Pergamon

SCIENCE DIRECT®

Tetrahedron 59 (2003) 6273–6283

TETRAHEDRON

TFA-mediated intramolecular Friedel–Crafts reaction. An efficient metal and halogen free route to stereoselective synthesis of benzocycles

Shengming Ma* and Junliang Zhang

State Key Laboratory of Organometallic Chemistry, Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences, 354 Fenglin Lu Road, Shanghai 200032, People's Republic of China

Received 5 March 2003; revised 19 June 2003; accepted 24 June 2003

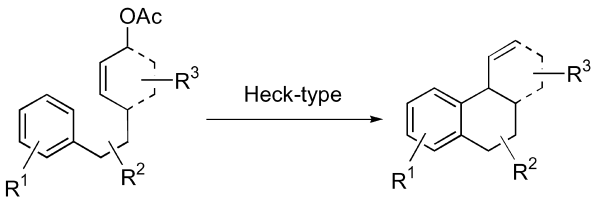
Dedicated to Professor Wei-shan Zhou on the occasion of his 80th birthday

Abstract—6-Acetoxy-4-alkenyl arenes undergo regio- and stereoselective intramolecular Friedel–Crafts reaction affording benzocycles in moderate to excellent yields in TFA/HOAc (3:1). It was observed that introduction of alkyls or phenyl group to the allylic acetate moiety facilitates the cyclization reaction. The optically active tricyclic (4b*R*,8a*S*)-4b,7,8,8a,9,10-hexahydrophenanthrene skeleton could also be easily obtained in excellent yields.

1. Introduction

Benzocycles are commonly observed structural units in many natural and unnatural products with biological potentials.[1] These compounds are usually prepared by the cyclic radical addition, carbopalladation (including acylpalladation) of the corresponding 2-alkenyl aryl halides or their corresponding alkynic analogues.[2–5] In spite of the excellence of these reactions in terms of efficiency, it is desirable to develop efficient and environmentally benign methodologies for the synthesis of these benzocycles.

Recently, we observed an intramolecular Friedel–Crafts reaction[6,7] of 6-acetoxy-4-alkenyl arenes which provided an efficient metal and halogen free route to stereoselective synthesis of benzocycles (Scheme 1).[8] Herein, we wish to disclose the full account of this study.



Scheme 1.

2. Results and discussion

2.1. Synthesis of starting materials

The starting materials **3a–e** were prepared by the alkylation of dimethyl 2-(4′-acetoxybut-2′-enyl)malonate **1**[9] with the corresponding benzylic halides **2a–d** or 1-chloromethylnaphthelene using sodium hydride as the base (Scheme 2).

Substrates **3f**, **g** were prepared by the alkylation reaction of dimethyl 2-benzylic malonates **4a**, **b** with 2-methyl-4-acetoxybut-2-enyl bromide **5** (Scheme 3).[10]

Compounds **3h–j** and **3k** were prepared by the palladium-catalyzed allylation of 2-benzylic malonates **4a**, **b** or *N*-benzyl *p*-toluenesulfonyl amide with 1-acetoxy-alk-2-en-4-ols **6a**, **b**[11] followed by treatment with acetic anhydride (Scheme 4).

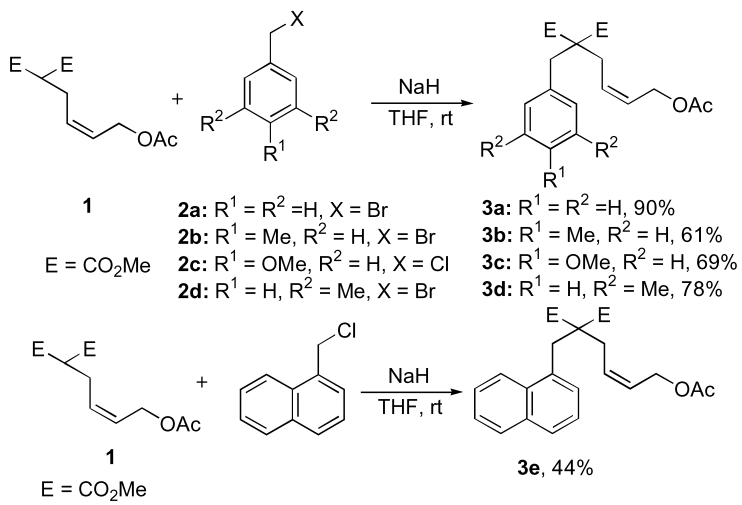
The bicyclic substrates (1*R**,4*S**)-**9a–d** were synthesized via the reaction of 2-substituted malonates **4a–d** with *cis*-4-chlorocyclohex-2-en-1-ol acetyl ester **8** under the catalysis of $Pd(OAc)_2$ and Ph_3P, while the *trans* isomer (1*R**,4*R**)-**9a** was prepared from the direct reaction of **4a** and **8** in CH_3CN at 80°C in the absence of any palladium catalyst (Scheme 5).[12]

2.2. Annulation of 6-acetoxy-4-alkenylarenes

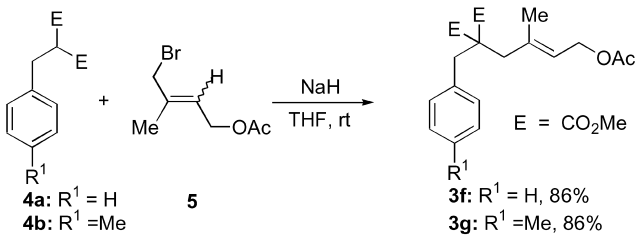
Originally, the reaction of **3a** was carried out in trifluoroacetic acid under the catalysis of $Pd(OAc)_2$, however,

Keywords: Friedel–Crafts reaction; benzocycles; stereoselective synthesis.
* Corresponding author. Tel.: +86-21-6416-3300; fax: +86-21-6416-6128; e-mail: masm@mail.sioc.ac.cn

0040–4020/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/S0040-4020(03)01026-3



Scheme 2.



Scheme 3.

control experiment showed that $Pd(OAc)_2$ was not required in this transformation. Finally, it is observed that the yield of the reaction was improved to 66% by using TFA/HOAc (3:1) as the solvent (Scheme 6).

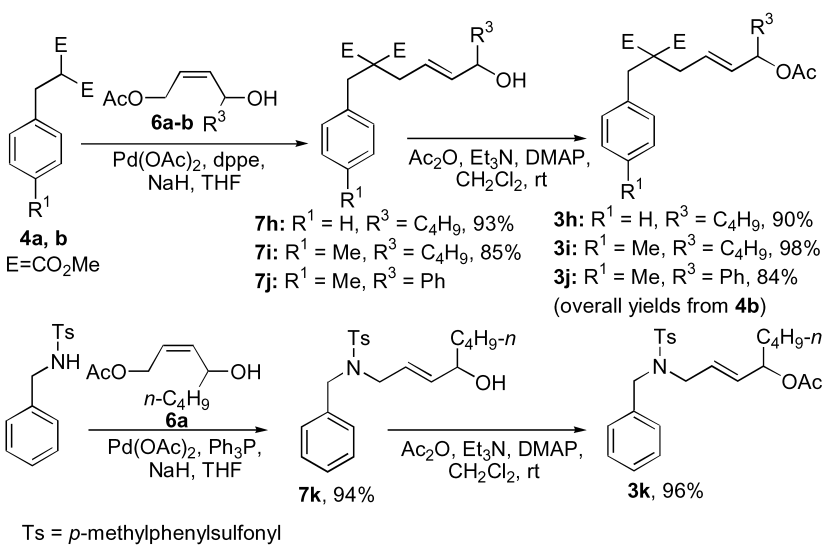
Using TFA/HOAc (3:1) as the standard reaction medium, the reaction of **3** with different substituents in the aryl moiety and the allylic moiety was studied (Table 1). It is surprising for us to observe that the rate and yields were not improved at all with the introduction of electron-donating groups to the aromatic ring. On the other hand, dramatic effect was found with the introduction of substitution in the allylic acetate part (compare entries 6–10 with entries 1–4, Table 1).

