Synthesis and NMR Spectroscopic Elucidation of Four Diastereoisomers of Oxygenated Bisabolane Side Chain

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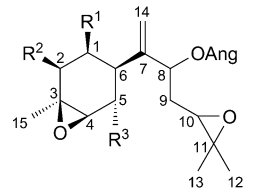
Four possible stereoisomers of a model compound of highly O-bearing bisabolane sesquiterpenes were synthesized and their NMR spectra were compared. Starting from isopulegol, allylic oxidation and *Grignard* reaction afforded a mixture of alcohols at C(8), which was separated. After metathesis reaction, both α- and β-epoxides were obtained *via* non-stereoselective epoxidation, while $VO(O^iPr)_3$-catalyzed epoxidation afforded a single diastereoisomer selectively. NMR Spectra of twelve synthesized compounds, four stereoisomers of acetates, isobutyrates, and tiglates, were measured. A difference between C(8α)- and C(8β)-acyloxy isomers was observed in the δ-values of H–C(8) in $CDCl_3$. Within the 8β-acyloxy compounds, the α- and the β-epoxides were distinguished by either the *J*-value of H–C(8) or the chemical shift of CH_2(9). Within the 8α-acyloxy compounds, two epoxide isomers were distinguished by the *J*-value of H–C(10) in C_6D_6 or in CD_3OD.

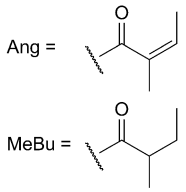
Introduction. – Bisabolanes are a major class of sesquiterpenoids found in various sources [1]. Highly oxidized bisabolane compounds with an OH or acyloxy group at C(8) and an epoxy group at C(10)–C(11) positions were previously isolated from various *Ligularia* species (Asteraceae), such as *L. dentata* [2–4], *L. thyrsoidea* [5], *L. songarica* [6][7], and *L. cymbulifera* [8][9]. Although a number of compounds were isolated, the configurations at C(8) and C(10) of the isolated compounds had not been determined. Over the course of our continuous study on the diversity in chemical composition of *Ligularia* species in the Hengduan Mountains area of P. R. China [10], we isolated nine O-bearing bisabolane compounds **1**–**5** [11] and **6**–**9** [12] from *L. lankongensis*, but the configurations at C(8) and C(10) could not be determined for any of them. The configurations of related highly O-bearing bisabolanes had also not been determined [2–9], except for diol **10**, the structure and relative configuration of which was determined by X-ray analysis [13].

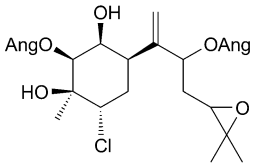
Various *J*-values were recorded for H–C(8) of these compounds. For example, the corresponding signal in compounds **1**–**5** was observed as *dd* (*doublet* of *doublet*s) with $J = 5–5.5$ and 8–8.5 Hz [11], while the signal in **11** was observed with $J = 2.2$ and 11.6 Hz [6]. The H–C(8) was observed as a *triplet* ($J = 7–7.5$) for both compounds **12** [9] and **13** [5]. These data suggest the presence of various configurations in the side chain. Because the use of X-ray analysis is limited, it would be useful to synthesize model compounds of all four possible stereoisomers with respect to the stereogenic

centers of the side chain, that is, C(8) and C(10). Based on this background, we planned to synthesize model compounds starting from isopulegol. Twelve compounds, acetates **14a**–**17a**, isobutyrates **14b**–**17b**, and tiglates **14c**–**17c** were the target molecules as models with various ester groups at the C(1) and C(8). These ester groups are often found in nature.



	R^1	R^2	R^3
1	AngO	OH	AngO
2	AngO	OH	H
3	MeBuO	OH	H
4	OH	AngO	H
6	H	AngO	H
7	MeBuO	OH	AngO
8	OH	MeBuO	H





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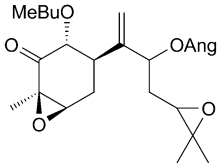

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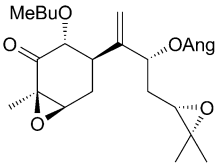
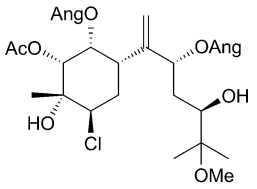


9a



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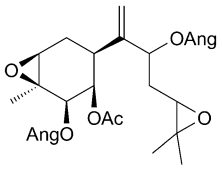

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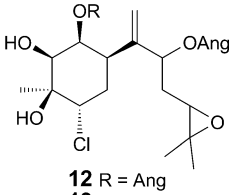
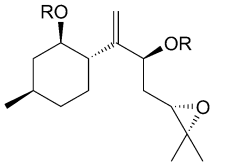
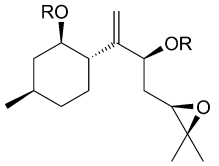


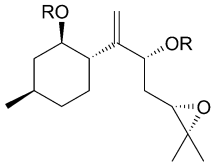
12 R = Ang
13 R = Ac



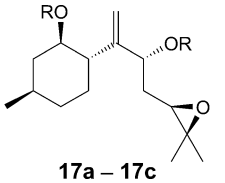
14a – 14c



15a – 15c



16a – 16c



17a – 17c

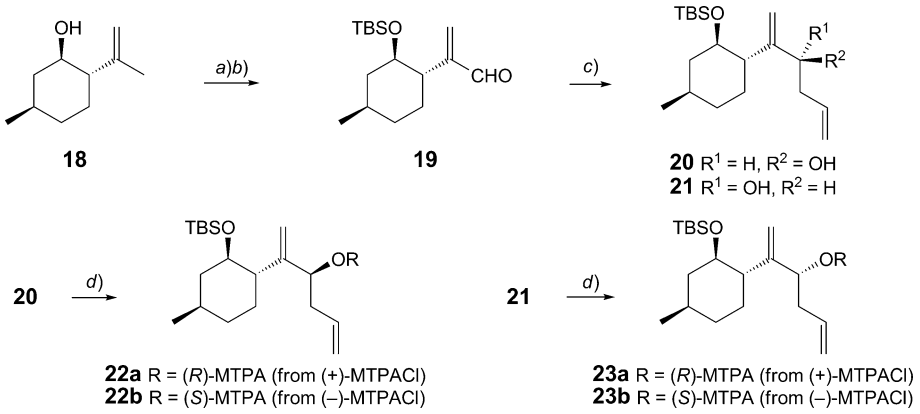
a R = Ac
b R = $Me_2CHC(O)$
c R = (*E*)-MeCH=CMeC(O)

Results and Discussion. – *Synthesis.* (–)-Isopulegol (**18**) was used after separation from its epimer with respect to the OH-bearing C-atom. Protection of the OH group with TBS followed by oxidation with SeO_2 afforded aldehyde **19** [14]. In order to obtain both 8*α*- and 8*β*-OH isomers, a non-stereoselective alkylation reaction was employed using allylmagnesium chloride, giving a 1:1 mixture of **20** and **21**, and the two isomers

were separated by HPLC (*Scheme 1*). The configuration of the newly generated chiral center was determined by advanced *Mosher*'s method [15]. Namely, compounds **20** and **21** were converted to both (*R*)-MTPA (obtained from (*S*)-(+)-MTPACl) and (*S*)-MTPA (obtained from (*R*)-(−)-MTPACl) esters **22a**, **22b** and **23a**, **23b**, respectively, and the configuration at C(8) was determined to be (*S*) for **20** and (*R*) for **21** from the difference in chemical shifts in the ^{1}H-NMR spectra (*Fig. 1*).

Compounds **20** and **21** were then subjected to the metathesis reaction with 2-methylbut-2-ene in the presence of *Grubbs* II catalyst [16] to afford **24** (89% yield) and **25** (83% yield), respectively (*Scheme 2*). Direct prenylation of aldehyde **19** or its analog to **24**/**25** was also tried but was unsuccessful. To obtain each stereoisomer of the epoxide selectively, *Yamamoto*'s enantioselective epoxidation for homoallylic alcohols [17] was examined. However, the same isomer of the epoxide was obtained selectively when **24** was treated with $VO(O^iPr)_3$ in the presence of either **26a** (30% yield) or **26b** (45% yield), indicating that the chiral environment in the substrate was more effective than in the chiral ligand. The product was determined to be β-epoxide **28** by *Moscher*'s method at a later stage (*vide infra*). Similarly, **25** afforded epoxide **29** in 61% (**26a** as the ligand) or 17% (**26b**) yield under the same reaction conditions. The method was also examined without *Yamamoto*'s ligand to obtain the same

Scheme 1



a) TBSOTf, 2,6-lutidine, CH_2Cl_2, r.t. *b*) SeO_2, ^{t}BuOOH, CH_2Cl_2, 60°; *c*) CH_2=$CHCH_2MgCl$, Et_2O, − 50°, then HPLC. *d*) (+)- or (−)-MTPACl, Et_3N, CH_2Cl_2, r.t.

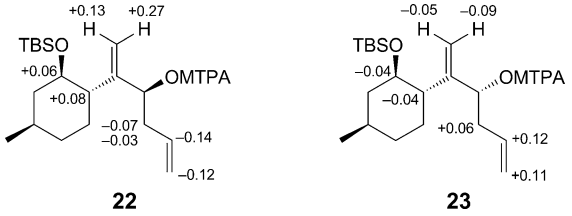
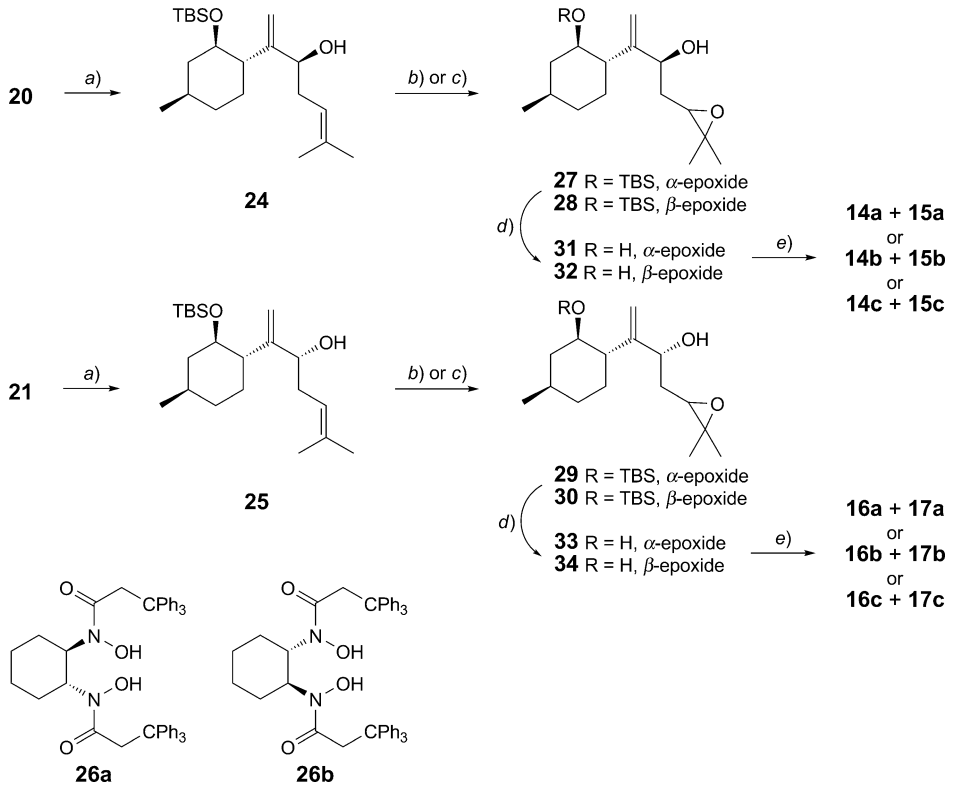


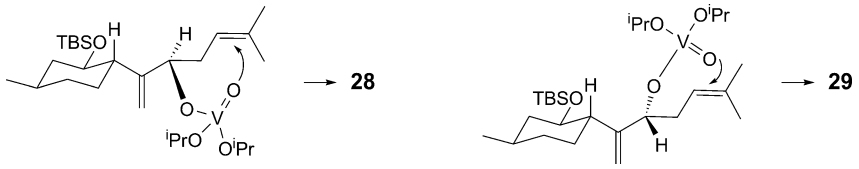
Fig. 1. $\Delta\delta$ ($\delta_{(S)\text{MTPA}} - \delta_{(R)\text{MTPA}}$) *Value of MTPA esters* **22** *and* **23**

Scheme 2



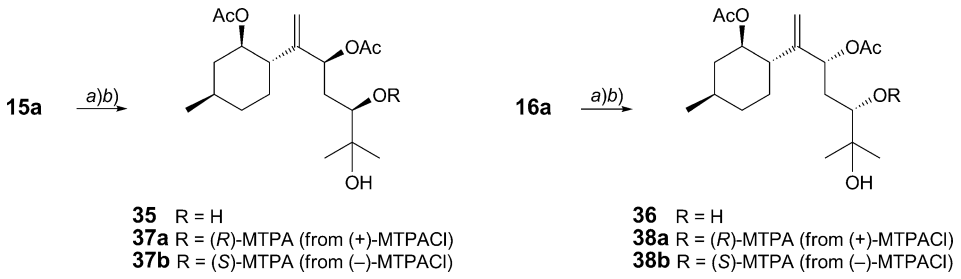
a) 2-Methylbut-2-ene, *Grubbs* II catalyst, r.t. *b*) $VO(O^iPr)_3$, ^{t}BuOOH, **26a** or **26b**, toluene, 0°. *c*) *m*-CPBA, CH_2Cl_2, r.t. *d*) TBAF, THF, r.t. *e*) for **14a**–**17a**, Ac_2O, pyridine, r.t., then HPLC; for **14b**–**17b**, $(Me_2CHCO)_2O$, pyridine, r.t., then HPLC; for **14c**–**17c**, tiglic anhydride, DMAP, CH_2Cl_2, r.t., then HPLC.

Scheme 3. *Stereoselective Formation of Epoxides*



epoxides (from **24** to **28**: 39%; from **25** to **29**: 46%), confirming that the selectivity was determined by the chirality of the substrates. The stereoselective formation of the epoxides can be explained by the attack of the vanadium reagent coordinated with the OH group at C(8) (*Scheme 3*; see below for the conformation). Then, to obtain all four possible stereoisomers, a non-stereoselective method was carried out. When **24** was treated with *m*-CPBA, a 1:1 mixture of **27** and **28** was obtained; however,

Scheme 4



35 R = H
37a R = (*R*)-MTPA (from (+)-MTPACl)
37b R = (*S*)-MTPA (from (–)-MTPACl)

36 R = H
38a R = (*R*)-MTPA (from (+)-MTPACl)
38b R = (*S*)-MTPA (from (–)-MTPACl)

a) AcOH, H_2O, THF, r.t. *b*) (+)- or (–)-MTPACl, Et_3N, CH_2Cl_2, r.t.

