 11.1), 2.94 (1, qd, J = 7.1, 11.1), 4.23 (2, q, J = 7.1), 4.34 (1, dd, J = 6.4, 9.2); EI-MS m/z 186 ($M^+ - CH_2{=}CH_2$, 8), 171 (34), 143 (85), 115 (59), 97 (64), 87 (42), 69 (100). *TC*-10: oil; IR (neat) 1780, 1735; ^{1}H NMR δ 0.99 (6, d, J = 6.7), 1.30 (3, t, J = 7.2), 1.31 (3, d, J = 7.3), 1.92 (1, m), 3.02 (1, quint, J = 7.2), 3.11 (1, t, J = 7.3), 4.22 (2, dq, J = 1.1, 7.2), 4.39 (1, t, J = 7.2); EI-MS m/z 171 ($M^+ - CH(CH_3)_2$, 35), 143 (80), 115 (32), 97 (54), 87 (32), 69 (100). *CT*-10: oil; IR (neat) 1780, 1735; ^{1}H NMR δ 0.96 (3, d, J = 7.0), 1.02 (3, d, J = 6.7), 1.23 (3, d, J = 7.6), 1.30 (3, t, J = 7.2), 1.87 (1, m), 2.96 (1, qd, J = 7.6, 9.8), 3.18 (1, dd, J = 6.4, 9.8), 4.21 (2, dq, J = 0.8, 7.1), 4.50 (1, t, J = 6.6); EI-MS m/z 186 ($M^+ - CH_2{=}CH_2$, 4), 171 (52), 143 (80), 115 (69), 97 (52), 87 (42), 69 (100). *CC*-10: oil; IR (neat) 1785; 1730; ^{1}H NMR δ 0.94 (3, d, J = 6.7), 1.12 (3, d, J = 6.4), 1.24 (3, d, J = 7.0), 1.29 (3, t, J = 7.0), 1.92 (1, m), 2.91 (1, quint, J = 7.2), 3.34 (1, dd, J = 4.9, 7.6), 3.96 (1, dd, J = 4.9, 10.7), 4.22 (2, m); EI-MS m/z 171 ($M^+ - CH(CH_3)_2$, 32), 143 (55), 115 (41), 97 (36), 87 (35), 69 (100).

3-(Ethoxycarbonyl)-2,5,5-trimethyl-4-hexanolide (11): ot 130 °C (0.5 Torr). A mixture of four isomers was submitted for elemental analysis. Anal. Calcd for $C_{12}H_{20}O_4$: C, 63.14; H, 8.83. Found: C, 62.99; H, 8.83. The isomeric mixture of **11** was separated by column chromatography (6–17% EtOAc–hexane). The TC isomer could not be separated from the major (CT) isomer and could not be characterized. *TT*-11: oil; IR (neat) 1785, 1735; ^{1}H NMR δ 0.95 (9, s), 1.29 (3, t, J = 7.0), 1.32 (3, d, J = 7.3), 2.74 (1, dd, J = 9.5, 11.0), 2.92 (1, qd, J = 7.2, 11.0), 4.22 (2, q, J = 7.2), 4.37 (1, d, J = 9.5); EI-MS m/z 200 ($M^+ - CH_2{=}CH_2$, 4), 171 (57), 143 (100), 115 (43), 97 (64), 69 (90), 57 (90). *CT*-11: oil; IR (neat) 1785, 1740; ^{1}H NMR δ 0.95 (9, s), 1.23 (3, d, J = 7.6), 1.30 (3, t, J = 7.2), 2.96 (1, qd, J = 7.6, 10.2), 3.24 (1, dd, J = 6.6, 10.2), 4.21 (2, q, J = 7.2), 4.50 (1, d, J = 6.4); EI-MS m/z 213 ($M^+ - CH_3$, 1), 171 (98), 143 (100), 115 (66), 97 (57), 69 (93), 57 (75). *CC*-11: mp 62–64 °C; IR (KBr) 1780, 1735; ^{1}H NMR δ 1.02 (9, s), 1.24 (3, d, J = 7.0), 1.29 (3, t, J = 7.2), 2.86 (1, quint, J = 6.9), 3.22 (1, dd, J = 4.6, 6.4), 4.06 (1, d, J = 4.6), 4.11 (1, qd, J = 7.2, 10.8), 4.22 (1, qd, J = 7.2, 10.8); EI-MS m/z 213 ($M^+ - CH_3$, 0.5), 173 (31), 143 (38), 115 (31), 99 (33), 71 (31), 69 (87), 57 (100), 43 (51), 41 (74).