2.3. Annulation of racemic bicyclic substrates

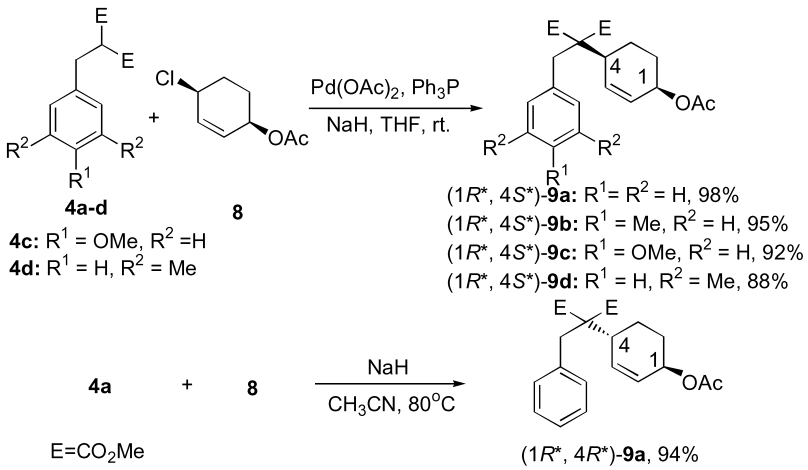
Under the encouragement of the above results, we are interested in applying this transformation to the bicyclic substrates. Tricyclic skeleton (4b*R* *,8a*S* *)-**11a–d** were formed in excellent yields and stereoselectivity from bicyclic (1*S* *,4*R* *)-**9a–d**. Surprisingly, we found the reaction of (1*R* *,4*R* *)-**9a** afforded the same product (4b*S* *,8a*R* *)-**11a** in 97% yield, indicating that the stereochemistry of the newly created sp^3 carbon center is controlled by that of 4-carbon in **9a** (Scheme 7). The ring junction was established as *cis*-fused by an X-ray diffraction study of (4b*R* *,8a*S* *)-**11c** (Fig. 1).[13]

2.4. Annulation of optically active bicyclic substrates

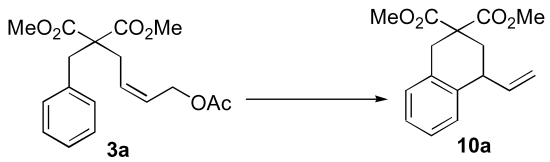
It is interesting to observe that this transformation could also be applied to highly diastereoselective synthesis of optically active tricyclic skeleton (4b*R*,8a*S*)-**11a–d** as exemplified by



Scheme 4.



Scheme 5.



Scheme 6.

the cyclization of optically active bicyclic (1*R*,4*S*)-**13a**–**d**, which were easily prepared from the 2-substituted malonates **4a**–**d** and *meso*-cyclohexen-1,4-diol dibenzoate **12** via a method developed by B. M. Trost using the optically active ligand L* (Scheme 8).[14]

2.5. Mechanism and substituent effect

The reaction was believed to proceed via the generation of an allylic cation from the allylic acetate moiety followed by the intramolecular electrophilic substitution reaction. Thus, the introduction of substituents in the allylic acetate part may facilitate the formation of the allylic cation, which will afford the products in higher yields. As a comparison, the corresponding reaction of the alcoholic analogue **14** afforded **10a** in only 40% yield, however, higher yield (53%) could be obtained when the reaction medium was changed to TFA/$(CF_3CO)_2O$ (4:1) (Scheme 9).

3. Conclusion

In conclusion, we have developed an efficient methodology for the synthesis of benzocycles, the yields and rates of the cyclization depend largely on the substituents in the substrates. Due to the advantage of simple operation, ready availability of starting materials, high yields and excellent stereoselectivity and diastereoselectivity, this reaction will show its utility in organic synthesis. Further studies on the synthetic applications of this reaction are being carried out in our laboratory.

4. Experimental

4.1. Synthesis of starting materials

4.1.1. Typical procedure for synthesis of 3a–e: dimethyl 2-(4′-acetoxybut-2′(*Z*)-enyl)-2-benzylmalonate (3a). Dimethyl 2-(4′-acetoxybut-2′(*Z*)-enyl)malonate **1** (0.732 g, 3 mmol) was treated with NaH (120 mg, 80% in mineral oil, 4 mmol) in 10 mL of dry THF at rt for 10 min followed by the addition of a solution of benzyl bromide **2a** (0.616 g, 3.6 mmol) in THF. The reaction mixture was stirred for 10 h at rt. After the usual work-up, the residue was purified by column chromatography on silica gel to afford 0.902 g (90%) of **3a**: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.28–7.18 (m, 3H), 7.08–7.01 (m, 2H), 5.76–5.60 (m, 2H), 4.50 (d, J=5.1 Hz, 2H), 3.70 (s, 6H), 3.22 (s, 2H), 2.53 (d, J=6.0 Hz, 2H), 2.05 (s, 3H); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 170.8, 170.5, 135.5, 129.7, 129.5, 128.5, 128.2, 127.0, 64.4, 58.9, 52.2, 38.3, 35.0, 20.8; MS *m*/*z* (%) 334 (M^+, 2.22), 215 (100); IR (neat) 1737, 1240, 973, 703 cm^{-1}. Anal. calcd for $C_{18}H_{22}O_6$: C 64.66, H 6.63. Found: C 64.71, H 6.71.

4.1.2. Dimethyl 2-(4′-acetoxybut-2′(*Z*)-enyl)-2-(4″-methylbenzyl)malonate (3b). The reaction of dimethyl 2-(4′-acetoxybut-2′(*Z*)-enyl)malonate **1** (2.44 g, 10 mmol) with NaH (360 mg, 80% in mineral oil, 12 mmol) and 4-methylbenzyl bromide **2b** (2.20 g, 12 mmol) afforded 2.11 g (61%) of **3b**: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.05 (d, J=7.7 Hz, 2H), 6.92 (d, J=7.7 Hz, 2H), 5.76–5.55 (m, 2H), 4.55 (d, J=6.1 Hz, 2H), 3.72 (s, 6H), 3.20 (s, 2H), 2.57 (d, J=6.7 Hz, 2H), 2.29 (s, 3H), 2.05 (s, 3H); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 170.9, 170.6, 136.5, 132.2, 129.5, 128.9, 127.8, 127.2, 60.1, 58.6, 52.3, 37.8, 29.9, 20.9, 20.7; ESI-MS *m*/*z* (%) 371.2 ($M+Na^+$); IR (neat) 1738, 1234 cm^{-1}. Anal. calcd for $C_{19}H_{24}O_6$: C 65.50, H 6.94. Found: C 65.23, H 6.90.