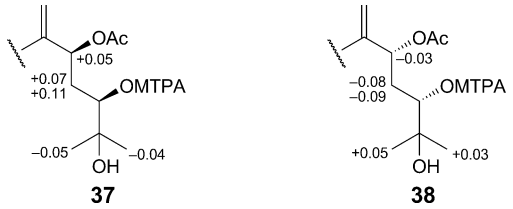


Fig. 2. $\Delta\delta$ ($\delta_{(S)\text{MTPA}} - \delta_{(R)\text{MTPA}}$) *Value of MTPA esters* **37** *and* **38**

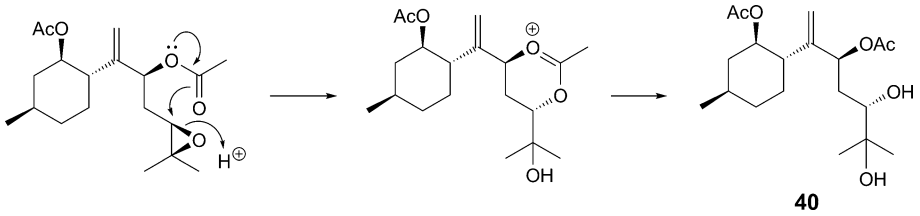
separation of the isomers was unsuccessful at this stage. Similarly, **25** afforded a mixture of **29** and **30**.

A mixture of **27** and **28** was converted to the acetates *via* deprotection followed by acetylation reaction, and the resulting diacetates **14a** and **15a** were separated by repeated HPLC (SiO_2, hexane/AcOEt; *Scheme 2*). Similarly, **16a** and **17a** were obtained from a mixture of epoxides **29** and **30**. Compounds **28** and **29**, respectively, prepared by $VO(O^iPr)_3$ epoxidation, were also converted to **15a** and **16a**, respectively, in the same way. Isobutyrates **14b**–**17b** were prepared by the related procedures. In the synthesis of tiglates **14c**–**17c**, DMAP was used as the base, because the esterification reaction of HO–C(1) was very slow.

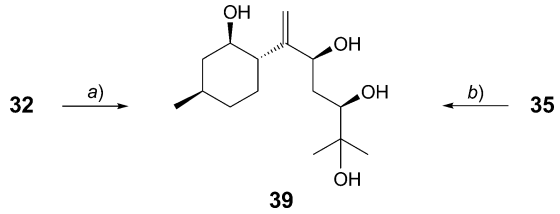
The absolute configuration of the epoxides was determined at this stage. Compounds **15a** and **16a** were hydrolyzed to diols **35** and **36**, respectively, by treatment with aqueous AcOH [18] (*Scheme 4*). Then, the configuration at C(10) was determined to be (*R*) for **35** and (*S*) for **36** by *Mosher*'s method after conversion to (*R*)- and (*S*)-MTPA esters **37a**, **37b** and **38a**, **38b**, respectively (*Fig. 2*).

In the above epoxide-opening reaction, an acetate-assisted mechanism is possible (*Scheme 5*). If the reaction proceeds by this mechanism, **40** is also a possible product from **15a**. This type of reaction product has been reported as an artifact of natural bisabolane sesquiterpenes [3]. To confirm the configuration, diol **32** was treated under the same epoxide-opening reaction conditions. As a result, tetraol **39** was obtained, and the same compound was obtained by hydrolysis of **35** (*Scheme 6*). These results indicate that the epoxide-opening reaction did not occur in the acetate-assisted mode but in 'normal' mode. Thus, the configuration of C(10) was established.

Scheme 5. *Proposal of an Acetate-Assisted Mechanism of Epoxide Opening*



Scheme 6



a) AcOH, H_2O, THF, r.t. *b*) K_2CO_3, MeOH, r.t.

Comparison of NMR Spectra of Four Stereoisomers. NMR Spectra were first measured in $CDCl_3$ for all twelve compounds **14**–**17**. All ^{1}H- and ^{13}C-signals of each compound were assigned using COSY, HSQC, and HMBC spectra, and the results are listed in *Tables 1* and *2*. A variety of *J*-values was observed for H–C(8), as in natural products. However, compounds **15b** and **16b** showed the same *J*-values (*dd*, $J = 4.5$, 8.0), indicating that the estimation of the configuration of the natural products from only the *J*-value of H–C(8) is difficult (*Table 1*). The ^{13}C-NMR data were too similar to distinguish isomers (*Table 2*).

Distinct differences in chemical shifts were observed between compounds having an 8β-acyloxy group (**14** and **15**) and an 8α-acyloxy group (**16** and **17**). The chemical shift of H–C(8) of 8β-acyloxy compounds was observed at about 0.2 ppm higher field than that of 8α-acyloxy compounds (*Table 1*). The H-atoms of **14a**–**14c** and **15a**–**15c** were observed at 5.18–5.33, while those of **16a**–**16c** and **17a**–**17c** at 5.41–5.51 ppm. The chemical shift of H_{eq}–C(5) was also different between 8β-acyloxy (2.00–2.12 ppm) and 8α-acyloxy compounds (1.78–1.87 ppm). These data indicate that 8β-acyloxy and 8α-acyloxy derivatives are distinguishable. For the 8β-acyloxy compounds, differences between **14** (α-epoxide) and **15** (β-epoxide) were recorded both in the *J*-value of H–C(8) and in the δ-value of CH_2(9). The difference between two *J*-values in H–C(8) was large in **14** ($|J(8,9a) - J(8,9b)| = 6.0$ Hz for **14a**, 6.2 Hz for **14b**, 6.3 Hz for **14c**) and small in **15** (2.3 Hz for **15a**, 3.5 Hz for **15b**, 2.3 Hz for **15c**). Two H-atoms (CH_2(9)) of **14a**–**14c** resonated separately ($\Delta\delta > 0.1$ ppm) while those of **15a**–**15c** did not.

Some of these observations can be explained by conformer **A** with respect to the orientation of the exo-methylene group (*Fig. 3*). Predominance of conformer **A** over **B** was confirmed by NOE observation between H_E–C(14) and H_{ax}–C(5), and between H–C(6) and H–C(8), for all twelve compounds. The lower shift of H_{eq}–C(5) in compounds **14** and **15** (2.00–2.12 ppm) can be explained by conformer **A**, in which the

Table 1. *^{1}H-NMR Data* (500 MHz; $CDCl_3$)[a]) *of Compounds* **14**–**17**

Position	**14a**	**15a**	**16a**	**17a**
1	4.85 (*dt*, *J* = 4.5, 10.8)	4.86 (*dt*, *J* = 4.3, 10.8)	4.76 (*dt*, *J* = 4.5, 11.0)	4.77 (*dt*, *J* = 4.3, 10.8)
2α (eq)	2.01–2.08 (*m*)	2.02–2.09 (*m*)	2.02–2.09 (*m*)	2.02–2.09 (*m*)
2β (ax)	1.00 (*q-like*, *J* ≈ 11.5)	1.00 (*q-like*, *J* ≈ 11.5)	0.95–1.04 (*m*)	0.96–1.05 (*m*)
3	1.54–1.66 (*m*)	1.55–1.67 (*m*)	1.54–1.66 (*m*)	1.55–1.66 (*m*)
4α (eq)	1.66–1.72 (*m*)	1.66–1.72 (*m*)	1.66–1.72 (*m*)	1.65–1.72 (*m*)
4β (ax)	0.88–0.99 (*m*)	0.88–0.99 (*m*)	0.89–0.99 (*m*)	0.89–0.99 (*m*)
5α (ax)	1.16–1.27 (*m*)	1.18–1.29 (*m*)	1.28–1.39 (*m*)	1.28–1.38 (*m*)
5β (eq)	1.97–2.04 (*m*)	1.96–2.03 (*m*)	1.82 (br. *qd*, *J* = 3.3, 13.5)	1.73–1.79 (*m*)
6	1.96–2.03 (*m*)	1.97–2.05 (*m*)	2.01–2.08 (*m*)	2.02–2.09 (*m*)
8	5.23 (*dd*, *J* = 3.5, 9.5)	5.27 (*dd*, *J* = 5.0, 7.3)	5.48 (*t*, *J* = 6.3)	5.41 (*dd*, *J* = 4.5, 9.0)
9	1.81 (*ddd*, *J* = 5.6, 9.4, 14.3), 1.88–1.97 (*m*)	1.86–1.96[b]) (*m*, 2 H)	1.86–1.91[b]) (*m*, 2 H)	1.79–1.92[c]) (*m*, 2 H)
10	2.80 (*t*, *J* = 6.0)	2.77 (*t*, *J* = 6.0)	2.76 (*t*, *J* = 5.8)	2.78 (*t*, *J* = 6.0)
12	1.29 (*s*)	1.29 (*s*)	1.29 (*s*)	1.29 (*s*)
13	1.31 (*s*)	1.30 (*s*)	1.30 (*s*)	1.30 (*s*)
14*E*	4.98 (*s*)	5.00 (*s*)	5.04 (*s*)	5.02 (*s*)
14*Z*	5.12 (*s*)	5.12 (*s*)	5.15 (*s*)	5.13 (*s*)
15	0.93 (*d*, *J* = 6.5)	0.93 (*d*, *J* = 6.5)	0.93 (*d*, *J* = 6.5)	0.93 (*d*, *J* = 6.5)
AcO–C(1)	1.94 (*s*)	1.95 (*s*)	1.99 (*s*)	1.99 (*s*)
AcO–C(8)	2.09 (*s*)	2.10 (*s*)	2.09 (*s*)	2.08 (*s*)

Table 1 (cont.)

Position	**14b**	**15b**	**16b**	**17b**
1	4.87 (*dt*, *J* = 4.3, 10.5)	4.88 (*dt*, *J* = 4.5, 10.0)	4.77 (*dt*, *J* = 4.5, 11.0)	4.79 (*dt*, *J* = 4.0, 10.8)
2α (eq)	2.01–2.07 (*m*)	2.01–2.08 (*m*)	2.00–2.07 (*m*)	2.00–2.06 (*m*)
2β (ax)	0.93–1.03 (*m*)	0.93–1.02 (*m*)	0.93–1.03 (*m*)	0.94–1.04 (*m*)
3	1.54–1.66 (*m*)	1.54–1.66 (*m*)	1.55–1.67 (*m*)	1.55–1.67 (*m*)
4α (eq)	1.66–1.73 (*m*)	1.66–1.73 (*m*)	1.64–1.71 (*m*)	1.64–1.71 (*m*)
4β (ax)	0.89–1.00 (*m*)	0.87–0.98 (*m*)	0.88–0.99 (*m*)	0.88–0.99 (*m*)
5α (ax)	1.14–1.25 (*m*)	1.15–1.26 (*m*)	1.25–1.36 (*m*)	1.24–1.35 (*m*)
5β (eq)	2.12 (br. *qd*, *J* = 3.3, 13.4)	2.05–2.11 (*m*)	1.81–1.88 (*m*)	1.80 (br. *qd*, *J* = 3.3, 13.4)
6	1.93–2.00 (*m*)	1.93–2.01 (*m*)	2.04–2.12 (*m*)	2.11 (br. *dt*, *J* = 3.6, 11.5)
8	5.18 (*dd*, *J* = 3.3, 9.5)	5.25 (*dd*, *J* = 4.5, 8.0)	5.47 (*dd*, *J* = 4.5, 8.0)	5.41 (*dd*, *J* = 6.3, 6.8)
9	1.79 (*ddd*, *J* = 5.6, 9.5, 14.6), 1.93–2.00 (*m*)	1.86–1.96[b]) (*m*, 2 H)	1.82–1.89 (*m*), 1.90–1.97 (*m*)	1.84–1.91[b]) (*m*, 2 H)
10	2.81 (*t*, *J* = 6.0)	2.77 (*t*, *J* = 6.3)	2.74 (*dd*, *J* = 5.0, 6.5)	2.77 (*t*, *J* = 6.0)
12	1.29 (*s*)	1.29 (*s*)	1.28 (*s*)	1.28 (*s*)
13	1.31 (*s*)	1.30 (*s*)	1.29 (*s*)	1.29 (*s*)
14*E*	4.91 (*s*)	4.94 (*s*)	5.02 (*s*)	5.01 (*s*)
14*Z*	5.05 (*s*)	5.08 (*s*)	5.17 (*s*)	5.15 (*s*)
15	0.93 (*d*, *J* = 6.5)	0.93 (*d*, *J* = 6.5)	0.93 (*d*, *J* = 6.5)	0.93 (*d*, *J* = 6.5)
$Me_2CHC(O)O$–C(1)	1.08 (*d*, *J* = 7.0)	1.08 (*d*, *J* = 7.0)	1.07 (*d*, *J* = 7.0)	1.07 (*d*, *J* = 7.0)
	1.10 (*d*, *J* = 7.0)	1.10 (*d*, *J* = 7.0)	1.07 (*d*, *J* = 7.0)	1.11 (*d*, *J* = 7.0)
	2.40 (*sept.*, *J* = 7.0)	2.42 (*sept.*, *J* = 7.0)	2.45 (*sept.*, *J* = 7.0)	2.47 (*sept.*, *J* = 7.0)
$Me_2CHC(O)O$–C(8)	1.19 (*d*, *J* = 7.0)	1.20 (*d*, *J* = 7.0)	1.18 (*d*, *J* = 7.0)	1.18 (*d*, *J* = 7.0)
	1.20 (*d*, *J* = 7.0)	1.21 (*d*, *J* = 7.0)	1.19 (*d*, *J* = 7.0)	1.18 (*d*, *J* = 7.0)
	2.58 (*sept.*, *J* = 7.0)	2.60 (*sept.*, *J* = 7.0)	2.58 (*sept.*, *J* = 7.0)	2.56 (*sept.*, *J* = 7.0)

Table 1 (cont.)