3-(Ethoxycarbonyl)-2-methyl-4-phenyl-4-butanolide (12): ot 150–155 °C (0.5 Torr). A mixture of four isomers was submitted for elemental analysis. Anal. Calcd for $C_{14}H_{16}O_4$: C, 67.73; H, 6.50. Found: C, 67.54; H, 6.63. The isomeric mixture of **12** was separated by PTLC (three elutions with 13% EtOAc–hexane). *TT*-12: oil; IR (neat) 1790, 1740; ^{1}H NMR δ 1.26 (3, t, J = 7.2), 1.41 (3, d, J = 7.0), 2.94 (1, dd, J = 9.5, 11.6), 3.07 (1, qd, J = 7.0, 11.4), 4.17–4.27 (2, m), 5.53 (1, d, J = 9.5), 7.33–7.46 (5, m); EI-MS m/z 248 (M^+, 18), 220 (16), 192 (23), 115 (66), 105 (95), 69 (100). *TC*-12: mp 83–84 °C; IR (KBr) 1780, 1740; ^{1}H NMR δ 0.97 (3, t, J = 7.2), 1.36 (3, d, J = 7.3), 3.27 (1, qd, J = 7.3, 9.4), 3.44 (1, t, J = 9.2), 3.78 (1, qd, J = 7.2, 10.8), 3.85 (1, qd, J = 7.2, 10.8), 5.74 (1, d, J = 8.6), 7.19–7.24 (2, m), 7.30–7.37 (3, m); EI-MS m/z 248 (M^+, 6), 142 (65), 105 (23), 69 (100). *CT*-12: oil; IR (neat) 1790, 1740; ^{1}H NMR δ 1.30 (3, t, J = 7.3), 1.31 (3, d, J = 7.6), 3.07 (1, qd, J = 7.6, 9.0), 3.38 (1, dd, J = 6.6, 9.0), 4.17–4.30 (2, m), 5.77 (1, d, J = 6.7), 7.34–7.45 (5, m); EI-MS m/z 248 (M^+, 13), 220 (12), 192 (22), 142 (16), 115 (62), 105 (79), 69 (100). *CC*-12: mp 69–71 °C; IR (KBr) 1780, 1725; ^{1}H NMR δ 0.86 (3, t, J = 7.2), 1.32 (3, d, J = 7.0), 3.08 (1, quint, J = 7.2), 3.64 (1, dd, J = 5.8, 7.3), 3.78 (2, q, J = 7.2), 5.61 (1, d, J = 5.8), 7.26–7.40 (5, m); EI-MS m/z 248 (M^+, 6), 142 (74), 105 (21), 69 (100).