4.1.3. Dimethyl 2-(4′-acetoxybut-2′(*Z*)-enyl)-2-(4″-methoxybenzyl)malonate (3c). The reaction of dimethyl 2-(4′-acetoxybut-2′(*Z*)-enyl)malonate **1** (0.732 g, 3 mmol) with NaH (120 mg, 80% in mineral oil, 4 mmol) and 4-methoxybenzyl chloride **2c** (0.564 g, 3.6 mmol) afforded 0.756 g (69%) of **3c**: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.97 (d,

Table 1. Cyclic Friedel–Crafts reaction of allylic acetates **1**

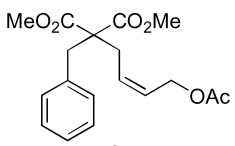
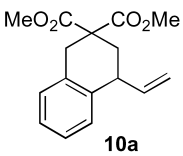
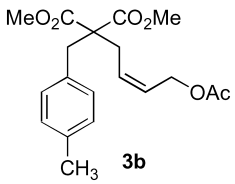
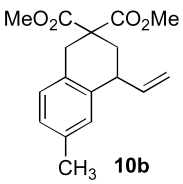
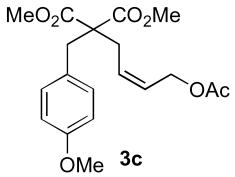
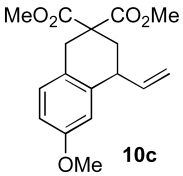
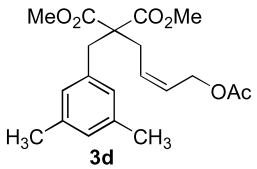
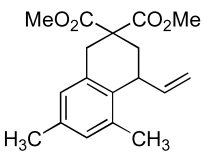
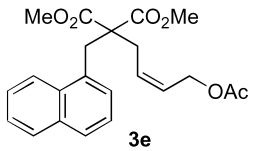
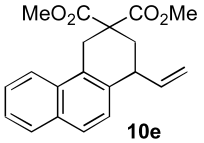
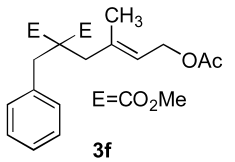
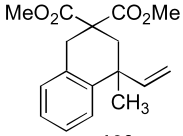
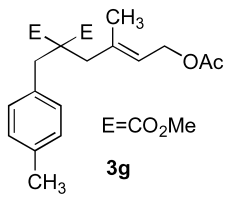
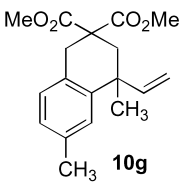
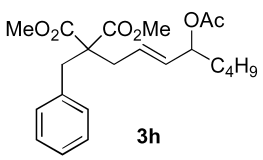
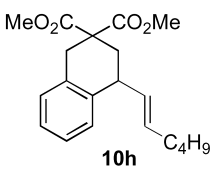
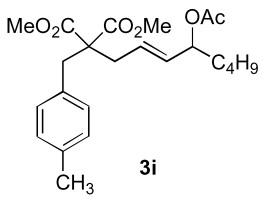
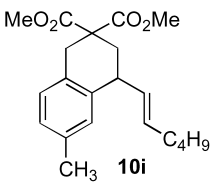
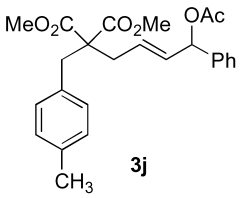
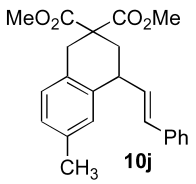
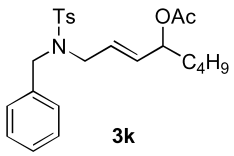
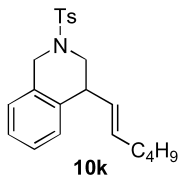
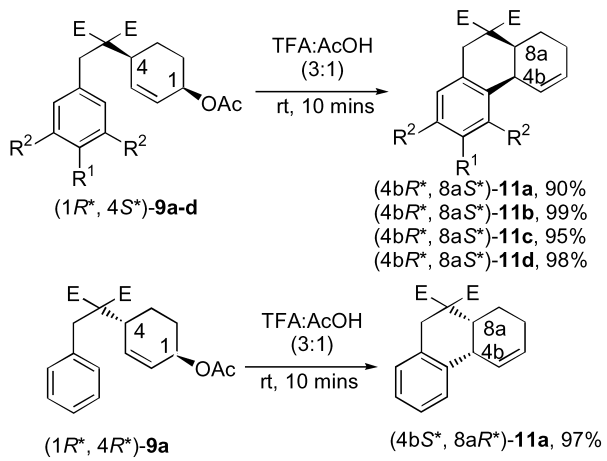
Entry	Substrates	Time (h)	Product	Yield (%)
1	 **3a**	14	 **10a**	66
2	 **3b**	14	 **10b**	66
3	 **3c**	14	 **10c**	66
4	 **3d**	14	 **10d**	68
5	 **3e**	14	 **10e**	72
6	 **3f**	3	 **10f**	84
7	 **3g**	4	 **10g**	85
8	 **3h**	1	 **10h**	85
9	 **3i**	1.5	 **10i**	99[a,b]

Table 1 (*continued*)

Entry	Substrates	Time (h)	Product	Yield (%)
10	 **3j**	0.5	 **10j**	94[a,b]
11	 **3k**	3	 **10k**	92[a,b]

Unless otherwise stated, the reaction was carried out using **3** (0.5 mmol) in 1.0 mL of TFA/AcOH (3:1) at 70°C.
[a] The reaction was carried out at rt.
[b] The configuration of the C=C bond was determined by the coupling constants of the olefinic protons to be *E*.



Scheme 7.

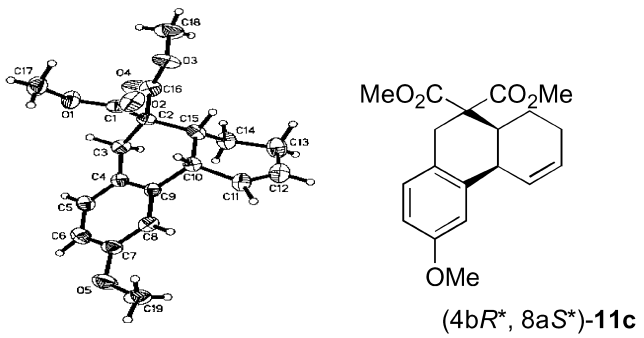


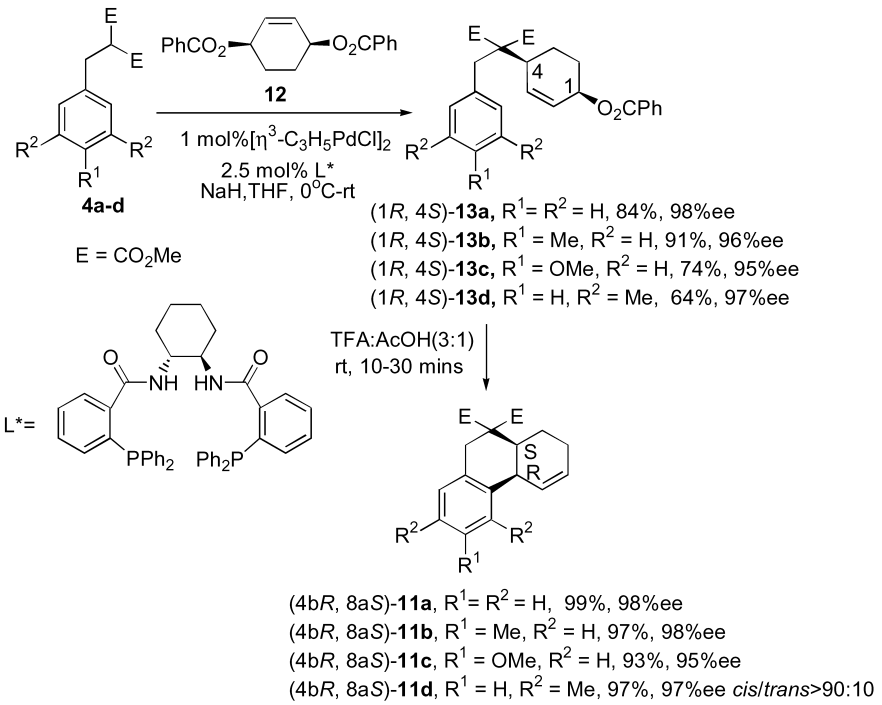
Figure 1.