Position	**14c**	**15c**	**16c**	**17c**
1	4.97 (*dt*, *J* = 4.4, 10.9)	4.99 (*dt*, *J* = 4.3, 10.9)	4.90 (*dt*, *J* = 4.3, 10.9)	4.91 (*dt*, *J* = 4.3, 10.9)
2α (eq)	2.04–2.10 (*m*)	2.05–2.12 (*m*)	2.05–2.11 (*m*)	2.06–2.12 (*m*)
2β (ax)	1.03 (*q-like*, *J* ≈ 11.5)	1.03 (*q-like*, *J* ≈ 11.5)	1.04 (*q-like*, *J* ≈ 11.5)	1.04 (*q-like*, *J* ≈ 11.5)
3	1.56–1.68 (*m*)	1.56–1.67 (*m*)	1.56–1.68 (*m*)	1.57–1.69 (*m*)
4α (eq)	1.66–1.73 (*m*)	1.67–1.74 (*m*)	1.64–1.71 (*m*)	1.65–1.72 (*m*)
4β (ax)	0.90–1.01 (*m*)	0.89–1.00 (*m*)	0.88–0.98 (*m*)	0.89–0.99 (*m*)
5α (ax)	1.16–1.27 (*m*)	1.18–1.28 (*m*)	1.24–1.35 (*m*)	1.23–1.34 (*m*)
5β (eq)	2.09–2.16 (*m*)	2.06–2.13 (*m*)	1.80–1.87 (*m*)	1.78–1.85 (*m*)
6	2.00–2.08 (*m*)	2.00–2.08 (*m*)	2.21 (br. *dt*, *J* = 3.6, 11.6)	2.23 (br. *dt*, *J* = 3.5, 11.5)
8	5.32 (*dd*, *J* = 3.2, 9.5)	5.33 (*dd*, *J* = 4.9, 7.2)	5.51 (*dd*, *J* = 5.4, 7.5)	5.50 (*dd*, *J* = 5.3, 7.5)
9	1.76–1.85 (*m*), 1.95–2.01 (*m*)	1.89–1.99[b]) (*m*, 2 H)	1.85–1.98[c]) (*m*, 2 H)	1.85–1.95[b]) (*m*, 2 H)
10	2.81 (*t*, *J* = 6.0)	2.76 (*t*, *J* = 5.9)	2.71 (*dd*, *J* = 5.3, 6.2)	2.77 (*dd*, *J* = 5.3, 6.4)
12	1.25 (*s*)	1.26 (*s*)	1.25 (*s*)	1.25 (*s*)
13	1.27 (*s*)	1.29 (*s*)	1.25 (*s*)	1.24 (*s*)
14*E*	4.96 (*s*)	4.97 (*s*)	5.06 (*s*)	5.04 (*s*)
14*Z*	5.08 (*s*)	5.08 (*s*)	5.19 (*s*)	5.17 (*s*)
15	0.93 (*d*, *J* = 6.5)	0.93 (*d*, *J* = 6.5)	0.93 (*d*, *J* = 6.5)	0.93 (*d*, *J* = 6.5)
(*E*)-MeCH=CMeC(O)O–C(1)	1.74 (*qd*, *J* = 1.1, 7.1)	1.74 (*qd*, *J* = 1.1, 7.1)	1.74 (*qd*, *J* = 1.1, 7.0)	1.74 (*qd*, *J* = 1.1, 7.0)
	1.75–1.77 (*m*)	1.76 (*quint.*, *J* = 1.1)	1.77 (*quint.*, *J* = 1.1)	1.77 (*quint.*, *J* = 1.1)
	6.74 (*qq*, *J* = 1.4, 7.1)	6.74 (*qq*, *J* = 1.4, 7.1)	6.76 (*qq*, *J* = 1.4, 7.0)	6.77 (*qq*, *J* = 1.4, 7.0)
(*E*)-MeCH=CMeC(O)O–C(8)	1.81 (*qd*, *J* = 1.2, 7.1)	1.81 (*qd*, *J* = 1.1, 7.1)	1.80 (*qd*, *J* = 1.1, 7.1)	1.81 (*qd*, *J* = 1.1, 7.1)
	1.84–1.86 (*m*)	1.85 (*quint.*, *J* = 1.1)	1.84 (*quint.*, *J* = 1.1)	1.84 (*quint.*, *J* = 1.1)
	6.92 (*qq*, *J* = 1.4, 7.1)	6.92 (*qq*, *J* = 1.4, 7.1)	6.88 (*qq*, *J* = 1.4, 7.1)	6.87 (*qq*, *J* = 1.4, 7.1)

[a]) The *J*-values are given in Hz. '*m*' indicates either *multiplet* or overlapped signal. [b]) The δ values of the two H-atoms at C(9) may be slightly different (within 0.02 ppm), but the exact value of each H-atom could not be determined. [c]) The δ values of the two H-atoms at C(9) may be different (*ca.* 0.05 ppm), but the exact value of each H-atom could not be determined.

Table 2. *^{13}C-NMR Data* ($CDCl_3$) *of Compounds* **14**–**17**

Position[a])	**14a**	**15a**	**16a**	**17a**	**14b**	**15b**	**16b**	**17b**	**14c**	**15c**	**16c**	**17c**
1	74.9	74.8	76.4	76.1	73.9	73.9	75.3	75.0	74.4	74.2	75.4	75.1
2	40.6	40.6	40.7	40.7	40.5	40.5	40.6	40.6	40.6	40.7	40.8	40.7
3	31.3	31.2	31.2	31.2	31.3	31.3	31.2	31.2	31.3	31.3	31.3	31.3
4	34.4	34.4	34.4	34.4	34.5	34.5	34.4	34.4	34.4	34.5	34.5	34.5
5	33.4	33.4	32.8	33.0	33.2	33.2	33.0	33.1	33.2	33.3	33.4	33.4
6	45.1	45.2	44.2	44.2	45.8	45.9	44.6	44.6	45.9	46.0	44.3	44.7
7	149.4	149.0	148.8	149.1	149.8	149.3	148.7	148.9	149.7	149.2	148.5	148.8
8	74.0	74.2	74.9	74.7	73.3	73.5	74.3	74.1	73.4	73.7	75.1	74.4
9	33.0	33.0	32.9	33.1	33.8	33.4	33.2	33.4	33.7	33.1	33.2	33.7
10	61.0	61.0	60.8	61.0	61.2	61.1	60.8	61.0	61.2	61.1	60.8	61.1
11	58.3	57.7	57.5	58.3	58.3	57.7	57.6	58.3	58.3	57.7	57.7	58.3
12	19.0	18.9	18.9	19.0	19.1	19.0	18.9	19.1	18.9	18.8	18.9	18.8
13	24.7	24.7	24.6	24.7	24.7	24.7	24.6	24.7	24.7	24.6	24.6	24.7
14	110.1	110.3	111.4	111.4	108.4	109.0	111.4	111.5	108.9	109.1	112.1	112.1
15	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9	22.0	22.0
1′	170.4	170.5	170.5	170.7	176.4	176.6	176.6	176.7	167.4	167.4	167.4	167.5
2′	21.1	21.1	21.2	21.2	34.1	34.1	34.0	34.0	128.6	128.7	128.6	128.6
3′	–	–	–	–	18.9	18.8	18.8	18.7	136.7	136.9	136.9	137.1
4′	–	–	–	–	19.0	18.9	19.0	18.8	14.3	14.3	14.3	14.3
5′	–	–	–	–	–	–	–	–	12.1	12.1	12.0[b])	12.0
1″	169.9	170.0	169.8	169.7	175.9	176.1	175.9	175.8	167.0	167.0	166.9	166.8
2″	21.2	21.3	21.2	21.1	34.1	34.2	34.2	34.2	128.6	128.6	128.7	128.6
3″	–	–	–	–	19.0	18.9	19.0	18.9	137.5	137.6	137.4	137.4
4″	–	–	–	–	19.0	18.9	19.1	19.0	14.4	14.5	14.4	14.4
5″	–	–	–	–	–	–	–	–	12.1	12.1	12.1[b])	12.1

[a]) The moieties with numbering of 1′–5′ and 1″–5″ indicate the acid part of the acyloxy group at C(1) and C(8), respectively. [b]) The assignment may be interchanged.

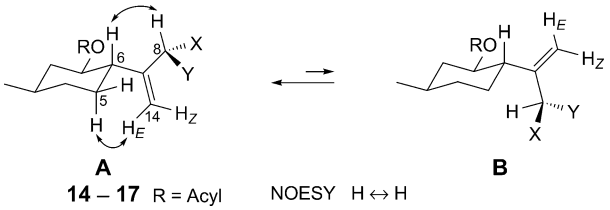


Fig. 3. *Conformation of cyclohexane and exo-methylene moieties*

H-atom and the C(8)-acyloxy group were on the same side. Although H–C(6) and H–C(8) do not appear on the plane of the C(7)=C(14) bond, hereafter conformer **A** is used as the dominant conformation.

The *J*-value of H–C(8) depends on the contribution of two conformers **C** and **D** (or **C′** and **D′**) with respect to the C(8)–C(9) bond (*Fig. 4*). The third possible conformer can be ruled out because of steric hindrance. Conformer **C** (**14** and **15**) is unfavorable because of the presence of steric interaction between C(10) and C(1)-acyloxy group (*Fig. 5*), while such interaction is absent in conformer **D**. The large difference between *J*(8,9a) and *J*(8,9b) in **14** indicates that the disadvantage of conformer **C** is larger in **14** than in **15**, suggesting that **14** exists mainly in one conformer **D**. This was supported by the difference in the chemical shifts between two H-atoms (CH_2(9)) in **14**.

In contrast to the 8*β*-acyloxy derivatives (**14** and **15**), it was difficult to distinguish the two 8*α*-acyloxy derivatives, **16** (*α*-epoxide) and **17** (*β*-epoxide), from the data obtained in $CDCl_3$. Then, the NMR spectra were taken in C_6D_6, which is often used in natural product chemistry (*Tables 3* and *4*). As a result, H–C(10) of **16a**–**16c** was observed as *dd* ($|J(9a,10)-J(9b,10)| > 1.5$ Hz), while that of **17** as a *triplet* (**17a** and **17b**) or a *triplet*-like *dd* (**17c**, $|J(9a,10)-J(9b,10)| = 0.7$ Hz). The results suggest that **16** and **17** can be distinguished on the basis of the NMR data. A difference in chemical shifts of H–C(8) between 8*β*-acyloxy compounds (**14** and **15**) and 8*α*-acyloxy compounds (**16** and **17**) was observed as in $CDCl_3$, however, the difference was not distinct enough to be useful for the structure determination. A large difference between

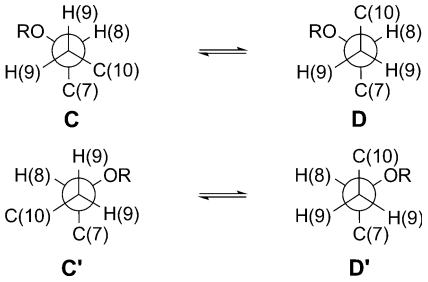


Fig. 4. Newman *projection with respect to C(8)* (circle) *and C(9)* (dot). Conformers **C** and **D** for compounds **14** and **15**; conformers **C′** and **D′** for compounds **16** and **17**.

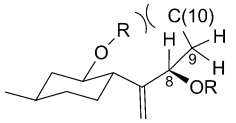


Fig. 5. *Conformer* **C** *of compounds* **14** *and* **15**

Table 3. *^{1}H-NMR Data* (400 MHz; C_6D_6)[a]) *of Compounds* **14**–**17**

Position	**14a**	**15a**	**16a**	**17a**
1	5.01 (*dt*, *J* = 4.4, 10.6)	5.03 (*dt*, *J* = 4.4, 10.9)	4.94 (*dt*, *J* = 4.4, 10.8)	4.94 (*dt*, *J* = 4.4, 10.8)
2α (eq)	2.01–2.08 (*m*)	2.02–2.10 (*m*)	2.04–2.12 (*m*)	2.02–2.10 (*m*)
2β (ax)	0.84 (*dt*, *J* = 10.7, 12.0)	0.87 (*q-like*, *J* ≈ 11.5)	0.90 (*q-like*, *J* ≈ 11.5)	0.88 (*dt*, *J* = 10.9, 12.0)
3	1.14–1.29 (*m*)	1.15–1.30 (*m*)	1.18–1.32 (*m*)	1.16–1.30 (*m*)
4α (eq)	1.29–1.36 (*m*)	1.30–1.38 (*m*)	1.33–1.41 (*m*)	1.32–1.39 (*m*)
4β (ax)	0.53–0.66 (*m*)	0.58–0.70 (*m*)	0.62–1.74 (*m*)	0.60–0.72 (*m*)
5α (ax)	1.01–1.15 (*m*)	1.03–1.17 (*m*)	1.13–1.26 (*m*)	1.10–1.24 (*m*)
5β (eq)	1.93–2.01 (*m*)	1.88–1.95 (*m*)	1.72–1.80 (*m*)	1.62–1.70 (*m*)
6	1.92–2.00 (*m*)	1.96–2.04 (*m*)	1.97–2.05 (*m*)	1.98–2.07 (*m*)
8	5.46 (*dd*, *J* = 3.8, 9.2)	5.50 (*dd*, *J* = 4.9, 7.5)	5.75 (*dd*, *J* = 4.8, 7.5)	5.65 (*dd*, *J* = 4.2, 8.9)
9	1.76–1.86 (*m*), 1.94–2.03 (*m*)	1.82–1.99[c]) (*m*, 2 H)	1.77–1.92[b]) (*m*, 2 H)	1.82 (*ddd*, *J* = 6.3, 8.9, 14.3), 1.90–1.98 (*m*)
10	2.79 (*dd*, *J* = 5.7, 6.4)	2.79 (*t*, *J* = 5.9)	2.77 (*dd*, *J* = 4.9, 6.8)	2.77 (*t*, *J* = 6.0)
12	1.14 (*s*)	1.11 (*s*)	1.10 (*s*)	1.13 (*s*)
13	1.14 (*s*)	1.14 (*s*)	1.11 (*s*)	1.14 (*s*)
14*E*	5.03 (*s*)	5.06 (*s*)	5.02 (*s*)	4.99 (*s*)
14*Z*	5.19 (*s*)	5.20 (*s*)	5.20 (*s*)	5.15 (*s*)
15	0.71 (*d*, *J* = 6.5)	0.73 (*d*, *J* = 6.5)	0.75 (*d*, *J* = 6.5)	0.74 (*d*, *J* = 6.5)
AcO–C(1)	1.74 (*s*)	1.79 (*s*)	1.91 (*s*)	1.92 (*s*)
AcO–C(8)	1.73 (*s*)	1.76 (*s*)	1.73 (*s*)	1.68 (*s*)

Table 3 (cont.)

Position	**14b**	**15b**	**16b**	**17b**
1	5.06 (*dt*, *J* = 4.4, 10.9)	5.07 (*dt*, *J* = 4.3, 10.7)	4.96 (*dt*, *J* = 4.3, 10.8)	4.95 (*dt*, *J* = 4.4, 10.8)
2α (eq)	2.02–2.09 (*m*)	2.04–2.11 (*m*)	2.05–2.12 (*m*)	2.04–2.11 (*m*)
2β (ax)	0.84 (*dt*, *J* = 11.0, 12.0)	0.90 (*q-like*, *J* ≈ 11.5)	0.90 (*q-like*, *J* ≈ 11.5)	0.89 (*dt*, *J* = 10.8, 12.0)
3	1.12–1.26 (*m*)	1.14–1.29 (*m*)	1.17–1.32 (*m*)	1.14–1.29 (*m*)
4α (eq)	1.29–1.37 (*m*)	1.33–1.40 (*m*)	1.34–1.42 (*m*)	1.32–1.40 (*m*)
4β (ax)	0.54–0.66 (*m*)	0.61–0.74 (*m*)	0.63–0.76 (*m*)	0.62–0.74 (*m*)
5α (ax)	1.01–1.14 (*m*)	1.03–1.17 (*m*)	1.12–1.25 (*m*)	1.09–1.23 (*m*)
5β (eq)	2.07–2.15 (*m*)	2.02–2.09 (*m*)	1.81 (br. *qd*, *J* = 3.3, 13.5)	1.72 (br. *qd*, *J* = 3.3, 13.5)
6	1.95 (br. *dt*, *J* = 3.5, 11.5)	1.95–2.04 (*m*)	2.03–2.12 (*m*)	2.04–2.12 (*m*)
8	5.48 (*dd*, *J* = 3.3, 9.2)	5.54 (*t*, *J* = 6.2)	5.77 (*dd*, *J* = 4.3, 8.2)	5.66 (*dd*, *J* = 4.4, 8.5)
9	1.87 (*ddd*, *J* = 5.4, 9.3, 14.5), 2.04–2.13 (*m*)	1.94–2.00[b]) (*m*, 2 H)	1.87 (*td*, *J* = 4.6, 14.5), 1.93 (*ddd*, *J* = 6.5, 8.2, 14.5)	1.87 (*ddd*, *J* = 6.2, 8.5, 14.5), 1.97 (*ddd*, *J* = 4.4, 5.8, 14.5)
10	2.85 (*dd*, *J* = 5.5, 6.4)	2.82 (*t*, *J* = 5.9)	2.79 (*dd*, *J* = 4.8, 6.5)	2.81 (*t*, *J* = 5.9)
12	1.18 (*s*)	1.15 (*s*)	1.13 (*s*)	1.17 (*s*)
13	1.16 (*s*)	1.16 (*s*)	1.13 (*s*)	1.15 (*s*)
14*E*	5.04 (*s*)	5.06 (*s*)	5.03 (*s*)	5.01 (*s*)
14*Z*	5.20 (*s*)	5.21 (*s*)	5.22 (*s*)	5.18 (*s*)
15	0.70 (*d*, *J* = 6.5)	0.72 (*d*, *J* = 6.5)	0.74 (*d*, *J* = 6.5)	0.73 (*d*, *J* = 6.5)
$Me_2CHC(O)O$–C(1)	1.09 (*d*, *J* = 7.0)	1.10 (*d*, *J* = 7.0)	1.13 (*d*, *J* = 7.0)	1.14 (*d*, *J* = 7.0)
	1.11 (*d*, *J* = 7.0)	1.12 (*d*, *J* = 7.0)	1.15 (*d*, *J* = 7.0)	1.16 (*d*, *J* = 7.0)
	2.40 (*sept.*, *J* = 7.0)	2.46 (*sept.*, *J* = 7.0)	2.54 (*sept.*, *J* = 7.0)	2.57 (*sept.*, *J* = 7.0)
$Me_2CHC(O)O$–C(8)	1.09 (*d*, *J* = 7.0)	1.12 (*d*, *J* = 7.0)	1.11 (*d*, *J* = 7.0)	1.09 (*d*, *J* = 7.0)
	1.09 (*d*, *J* = 7.0)	1.14 (*d*, *J* = 7.0)	1.13 (*d*, *J* = 7.0)	1.09 (*d*, *J* = 7.0)
	2.43 (*sept.*, *J* = 7.0)	2.47 (*sept.*, *J* = 7.0)	2.46 (*sept.*, *J* = 7.0)	2.40 (*sept.*, *J* = 7.0)

Table 3 (cont.)