3-(Ethoxycarbonyl)-2-ethyl-6-phenyl-4-hexanolide(13): ot 180 °C (0.7 Torr). A mixture of four isomers was submitted for elemental analysis. Anal. Calcd for $C_{17}H_{22}O_4$: C, 70.32; H, 7.64. Found: C, 70.42; H, 7.67. The isomeric mixture of **13** was separated by PTLC (three elutions with 14% EtOAc–hexane). *TT*-13: oil; IR (neat) 1780, 1735; ^{1}H NMR δ 0.99 (3, t, J = 7.5), 1.26 (3, t, J = 7.2), 1.63–1.74 (1, m), 1.85–2.15 (3, m), 2.73 (1, ddd, J = 7.1, 9.6, 13.8), 2.77 (1, dd, J = 9.2, 11.0), 2.88 (1, ddd, J = 5.1, 9.9, 13.8), 2.98 (1, ddd, J = 5.1, 7.5, 11.0), 4.20 (2, q, J = 7.2), 4.41 (1, td, J = 3.8, 9.0), 7.15–7.33 (5, m); EI-MS m/z 290 (M^+, 11), 129 (38), 92 (52), 91 (100), 83 (45), 55 (33). *TC*-13: oil; IR (neat) 1780, 1735; ^{1}H NMR δ 0.99 (3, t, J = 7.5), 1.27 (3, t, J = 7.2), 1.57–1.96 (4, m), 2.70 (1, td, J = 8.2, 14.2), 2.88 (1, ddd, J = 4.9, 9.3, 13.8), 3.02 (1, ddd, J = 5.7, 7.7, 8.9), 3.21 (1, t, J = 8.7), 4.20 (2, q, J = 7.2), 4.61 (1, ddd, J = 3.2, 8.4, 10.7), 7.15–7.32 (5, m); EI-MS m/z 290 (M^+, 15), 129 (41), 117 (31), 92 (51), 91 (100), 83 (46), 55 (37). *CT*-13: oil; IR (neat) 1775, 1735; ^{1}H NMR δ 1.05 (3, t, J = 7.5), 1.27 (3, t, J = 7.2), 1.50–1.61 (1, m), 1.75–1.85 (1, m), 1.94–2.01 (2, m), 2.69–2.91 (3, m), 3.13 (1, dd, J = 5.9, 9.0), 4.19 (2, dq, J = 1.4, 7.2), 4.66 (1, td, J = 6.0, 7.3), 7.16–7.32 (5, m); EI-MS m/z 290 (M^+, 9), 129 (31), 92 (36), 91 (100), 83 (46), 55 (33). *CC*-13: oil; IR (neat) 1780, 1730; ^{1}H NMR δ 0.99 (3, t, J = 7.6), 1.28 (3, t, J = 7.0), 1.45–1.57 (1, m), 1.85–2.03 (2, m), 2.05–2.15 (1, m), 2.67 (1, ddd, J = 5.5, 7.3, 9.8), 2.76 (1, td, J = 8.1, 13.9), 2.88 (1, ddd, J = 5.5, 8.9, 14.0), 3.30 (1, dd, J = 5.2, 7.3), 4.21 (2, dq, J = 1.5, 7.0), 4.35 (1, quint, J = 4.8), 7.18–7.32 (5, m); EI-MS m/z 290 (M^+, 17), 156 (39), 129 (30), 127 (36), 92 (38), 91 (100), 83 (43), 55 (27).

4-Cyclohexyl-3-(ethoxycarbonyl)-2-ethyl-4-butanolide (14): ot 155 °C (0.6 Torr). A mixture of four isomers was submitted for elemental analysis. Anal. Calcd for $C_{18}H_{24}O_4$: C, 67.14; H, 9.01. Found: C, 66.89; H, 8.93. The isomeric mixture of **14** was separated by column chromatography (5–14% EtOAc–hexane). The TC isomer could not be separated from the major (CT) isomer and was characterized by only GC-MS analysis. *TT*-14: oil; IR (neat) 1780, 1740; ^{1}H NMR δ 1.00–1.30 (5, m), 1.00 (3, t, J = 7.5), 1.29 (3, t, J = 7.0), 1.46–1.95 (8, m), 2.85 (1, dd, J = 8.5, 10.7), 2.90 (1, ddd, J = 4.7, 7.0, 10.7), 4.22 (2, q, J = 7.2), 4.30 (1, dd, J = 6.9, 8.3); EI-MS m/z 240 ($M^+ - CH_2{=}CH_2$, 13), 185 (31), 157 (92), 129 (95), 111 (80), 83 (100), 55 (74). *TC*-14: EI-MS m/z 223 ($M^+ - OC_2H_5$, 4), 177 (45), 157 (68), 129 (35), 111 (64), 83 (100), 55 (91). *CT*-14: oil; IR (neat) 1780, 1740; ^{1}H NMR δ 0.98–1.30 (5, m), 1.05 (3, t, J = 7.5), 1.29 (3, t, J = 7.2), 1.46–1.85 (7, m), 1.89 (1, br d, J = 12.5), 2.74 (1, td, J = 7.3, 9.5), 3.24 (1, dd, J = 5.9, 9.3), 4.20 (2, q, J = 7.2), 4.43 (1, t, J = 6.6); EI-MS m/z 240 ($M^+ - CH_2{=}CH_2$, 15), 185 (50), 157 (75), 129 (92), 111 (68), 83 (100), 55 (80). *CC*-14: mp 101–102 °C; IR (KBr) 1775, 1720; ^{1}H NMR δ 0.85–1.10 (2, m), 1.02 (3, t, J = 7.5), 1.12–1.35 (3, m), 1.28 (3, t, J = 7.2), 1.39–1.50 (1, m), 1.55–1.80 (5, m), 1.90–2.02 (1, m), 2.14 (1, br d, J = 13.1), 2.66 (1, ddd, J = 5.2, 7.3, 9.8), 3.38 (1, dd, J = 4.9, 7.3), 4.02 (1, dd, J = 4.9, 10.7), 4.16–4.30 (2, m); EI-MS m/z 250 ($M^+ - H_2O$, 9), 185 (16), 157 (39), 129 (31), 111 (35), 83 (100), 55 (96).