J=9.0 Hz, 2H), 6.79 (d, *J*=9.0 Hz, 2H), 5.70–5.60 (m, 2H), 4.51 (d, *J*=5.1 Hz, 2H), 3.80 (s, 3H), 3.71 (s, 6H), 3.16 (s, 2H), 2.53 (d, *J*=6.0 Hz, 2H), 2.06 (s, 3H); ESI-MS *m*/*z* (%) 387.2 ($M+Na^+$); IR (neat) 1738, 1234 cm^{-1}. HRMS calcd for $C_{19}H_{24}O_7Na$: 387.1420. Found: 387.1417.

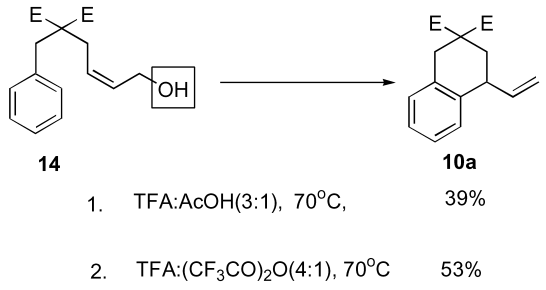
4.1.4. Dimethyl 2-(4′-acetoxybut-2′(*Z*)-enyl)-2-(3″,5″-dimethylbenzyl)malonate (3d). The reaction of dimethyl 2-(4′-acetoxybut-2′(*Z*)-enyl)malonate **1** (0.732 g, 3 mmol) with NaH (160 mg, 60% in mineral oil, 4 mmol) and 3,5-dimethylbenzyl bromide **2d** (0.716 g, 3.6 mmol) afforded 0.847 g (78%) of **3d**: oil; ^1H NMR (300 MHz, $CDCl_3$) δ 6.85 (s, 1H), 6.65 (s, 2H), 5.80–5.60 (m, 2H), 4.51 (d, *J*=5.4 Hz, 2H), 3.71 (s, 6H), 3.14 (s, 2H), 2.52 (d, *J*=6.3 Hz, 2H), 2.25 (s, 6H), 2.05 (s, 3H); MS *m*/*z* (%) 362 (M^+, 0.03), 361 (48), 131 (100); IR (neat) 1735, 1234, 960 cm^{-1}. Anal. calcd for $C_{20}H_{26}O_6$: C 66.28, H 7.23. Found: C 66.23, H 7.20.

4.1.5. Dimethyl 2-(4′-acetoxybut-2′(*Z*)-enyl)-2-(naphthalen-1″-yl)methyl malonate (3e). The reaction of dimethyl 2-(4′-acetoxybut-2′(*Z*)-enyl)malonate **1** (0.732 g, 3 mmol) with NaH (120 mg, 80% in mineral oil, 4 mmol) and (1-chloromethyl)naphthalene (0.640 g, 3.6 mmol) afforded 0.504 g (44%) of **3e**: white solid; mp 48–49°C (Et_2O–hexanes); ^1H NMR (300 MHz, $CDCl_3$) δ 8.05–7.98 (m, 1H), 7.86–7.80 (m, 1H), 7.78–7.70 (m, 1H), 7.56–7.24 (m, 4H), 5.80–5.60 (m, 2H), 4.53 (d, *J*=4.9 Hz, 2H), 3.76 (s, 2H), 3.59 (s, 6H), 2.68 (d, *J*=5.5 Hz, 2H), 2.05 (s, 3H); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 171.1, 170.5, 133.7, 132.5, 132.1, 129.7, 128.7, 128.5, 128.0, 127.7, 125.6, 125.3, 125.0, 123.6, 64.5, 59.0, 52.2, 36.0, 34.0, 20.8; MS *m*/*z* (%) 384 (M^+, 0.80), 141 (100); IR (neat) 1745, 1737, 1725, 1597, 973 cm^{-1}. Anal. calcd for $C_{22}H_{24}O_6$: C 68.74, H 6.29. Found: C 68.38, H 6.32.

4.1.6. Dimethyl 2-(2′-methyl-4′-acetoxybut-2′(*E*)-enyl)-2-benzylmalonate (3f). The reaction of dimethyl 2-benzylmalonate **4a** (1.11 g, 5 mmol) with NaH (210 mg, 60% in mineral oil, 5.3 mmol) and 2-methyl-4-acetoxybut-2-enyl bromide **5** (1.04 g, 5 mmol) afforded 1.50 g (86%) of **3f**: white solid; mp 52–53°C (Et_2O–hexanes); ^1H NMR (300 MHz, $CDCl_3$) δ 7.30–7.20 (m, 3H), 7.15–7.05 (m, 2H), 5.40 (t, *J*=7.0 Hz, 1H), 4.59 (d, *J*=7.0 Hz, 2H), 3.68 (s, 6H), 3.26 (s, 2H), 2.68 (s, 2H), 2.06 (s, 3H), 1.68 (s, 3H); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 171.2, 170.7, 136.9, 135.9, 129.8, 128.0, 126.8, 123.8, 60.8, 58.8, 52.1, 42.6, 39.3, 20.8, 17.1; MS *m*/*z* (%) 289 ($M^+-CH_3CO_2$, 9.04), 215 (100); IR (KBr) 1720, 1270, 690 cm^{-1}. Anal. calcd for $C_{19}H_{24}O_6$: C 65.50, H 6.94. Found: C 65.50, H 6.88.



Scheme 8.



Scheme 9.

4.1.7. Dimethyl 2-(2′-methyl-4′-acetoxybut-2′(*E*)-enyl)-2-(4″-methylbenzyl)malonate (3g). The reaction of dimethyl 2-(4′-methylbenzyl)malonate **4b** (0.472 g, 2 mmol) with NaH (88 mg, 60% in mineral oil, 2.2 mmol) and 2-methyl-4-acetoxybut-2-enyl bromide **5** (0.414 g, 2 mmol) afforded 0.603 g (86%) of **3g**: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.06 (d, J=9.2 Hz, 2H), 6.98 (d, J=9.2 Hz, 2H), 5.42 (t, J=6.7 Hz, 1H), 4.58 (d, J=6.7 Hz, 2H), 3.68 (s, 6H), 3.22 (s, 2H), 2.66 (s, 2H), 2.30 (s, 3H), 2.06 (s, 3H), 1.65 (s, 3H); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 171.3, 170.8, 137.0, 136.4, 132.7, 129.6, 128.8, 123.7, 60.8, 58.8, 52.1, 42.5, 38.9, 20.9, 20.8, 17.1; MS m/z (%) 271 ($M^+-CH_3CO_2H-OMe$, 1.61), 105 (100); IR (neat) 1735, 1235 cm^{-1}. Anal. calcd for $C_{20}H_{26}O_6$: C 66.28, H 7.23. Found: C 65.97, H 7.24.

4.1.8. Typical procedure for synthesis of 7h, i, k: dimethyl 2-(4′-hydroxyoct-2′(*E*)-enyl)-2-benzylmalonate (7h). A solution of dimethyl 2-benzylmalonate **4a** (2.1 g, 9.5 mmol) in THF was treated with NaH (400 mg, 60% in mineral oil, 10 mmol) under Ar for 10 min. **6a** (2.0 g, 10.8 mmol), $Pd(OAc)_2$ (11 mg, 0.05 mmol), and dppe (40 mg, 0.1 mmol) were added. The reaction mixture was stirred for another 10 h at rt. After the usual work-up, the residue was purified through column chromatography on silica gel to afford 3.4 g (93%) of **7h**: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.34–7.20 (m, 3H), 7.14–7.08 (m, 2H), 5.65–5.55 (m, 2H), 4.16–4.06 (m, 1H), 3.67 (s, 6H), 3.28 (s, 2H), 2.57–2.50 (m, 2H), 1.70 (bs, 1H), 1.64–1.46 (m, 2H), 1.44–1.26 (m, 4H), 0.89 (t, J=7.0 Hz, 3H); ESI-MS m/z (%) 371.3 ($M+Na^+$); IR (neat) 3475, 1737, 1674, 979, 703 cm^{-1}. HRMS calcd for $C_{20}H_{28}O_5Na$: 371.1834. Found: 371.1816.