Position	**14c**	**15c**	**16c**	**17c**
1	5.21 (*dt*, *J* = 4.4, 10.8)	5.24 (*dt*, *J* = 4.4, 10.8)	5.13 (*dt*, *J* = 4.3, 10.8)	5.12 (*dt*, *J* = 4.2, 10.8)
2α (eq)	2.07–2.15 (*m*)	2.10–2.18 (*m*)	2.12–2.19 (*m*)	2.12–2.19 (*m*)
2β (ax)	0.90 (*dt*, *J* = 10.9, 12.0)	0.94 (*dt*, *J* = 10.8, 12.0)	0.95 (*dt*, *J* = 10.8, 12.0)	0.95 (*dt*, *J* = 10.9, 12.0)
3	1.16–1.31 (*m*)	1.18–1.33 (*m*)	1.21–1.35 (*m*)	1.19–1.33 (*m*)
4α (eq)	1.31–1.39 (*m*)	1.34–1.42 (*m*)	1.35–1.43 (*m*)	1.34–1.42 (*m*)
4β (ax)	0.58–0.71 (*m*)	0.64–0.76 (*m*)	0.67–0.79 (*m*)	0.66–0.78 (*m*)
5α (ax)	1.06–1.19 (*m*)	1.08–1.22 (*m*)	1.14–1.28 (*m*)	1.13–1.27 (*m*)
5β (eq)	2.08–2.16 (*m*)	2.07–2.15 (*m*)	1.83–1.91 (*m*)	1.76–1.84 (*m*)
6	2.00–2.09 (*m*)	2.04–2.13 (*m*)	2.24 (br. *dt*, *J* = 3.5, 11.5)	2.24 (br. *dt*, *J* = 3.5, 11.5)
8	5.67 (*dd*, *J* = 3.4, 9.0)	5.65 (*dd*, *J* = 5.3, 6.7)	5.88 (*dd*, *J* = 5.0, 7.7)	5.82 (*dd*, *J* = 4.8, 8.4)
9	1.90 (*ddd*, *J* = 5.6, 9.0, 14.5), 2.08–2.18 (*m*)	1.97–2.10[b]) (*m*, 2 H)	1.95 (*td*, *J* = 5.0, 14.4), 2.04 (*ddd*, *J* = 6.6, 7.6, 14.4)	1.94 (*ddd*, *J* = 6.6, 8.4, 14.3), 2.07 (*ddd*, *J* = 4.7, 5.7, 14.3)
10	2.91 (*t*, *J* = 5.9)	2.84 (*t*, *J* = 5.9)	2.81 (*dd*, *J* = 5.0, 6.6)	2.87 (*dd*, *J* = 5.8, 6.5)
12	1.17 (*s*)	1.15 (*s*)	1.13 (*s*)	1.18 (*s*)
13	1.14 (*s*)	1.14 (*s*)	1.11 (*s*)	1.14 (*s*)
14*E*	5.13 (*s*)	5.14 (*s*)	5.12 (*s*)	5.08 (*s*)
14*Z*	5.27 (*s*)	5.26 (*s*)	5.29 (*s*)	5.22 (*s*)
15	0.71 (*d*, *J* = 6.5)	0.73 (*d*, *J* = 6.5)	0.74 (*d*, *J* = 6.5)	0.74 (*d*, *J* = 6.5)
(*E*)-MeCH=CMeC(O)O–C(1)	1.43 (*qd*, *J* = 1.2, 7.0)	1.46 (*qd*, *J* = 1.2, 7.0)	1.47 (*qd*, *J* = 1.2, 7.0)	1.50 (*qd*, *J* = 1.2, 7.0)
	1.82 (*quint.*, *J* = 1.2)	1.85 (*quint.*, *J* = 1.2)	1.86 (*quint.*, *J* = 1.2)	1.88 (*quint.*, *J* = 1.2)
	6.93 (*qq*, *J* = 1.3, 7.0)	6.96 (*qq*, *J* = 1.3, 7.0)	6.98 (*qq*, *J* = 1.3, 7.0)	7.02 (*qq*, *J* = 1.3, 7.0)
(*E*)-MeCH=CMeC(O)O–C(8)	1.36 (*dq*, *J* = 7.0, 1.2)	1.36 (*dq*, *J* = 7.0, 1.2)	1.37 (*dq*, *J* = 7.0, 1.2)	1.37 (*dq*, *J* = 7.0, 1.2)
	1.80 (*quint.*, *J* = 1.2)	1.82 (*quint.*, *J* = 1.2)	1.81 (*quint.*, *J* = 1.2)	1.78 (*quint.*, *J* = 1.2)
	6.98 (*qq*, *J* = 7.0, 1.3)	7.02 (*qq*, *J* = 7.0, 1.3)	6.99 (*qq*, *J* = 7.0, 1.3)	6.94 (*qq*, *J* = 7.0, 1.3)

[a]) The *J*-values are given in Hz. '*m*' indicates either *multiplet* or overlapped signal. [b]) The δ values of the two H-atoms at C(9) may be slightly different (within 0.02 ppm), but the exact value of each H-atom could not be determined. [c]) The δ values of the two H-atoms at C(9) may be different (*ca.* 0.05 ppm), but the exact value of each H-atom could not be determined.

Table 4. *^{13}C-NMR Data* (C_6D_6) *of Compounds* **14**–**17**

Position[a])	**14a**	**15a**	**16a**	**17a**	**14b**	**15b**	**16b**	**17b**	**14c**	**15c**	**16c**	**17c**
1	74.8	74.6	76.2	75.9	73.9	73.9	75.3	75.1	74.6	74.4	75.6	75.3
2	40.2	40.9	41.1	41.0	40.8	40.9	41.0	40.9	41.0	41.1	41.1	41.1
3	31.2	31.2	31.2	31.2	31.2	31.2	31.2	31.2	31.3	31.3	31.3	31.3
4	34.4	34.5	34.5	34.4	34.5	34.6	34.5	34.5	34.5	34.7	34.6	34.6
5	33.6	33.6	32.8	33.0	33.4	33.5	33.0	33.1	33.5	33.6	33.4	33.4
6	45.6	45.7	44.9	44.9	46.3	46.4	45.3	45.3	46.5	46.6	45.1	45.5
7	150.4	149.8	149.7	150.0	150.8	150.2	149.7	149.9	150.8	150.2	149.6	149.8
8	74.2	74.2	74.9	74.7	73.5	73.6	74.3	74.2	73.8	73.9	75.1	74.6
9	34.1	33.4	33.5	33.8	34.4	34.0	33.9	34.0	34.4	33.6	33.9	34.4
10	60.6	60.5	60.4	60.7	60.8	60.8	60.5	60.7	61.0	60.9	60.5	60.8
11	57.5	56.9	56.7	57.6	57.6	56.9	56.7	57.5	57.6	57.0	56.9	57.6
12	19.0	19.0	19.0	19.0	19.1	19.0	19.0	19.1	19.1	19.0	19.0	19.0
13	24.7	24.7	24.6	24.7	24.8	24.7	24.7	24.8	24.8	24.7	24.6	24.8
14	110.1	110.5	111.0	111.0	108.6	109.3	111.1	111.2	109.2	109.4	111.8	111.7
15	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.1	22.0	22.0
1′	169.4	169.6	169.7	169.8	175.7	175.8	175.9	175.9	166.9	167.0	166.9	167.0
2′	20.8	20.8	21.0	21.0	34.4	34.3	34.3	34.3	129.5	129.3	129.3	129.2
3′	–	–	–	–	19.3	19.3	19.3	19.4	136.4	136.7	136.6	136.9
4′	–	–	–	–	19.2	19.2	19.1	19.1	14.0[b])	14.1	14.1	14.1
5′	–	–	–	–	–	–	–	–	12.3	12.3	12.3	12.3
1″	169.2	169.3	169.2	169.0	175.2	175.5	175.4	175.1	166.6	166.8	166.6	166.4
2″	20.8	20.8	20.7	20.6	34.4	34.4	34.5	34.4	129.3	129.2	129.2	129.2
3″	–	–	–	–	19.0	19.0	19.1	19.0	137.1	137.3	137.1	137.0
4″	–	–	–	–	19.1	19.1	19.1	19.1	14.1[b])	14.1	14.0	14.0
5″	–	–	–	–	–	–	–	–	12.2	12.2	12.2	12.1

[a]) The moieties with numbering of 1′–5′ and 1″–5″ indicate the acid part of the acyloxy group at C(1) and C(8), respectively. [b]) The assignment may be interchanged.

two *J*-values for H–C(8) of **14** was also observed ($|J(8,9a)-J(8,9b)|=5.4$ to 5.9 Hz). The ^{13}C-NMR data were too similar to distinguish isomers, as in $CDCl_3$ (*Table 4*).

The NMR spectra were also measured in CD_3OD (*Tables 5* and *6*). The difference of the *J*-value of H–C(10) between **16** and **17** was more distinct than in C_6D_6. Namely, H–C(10) was observed as *dd* ($|J(9a,10)-J(9b,10)|\geq 2$ Hz) in **16** and as a *triplet* in **17**. H–C(10) of **14** and **15** was observed as *triplet* (**14a**, **14c** and **15b**, **15c**) or *triplet*-like signal (**14b** and **15a**; $|J(9a,10)-J(9b,10)|\leq 1$ Hz), indicating that the 8α-acyloxy-10α-epoxide structure (*i.e.*, **16**) can be distinguished from the other stereoisomers (**14**, **15**, and **17**) only from NMR data in CD_3OD. However, other data such as the difference in δ- and *J*-values of H–C(8) were not distinct in CD_3OD. These data indicate that measurements of NMR spectra in various solvents are essential to determine the relative configuration.

As described, we isolated several bisabolane compounds from *Ligularia lankongensis*. Among them, compound **9** has *trans*-substituents at C(1) and C(6) with respect to the cyclohexane ring, as in the present model compounds (the absolute configuration of natural product has not been determined [12]). The δ value of H–C(8) of compound **9** (5.27 (*dd*, $J=5.0, 9.0$)) was very similar to that observed for **14** and **15**, suggesting that **9** has the C(8) configuration related to **14** or **15**. Two $CH_2(9)$ H-atoms were not separated (1.82–1.92 (*m*, 2 H)), suggesting that the compound has the same configuration as **15**. Thus, compound **9** is likely to have the structure either **9a** or its antipode.

Conclusions. – Twelve model compounds of highly O-bearing bisabolane sesquiterpenes **14a**–**14c**, **15a**–**15c**, **16a**–**16c**, and **17a**–**17c** were synthesized from isopulegol, using two non-stereoselective reactions to obtain all four possible stereoisomers. The NMR spectra of the compounds were compared. A distinct difference in chemical shifts in $CDCl_3$ was observed between 8β- and 8α-acyloxy isomers. Within the 8β-acyloxy compounds, the α-epoxides **14a**–**14c** and the β-epoxides **15a**–**15c** could be distinguished by either the *J*-value of H–C(8) or the chemical shift of $CH_2(9)$. Within the 8α-acyloxy compounds, the α-epoxides **16a**–**16c** and the β-epoxides **17a**–**17c** could be distinguished by the *J*-value of H–C(10) in C_6D_6 or in CD_3OD. Accordingly, the four stereoisomers can be distinguished by the NMR data. The present data will provide a guide regarding structural determination of natural products.

Experimental Part

General. Anal. TLC: *Merck Kieselgel 60 F_{254}* (0.2 mm thickness), using *p*-anisaldehyde/AcOH/H_2SO_4 as a visualizing agent. Column chromatography (CC): silica gel (*Wakogel C-200* or *C-300*). HPLC: *Kanto Mightysil Si60* (10 × 250 mm) column with a solvent system of hexane/AcOEt, *Shimadzu LC-20AT* pump, *SPD-20A Prominence* UV/VIS detector. Optical rotations: *JASCO DIP-370* digital polarimeter. IR Spectra: *JASCO FT/IR-230* spectrometer; $\tilde{\nu}$ in cm^{-1}. ^{1}H- and ^{13}C-NMR spectra: *JEOL ECX-400* (400 MHz for ^{1}H and 100 MHz for ^{13}C) or *JEOL ECA-500* (500 MHz for ^{1}H and 125 MHz for ^{13}C) spectrometer using $CDCl_3$ as the solvent unless otherwise noted; δ in ppm rel. to Me_4Si (0.00 ppm) or $CHCl_3$ (7.26 for ^{1}H and 77.0 ppm for ^{13}C) as internal standard, *J* in Hz. MS: *JEOL JMS-700V* (GC/MS (double focused), EI mode), *Agilent/Varian QFT-7* (hybrid of quadrupole and ICR/FT, ESI mode), or *Waters Synapt G2* (hybrid of quadrupole of TOF, ESI mode); in *m*/*z*.

*(3*S*)-2-[(1*S*,2*R*,4*R*)-2-{[*tert*-Butyl(dimethyl)silyl]oxy}-4-methylcyclohexyl]hexa-1,5-dien-3-ol* (**20**) *and (3*R*)-2-[(1*S*,2*R*,4*R*)-2-{[*tert*-Butyl(dimethyl)silyl]oxy}-4-methylcyclohexyl]hexa-1,5-dien-3-ol* (**21**).