3-(Ethoxycarbonyl)-2-ethyl-4-phenyl-4-butanolide (15): ot 175 °C (0.8 Torr). A mixture of four isomers was submitted for elemental analysis. Anal. Calcd for $C_{15}H_{18}O_4$: C, 68.68; H, 6.92. Found: C, 68.38; H, 6.91. The isomeric mixture of **15** was separated by PTLC (three elutions with 14% EtOAc–hexane). *TT*-15: oil; IR (neat) 1785, 1735; ^{1}H NMR δ 1.02 (3, t, J = 7.2), 1.25 (3, t, J = 7.2), 1.71–1.82 (1, m), 1.90–2.00 (1, m), 3.04 (1, dd, J = 8.2, 10.8), 3.08 (1, ddd, J = 4.7, 6.5, 10.8), 4.22 (2, q, J = 7.2), 5.49 (1, d, J = 8.2), 7.31–7.42 (5, m); EI-MS m/z 262 (M^+, 9), 192 (34), 129 (63), 105 (100), 83 (77), 77 (31). *TC*-15: mp 70–72 °C;

IR (KBr), 1775, 1740; ^{1}H NMR δ 0.94 (3, t, J = 7.2), 1.04 (3, t, J = 7.5), 1.66–1.78 (1, m), 1.88–1.98 (1, m), 3.19 (1, dt, J = 5.7, 8.0), 3.51 (1, t, J = 8.5), 3.73 (1, qd, J = 7.2, 10.8), 3.78 (1, qd, J = 7.2, 10.8), 5.73 (1, d, J = 8.9), 7.21–7.39 (5, m); EI-MS m/z 262 (M^+, 5), 156 (54), 127 (51), 105 (36), 99 (50), 83 (100). ***CT*-15**: oil; IR (neat) 1780, 1730; ^{1}H NMR δ 1.07 (3, t, J = 7.5), 1.30 (3, t, J = 7.2), 1.56–1.67 (1, m), 1.83–1.94 (1, m), 2.84 (1, td, J = 7.4, 8.7), 3.40 (1, dd, J = 6.1, 8.9), 4.17–4.30 (2, m, J = 7.2), 5.73 (1, d, J = 6.1), 7.31–7.43 (5, m); EI-MS m/z 262 (M^+, 10), 192 (40), 129 (72), 105 (100), 83 (92), 77 (44), 44 (52). ***CC*-15**: oil; IR (neat) 1785, 1730; ^{1}H NMR δ 0.86 (3, t, J = 7.2), 1.05 (3, t, J = 7.5), 1.56–1.62 (1, m), 2.00–2.05 (1, m), 2.89 (1, ddd, J = 5.5, 7.3, 9.8), 3.68 (1, dd, J = 5.8, 7.3), 3.77 (2, q, J = 7.2), 5.61 (1, d, J = 5.8), 7.29–7.36 (5, m); EI-MS m/z 262 (M^+, 4), 156 (52), 127 (47), 105 (36), 99 (49), 83 (100).