4.1.9. Dimethyl 2-(4′-hydroxyoct-2′(*E*)-enyl)-2-(4″-methylbenzyl)malonate (7i). The reaction of dimethyl 2-(4′-methylbenzyl)malonate **4b** (0.708 g, 3.0 mmol) with NaH (120 mg, 60% in mineral oil, 3.0 mmol) and **6a** (0.558 g, 3.0 mmol) in the presence of $Pd(OAc)_2$ (17 mg, 0.08 mmol) and dppe (60 mg, 0.15 mmol) afforded 0.924 g (85%) of **7i**: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.06 (d, J=8.1 Hz, 2H), 6.95 (d, J=8.1 Hz, 2H), 5.65–5.50 (m, 2H), 4.10–4.00 (m, 1H), 3.70 (s, 6H), 3.18 (s, 2H), 2.52 (d, J=5.4 Hz, 2H), 2.30 (s, 3H), 1.70–1.40 (m, 3H), 1.40–1.20 (m, 4H), 0.90 (t, J=6.3 Hz, 3H); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 171.1, 171.0, 138.2, 136.3, 132.3, 129.5, 128.8, 124.3, 72.2, 59.1, 52.10, 52.06, 37.5, 36.6, 34.6, 27.3, 22.4, 20.8, 13.8; MS m/z (%) 345 (M^+-OH, 57.60), 285 (100); IR (neat) 3500, 1737, 974, 733 cm^{-1}. Anal. calcd for $C_{21}H_{30}O_5$: C 69.59, H 8.34. Found: C 69.48, H 8.47.

4.1.10. *N*-Benzyl *N*-(4-hydroxyoct-2(*E*)-enyl)(4′-methylphenyl)sulfonyl amide (7k). The reaction of *N*-benzyl 4-methylphenylsufonyl amide (522 mg, 2 mmol) with NaH (100 mg, 60% in mineral oil, 2.5 mmol) and **6a** (372 mg, 2.0 mmol) in the presence of $Pd(OAc)_2$ (11 mg, 0.05 mmol) and dppe (40 mg, 0.1 mmol) afforded 724 mg (94%) of **7k**: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.68 (d, J=8.0 Hz, 2H), 7.40–7.20 (m, 7H), 5.40–5.20 (m, 2H), 4.42 (d, J=14.7 Hz, 1H), 4.25 (d, J=14.7 Hz, 1H), 3.90–3.80 (m, 1H), 3.77 (dd, J=15.3, 5.5 Hz, 1H), 3.69 (dd, J=15.3, 5.5 Hz, 1H), 2.44 (s,

3H), 1.60 (s, 1H), 1.40–1.00 (m, 6H), 0.88 (t, J=6.7 Hz, 3H); MS m/z (%) 369 (M^+-H_2O, 18.82), 91 (100); IR (neat) 3524, 1599, 1159, 974, 732 cm^{-1}. Anal. calcd for $C_{22}H_{29}NO_3S$: C 68.18, H 7.54, N 3.61. Found: C 68.15, H 7.57, N 3.50.

4.1.11. Typical procedure for synthesis of 3h, i, k: dimethyl 2-(4′-acetoxyoct-2′(*E*)-enyl)-2-benzylmalonate (3h). To a solution of alcohol **7h** (1.00 g, 2.87 mmol) in 20 mL of dichloromethane was added 1.0 mL of Ac_2O, 2.0 mL of Et_3N and DMAP (0.20 g, 1.5 mmol). After stirring at rt for overnight and the usual work-up, the residue was purified to afford 1.0 g (90%) of **3h**: oil; ^1H NMR (300 MHz, $CDCl_3$) δ 7.24–7.12 (m, 3H), 7.04–6.95 (m, 2H), 5.57 (dt, J=15.4, 6.9 Hz, 1H), 5.41 (dd, J=15.4, 6.9 Hz, 1H), 5.13 (q, J=6.9 Hz, 1H), 3.67 (s, 6H), 3.15 (s, 2H), 2.66 (d, J=7.1 Hz, 2H), 1.98 (s, 3H), 1.70–1.40 (m, 2H), 1.35–1.15 (m, 4H), 0.89 (t, J=6.7 Hz, 3H); MS m/z (%) 331 ($M^+-CH_3CO_2$, 100); IR (neat) 1737, 1737, 1605, 974, 703 cm^{-1}. HRMS calcd for $C_{20}H_{26}O_4$ [$M^+-CH_3CO_2H$]: 330.1831. Found: 330.1867.

4.1.12. Dimethyl 2-(4′-acetoxyoct-2′(*E*)-enyl)-2-(4″-methylbenzyl)malonate (3i). The reaction of **7i** (181 mg, 0.5 mmol) with Ac_2O (62 mg, 0.6 mmol) in the presence of Et_3N (61 mg, 0.6 mmol) and DMAP (10 mg, 0.7 mmol) afforded 197 mg (98%) of **3i**: oil; ^1H NMR (300 MHz, $CDCl_3$) δ 7.06 (d, J=8.1 Hz, 2H), 6.95 (d, J=8.1 Hz, 2H), 5.58 (dt, J=15.4, 7.1 Hz, 1H), 5.49 (dd, J=15.4, 7.0 Hz, 1H), 5.18 (q, J=7.0 Hz, 1H), 3.70 (s, 6H), 3.18 (s, 2H), 2.51 (d, J=7.0 Hz, 2H), 2.30 (s, 3H), 2.05 (s, 3H), 1.65–1.40 (m, 2H), 1.40–1.15 (m, 4H), 0.90 (t, J=6.8 Hz, 3H); ESI-MS m/z (%) 427.3 ($M+Na^+$); IR (neat) 1737, 1241, 974 cm^{-1}. HRMS calcd for $C_{23}H_{32}O_6Na$: 427.2097. Found: 427.2091.

4.1.13. Dimethyl 2-(4′-acetoxy-4′-phenylbut-2′(*E*)-enyl)-2-(4″-methylbenzyl)malonate (3j). The reaction of **4b** (0.472 g, 2.0 mmol) with NaH (88 mg, 60% in mineral oil, 2.2 mmol) and **6b** (0.412 g, 3 mmol) under the catalysis of $Pd(OAc)_2$ (22 mg, 0.1 mmol) and dppe (45 mg, 1.1 mmol) afforded a crude product, which was reacted with Ac_2O (0.306 g, 3.0 mmol) in the presence of Et_3N (303 mg, 3.0 mmol) and DMAP (13 mg, 0.1 mmol) to afford 0.710 g (the overall yield: 84%) of **3j**: oil; ^1H NMR (300 MHz, $CDCl_3$) δ 7.40–7.20 (m, 5H), 7.04 (d, J=8.1 Hz, 2H), 6.90 (d, J=8.1 Hz, 2H), 6.25–6.18 (m, 1H), 5.78–5.68 (m, 2H), 3.64 (s, 3H), 3.61 (s, 3H), 3.18 (s, 2H), 2.60–2.48 (m, 2H), 2.30 (s, 3H), 2.12 (s, 3H); ESI-MS m/z (%) 447.3 ($M+Na^+$); IR (neat) 1737, 1717, 1604, 990, 713 cm^{-1}. HRMS calcd for $C_{25}H_{28}O_6Na$: 447.1784. Found: 447.1778.