Table 5. *^{1}H-NMR Data* (400 MHz; CD_3OD)[a]) *of Compounds* **14**–**17**

Position	**14a**	**15a**	**16a**[b])	**17a**
1	4.84[c]) (*dt*, *J* = 4.5, 10.9)	4.85[c]) (*dt*, *J* = 4.3, 10.9)	4.75 (*dt*, *J* = 4.2, 10.9)	4.75 (*dt*, *J* = 4.5, 10.8)
2α (eq)	1.95–2.03 (*m*)	1.97–2.04 (*m*)	1.95–2.02 (*m*)	1.95–2.03 (*m*)
2β (ax)	0.96–1.07 (*m*)	0.97–1.07 (*m*)	0.98–1.07 (*m*)	0.98–1.08 (*m*)
3	1.52–1.67 (*m*)	1.52–1.66 (*m*)	1.54–1.65 (*m*)	1.52–1.66 (*m*)
4α (eq)	1.65–1.73 (*m*)	1.66–1.73 (*m*)	1.66–1.72 (*m*)	1.66–1.73 (*m*)
4β (ax)	0.91–1.04 (*m*)	0.91–1.04 (*m*)	0.92–1.03 (*m*)	0.92–1.04 (*m*)
5α (ax)	1.21–1.34 (*m*)	1.22–1.35 (*m*)	1.40 (br. *dq*, *J* = 3.4, 13.1)	1.39 (br. *dq*, *J* = 3.2, 13.0)
5β (eq)	1.95–2.03 (*m*)	1.92–2.00 (*m*)	1.80–1.87 (*m*)	1.74–1.81 (*m*)
6	2.03–2.11 (*m*)	2.05–2.14 (*m*)	2.06–2.13 (*m*)	2.05–2.14 (*m*)
8	5.23 (*ddd*, *J* = 0.8, 6.1, 7.0)	5.29 (*dd*, *J* = 4.9, 7.6)	5.46 (*dd*, *J* = 4.8, 7.6)	5.39 (*dd*, *J* = 4.4, 8.8)
9	1.85–1.90[d]) (*m*, 2 H)	1.79–1.87 (*m*), 1.94–2.03 (*m*)	1.77–1.85 (*m*), 1.94–2.01 (*m*)	1.79–1.92[d]) (*m*, 2 H)
10	2.85 (*t*, *J* = 6.1)	2.81 (*dd*, *J* = 5.5, 6.4)	2.80 (*dd*, *J* = 4.6, 7.1)	2.82 (*t*, *J* = 6.2)
12	1.28 (*s*)	1.28 (*s*)	1.28 (*s*)	1.28 (*s*)
13	1.28 (*s*)	1.28 (*s*)	1.27 (*s*)	1.28 (*s*)
14*E*	4.98 (*s*)	5.02 (*s*)	5.04 (*s*)	5.03 (*s*)
14*Z*	5.13 (*s*)	5.14 (*s*)	5.13 (*s*)	5.13 (*s*)
15	0.95 (*d*, *J* = 6.6)	0.95 (*d*, *J* = 6.6)	0.95 (*d*, *J* = 6.6)	0.95 (*d*, *J* = 6.5)
AcO–C(1)	1.92 (*s*)	1.93 (*s*)	1.96 (*s*)	1.97 (*s*)
AcO–C(8)	2.07 (*s*)	2.06 (*s*)	2.06 (*s*)	2.07 (*s*)

Table 5 (cont.)

Position	**14b**	**15b**	**16b**[b])	**17b**
1	4.86 (*dt*, *J* = 4.3, 10.7)	4.86 (*dt*, *J* = 4.0, 10.7)	4.77 (*dt*, *J* = 4.2, 10.9)	4.77 (*dt*, *J* = 4.2, 10.8)
2α (eq)	1.96 – 2.03 (*m*)	1.96 – 2.03 (*m*)	1.95 – 2.02 (*m*)	1.94 – 2.01 (*m*)
2β (ax)	0.96 – 1.06 (*m*)	0.96 – 1.06 (*m*)	0.96 – 1.07 (*m*)	0.96 – 1.07 (*m*)
3	1.53 – 1.67 (*m*)	1.53 – 1.67 (*m*)	1.53 – 1.67 (*m*)	1.53 – 1.67 (*m*)
4α (eq)	1.67 – 1.74 (*m*)	1.67 – 1.74 (*m*)	1.66 – 1.73 (*m*)	1.66 – 1.73 (*m*)
4β (ax)	0.92 – 1.04 (*m*)	0.92 – 1.04 (*m*)	0.92 – 1.04 (*m*)	0.92 – 1.04 (*m*)
5α (ax)	1.16 – 1.30 (*m*)	1.18 – 1.31 (*m*)	1.37 (br. *dq*, *J* = 3.1, 13.0)	1.37 (br. *dq*, *J* = 3.1, 13.2)
5β (eq)	2.04 – 2.11 (*m*)	2.00 – 2.08 (*m*)	1.82 – 1.90 (*m*)	1.77 – 1.85 (*m*)
6	2.01 – 2.09 (*m*)	2.04 – 2.12 (*m*)	2.13 (br. *dt*, *J* = 3.5, 11.5)	2.15 (br. *dt*, *J* = 3.5, 11.5)
8	5.22 (*dd*, *J* = 3.4, 9.1)	5.31 (*dd*, *J* = 4.0, 8.2)	5.48 (*dd*, *J* = 4.3, 7.9)	5.40 (*dd*, *J* = 3.9, 9.0)
9	1.80 – 1.89 (*m*),	1.82 (*ddd*, *J* = 6.2, 8.2, 14.7),	1.80 – 1.90 (*m*),	1.77 – 1.85 (*m*),
	1.88 – 1.96 (*m*)	1.97 – 2.07 (*m*)	1.92 – 2.00 (*m*)	1.89 – 1.98 (*m*)
10	2.83 (*dd*, *J* = 5.5, 6.5)	2.80 (*t*, *J* = 5.8)	2.77 (*dd*, *J* = 4.7, 6.8)	2.80 (*t*, *J* = 6.0)
12	1.28 (*s*)	1.27 (*s*)	1.27 (*s*)	1.27 (*s*)
13	1.28 (*s*)	1.27 (*s*)	1.26 (*s*)	1.27 (*s*)
14*E*	4.93 (*s*)	4.97 (*s*)	5.04 (*s*)	5.02 (*s*)
14*Z*	5.09 (*s*)	5.11 (*s*)	5.16 (*s*)	5.15 (*s*)
15	0.95 (*d*, *J* = 6.5)	0.95 (*d*, *J* = 6.5)	0.95 (*d*, *J* = 6.5)	0.95 (*d*, *J* = 6.5)
$Me_2CHC(O)O$–C(1)	1.06 (*d*, *J* = 7.0)	1.06 (*d*, *J* = 7.0)	1.05 (*d*, *J* = 7.0)	1.05 (*d*, *J* = 7.0)
	1.08 (*d*, *J* = 7.0)	1.09 (*d*, *J* = 7.0)	1.09 (*d*, *J* = 7.0)	1.09 (*d*, *J* = 7.0)
	2.41 (*sept.*, *J* = 7.0)	2.43 (*sept.*, *J* = 7.0)	2.47 (*sept.*, *J* = 7.0)	2.48 (*sept.*, *J* = 7.0)
$Me_2CHC(O)O$–C(8)	1.18 (*d*, *J* = 7.0)	1.17 (*d*, *J* = 7.0)	1.16 (*d*, *J* = 7.0)	1.17 (*d*, *J* = 7.0)
	1.18 (*d*, *J* = 7.0)	1.17 (*d*, *J* = 7.0)	1.17 (*d*, *J* = 7.0)	1.17 (*d*, *J* = 7.0)
	2.59 (*sept.*, *J* = 7.0)	2.59 (*sept.*, *J* = 7.0)	2.58 (*sept.*, *J* = 7.0)	2.58 (*sept.*, *J* = 7.0)

Table 5 (cont.)

Position	**14c**	**15c**	**16c**[b])	**17c**
1	4.93 (*dt*, *J* = 4.0, 10.8)	4.95 (*dt*, *J* = 4.0, 10.8)	4.90 (*dt*, *J* = 4.0, 10.8)	4.88 (*dt*, *J* = 3.8, 10.8)
2α (eq)	1.98 – 2.06 (*m*)	1.98 – 2.06 (*m*)	1.97 – 2.04 (*m*)	1.98 – 2.05 (*m*)
2β (ax)	1.00 – 1.10 (*m*)	1.00 – 1.10 (*m*)	1.01 – 1.12 (*m*)	1.02 – 1.13 (*m*)
3	1.54 – 1.68 (*m*)	1.54 – 1.68 (*m*)	1.54 – 1.68 (*m*)	1.54 – 1.68 (*m*)
4α (eq)	1.68 – 1.75 (*m*)	1.68 – 1.76 (*m*)	1.65 – 1.73 (*m*)	1.65 – 1.73 (*m*)
4β (ax)	0.94 – 1.06 (*m*)	0.93 – 1.05 (*m*)	0.92 – 1.04 (*m*)	0.92 – 1.04 (*m*)
5α (ax)	1.21 – 1.34 (*m*)	1.21 – 1.34 (*m*)	1.28 – 1.41 (*m*)	1.29 – 1.42 (*m*)
5β (eq)	2.01 – 2.09 (*m*)	2.00 – 2.08 (*m*)	1.79 – 1.87 (*m*)	1.77 – 1.85 (*m*)
6	2.14 (br. *dt*, *J* = 3.2, 11.4)	2.16 (br. *dt*, *J* = 3.5, 11.5)	2.26 (br. *dt*, *J* = 3.2, 11.5)	2.27 (br. *dt*, *J* = 3.2, 11.5)
8	5.35 (*dd*, *J* = 3.1, 9.2)	5.38 (*dd*, *J* = 4.4, 7.5)	5.49 (*t*, *J* = 6.3)	5.48 (*dd*, *J* = 3.8, 8.7)
9	1.80 – 1.89 (*m*)	1.81 – 1.91 (*m*)	1.81 – 1.91 (*m*)	1.78 – 1.88 (*m*)
	1.90 – 1.98 (*m*)	1.96 – 2.06 (*m*)	1.92 – 2.01 (*m*)	1.88 – 1.98 (*m*)
10	2.81 (*t*, *J* = 5.9)	2.76 (*t*, *J* = 5.9)	2.70 (*dd*, *J* = 4.9, 6.9)	2.78 (*t*, *J* = 6.1)
12	1.24 (*s*)	1.25 (*s*)	1.25 (*s*)	1.23 (*s*)
13	1.23 (*s*)	1.24 (*s*)	1.22 (*s*)	1.22 (*s*)
14*E*	4.98 (*s*)	5.00 (*s*)	5.08 (*s*)	5.04 (*s*)
14*Z*	5.11 (*s*)	5.10 (*s*)	5.17 (*s*)	5.16 (*s*)
15	0.95 (*d*, *J* = 6.5)	0.95 (*d*, *J* = 6.5)	0.95 (*d*, *J* = 6.5)	0.95 (*d*, *J* = 6.5)
(*E*)-MeCH=CMeC(O)O–C(1)	1.72 – 1.76 (*m*)	1.72 – 1.76 (*m*)	1.73 – 1.77 (*m*)	1.73 – 1.77 (*m*)
	1.74 (br. *s*)	1.75 (br. *s*)	1.76 (br. *s*)	1.76 (br. *s*)
	6.70 – 6.77 (*m*)	6.70 – 6.78 (*m*)	6.74 – 6.81 (*m*)	6.74 – 6.81 (*m*)
(*E*)-MeCH=CMeC(O)O–C(8)	1.79 – 1.84 (*m*)	1.79 – 1.83 (*m*)	1.79 – 1.84 (*m*)	1.80 – 1.85 (*m*)
	1.83 (br. *s*)	1.83 (br. *s*)	1.83 (br. *s*)	1.83 (br. *s*)
	6.92 (br. *q*, *J* = 6.7)	6.91 (br. *q*, *J* = 6.7)	6.89 (br. *q*, *J* = 6.7)	6.90 (br. *q*, *J* = 6.7)

[a]) The solvent signal (3.30 ppm) was used as the reference. The *J*-values are given in Hz. '*m*' indicates either *multiplet* or overlapped signal. [b]) 500 MHz. [c]) The *J* value was observed from the spectrum taken at 308 K. [d]) The δ values of the two H-atoms at C(9) may be slightly different (within 0.02 ppm), but the exact value of each H-atom could not be determined.

Table 6. *^{13}C-NMR Data* (CD_3OD) *of Compounds* **14**–**17**

Position[a])	**14a**	**15a**	**16a**	**17a**	**14b**	**15b**	**16b**	**17b**	**14c**	**15c**	**16c**	**17c**
1	76.4	76.4	78.0	77.8	75.5	75.5	77.0	76.8	75.9	75.8	77.1	76.8
2	41.7	41.7	41.8	41.8	41.6	41.6	41.7	41.7	41.7	41.7	41.8	41.8
3	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.6	32.6	32.6	32.6
4	35.5	35.5	35.5	35.4	35.5	35.5	35.5	35.4	35.5	35.5	35.5	35.5
5	34.5	34.5	33.8	34.0	34.3	34.3	34.0	34.1	34.2	34.3	34.4	34.4
6	46.3	46.5	45.6	45.7	47.1	47.1	46.0	46.0	47.4	47.4	45.7	46.1
7	151.2	150.7	150.7	151.1	151.5	151.0	150.6	150.9	151.4	150.9	150.3	150.8
8	75.3	75.5	76.3	75.9	74.5	74.8	75.7	75.3	74.5	74.8	76.4	75.7
9	34.6	34.0	33.8	34.2	34.8	34.5	34.2	34.5	34.9	34.1	34.0	34.9
10	62.6	62.7	62.6	62.7	62.6	62.7	62.5	62.6	62.7	62.7	62.5	62.7
11	60.2	59.5	59.3	60.2	60.1	59.2	59.2	60.1	60.0	59.3	59.4	60.1
12	19.1	19.1	19.1	19.1	19.2	19.1	19.1	19.1	19.1	19.1	19.1	19.1
13	24.9	24.8	24.8	24.9	24.9	24.9	24.8	24.9	24.9	24.8	24.8	24.9
14	111.0	111.4	111.8	111.7	109.6	110.2	111.9	111.9	110.4	110.6	112.7	112.6
15	22.3	22.3	22.3	22.3	22.4	22.4	22.3	22.3	22.4	22.4	22.3	22.4
1′	172.2	172.3	172.4	172.5	178.1	178.1	178.3	178.3	168.8	168.9	168.8	168.9
2′	21.1	21.1	21.3	21.2	35.3	35.3	35.3	35.3	129.9	129.8	129.8	129.8[c])
3′	–	–	–	–	19.4	19.3	19.2	19.2	138.3	138.4	138.5	138.6
4′	–	–	–	–	19.5	19.5	19.6	19.6	14.4	14.4	14.4	14.4
5′	–	–	–	–	–	–	–	–	12.2	12.2	12.2[b])	12.2
1″	171.8	171.8	171.6	171.5	177.4	177.5	177.4	177.4	168.3	168.4	168.2	168.2
2″	21.2	21.2	21.1	21.0	35.3	35.4	35.4	35.4	129.7	129.8	129.8	129.7[c])
3″	–	–	–	–	19.3	19.3	19.3	19.3	139.1	139.0	139.0	139.1
4″	–	–	–	–	19.4	19.3	19.4	19.5	14.5	14.5	14.4	14.5
5″	–	–	–	–	–	–	–	–	12.2	12.2	12.1[b])	12.2

[a]) The moieties with numbering of 1′–5′ and 1″–5″ indicate the acid part of the acyloxy group at C(1) and C(8), respectively. [b])[c]) The assignment may be interchanged.