4-Cyclohexyl-3-(ethoxycarbonyl)-2-(1-methylethyl)-4-butanolide (16): ot 150 °C (0.3 Torr). A mixture of four isomers was submitted for elemental analysis. Anal. Calcd for $C_{16}H_{24}O_4$: C, 68.06; H, 9.28. Found: C, 67.76; H, 9.19. The isomeric mixture of **16** was separated by column chromatography (3.8–4.5% EtOAc–hexane). The TC isomer could not be separated from the major (CT) isomer and was characterized by only GC-MS analysis. ***TT*-16**: oil; IR (neat) 1780, 1735; ^{1}H NMR δ 0.97 (3, d, J = 6.7), 1.00 (3, d, J = 7.0), 1.00–1.32 (5, m), 1.29 (3, t, J = 7.0), 1.52–1.62 (1, m), 1.64–1.81 (4, m), 1.88 (1, br d, J = 12.5), 2.29 (1, d septet, J = 3.4, 7.0), 2.94–3.01 (2 m), 4.19–4.26 (3, m); EI-MS m/z 240 ($M^+ - CH_2{=}CHCH_3$, 19), 171 (64), 167 (64), 97 (59), 55 (72), 41 (100). ***TC*-16**: EI-MS m/z 264 (M^+, 4), 171 (48), 125 (45), 97 (52), 55 (72), 41 (100). ***CT*-16**: oil; IR (neat) 1780, 1735; ^{1}H NMR δ 0.96–1.30 (6, m), 1.08 (3, d, J = 7.0), 1.09 (3, d, J = 7.0), 1.30 (3, t, J = 7.0), 1.44–1.53 (1, m), 1.55–1.63 (1, m), 1.65–1.72 (1, m), 1.73–1.82 (1, m), 1.89–2.05 (2, m), 2.68 (1, dd, J = 5.7, 9.6), 3.24 (1, dd, J = 6.6, 9.6), 4.16–4.27 (2, m), 4.39 (1, t, J = 7.2); EI-MS m/z 254 ($M^+ - CH_2{=}CH_2$, 1), 199 (45), 167 (66), 97 (61), 55 (73), 41 (100). ***CC*-16**: mp 111–112 °C; IR (KBr) 1760, 1720; ^{1}H NMR δ 0.85–1.32 (5, m), 0.92 (3, d, J = 6.7), 1.26 (3, d, J = 6.7), 1.29 (3, t, J = 7.2), 1.43–1.55 (1, m), 1.63–1.87 (4, m), 1.97–2.07 (1, m), 2.08–2.16 (1, m), 2.36 (1, dd, J = 6.6, 10.2), 3.35 (1, dd, J = 4.7, 6.6), 3.96 (1, dd, J = 4.6, 10.7), 4.15–4.32 (2, m); EI-MS m/z 264 (M^+, 7), 167 (80), 97 (50), 55 (78), 41 (100).

15-Bromo-2-pentadecanone (29). A solution of acetone dimethylhydrazone (**28**) (3.48 g, 34.7 mmol) in dry THF (40 mL) was stirred and cooled to −7 °C while a 1.68 M hexane solution of *n*-BuLi (20.8 mL, 34.9 mmol) was added drop by drop. This solution was stirred at that temperature for 1 h and the slowly transferred by a cannula to a solution of 1,12-dibromododecane (23.31 g, 71.0 mmol) in dry THF (35 mL) at rt. After being stirred for 2.5 h at rt, the reaction mixture was transferred into a separatory funnel and vigorously shaken with 1.5 M HCl (65 mL). The mixture was extracted with toluene (1 × 300 mL, then 4 × 40 mL); the combined extracts were washed with brine (60 mL) and dried over Na_2SO_4. After removal of the volatiles, the crude mixture was separated by column chromatography (1–4% EtOAc–hexane) to give 14.5 g of unreacted dibromide and 7.15 g (87% based on the consumed dibromide) of **29**: mp 34–35 °C; IR (KBr) 2920, 2850, 1720; ^{1}H NMR δ 1.20–1.33 (16, m), 1.35–1.47 (2, m), 1.50–1.62 (2, m), 1.85 (2, quintet, J = 7.0), 2.13 (3, s), 2.42 (2, t, J = 7.5), 3.41 (2, t, J = 6.9); EI-MS m/z 306 (M + 2, 1), 304 (M^+, 1), 71 (26), 59 (40), 58 (100), 43 (72). Anal. Calcd for $C_{15}H_{29}BrO$: C, 59.01; H, 9.58; Br, 26.17. Found: C, 59.02; H, 9.38; Br, 26.03.