4.1.14. *N*-Benzyl *N*-(4-acetoxyoct-2(*E*)-enyl)(4′-methylphenyl)sulfonyl amide (3k). The reaction of **7k** (387 mg, 1.0 mmol) with Ac_2O (112 mg, 1.1 mmol) in the presence of Et_3N (151 mg, 1.5 mmol) and DMAP (13 mg, 0.1 mmol) afforded 410 mg (96%) of **3k**: oil; ^1H NMR (300 MHz, $CDCl_3$) δ 7.67 (d, J=8.6 Hz, 2H), 7.30–7.10 (m, 7H), 5.30–5.10 (m, 2H), 4.97 (q, J=6.1 Hz, 1H), 4.24 (s, 2H), 3.70–3.60 (m, 2H), 2.37 (s, 3H), 1.91 (s, 3H), 1.50–1.00 (m, 6H), 0.80 (t, J=7.3 Hz, 3H); ESI-MS m/z (%) 452.3 ($M+Na^+$); IR (neat) 1737, 1599, 1161, 973, 733 cm^{-1}. Anal. calcd for $C_{24}H_{31}NO_4S$: C 67.10, H 7.27, N 3.26. Found: C 67.13, H 7.27, N 3.19.

4.1.15. (1*R,4*R**)-4-(1′,1′-Bis(methoxycarbonyl)-2′-phenylethyl)cyclohex-2-en-1-ol acetyl ester (1*R**,4*R**-9a).** Under Ar, to a suspension of NaH (60 mg, 60% in mineral oil, 1.5 mmol) in 4 mL of THF was added dropwise a solution of dimethyl 2-benzyl malonate **4a** (333 mg, 1.5 mmol) in THF. After being stirred for 10 min, THF was removed and *cis*-4-chlorocyclohex-2-en-1-ol acetyl ester **8** (175 mg, 1.0 mmol) in 4 mL of CH_3CN was added and the mixture was refluxed for 4 h. After removal of the solvent, the residue was purified by column chromatography on silica gel (hexanes/ether=20:1) to afford 339 mg (94%) of (1*R**,4*R**)-**9a**: white solid; mp 93–94°C (Et_2O–hexanes); ^1H NMR (300 MHz, $CDCl_3$) δ 7.30–7.20 (m, 3H), 7.13–7.11 (m, 2H), 5.94 (d, J=10.5 Hz, 1H), 5.63 (d, J=10.5 Hz, 1H), 5.29 (bs, 1H), 3.64 (s, 3H), 3.58 (s, 3H), 3.33 (d, J=14.0 Hz, 1H), 3.23 (d, J=14.0 Hz, 1H), 2.93 (bs, 1H), 2.20–2.06 (m, 1H), 2.05 (s, 3H), 1.60–1.42 (m, 3H); ^1H NMR (300 MHz, $CDCl_3$) δ 170.8, 170.5, 170.3, 136.1, 131.8, 130.0, 128.2, 128.1, 127.0, 69.7, 62.8, 52.1, 52.0, 39.4, 38.5, 28.4, 23.0, 21.3; MS m/z (%) 361 (2.30) [M^++1], 301 ($M^+-CH_3CO_2$, 100); IR (KBr) 1740, 1724, 1602, 740, 724 cm^{-1}. Anal. calcd for $C_{20}H_{24}O_6$: C 66.65, H 6.71. Found C 66.79, H 6.66.

4.1.16. Typical procedure for synthesis of 1*R,4*S**-9a–d: (1*R**,4*S**)-4-(1′,1′-bis(methoxycarbonyl)-2′-phenylethyl)cyclohex-2-en-1-ol acetyl ester (1*R**,4*S**-9a).** Under Ar, to a suspension of NaH (60 mg, 60% in mineral oil, 1.5 mmol) in 15 mL of THF was added dropwise a solution of dimethyl 2-benzylmalonate **4a** (333 mg, 1.5 mmol) in THF. After being stirred for 10 min, $Pd(OAc)_2$ (4 mg, 0.02 mmol), PPh_3 (25 mg, 0.1 mol) and *cis*-4-chlorocyclohex-2-en-1-ol acetyl ester **8** (175 mg, 1.0 mmol) in THF were added. The mixture was stirred for 0.75 h at rt. After evaporation of the solvent, the residue was purified by column chromatography on silica gel (hexanes/ether=20:1) to afford 354 mg (98%) of (1*R**,4*S**)-**9a**: white solid; mp 68–69°C (Et_2O–hexanes); ^1H NMR (300 MHz, $CDCl_3$) δ 7.30–7.16 (m, 3H), 7.16–7.06 (m, 2H), 6.06 (d, J=10.3 Hz, 1H), 5.82–5.74 (m, 1H), 5.12 (bs, 1H), 3.64 (s, 3H), 3.58 (s, 3H), 3.36 (d, J=14.0 Hz, 1H), 3.25 (d, J=14.0 Hz, 1H), 2.85–2.75 (m, 1H), 2.04 (s, 3H), 2.00–1.52 (m, 4H); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 170.5, 170.5, 170.4, 136.1, 134.6, 130.0, 128.1, 127.0, 125.2, 65.7, 62.7, 52.0, 51.8, 39.6, 38.5, 27.8, 21.2, 19.5; MS m/z (%) 359 (M^+-1, 2.30), 301 ($M^+-CH_3CO_2$, 100); IR (KBr) 1726, 1722, 1600 cm^{-1}. Anal. calcd for $C_{20}H_{24}O_6$: C 66.65, H 6.71. Found: C 66.62, H 6.54.

4.1.17. (1*R,4*S**)-4-(1′,1′-Bis(methoxycarbonyl)-4″-methylphenylethyl)cyclohex-2-en-1-ol acetyl ester (1*R**,4*S**-9b).** The reaction of dimethyl 2-(4′-methylbenzyl)malonate **4b** (283 mg, 1.2 mmol) with NaH (48 mg, 60% in mineral oil, 1.2 mmol) and *cis*-4-chlorocyclohex-2-en-1-ol acetyl ester **8** (175 mg, 1.0 mmol) under the catalysis of $Pd(OAc)_2$ (6 mg, 0.03 mmol) and PPh_3 (25 mg, 1 mmol) afforded 355 mg (95%) of (1*R**,4*S**)-**9b**: white solid; mp 87–88°C (Et_2O–hexanes); ^1H NMR (300 MHz, $CDCl_3$) δ 7.06 (d, J=7.9 Hz, 2H), 7.00 (d, J=7.9 Hz, 2H), 6.07 (d, J=10.0 Hz, 1H), 5.90–5.72 (m, 1H), 5.13 (bs, 1H), 3.66 (s, 3H), 3.65 (s, 3H), 3.32 (d, J=14.0 Hz, 1H), 3.22 (d, J=14.0 Hz, 1H), 2.80–2.70 (m, 1H), 2.30 (s, 3H), 2.02 (s, 3H), 2.00–1.40 (m, 4H); ^{13}C

NMR (75.4 MHz, $CDCl_3$) δ 170.62, 170.58, 170.5, 136.6, 134.7, 132.8, 129.8, 128.9, 125.1, 65.8, 62.6, 52.1, 51.8, 39.3, 38.1, 27.8, 21.3, 21.0, 19.5; MS *m/z* (%) 315 ($M^+-CH_3CO_2$, 9.06), 105 (100); IR (KBr) 1736, 1720. Anal. calcd for $C_{21}H_{26}O_6$: C 67.36, H 7.00. Found: C 67.30, H 7.28.