To a stirred soln. of **19** [14] (421.2 mg, 1.49 mmol) in dry Et_2O (16 ml), a soln. of allyl magnesium chloride (2M in THF, 1.50 ml, 2.98 mmol) was added at $-50°$ under Ar. After stirring for 1 h, an aq. soln. of NH_4Cl was added, and the mixture was extracted with Et_2O and dried (Na_2SO_4). Evaporation of the solvent followed by CC (SiO_2, 10 g) using hexane/AcOEt 99:1 as eluent afforded a mixture of **20** and **21** (374.3 mg, 77%), which was separated by HPLC to yield **20** (137.0 mg) and **21** (149.5 mg).

Data of **20**: Oil. $[\alpha]_D^{23.3} = -73.0$ ($c = 0.1$, MeOH). IR (neat): 3455, 1643, 1254, 1054, 834. ^{1}H-NMR: 0.03 (*s*, 3 H); 0.07 (*s*, 3 H); 0.87 (*s*, 9 H); 0.93 (*d*, $J = 6.5$, Me); 1.08 (*dt*, $J = 10.9, 12.2$, 1 H); 1.33–1.71 (*m*, 5 H); 1.89 (*ddt*, $J = 1.5, 12.4, 3.6$, 1 H); 2.13–2.21 (*m*, 2 H); 2.35 (*dt*, $J = 14.0, 6.9$, 1 H); 3.41 (*dt*, $J = 3.9, 10.2$, H–C(1)); 3.98 (br., OH); 4.13 (*t*, $J = 6.9$, H–C(8)); 4.91 (*s*, =CH_2, 1 H); 4.98 (*s*, =CH_2, 1 H); 5.01–5.09 (*m*, CH_2(11)); 5.77 (*ddt*, $J = 10.0, 17.2, 7.1$, H–C(10)). ^{13}C-NMR: −4.5 (Me); −4.4 (Me); 18.0 (C); 22.2 (Me); 25.8 (*t*-Bu); 31.7 (CH); 32.1 (CH_2); 34.5 (CH_2); 41.3 (CH_2); 43.8 (CH); 44.7 (CH_2); 76.0 (CH); 78.6 (CH); 110.6 (CH_2); 116.7 (CH_2); 135.2 (CH); 153.5 (C). EI-MS: 306 (0.4, $[M - H_2O]^+$), 283 (23), 267 (12), 225 (25), 175 (53), 133 (59), 81 (91), 75 (100). HR-MS: 306.2366 ($[M - H_2O]^+$, $C_{19}H_{34}OSi^+$; calc. 306.2380).

Data of **21**: Oil. $[\alpha]_D^{23.5} = -47.2$ ($c = 0.1$, MeOH). IR (neat): 3448, 1643, 1254, 1063, 835. ^{1}H-NMR: −0.01 (*s*, 3 H); 0.04 (*s*, 3 H); 0.85 (*s*, 9 H); 0.92 (*d*, $J = 6.5$, Me); 1.03 (*dt*, $J = 10.9, 12.2$, 1 H); 1.33 (*dq*, $J = 3.3, 13.1$, 1 H); 1.42–1.74 (*m*, 4 H); 1.81–1.91 (*m*, 2 H); 2.24 (*dt*, $J = 14.4, 7.2$, 1 H); 2.40–2.48 (*m*, 1 H); 3.47 (*dt*, $J = 4.1, 10.2$, H–C(1)); 3.55 (br., OH); 4.07 (*dd*, $J = 4.3, 7.5$, H–C(8)); 4.92 (*s*, =CH_2, 1 H); 5.14 (*s*, =CH_2, 1 H); 5.08–5.16 (*m*, CH_2(11)); 5.88 (*ddt*, $J = 10.0, 17.1, 6.9$, H–C(10)). ^{13}C-NMR: −4.4 (2 Me); 17.9 (C); 22.2 (Me); 25.8 (*t*-Bu); 31.6 (CH); 32.5 (CH_2); 34.6 (CH_2); 39.4 (CH_2); 45.2 (CH_2); 48.3 (CH); 73.9 (CH); 77.3 (CH); 107.7 (CH_2); 117.3 (CH_2); 135.4 (CH); 155.0 (C). EI-MS: 306 (0.3, $[M - H_2O]^+$), 283 (7), 267 (13), 225 (18), 175 (55), 133 (49), 81 (93), 75 (100). HR-MS: 306.2375 ($[M - H_2O]^+$, $C_{19}H_{34}OSi^+$; calc. 306.2380).

Mosher's *Esters* (**22a**, **22b**, **23a**, **23b**). To a stirred soln. of **21** (13.5 mg, 0.043 mmol) in CH_2Cl_2 (1 ml), Et_3N (0.035 ml, 0.35 mmol) and (+)-MTPACl (0.015 ml, 0.059 mmol) were added at r.t. under Ar. After stirring for 2 h, H_2O was added, and the mixture was extracted with Et_2O. The org. layer was washed successively with 1M HCl and aq. $NaHCO_3$ and dried (Na_2SO_4). Evaporation of the solvent followed by CC (SiO_2, 9 g) afforded **23a** (19.3 mg, 83%). In the same way, compounds **22a**, **22b**, and **23b** were prepared.

*(3S)-2-[(1S,2R,4R)-2-{[*tert*-Butyl(dimethyl)silyl]oxy}-4-methylcyclohexyl]hexa-1,5-dien-3-yl (2R)-3,3,3-Trifluoro-2-methoxy-2-phenylpropanoate* (**22a**). ^{1}H-NMR: −0.07 (*s*, 3 H); 0.02 (*s*, 3 H); 0.72–1.97 (*m*, 7 H); 0.83 (*s*, 9 H); 0.90 (*d*, $J = 6.3$, Me–C(3)); 1.64 (*ddd*, $J = 3.3, 10.0, 12.1$, H–C(6)); 2.33 (br. *dt*, $J = 15, 9$, H–C(9)); 2.71 (*dddt*, $J = 2.8, 6.0, 15.3, 1.5$, H–C(9)); 3.52–3.60 (*m*, H–C(1)); 3.57 (*s*, MeO); 4.81 (br. *s*, =CH_2, 1 H); 4.86 (br. *s*, =CH_2, 1 H); 5.05–5.15 (*m*, CH_2(11)); 5.30 (*dd*, $J = 2.4, 9.4$, H–C(8)); 5.81 (*ddt*, $J = 10.1, 16.9, 6.9$, H–C(10)); 7.34–7.56 (*m*, 5 arom. H).

*(3S)-2-[(1S,2R,4R)-2-{[*tert*-Butyl(dimethyl)silyl]oxy}-4-methylcyclohexyl]hexa-1,5-dien-3-yl (2S)-3,3,3-Trifluoro-2-methoxy-2-phenylpropanoate* (**22b**). ^{1}H-NMR: −0.04 (*s*, 3 H); 0.04 (*s*, 3 H); 0.78–1.97 (*m*, 7 H); 0.83 (*s*, 9 H); 0.91 (*d*, $J = 6.6$, Me–C(3)); 1.72 (*ddd*, $J = 3.3, 10.0, 12.1$, H–C(6)); 2.30 (br. *dt*, $J = 15, 8$, H–C(9)); 2.64 (*dddt*, $J = 3.0, 6.4, 15.2, 1.6$, H–C(9)); 3.61 (*dt*, $J = 4.2, 10.1$, H–C(1)); 3.52 (*s*, MeO); 4.94 (br. *s*, =CH_2, 1 H); 4.93–5.13 (*m*, CH_2(11)); 5.13 (br. *s*, =CH_2, 1 H); 5.35 (*dd*, $J = 2.6, 9.2$, H–C(8)); 5.67 (*ddt*, $J = 10.1, 16.9, 6.8$, H–C(10)); 7.34–7.55 (*m*, 5 arom. H).

*(3R)-2-[(1S,2R,4R)-2-{[*tert*-Butyl(dimethyl)silyl]oxy}-4-methylcyclohexyl]hexa-1,5-dien-3-yl (2R)-3,3,3-Trifluoro-2-methoxy-2-phenylpropanoate* (**23a**). ^{1}H-NMR: −0.06 (*s*, 3 H); 0.03 (*s*, 3 H); 0.71–1.68 (*m*, 6 H); 0.84 (*s*, 9 H); 0.91 (*d*, $J = 6.9$, Me–C(3)); 1.83 (*ddd*, $J = 3.0, 9.4, 12.6$, H–C(6)); 1.87 (br. *q*, $J = 12$, H–C(2)); 2.42–2.56 (*m*, CH_2(9)); 3.52 (br. *s*, MeO); 3.52 (*dt*, $J = 4.0, 10.5$, H–C(1)); 4.93–4.99 (*m*, CH_2(11)); 4.98 (br. *s*, =CH_2, 1 H); 5.21 (br. *s*, =CH_2, 1 H); 5.64 (*ddt*, $J = 9.8, 16.9, 7.2$, H–C(10)); 5.61–5.66 (*m*, H–C(8)); 7.32–7.59 (*m*, 5 arom. H).

*(3R)-2-[(1S,2R,4R)-2-{[*tert*-Butyl(dimethyl)silyl]oxy}-4-methylcyclohexyl]hexa-1,5-dien-3-yl (2S)-3,3,3-Trifluoro-2-methoxy-2-phenylpropanoate* (**23b**). ^{1}H-NMR: −0.07 (*s*, 3 H); 0.01 (*s*, 3 H); 0.71–1.68 (*m*, 6 H); 0.84 (*s*, 9 H); 0.89 (*d*, $J = 6.6$, Me–C(3)); 1.79 (*ddd*, $J = 3.0, 9.4, 12.6$, H–C(6)); 1.87 (br. *q*, $J = 12$, H–C(2)); 2.55 (*t*-like, $J = 6.8$, CH_2(9)); 3.56 (br. *s*, MeO); 3.48 (*dt*, $J = 4.0, 10.2$, H–C(1)); 4.93 (br. *s*, =CH_2, 1 H); 5.03–5.11 (*m*, CH_2(11)); 5.12 (br. *s*, =CH_2, 1 H); 5.62 (*t*-like, $J = 5.6$, H–C(8)); 5.76 (*ddt*, $J = 10.1, 17.2, 6.9$, H–C(10)); 7.32–7.59 (*m*, 5 arom. H).

*(3S)-2-[(1S,2R,4R)-2-{[*tert*-Butyl(dimethyl)silyl]oxy}-4-methylcyclohexyl]-6-methylhepta-1,5-dien-3-ol* (**24**) *and (3R)-2-[(1S,2R,4R)-2-{[*tert*-Butyl(dimethyl)silyl]oxy}-4-methylcyclohexyl]-6-methylhepta-1,5-dien-3-ol* (**25**). In a 30 ml two-necked flask, *Grubbs* II catalyst (1.4 mg, 0.0017 mmol) and **20** (23.6 mg, 0.07 mmol) were dissolved in 2-methylbut-2-ene (2.5 ml) under Ar. After stirring at r.t. for 1 h, the solvent was evaporated, and the residue was chromatographed (SiO_2, 6 g) using hexane/AcOEt (gradient) to afford **24** (22.7 mg, 89%). By the same procedure, **21** (82.5 mg, 0.25 mmol) yielded **25** (74.3 mg, 83%).

Data of **24**: Oil. $[\alpha]_D^{23} = -61.2$ ($c = 0.1$, MeOH). IR (neat): 3460, 1645, 1450, 1254, 1055. ^{1}H-NMR: 0.03 (*s*, Me); 0.07 (*s*, Me); 0.87 (*s*, *t*-Bu, 9 H); 0.93 (*d*, $J = 6.5$, Me); 1.08 (*dt*, $J = 11.0, 12.2$, 1 H); 1.33–1.69 (*m*, 5 H); 1.61 (br. *s*, Me); 1.69 (*q*, $J = 1.0$, Me); 1.86–1.92 (*m*, 1 H); 2.05–2.35 (*m*, 3 H); 3.41 (*dt*, $J = 4.0, 10.3$, H–C(1)); 3.91 (*d*, $J = 1.3$, OH); 4.07 (br. *t*, $J = 6.9$, H–C(8)); 4.89 (*s*, =CH_2, 1 H); 4.97 (*s*, =CH_2, 1 H); 5.06–5.12 (*m*, H–C(10)). ^{13}C-NMR: −4.5; −4.4; 18.0 (2 C); 22.2; 25.8 (4 C); 31.7; 32.3; 34.6; 35.2; 43.9; 44.8; 76.3; 78.5; 110.4; 120.5; 133.0; 153.9. EI-MS: 352 (0.2, M^+), 295 (11), 283 (67), 203 (32), 151 (100), 133 (80), 75 (72). HR-MS: 295.2089 ([$M - t$-Bu]$^+$, $C_{17}H_{31}O_2Si^+$; calc. 295.2094).

Data of **25**: Oil. $[\alpha]_D^{23} = -43.0$ ($c = 0.1$, MeOH). IR (neat): 3354, 1651, 1452, 1261, 1053. ^{1}H-NMR: −0.01 (*s*, Me); 0.04 (*s*, Me); 0.85 (*s*, *t*-Bu, 9 H); 0.92 (*d*, $J = 6.5$, Me); 1.02 (*dt*, $J = 10.9, 12.2$, 1 H); 1.32 (*dq*, $J = 3.4, 13.0$, 1 H); 1.42–1.73 (*m*, 4 H); 1.64 (br. *s*, Me); 1.72 (*q*, $J = 1.0$, Me); 1.80–1.91 (*m*, 2 H); 2.16–2.39 (*m*, 2 H); 2.47 (*d*, $J = 3.7$, OH); 3.47 (*dt*, $J = 4.3, 10.2$, H–C(1)); 4.02 (*dt*-like, $J = 7.0, 4.0$, H–C(8)); 4.90 (*s*, =CH_2, 1 H); 5.12 (*s*, =CH_2, 1 H); 5.16–5.22 (*m*, H–C(10)). ^{13}C-NMR: −4.4 (2 C); 18.0 (2 C); 22.2; 25.9 (4 C); 31.6; 32.6; 33.8; 34.7; 45.3; 48.4; 74.7; 77.2; 107.5; 120.7; 134.1; 155.2. EI-MS: 352 (0.4, M^+), 295 (11), 283 (41), 225 (55), 203 (39), 151 (100), 133 (97), 75 (96). HR-MS: 295.2086 ([$M - t$-Bu]$^+$, $C_{17}H_{31}O_2Si^+$; calc. 295.2094).