2-(13-Bromotridecyl)-2-methyl-1,3-dithiolane (30). A mixture of **29** (11.3 g, 37 mmol), ethanedithiol (4.7 mL, 56 mmol), and $BF_3{\cdot}OEt_2$ (1.2 g, 8.5 mmol) in dry CH_2Cl_2 (130 mL) was stirred for 45 h at rt. The mixture was treated with water (10 mL), and the organic phase was separated and dried over Na_2SO_4. After removal of the volatiles, the crude product was purified by column chromatography (2–2.5% EtOAc–hexane) to give 14.0 g (99%) of **30**: oil; IR (neat) 2925, 2850; ^{1}H NMR δ 1.22–1.34 (16, m), 1.37–1.54 (4, m), 1.75 (3, s), 1.85 (2, quintet, J = 7.2), 1.90–1.95 (2, m), 3.26–3.37 (4, m), 3.40 (2, t, J = 6.9). Anal. Calcd for $C_{17}H_{33}BrS_2$: C, 53.52; H, 8.72; Br, 20.95; S, 16.81. Found: C, 53.78; H, 8.59; Br, 21.30; S, 17.22.

15,15-(Ethylenedithio)hexadecanal (31). Magnesium turnings (313 mg, 12.9 mmol) were heated at 140 °C under vacuum for 1.3 h and then cooled to rt under Ar. The magnesium was covered by THF (2 mL), and I_2 (1 mg) was added. To this mixture was added a portion (3 mL) of a solution of **30** (4.46 g, 11.7 mmol) in THF (25 mL), and the mixture was heated to reflux in order to initiate the reaction. After the disappearance of I_2 color, the rest of the THF solution of **30** was added drop by drop; the mixture was then refluxed for 11 h. Upon cooling to 0 °C, a solution of *N*-formylpiperidine (1.58 g, 14.0 mmol) in THF (6 mL) was added to the mixture. After being stirred for 40 min at 0 °C, the mixture was allowed to warm to rt and stirred for 20 min. To this mixture were added H_2O (3 mL), 3 M HCl (8 mL), and ether (30 mL). The organic phase was separated, and the aqueous layer was extracted with ether (3 × 15 mL). The combined organic layers were washed successively with H_2O (20 mL), 1 M aqueous $NaHCO_3$ (2 × 20 mL), and brine (20 mL) and dried over Na_2SO_4. After removal of the volatiles, the crude product was purified by column chromatography (2–6% EtOAc–hexane) to give 1.05 g (27%) of **31**: mp 29–31 °C; IR (KBr) 2925, 2850, 1720; ^{1}H NMR δ 1.23–1.37 (18, m), 1.45–1.67 (4, m), 1.75 (3, s), 1.91–1.95 (2, m), 2.42 (2, dt, J = 1.8, 7.3), 3.28–3.38 (4, m), 9.77 (1, t, J = 1.8). Anal. Calcd for $C_{18}H_{34}OS_2$: C, 65.39; H, 10.37; S, 19.40. Found: C, 65.36; H, 10.19; S, 19.18.

18,18-(Ethylenedithio)-3-(methoxycarbonyl)-2-methyl-4-nonadecanolide (32). The reaction was performed by using **1e** (2.08 g, purity of **1e** was ca. 90%, corrected amount of **1e** is ca. 10.8 mmol)[25] and aldehyde **31** (2.09 g, 6.32 mmol) in the presence of $ZrCl_4$ (2.10 g, 9.01 mmol), as described above, at −94 °C to −78 °C (−94 °C (liquid N_2–acetone) for 35 min, at −84 °C (liquid N_2–AcOEt) for 3 h, and finally at −78 °C for 13.5 h). After lactonization, as described above, the crude product was separated by column chromatography (9–33% EtOAc–hexane) to give three fractions: the first fraction (0.44 g) was a mixture of the TT, TC, and CT isomers of **32**; the second fraction (1.85 g, 64%) mainly consisted of the CT isomer (more than 90% purity based on the ^{1}H NMR integration) accompanied by the TT and CC isomers. The third fraction (0.77 g) contained the CC and CT isomers. A part (1.4 g) of the second fraction was subjected to optical resolution by using a chiral HPLC column (hexane/i-PrOH, 9/1) to give $(-)_{589}$-**32c** (0.61 g, 97.7% ee) and $(+)_{589}$-**32c** (0.53 g, 99.4% ee). The $(+)_{589}$-isomer was crystalline, whereas the $(-)_{589}$-isomer did not crystallize probably due to small amounts of impurities. $(-)_{589}$-**32c**: oil; IR (neat) 2925, 2850, 1780, 1740; ^{1}H NMR δ 1.20–1.54 (22, m), 1.22 (3, d, J = 7.3), 1.62–1.72 (2, m), 1.75 (3, s), 1.91–1.95 (2, m), 2.98 (1, qd, J = 7.4, 9.3), 3.11 (1, dd, J = 6.4, 9.3), 3.28–3.38 (4, m), 3.75 (3, s), 4.70 (1, q, J = 6.4). $(+)_{589}$-**32c**: mp 29–31 °C; $[\alpha]^{20}_D$ +36.2° (*c* 1.00, $CHCl_3$); IR (KBr) 2930, 2860, 1775, 1725. ^{1}H NMR spectrum of $(+)_{589}$-**32c** was identical with $(-)_{589}$-**32c**. Anal. Calcd for $C_{24}H_{42}O_4S_2$: C, 62.84; H, 9.23; S, 13.98. Found: C, 62.70; H, 8.95; S, 13.72.