4.1.18. (1*R,4*S**)-4-(1′,1′-Bis(methoxycarbonyl)-4″-methoxyphenylethyl)cyclohex-2-en-1-ol acetyl ester (1*R**,4*S**-9c).** The reaction of dimethyl 2-(4′-methoxybenzyl)malonate **4c** (302 mg, 1.2 mmol) with NaH (48 mg, 60% in mineral oil, 1.2 mmol) and *cis*-4-chlorocyclohex-2-en-1-ol acetyl ester **8** (175 mg, 1.0 mmol) under the catalysis of $Pd(OAc)_2$ (5 mg, 0.02 mmol) and PPh_3 (25 mg, 1 mmol) afforded 360 mg (92%) of (1*R**,4*S**)-**9c**: white solid; mp 87–88°C (Et_2O–hexanes); ^1H NMR (300 MHz, $CDCl_3$) δ 7.03 (d, *J*=8.5 Hz, 2H), 6.77 (d, *J*=8.5 Hz, 2H), 6.04 (d, *J*=10.3 Hz, 1H), 5.90–5.80 (m, 1H), 5.11 (bs, 1H), 3.75 (s, 3H), 3.64 (s, 3H), 3.62 (s, 3H), 3.29 (d, *J*=14.2 Hz, 1H), 3.18 (d, *J*=14.2 Hz, 1H), 2.85–2.75 (m, 1H), 2.03 (s, 3H), 2.00–1.50 (m, 4H); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 170.6, 170.5, 170.4, 158.5, 134.6, 131.0, 127.8, 125.1, 113.4, 65.7, 62.7, 55.0, 52.0, 51.8, 39.4, 37.7, 27.8, 21.2, 19.4; MS *m/z* (%) 390 (M^+, 0.47), 121 (100); IR (KBr) 1738, 1720, 1620 cm^{-1}. Anal. calcd for $C_{21}H_{26}O_7$: C 64.60, H 6.71. Found: C 64.51, H 6.67.

4.1.19. (1*R,4*S**)-4-(1′,1′-Dimethoxycarbonyl-3″,5″-dimethylphenylethyl)cyclohex-2-en-1-ol acetyl ester (1*R**,4*S**-9d).** The reaction of dimethyl 2-(3′,5′-dimethylbenzyl)malonate **4d** (275 mg, 1.1 mmol) with NaH (44 mg, 60% in mineral oil, 1.1 mmol) and *cis*-4-chlorocyclohex-2-en-1-ol acetyl ester **8** (175 mg, 1.0 mmol) under the catalysis of $Pd(OAc)_2$ (6 mg, 0.03 mmol) and PPh_3 (26 mg, 1 mmol) afforded 342 mg (88%) of (1*R**,4*S**)-**9d**: mp 81–82°C (Et_2O–hexanes); ^1H NMR (300 MHz, $CDCl_3$) δ 6.84 (s, 1H), 6.70 (s, 2H), 6.04 (d, *J*=10.2 Hz, 1H), 5.80–5.70 (m, 1H), 5.12 (bs, 1H), 3.65 (s, 3H), 3.64 (s, 3H), 3.27 (d, *J*=14.0 Hz, 1H), 3.18 (d, *J*=14.0 Hz, 1H), 2.82–2.74 (m, 1H), 2.25 (s, 6H), 2.01 (s, 3H), 2.00–1.40 (m, 4H); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 170.6, 170.5, 170.4, 137.4, 135.7, 134.7, 128.6, 127.8, 125.0, 65.7, 62.5, 51.9, 51.7, 39.2, 38.2, 27.8, 21.24, 21.20, 19.5; MS *m/z* (%) 388 (M^+, 0.47), 119 (100); IR (KBr) 1736, 1720, 1602 cm^{-1}. Anal. calcd for $C_{22}H_{28}O_6$: C 68.02, H 7.27. Found: C 68.01, H 7.25.

4.1.20. Typical procedure for synthesis of (1*R*,4*S*)-13a–d: (1*R*,4*S*)-4-(1′,1′-bis(methoxycarbonyl)-phenylethyl)-cyclohex-2-en-1-ol benzolate (1*R*,4*S*-13a). Under Ar, **4a** (133 mg, 0.6 mmol) was added to a suspension of NaH (24 mg, 60% in mineral oil, 0.6 mmol) in 5 mL of THF. After being stirred for 15 min, the mixture was cooled to 0°C, $[Pd(\eta^3\text{-}C_3H_5)]_2Cl_2$ (1.8 mg, 0.005 mmol) and the chiral ligand L^* (9.9 mg, 0.0125 mmol) were added. After being stirred for 10 min, **12** (161 mg, 0.5 mmol) was added and the reaction mixture was warmed up to rt. After being stirred for 2 h, the mixture was concentrated and the residue was purified by column chromatography on silica gel to afford 177 mg (84%) of (1*R*,4*S*)-**13a**: oil; 98% ee (HPLC Conditions: Chiralcel OJ Column (0.46 cmϕ×25 cm), λ=254 nm, rate: 0.8 mL/min, eluent: *n*-hexane/*iso*-propanol=80:20); ^1H NMR (300 MHz, $CDCl_3$) δ 8.03 (d, *J*=7.0 Hz, 2H), 7.60–7.50 (m, 1H), 7.50–7.40 (m, 2H), 7.30–7.18 (m, 3H), 7.18–7.08 (m, 2H), 6.17 (d, *J*=10.1 Hz, 1H), 6.00–5.90 (m, 1H), 5.39 (s, 1H), 3.66 (s, 3H), 3.65 (s, 3H), 3.40 (d, *J*=14.0 Hz, 1H), 3.28 (d, *J*=14.0 Hz, 1H), 2.92–2.82 (m, 1H), 2.10–1.60 (m, 4H); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 170.6, 170.5, 165.9, 136.1, 135.0, 132.9, 130.6, 130.0, 129.5, 128.3, 128.2, 127.1, 125.1, 66.2, 62.8, 52.1, 51.9, 39.7, 38.6, 27.9, 19.6; MS *m/z* (%) 373 (7.08), 372 (7.04), 105 (100); IR (neat) 1730, 1710, 1603, 1271, 713 cm^{-1}. Anal. calcd for $C_{25}H_{26}O_6$: C 71.07, H 6.20. Found: C 71.11, H 6.25.

4.1.21. (1*R*,4*S*)-4-(1′,1′-Bis(methoxycarbonyl)-4″-methylphenylethyl)cyclohex-2-en-1-ol benzolate (1*R*,4*S*-13b). The reaction of **4b** (96 mg, 0.4 mmol) with NaH (20 mg, 60%in mineral oil, 0.5 mmol) and **12** (97 mg, 0.3 mmol) under the catalysis of $[Pd(\eta^3\text{-}C_3H_5)]_2Cl_2$ (2.0 mg, 0.0055 mmol) and the chiral ligand L^* (20 mg, 0.025 mmol) afforded 119 mg (91%) of (1*R*,4*S*)-**13b**: oil; 96% ee (HPLC Conditions: Chiralcel AD Column (0.46 cmϕ×25 cm), λ=254 nm, rate: 1 mL/min, eluent: *n*-hexane/*iso*-propanol=100:1.25); ^1H NMR (300 MHz, $CDCl_3$) δ 8.03 (d, *J*=7.0 Hz, 2H), 7.60–7.50 (m, 1H), 7.46–7.38 (m, 2H), 7.10–6.90 (m, 4H), 6.09 (d, *J*=10.4 Hz, 1H), 5.98–5.88 (m, 1H), 5.39 (bs, 1H), 3.68 (s, 3H), 3.63 (s, 3H), 3.36 (d, *J*=14.0 Hz, 1H), 3.26 (d, *J*=14.0 Hz, 1H), 2.90–2.80 (m, 1H), 2.31 (s, 3H), 2.10–1.60 (m, 4H); ESI-MS *m/z* (%) 459.3 ($M+Na^+$); IR (neat) 1731, 1716, 1602, 1271, 713 cm^{-1}. HRMS calcd for $C_{26}H_{28}O_6Na$: 459.1789. Found: 459.1778.