*(2S)-3-[(1S,2R,4R)-2-{[*tert*-Butyl(dimethyl)silyl]oxy}-4-methylcyclohexyl]-1-(3,3-dimethyloxiran-2-yl)but-3-en-2-ol* (**27** and **28**) *and (2R)-3-[(1S,2R,4R)-2-{[*tert*-Butyl(dimethyl)silyl]oxy}-4-methylcyclohexyl]-1-(3,3-dimethyloxiran-2-yl)but-3-en-2-ol* (**29** and **30**). By *m*-CPBA: To a stirred soln. of **24** (8.5 mg, 0.024 mmol) in CH_2Cl_2 (2 ml), *m*-CPBA (4.7 mg, 0.07 mmol) was added at −30°. After stirring for 3.5 h, a sat. aq. soln. of $NaHCO_3$ was added, and the mixture was extracted with CH_2Cl_2 and dried (Na_2SO_4). Evaporation of the solvent followed by CC (SiO_2, 6 g) using Et_2O/AcOEt (gradient) as eluent afforded an inseparable mixture of **27** and **28** (7.1 mg, 80%). Similarly, **25** (10.0 mg, 0.028 mmol) was treated with *m*-CPBA (6.8 mg, 0.04 mmol) to afford a mixture of **29** and **30** (11.7 mg, 89%), which was used in the next step without purification.

By *Yamamoto*'s method: To a stirred soln. of **26a** (40.9 mg, 0.12 mmol) in toluene (1 ml), $VO(O^iPr)_3$ (3 µl, 0.013 mmol) was added, and the mixture was stirred for 1 h at r.t. After being cooled to 0°, a soln. of **24** (8.8 mg, 0.012 mmol) in toluene (1 ml) was added, and the stirring was continued for an additional 4.5 h. A sat. aq. soln. of Na_2SO_3 was added, and the mixture was extracted with Et_2O and dried (Na_2SO_4). Evaporation of the solvent followed by CC (SiO_2, 5 g) using hexane/AcOEt (gradient) afforded **28** (13.1 mg, 30%). Similarly, **25** (13.8 mg, 0.039 mmol) was treated with **26a** (5.9 mg, 0.008 mmol) and $VO(O^iPr)_3$ (3 µl, 0.013 mmol) at 0° for 3.5 h to afford **29** (8.8 mg, 61%).

Data of **28**: Oil. $[\alpha]_D^{21} = -42.0$ ($c = 0.05$, MeOH). IR (neat): 3444, 1450, 1255, 1049. ^{1}H-NMR: 0.03 (*s*, Me); 0.07 (*s*, Me); 0.87 (*s*, *t*-Bu, 9 H); 0.94 (*d*, $J = 6.5$, Me); 1.01–1.93 (*m*, 9 H); 1.27 (*s*, Me); 1.30 (*s*, Me); 2.19 (*ddd*, $J = 3.2, 9.9, 12.7$, 1 H); 2.78 (*dd*, $J = 5.0, 7.4$, H–C(10)); 3.42 (*dt*, $J = 4.0, 10.4$, H–C(1)); 4.04 (*d*, $J = 0.7$, OH); 4.29 (*t*, $J = 7.2$, H–C(8)); 4.96 (*s*, =CH_2, 1 H); 5.08 (*s*, =CH_2, 1 H). ^{13}C-NMR: −4.5; −4.4; 18.0; 19.0; 22.2; 24.8; 25.8 (3 C); 31.7; 32.4; 34.5; 35.8; 43.9; 44.8; 57.9; 61.5; 74.1; 78.6; 110.8; 153.6. EI-MS: 368 (1, M^+); 311 (30), 225 (58), 149 (46), 75 (100), 71 (96). HR-MS: 311.2047 ([$M - t$-Bu]$^+$, $C_{17}H_{31}O_3Si^+$; calc. 311.2043).

Data of **29**: Oil. $[\alpha]_D^{21} = -36.6$ ($c = 0.1$, MeOH). IR (neat): 3456, 1452, 1257, 1082. ^{1}H-NMR: −0.01 (*s*, Me); 0.05 (*s*, Me); 0.84 (*s*, *t*-Bu, 9 H); 0.92 (*d*, $J = 6.5$, Me); 1.07–1.95 (*m*, 11 H); 1.29 (*s*, Me); 1.33 (*s*, Me); 2.99 (*dd*, $J = 5.5, 6.5$, H–C(10)); 3.48 (*dt*, $J = 4.0, 10.1$, H–C(1)); 4.24 (*dd*, $J = 3.6, 8.0$, H–C(8)); 4.99 (*s*, =CH_2, 1 H); 5.17 (*s*, =CH_2, 1 H). ^{13}C-NMR: −4.4; −4.3; 18.0; 19.0; 22.2; 24.8; 25.9 (3 C); 31.6; 32.6; 34.1; 34.6; 45.2; 48.2; 57.9; 62.2; 73.6; 107.9; 154.8 (one C-atom signal overlapped with the signal of $CDCl_3$). EI-MS: 368 (3, M^+), 311 (55), 225 (52), 149 (52), 75 (100), 71 (99). HR-MS: 368.2733 (M^+, $C_{21}H_{40}O_3Si^+$; calc. 368.2748).

*(1*R*,2*S*,5*R*)-2-[(3*S*)-4-(3,3-Dimethyloxiran-2-yl)-3-hydroxybut-1-en-2-yl]-5-methylcyclohexanol* (**31** and **32**) *and (1*R*,2*S*,5*R*)-2-[(3*R*)-4-(3,3-Dimethyloxiran-2-yl)-3-hydroxybut-1-en-2-yl]-5-methylcyclohexanol* (**33** and **34**). A mixture of **27** and **28** (7.1 mg, 0.02 mmol) was dissolved in THF (2 ml). TBAF (0.02 ml, 0.02 mmol) was added, and the mixture was stirred at r.t. for 30 min. A sat. aq. soln. of NH_4Cl was added, and the mixture was extracted with AcOEt. After drying (Na_2SO_4), the solvent was evaporated, and the resultant residue was chromatographed (SiO_2, 6 g) using hexane/AcOEt (gradient) to give a mixture of **31** and **32** (4.9 mg, 100%). By the same procedure, a mixture of **29** and **30** (29.4 mg, 0.080 mmol) afforded a mixture of **33** and **34** (19.6 mg, 96%); **28** (10.5 mg, 0.028 mmol), obtained by *Yamamoto*'s epoxidation, afforded **32** (6.9 mg, 97%); **29** (23.1 mg, 0.063 mmol) afforded **33** (11.9 mg, 74%).

Data of **32**: Oil. $[\alpha]_D^{24} = -16.0$ ($c = 0.025$, MeOH). IR (neat): 3200–3400, 1647, 1444, 1039. ^{1}H-NMR: 0.95 (*d*, $J = 6.5$, Me); 0.97–2.05 (*m*, 12 H); 1.30 (*s*, Me); 1.32 (*s*, Me); 2.94 (*dd*, $J = 3.7$, 8.5, H–C(10)); 3.53 (*dt*, $J = 4.1$, 10.5, H–C(1)); 4.38 (*dd*, $J = 5,8$, 6.6, H–C(8)); 5.08 (*s*, $=CH_2$, 1 H); 5.26 (*s*, $=CH_2$, 1 H). ^{13}C-NMR: 18.9; 22.1; 24.7; 31.4; 32.7; 34.2; 34.6; 43.7; 46.5; 57.9; 61.7; 73.7; 74.6; 111.5; 153.5. EI-MS: 254 (19, M^+), 236 (17), 182 (15), 81 (59), 71 (100). HR-MS: 254.1880 (M^+, $C_{15}H_{26}O_3^+$; calc. 254.1883).

Data of **33**: Oil. $[\alpha]_D^{24} = -22.8$ ($c = 0.05$, MeOH). IR (neat): 3402, 1646, 1454, 1051. ^{1}H-NMR: 0.94 (*d*, $J = 6.5$, Me); 0.97–2.07 (*m*, 12 H); 1.31 (*s*, Me); 1.33 (*s*, Me); 2.98 (*dd*, $J = 4.2$, 8.2, H–C(10)); 3.52 (*dt*, $J = 4.0$, 10.4, H–C(1)); 4.35 (*dd*, $J = 4.0$, 8.0, H–C(8)); 5.08 (*s*, $=CH_2$, 1 H); 5.28 (*s*, $=CH_2$, 1 H). ^{13}C-NMR: 19.0; 22.2; 24.7; 31.5; 32.3; 34.1; 34.6; 43.7; 49.4; 58.1; 62.3; 73.5; 74.5; 110.4; 153.7. EI-MS: 254 (6, M^+), 236 (14), 190 (17), 71 (82), 43 (100). HR-MS: 254.1879 (M^+, $C_{15}H_{26}O_3^+$; calc. 254.1883).

*(1*R*,2*S*,5*R*)-2-{(3*S*)-3-(Acetyloxy)-4-[(2*S*)-3,3-dimethyloxiran-2-yl]but-1-en-2-yl}-5-methylcyclohexyl Acetate* (**14a**), *(1*R*,2*S*,5*R*)-2-{(3*S*)-3-(Acetyloxy)-4-[(2*R*)-3,3-dimethyloxiran-2-yl]but-1-en-2-yl}-5-methylcyclohexyl Acetate* (**15a**), *(1*R*,2*S*,5*R*)-2-{(3*R*)-3-(Acetyloxy)-4-[(2*S*)-3,3-dimethyloxiran-2-yl]-but-1-en-2-yl}-5-methylcyclohexyl Acetate* (**16a**), *and (1*R*,2*S*,5*R*)-2-{(3*R*)-3-(Acetyloxy)-4-[(2*R*)-3,3-dimethyloxiran-2-yl]but-1-en-2-yl}-5-methylcyclohexyl Acetate* (**17a**). To a stirred soln. of a mixture of **31** and **32** (4.9 mg, 0.02 mmol) in pyridine (2 ml), Ac_2O (10 µl) was added, and the mixture was stirred at r.t. for 1 d. H_2O was added, the mixture was extracted with Et_2O, and the org. layer was dried (Na_2SO_4). Evaporation of the solvent followed by CC (SiO_2, 6 g) using hexane/AcOEt (gradient) afforded a mixture of **14a** and **15a** (5.4 mg, 83%), which was further separated by HPLC. By the same procedure, a mixture of **33** and **34** (19.6 mg, 0.077 mmol) was acetylated to yield a mixture of **16a** and **17a** (22.0 mg, 84%), which was separated by HPLC. Compound **32** (15.3 mg, 0.06 mmol) afforded **15a** (20.9 mg, 99%); **33** (37.0 mg, 0.15 mmol) afforded **16a** (47.3 mg, 93%).

Data of **14a**: Oil. $[\alpha]_D^{26} = -40.5$ ($c = 0.2$, MeOH). IR (neat): 1738, 1664, 1242, 1034. ^{1}H-NMR: *Tables 1*, *3*, and *5*. ^{13}C-NMR: *Tables 2*, *4*, and *6*. EI-MS: 278 (3, $[M - AcOH]^+$), 218 (36), 81 (28), 43 (100). HR-MS: 278.1881 ($[M - AcOH]^+$, $C_{17}H_{26}O_3^+$; calc. 278.1883).

Data of **15a**: Oil. $[\alpha]_D^{26} = -27.2$ ($c = 0.42$, MeOH). IR (neat): 1737, 1651, 1241, 1027. ^{1}H-NMR: *Tables 1*, *3*, and *5*. ^{13}C-NMR: *Tables 2*, *4*, and *6*. EI-MS: 278 (2, $[M - AcOH]^+$), 218 (27), 85 (48), 43 (100). HR-MS: 278.1886 ($[M - AcOH]^+$, $C_{17}H_{26}O_3^+$; calc. 278.1883).

Dat of **16a**: Oil. $[\alpha]_D^{26} = -22.9$ ($c = 0.37$, MeOH). IR (neat): 1738, 1648, 1243, 1027. ^{1}H-NMR: *Tables 1*, *3*, and *5*. ^{13}C-NMR: *Tables 2*, *4*, and *6*. EI-MS: 278 (2, $[M - AcOH]^+$), 218 (26), 85 (41), 43 (100). HR-MS: 278.1882 ($[M - AcOH]^+$, $C_{17}H_{26}O_3^+$; calc. 278.1883).

Data of **17a**: Oil. $[\alpha]_D^{26} = -23.9$ ($c = 0.24$, MeOH). IR (neat): 1738, 1664, 1242, 1036. ^{1}H-NMR: *Tables 1*, *3*, and *5*. ^{13}C-NMR: *Tables 2*, *4*, and *6*. EI-MS: 278 (2, $[M - AcOH]^+$), 218 (17), 85 (22), 43 (100). HR-MS: 278.1888 ($[M - AcOH]^+$, $C_{17}H_{26}O_3^+$; calc. 278.1883).

*(2*S*)-1-[(2*S*)-3,3-Dimethyloxiran-2-yl]-3-{(1*S*,2*R*,4*R*)-4-methyl-2-[(2-methylpropanoyl)oxy]cyclohexyl}but-3-en-2-yl 2-Methylpropanoate* (**14b**), *(2*S*)-1-[(2*R*)-3,3-Dimethyloxiran-2-yl]-3-{(1*S*,2*R*,4*R*)-4-methyl-2-[(2-methylpropanoyl)oxy]cyclohexyl}but-3-en-2-yl 2-Methylpropanoate* (**15b**), *(2*R*)-1-[(2*S*)-3,3-Dimethyloxiran-2-yl]-3-{(1*S*,2*R*,4*R*)-4-methyl-2-[(2-methylpropanoyl)oxy]cyclohexyl}but-3-en-2-yl 2-Methylpropanoate* (**16b**), *and (2*R*)-1-[(2*R*)-3,3-Dimethyloxiran-2-yl]-3-{(1*S*,2*R*,4*R*)-4-methyl-2-[(2-methylpropanoyl)oxy]cyclohexyl}but-3-en-2-yl 2-Methylpropanoate* (**17b**). By the same procedure, a mixture of **31** and **32** (60.8 mg, 0.24 mmol) was treated with isobutyric anhydride (160 µl) to afford a

mixture of **14b** and **15b** (88.7 mg, 94%), and the two compounds were separated. Similarly, a mixture of **33** and **34** afforded **15b** and **16b** (81%); **32** afforded **15b** (45%); **33** afforded **16b** (42%).

Data of **14b**: Oil. $[\alpha]_D^{21} = -78.4$ ($c = 0.40$, MeOH). IR (neat): 1734, 1653, 1157. ^{1}H-NMR: *Tables 1*, *3*, and *5*. ^{13}C-NMR: *Tables 2*, *4*, and *6*. ESI-MS: 417 ($[M+Na]^+$). HR-MS: 417.2610 ($[M+Na]^+$, $C_{23}H_{38}NaO_5^+$; calc. 417.2617).

Data of **15b**: Oil. $[\alpha]_D^{23} = -28.2$ ($c = 0.44$, MeOH). IR (neat): 1735, 1651, 1158. ^{1}H-NMR: *Tables 1*, *3*, and *5*. ^{13}C-NMR: *Tables 2*, *4*, and *6*. ESI-MS: 417 ($[M+Na]^+$). HR-MS: 417.2614 ($[M+Na]^+$, $C_{23}H_{38}NaO_5^+$; calc. 417.2617).