The first fraction was separated by PTLC (eluted six times with 10% EtOAc–hexane) to give the TT isomer (**32a**, 175 mg, 6%) and a mixture of the TC and CT isomers (119 mg). **32a**: oil; IR (neat) 2930, 2860, 1780, 1740; ^{1}H NMR δ 1.22–1.57 (22, m), 1.33 (3, d, J = 7.0), 1.60–1.83 (2, m), 1.75 (3, s), 1.91–1.95 (2, m), 2.66 (1, dd, J = 9.5, 11.5), 2.96 (1, qd, J = 7.0, 11.5), 3.28–3.38 (4, m), 3.78 (3, s), 4.45 (1, ddd, J = 4.2, 8.3, 9.4).

The TC isomer (**32b**) was enriched to more than 60% purity (47 mg) by further PTLC separation of the mixture (eluted five times with 10–12% acetone–hexane). TC isomer **32b** was subjected to the next dedithioacetalization reaction without further purification. IR and ^{1}H NMR data of **32b** were taken for the **32b**-enriched mixture. **32b**: oil; IR (neat) 2930, 2860, 1785, 1740; ^{1}H NMR δ 1.22–1.70 (24, m), 1.29 (3, d, J = 7.1), 1.75 (3, s), 1.90–1.96 (2, m), 3.06 (1, qd, J = 7.1, 10.0), 3.17 (1, dd, J = 8.1, 10.0), 3.26–3.40 (4, m), 3.77 (3, s), 4.64 (1, ddd, J = 3.2, 8.1, 10.0).

A part (400 mg) of the third fraction was separated by PTLC (eluted four times with hexane/CH_2Cl_2/EtOAc = 10/5/1) to give the CC isomer (**32d**, 62.1 mg) and the CT isomer (**32c**, 25.4 mg). The amounts of **32d** and **32c** in the third fraction, therefore, were estimated to be ca. 120 mg (4%) and ca. 49 mg (1.7%), respectively. **32d**: mp 42–44 °C; IR (KBr) 2920, 2850, 1765, 1735; ^{1}H NMR δ 1.20–1.80 (27, m), 1.75 (3, s), 1.91–1.95 (2, m), 2.90 (1, quintet, J = 7.2), 3.28–3.38 (5, m), 3.74 (3, s), 4.41 (1, td, J = 5.2, 8.6). Anal. Calcd for $C_{24}H_{42}O_4S_2$: C, 62.84; H, 9.23; S, 13.98. Found: C, 62.70; H, 8.95; S, 13.89.

$(-)_{589}$-Methyl Dihydropertusarate ($(-)_{589}$-33c). A solution of *N*-bromosuccinimide (1.78 g, 10.0 mmol) in 97% aqueous acetone (35 mL) was stirred and cooled to −9 °C while a solution of (−)-**32c** (514 mg, 1.12 mmol) in acetone (4 mL) was added. After being stirred at that temperature for 10 min, saturated aqueous Na_2SO_3 (8 mL) and hexane–CH_2Cl_2 (1:1, 30 mL) were added to the reaction mixture; the mixture was vigorously stirred for 5 min. The mixture was extracted with hexane–CH_2Cl_2 (1:1, 1 × 70 mL and 2 × 20 mL), and the organic extracts were combined, washed with 1 M aqueous $NaHCO_3$ and then with water, and dried over Na_2SO_4. After removal of the volatiles, the crude mixture was separated by column chromatography (hexane/CH_2Cl_2/EtOAc = 10/5/1) to give 414 mg (97%) of $(-)_{589}$-**33c**: mp 78–78.5 °C; $[\alpha]^{20}_D$ −45.2° (*c* 0.84, $CHCl_3$); IR (KBr) 2920, 2850, 1775, 1720, 1700; ^{1}H NMR δ 1.20–1.70 (24, m), 1.22 (3, d, *J* = 7.3), 2.14 (3, s), 2.42 (2, t, *J* = 7.5), 2.97 (1, qd, *J* = 7.6, 9.3), 3.11 (1, dd, *J* = 6.3, 9.3), 3.75 (3, s), 4.70 (1, q, *J* = 6.3). Anal. Calcd for $C_{22}H_{38}O_5$: C, 69.08; H, 10.01. Found: C, 68.82; H, 9.83.