Data of **16b**: Oil. $[\alpha]_D^{23} = -19.0$ ($c = 0.56$, MeOH). IR (neat): 1733, 1652, 1159. ^{1}H-NMR: *Tables 1*, *3*, and *5*. ^{13}C-NMR: *Tables 2*, *4*, and *6*. ESI-MS: 417 ($[M+Na]^+$. HR-MS: 417.2614 ($[M+Na]^+$, $C_{23}H_{38}NaO_5^+$; calc. 417.2617).

Data of **17b**: Oil. $[\alpha]_D^{21} = -8.8$ ($c = 0.24$, MeOH). IR (neat): 1734, 1651, 1157. ^{1}H-NMR: *Tables 1*, *3*, and *5*. ^{13}C-NMR: *Tables 2*, *4*, and *6*. ESI-MS: 417 ($[M+Na]^+$). HR-MS: 417.2611 ($[M+Na]^+$, $C_{23}H_{38}NaO_5^+$; calc. 417.2617).

*(1*R*,2*S*,5*R*)-2-[(3*S*)-4-[(2*S*)-3,3-Dimethyloxiran-2-yl]-3-{[(2*E*)-2-methylbut-2-enoyl]oxy}but-1-en-2-yl]-5-methylcyclohexyl (2*E*)-2-Methylbut-2-enoate* (**14c**), *(1*R*,2*S*,5*R*)-2-[(3*S*)-4-[(2*R*)-3,3-Dimethyloxiran-2-yl]-3-{[(2*E*)-2-methylbut-2-enoyl]oxy}but-1-en-2-yl]-5-methylcyclohexyl (2*E*)-2-Methylbut-2-enoate* (**15c**), *(1*R*,2*S*,5*R*)-2-[(3*R*)-4-[(2*S*)-3,3-Dimethyloxiran-2-yl]-3-{[(2*E*)-2-methylbut-2-enoyl]oxy}but-1-en-2-yl]-5-methylcyclohexyl (2*E*)-2-Methylbut-2-enoate* (**16c**), *and (1*R*,2*S*,5*R*)-2-[(3*R*)-4-[(2*R*)-3,3-Dimethyloxiran-2-yl]-3-{[(2*E*)-2-methylbut-2-enoyl]oxy}but-1-en-2-yl]-5-methylcyclohexyl (2*E*)-2-Methylbut-2-enoate* (**17c**). A mixture of **31** and **32** (67.4 mg, 0.26 mmol) in dry CH_2Cl_2 (15 ml) was treated with tiglic anhydride (235 µl) and DMAP (211.1 mg) to afford a mixture of **14c** and **15c** (103.0 mg, 95%), and the two compounds were separated by HPLC. Similarly, a mixture of **33** and **34** afforded **15c** and **16c** (83%); **32** afforded **15c** (71%); **33** afforded **16c** (84%).

Data of **14c**: Oil. $[\alpha]_D^{25} = -45.7$ ($c = 0.39$, MeOH). IR (neat): 1710, 1652, 1256. ^{1}H-NMR: *Tables 1*, *3*, and *5*. ^{13}C-NMR: *Tables 2*, *4*, and *6*. ESI-MS: 441 ($[M+Na]^+$). HR-MS: 441.2615 ($[M+Na]^+$, $C_{25}H_{38}NaO_5^+$; calc. 441.2617).

Data of **15c**: Oil. $[\alpha]_D^{25} = -55.8$ ($c = 0.29$, MeOH). IR (neat): 1713, 1705, 1652, 1256. ^{1}H-NMR: *Tables 1*, *3*, and *5*. ^{13}C-NMR: *Tables 2*, *4*, and *6*. ESI-MS: 441 ($[M+Na]^+$). HR-MS: 441.2619 ($[M+Na]^+$, $C_{25}H_{38}NaO_5^+$; calc. 441.2617).

Data of **16c**: Oil. $[\alpha]_D^{26} = -42.4$ ($c = 0.22$, MeOH). IR (neat): 1706; 1652; 1255. ^{1}H-NMR: *Tables 1*, *3*, and *5*. ^{13}C-NMR: *Tables 2*, *4*, and *6*. ESI-MS: 441 ($[M+Na]^+$). HR-MS: 441.2619 ($[M+Na]^+$, $C_{25}H_{38}NaO_5^+$; calc. 441.2617).

Data of **17c**: Oil. $[\alpha]_D^{25} = -27.0$ ($c = 0.25$, MeOH). IR (neat): 1713, 1705, 1652, 1255. ^{1}H-NMR: *Tables 1*, *3*, and *5*. ^{13}C-NMR: *Tables 2*, *4*, and *6*. ESI-MS: 441 ($[M+Na]^+$). HR-MS: 441.2614 ($[M+Na]^+$, $C_{25}H_{38}NaO_5^+$; calc. 441.2617).

*(1*R*,2*S*,5*R*)-2-[(3*S*,5*R*)-3-(Acetyloxy)-5,6-dihydroxy-6-methylhept-1-en-2-yl]-5-methylcyclohexyl Acetate* (**35**) *and (1*R*,2*S*,5*R*)-2-[(3*R*,5*S*)-3-(Acetyloxy)-5,6-dihydroxy-6-methylhept-1-en-2-yl]-5-methylcyclohexyl Acetate* (**36**). To a stirred soln. of **15** (20.2 mg, 0.059 mmol) in THF (2 ml), AcOH/H_2O (2 ml, ratio 1:1) was added at r.t., and the stirring was continued for 1 d. An aq. soln. of Na_2SO_3 was added, and the mixture was extracted with Et_2O, washed with $NaHCO_3$ aq., and dried (Na_2SO_4). Evaporation of the solvent followed by CC (SiO_2, 4 g) using hexane/AcOEt (85:15) afforded **35** (16.1 mg, 77%). By the same procedure, **16** (65.8 mg, 0.19 mmol) was treated with AcOH/H_2O (6 ml) to yield **36** (52.8 mg, 78%).

Data of **35**: Oil. $[\alpha]_D^{28} = -28.4$ ($c = 0.37$, MeOH). IR (neat): 3438, 1726, 1645, 1254, 1038. ^{1}H-NMR: 0.93 (*d*, $J = 6.5$, Me); 0.96–2.14 (*m*, 11 H); 1.17 (*s*, Me); 1.20 (*s*, Me); 1.97 (*s*, Ac); 2.09 (*s*, Ac); 2.51 (br. *d*, $J = 2.6$, OH); 3.50 (br. *d*, $J = 9.8$, H–C(10)); 4.86 (*dt*, $J = 4.2$, 11.0, H–C(1)); 5.02 (*s*, $=CH_2$, 1 H); 5.17 (*s*, $=CH_2$, 1 H); 5.32 (*t*, $J = 6.3$, H–C(8)). ^{13}C-NMR: 21.1; 21.4; 21.9; 23.8; 25.9; 31.2; 33.5; 34.4; 35.7; 40.5; 44.7; 72.6; 74.9; 75.3; 75.7; 111.1; 148.8; 169.9; 170.5. ESI-MS: 379 ($[M+Na]^+$). HR-MS: 379.2091 ($[M+Na]^+$, $C_{19}H_{32}NaO_6^+$; calc. 379.2091).

Data of **36**: Oil. $[\alpha]_D^{28} = -23.2$ ($c = 0.48$, MeOH). IR (neat): 3465, 1726, 1250, 1039. ^{1}H-NMR: 0.93 (*d*, $J = 6.5$, Me); 0.96–2.21 (*m*, 11 H); 1.17 (*s*, Me); 1.20 (*s*, Me); 2.00 (*s*, Ac); 2.07 (*s*, Ac); 2.59 (br. *s*, OH); 3.46 (br. *d*, $J = 9.8$, H–C(10)); 4.82 (*dt*, $J = 4.2$, 10.9, H–C(1)); 5.06 (*s*, $=CH_2$, 1 H); 5.18 (*s*, $=CH_2$, 1 H); 5.49 (*t*, $J = 6.5$, H–C(8)). ^{13}C-NMR: 21.3; 21.4; 21.9; 23.9; 25.9; 31.2; 32.7; 34.3; 35.1; 40.6; 44.9;

72.6; 75.4; 75.7; 75.9; 112.6; 148.6; 170.0; 170.7. ESI-MS: 379 ($[M+Na]^+$). HR-MS: 379.2090 ($[M+Na]^+$, $C_{19}H_{32}NaO_6^+$; calc. 379.2091).

Mosher's *Esters* (**37a**, **37b**, **38a**, **38b**). By the same procedure described for **23a**, **37a**, **37b** and **38a**, **38b** were prepared from **35** and **36**, resp.

*(3*R*,5*S*)-5-(Acetyloxy)-6-[(1*S*,2*R*,4*R*)-2-(acetyloxy)-4-methylcyclohexyl]-2-hydroxy-2-methylhept-6-en-3-yl (2*R*)-3,3,3-Trifluoro-2-methoxy-2-phenylpropanoate* (**37a**). ^{1}H-NMR: 0.82–2.07 (*m*, 9 H); 0.93 (*d*, *J* = 6.5, Me); 1.18 (*s*, Me); 1.20 (*s*, Me); 1.74 (*ddd*, *J* = 7.0, 8.0, 15.0, CH_2(9), 1 H); 1.93 (*s*, Ac); 2.04 (*s*, Ac); 2.17 (*ddd*, *J* = 3.7, 5.7, 15.0, CH_2(9), 1 H); 3.53 (*s*, MeO); 4.81 (*dt*, *J* = 4.2, 10.8, H–C(1)); 4.98 (*dd*, *J* = 3.7, 6.9, H–C(10)); 5.01 (*s*, =CH_2, 1 H); 5.11 (*s*, =CH_2, 1 H); 5.15 (*dd*, *J* = 5.8, 8.0, H–C(8)); 7.40–7.62 (*m*, 5 arom. H).

*(3*R*,5*S*)-5-(Acetyloxy)-6-[(1*S*,2*R*,4*R*)-2-(acetyloxy)-4-methylcyclohexyl]-2-hydroxy-2-methylhept-6-en-3-yl (2*S*)-3,3,3-Trifluoro-2-methoxy-2-phenylpropanoate* (**37b**). ^{1}H-NMR: 0.82–2.07 (*m*, 9 H); 0.93 (*d*, *J* = 6.5, Me); 1.14 (*s*, Me); 1.15 (*s*, Me); 1.81 (*ddd*, *J* = 7.0, 8.5, 15.2, CH_2(9), 1 H); 1.94 (*s*, Ac); 1.95 (*s*, Ac); 2.28 (*ddd*, *J* = 3.2, 5.6, 15.3, CH_2(9), 1 H); 3.63 (*s*, MeO); 4.81 (*dt*, *J* = 4.1, 10.8, H–C(1)); 4.98 (*dd*, *J* = 3.1, 6.9, H–C(10)); 5.02 (*s*, =CH_2, 1 H); 5.11 (*s*, =CH_2, 1 H); 5.20 (*dd*, *J* = 5.7, 8.6, H–C(8)); 7.40–7.66 (*m*, 5 arom. H).

*(3*S*,5*R*)-5-(Acetyloxy)-6-[(1*S*,2*R*,4*R*)-2-(acetyloxy)-4-methylcyclohexyl]-2-hydroxy-2-methylhept-6-en-3-yl (2*R*)-3,3,3-Trifluoro-2-methoxy-2-phenylpropanoate* (**38a**). ^{1}H-NMR: 0.80–2.08 (*m*, 9 H); 0.93 (*d*, *J* = 6.5, Me); 1.14 (*s*, Me); 1.15 (*s*, Me); 1.94 (overlapped with other signals, δ value was determined by COSY spectrum, CH_2(9), 1 H); 1.95 (*s*, Ac); 2.02 (*s*, Ac); 2.17 (*ddd*, *J* = 3.2, 6.4, 14.8, CH_2(9), 1 H); 3.63 (*s*, MeO); 4.82 (*dt*, *J* = 4.0, 10.5, H–C(1)); 4.98 (*dd*, *J* = 3.2, 7.0, H–C(10)); 5.04 (*s*, =CH_2, 1 H); 5.08 (*s*, =CH_2, 1 H); 5.38 (*dd*, *J* = 6.5, 8.2, H–C(8)); 7.36–7.66 (*m*, 5 arom. H).

*(3*S*,5*R*)-5-(Acetyloxy)-6-[(1*S*,2*R*,4*R*)-2-(acetyloxy)-4-methylcyclohexyl]-2-hydroxy-2-methylhept-6-en-3-yl (2*S*)-3,3,3-Trifluoro-2-methoxy-2-phenylpropanoate* (**38b**). ^{1}H-NMR: 0.80–2.08 (*m*, 9 H); 0.93 (*d*, *J* = 6.5, Me); 1.17 (*s*, Me); 1.20 (*s*, Me); 1.86 (overlapped with other signals, δ value was determined by COSY spectrum, CH_2(9), 1 H); 2.01 (*s*, Ac); 2.03 (*s*, Ac); 2.08 (*ddd*, *J* = 3.8, 6.5, 15.0, CH_2(9), 1 H); 3.52 (*s*, MeO); 4.82 (*dt*, *J* = 4.1, 10.8, H–C(1)); 4.97 (*dd*, *J* = 3.7, 7.0, H–C(10)); 5.03 (*s*, =CH_2, 1 H); 5.10 (*s*, =CH_2, 1 H); 5.35 (*dd*, *J* = 6.5, 7.8, H–C(8)); 7.37–7.70 (*m*, 5 arom. H).

*(3*R*,5*S*)-6-[(1*S*,2*R*,4*R*)-2-Hydroxy-4-methylcyclohexyl]-2-methylhept-6-ene-2,3,5-triol* (**39**). From **32**: As described for **35**, compound **32** (39.0 mg, 0.15 mmol) was treated with AcOH/H_2O to yield **39** (17.6 mg, 43%).

From **35**: To a stirred soln. of **35** (17.9 mg, 0.05 mmol) in MeOH (3 ml), K_2CO_3 (40.7 mg) was added, and the stirring was continued at r.t. for 2.5 h. 1M HCl aq. was added, and the mixture was extracted with CH_2Cl_2 and dried (Na_2SO_4). Evaporation of the solvent followed by CC (SiO_2, 5 g) using hexane/AcOEt (2:3) afforded **39** (6.3 mg, 46%).

Data of **39**: Oil. $[\alpha]_D^{25} = -16.9$ (*c* = 0.38, MeOH). IR (neat): 3335, 1645. ^{1}H-NMR: 0.96 (*d*, *J* = 6.5, Me); 1.06 (*q*, *J* = 11.6, 1 H); 1.17 (*s*, Me); 1.22 (*s*, Me); 1.35–2.10 (*m*, 13 H); 3.46 (*dt*, *J* = 4.1, 11.5, H–C(1)); 3.68 (*dd*, *J* = 1.5, 9.9, H–C(10)); 4.40 (*dd*, *J* = 3.1, 9.7, H–C(8)); 5.02 (*s*, =CH_2, 1 H); 5.18 (*s*, =CH_2, 1 H). ^{13}C-NMR: 22.4; 24.2; 26.7; 31.8; 32.6; 34.7; 36.9; 44.5; 45.4; 72.8; 76.0; 76.7; 78.7; 112.2; 154.1. ESI-MS: 295 ($[M+Na]^+$). HR-MS: 295.1892 ($[M+Na]^+$, $C_{15}H_{28}NaO_4^+$; calc. 295.1885).

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