The $(+)_{589}$-isomer, $(+)_{589}$-**33c**, synthesized in a similar manner, was identical to $(-)_{589}$-**33c** regarding the melting point and IR and ^{1}H NMR spectra and only different regarding the sign of the optical rotation.

(±)-Methyl Pertusarinate (33b). (±)-Methyl pertusarinate was synthesized from the **32b**-enriched mixture (47 mg), as described for the synthesis of $(-)_{589}$-**33c**. Purification by column chromatography (12% acetone–hexane) gave 28 mg (73%) of **33b**, which was further recrystallized from MeOH to give pure **33b**: mp 63–64 °C; IR (KBr) 2925, 2850, 1785, 1735, 1710; ^{1}H NMR δ 1.20–1.62 (24, m), 1.29 (3, d, *J* = 7.0), 2.13 (3, s), 2.42 (2, t, *J* = 7.5), 3.06 (1, qd, *J* = 7.0, 10.1), 3.18 (1, dd, *J* = 8.2, 10.1), 3.77 (3, s), 4.65 (1, ddd, *J* = 3.2, 8.1, 10.1). Anal. Calcd for $C_{22}H_{38}O_5$: C, 69.08; H, 10.01. Found: C, 68.79; H, 9.97.

$(-)_{589}$-Dihydropertusaric Acid ($(-)_{589}$-26). A solution of $(-)_{589}$-**33c** (347 mg, 0.907 mmol) in a mixture of dioxane (15 mL) and 6 M aqueous HCl (12 mL) was heated to reflux with stirring for 5 h. After being cooled to rt, water (15 mL) and EtOAc (40 mL) were added to the mixture. The organic phase was separated, and the aqueous phase was extracted with EtOAc (2 × 10 mL). The combined organic layers were washed with H_2O (2 × 10 mL) and dried over Na_2SO_4. After removal of the volatiles, the crude product was recrystallized from CCl_4 to give 297 mg (89%) of $(-)_{589}$-**26**, which was contaminated with about 10% of isomerization product (TT isomer). Further purification was made by converting into i-Pr_2EtN salt; recrystallization from hexane–ether, followed by acidification and recrystallization from EtOAc–heptane, gave pure $(-)_{589}$-**26**: mp 99–101 °C; $[\alpha]^{20}_D$ −45.9° (*c* 2.15, MeOH); IR (KBr) 3025, 2925, 2855, 1740, 1710; ^{1}H NMR δ 1.20–1.73 (24, m), 1.30 (3, d, *J* = 7.3), 2.16 (3, s), 2.44 (2, t, *J* = 7.5), 3.04 (1, qd, *J* = 7.5, 8.9), 3.16 (1, dd, *J* = 6.2, 9.2), 4.71 (1, q, *J* = 6.3), 10.40 (1, br s); ^{13}C NMR δ 11.72, 23.78, 25.23, 29.04–29.74, 34.56, 36.95, 43.78, 49.74, 79.48, 174.36, 177.43, 210.64. Anal. Calcd for $C_{21}H_{36}O_5$: C, 68.44; H, 9.85. Found: C, 68.31; H, 9.66.

The $(+)_{589}$-isomer, $(+)_{589}$-**26**, synthesized from $(+)_{589}$-**33c** as described above, was identical to (−)-**26** regarding the melting point and IR and ^{1}H NMR spectra and only different regarding the sign of the optical rotation.

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Supplementary Material Available: Significant ^{1}H NMR data of γ-lactones **6–16** (4 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.