4.1.22. (1*R*,4*S*)-4-(1′,1′-Bis(methoxycarbonyl)-4″-methoxyphenylethyl)cyclohex-2-en-1-ol benzolate (1*R*,4*S*-13c). The reaction of **4c** (150 mg, 0.6 mmol) with NaH (16 mg, 60% in mineral oil, 0.4 mmol) and **12** (97 mg, 0.3 mmol) under the catalysis of $[Pd(\eta^3\text{-}C_3H_5)]_2Cl_2$ (2.0 mg, 0.0055 mmol) and the chiral ligand L^* (20 mg, 0.025 mmol) afforded 100 mg (74%) of (1*R*,4*S*)-**13c**: oil; 95% ee (HPLC Conditions: Chiralcel OJ Column (0.46 cmϕ×25 cm), λ=254 nm, rate: 0.7 mL/min, eluent: *n*-hexane/*iso*-propanol=80:20); ^1H NMR (300 MHz, $CDCl_3$) δ 7.94 (d, *J*=7.0 Hz, 2H), 7.56–7.44 (m, 1H), 7.40–7.30 (m, 2H), 7.01 (d, *J*=6.7 Hz, 2H), 6.72 (d, *J*=6.7 Hz, 2H), 6.04 (d, *J*=10.4 Hz, 1H), 5.90–5.80 (m, 1H), 5.31 (bs, 1H), 3.71 (s, 3H), 3.57 (s, 3H), 3.56 (s, 3H), 3.27 (d, *J*=14.0 Hz, 1H), 3.16 (d, *J*=14.0 Hz, 1H), 2.86–2.76 (m, 1H), 2.04–1.58 (m, 4H); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 170.6, 170.5, 165.9, 158.5, 135.0, 132.8, 131.0, 130.5, 129.4, 128.3, 127.9, 125.0, 113.5, 66.2, 62.8, 55.1, 52.1, 51.8, 39.5, 37.7, 27.9, 19.5; MS *m/z* (%) 452 (M^+, 0.95), 121 (100); IR (neat) 1730, 1716, 1613, 713 cm^{-1}. Anal. calcd for $C_{26}H_{28}O_7$: C 69.01, H 6.24. Found: C 69.09, H 6.23.

4.1.23. (1*R*,4*S*)-4-(1′,1′-Bis(methoxycarbonyl)-3″,5″-dimethylphenylethyl)cyclohex-2-en-1-ol benzolate (1*R*,4*S*-13d). The reaction of **4d** (150 mg, 0.6 mmol) with NaH (24 mg, 60% in mineral oil, 1.0 mmol) and **12** (97 mg, 0.3 mmol) under the catalysis of $[Pd(\eta^3\text{-}C_3H_5)]_2Cl_2$ (2.0 mg, 0.0055 mmol) and the chiral ligand L^* (20 mg, 0.025 mmol) afforded 84 mg (64%) of (1*R*,4*S*)-**13d**: oil; 97% ee (HPLC Conditions: Chiralcel AD Column (0.46 cmϕ×25 cm), λ=254 nm, rate: 0.7 mL/min, eluent:

n-hexane/*iso*-propanol=97:3); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.08–8.00 (m, 2H), 7.60–7.50 (m, 1H), 7.50–7.35 (m, 2H), 6.85 (s, 1H), 6.74 (s, 2H), 6.12 (d, J=10.1 Hz, 1H), 5.97–5.90 (m, 1H), 5.39 (bs, 1H), 3.66 (s, 3H), 3.63 (s, 3H), 3.32 (d, J=14.0 Hz, 1H), 3.22 (d, J=14.0 Hz, 1H), 2.92–2.82 (m, 1H), 2.25 (s, 6H), 2.15–1.60 (m, 4H); ESI-MS m/z (%) 473.3 (M+Na$^+$); IR (neat) 1736, 1716, 1604, 1271, 990, 713 cm^{-1}. HRMS calcd for $C_{27}H_{30}O_6Na$ (M+Na$^+$): 473.1940. Found: 473.1943.

4.2. Typical procedure for intramolecular Friedel–Crafts reaction

4.2.1. 2,2-Bis(methoxycarbonyl)-4-vinyl-1,2,3,4-tetrahydronaphthalene (10a). 3a (167 mg, 0.5 mmol) in 1 mL of TFA/HOAc (v/v=3:1) was stirred at 70°C under Ar atmosphere for 14 h. The reaction mixture was quenched with saturated NaCl (10 mL) and extracted with ether (15×3 mL). The combined organic phase was successively washed with water, saturated $NaHCO_3$, and dried over $MgSO_4$. After evaporation, the residue was purified by flash chromatography on silica gel (eluent: hexanes/ether=5:1) to afford 90 mg (66%) of **10a**: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.30–6.95 (m, 4H), 5.90–5.60 (m, 1H), 5.40–5.10 (m, 2H), 3.75 (s, 3H), 3.69 (s, 3H), 3.60–3.40 (m, 1H), 3.41 (dd, J=16.3 Hz, 1H), 3.18 (d, J=16.3 Hz, 1H), 2.59 (ddd, J=13.5, 6.0, 2.1 Hz, 1H), 2.03 (dd, J=13.5, 11.1 Hz, 1H); MS m/z (%) 274 (M$^+$, 0.31), 155 (100); IR (neat) 1737, 1639, 921 cm^{-1}. HRMS calcd for $C_{16}H_{18}O_4$: 274.1205. Found: 274.1217.

4.2.2. 2,2-Bis(methoxycarbonyl)-4-vinyl-6-methyl-1,2,3,4-tetrahydronaphthalene (10b). The reaction of **3b** (174 mg, 0.5 mmol) afforded 95 mg (66%) of **10b**: colorless needles; mp 74–75°C (Et_2O–hexanes). ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.95 (d, J=7.6 Hz, 1H), 6.90 (s, 1H), 6.89 (d, J=7.6 Hz, 1H), 5.68 (ddd, J=18.6, 10.0, 8.8 Hz, 1H), 5.12 (d, J=18.6 Hz, 1H), 5.11 (d, J=10.0 Hz, 1H), 3.68 (s, 3H), 3.61 (s, 3H), 3.40–3.28 (m, 1H), 3.30 (d, J=16.2 Hz, 1H), 3.06 (d, J=16.2 Hz, 1H), 2.51 (ddd, J=13.6, 6.1, 2.2 Hz, 1H), 2.20 (s, 3H), 1.93 (dd, J=13.6, 11.1 Hz, 1H); ^{13}C NMR ($CDCl_3$, 75.4 MHz) δ 172.1, 171.2, 141.1, 135.8, 135.7, 130.0, 128.9, 128.6, 127.4, 116.5, 53.41, 52.75, 52.65, 41.26, 35.03, 34.63, 21.02; MS m/z (%) 288 (M$^+$, 2.12), 169 (100); IR (neat) 1748, 1725, 1640, 929, 815 cm^{-1}. Anal. calcd for $C_{17}H_{20}O_4$: C 70.81, H 6.99. Found: C 70.95, H 7.08.

4.2.3. 2,2-Bis(methoxycarbonyl)-4-vinyl-6-methoxy-1,2,3,4-tetrahydronaphthalene (10c). The reaction of **3c** (182 mg, 0.5 mmol) afforded 100 mg (66%) of **10c**: white solid; mp 57–58°C (Et_2O–hexanes). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.04 (d, J=9.2 Hz, 1H), 6.75–6.65 (m, 2H), 5.73 (ddd, J=18.5, 9.8, 8.9 Hz, 1H), 5.23–5.15 (m, 2H), 3.74 (s, 6H), 3.70 (s, 3H), 3.58–3.44 (m, 1H), 3.34 (d, J=16.0, 1.9 Hz, 1H), 3.10 (d, J=16.0 Hz, 1H), 2.57 (ddd, J=13.5, 6.1, 2.2 Hz, 1H), 1.98 (dd, J=13.5, 11.1 Hz, 1H); MS m/z (%) 304 (M$^+$, 7.35), 185 (100); IR (KBr) 1740, 1720, 1620, 910, 805 cm^{-1}. HRMS calcd for $C_{17}H_{20}O_5$: 304.1311. Found: 304.1341.

4.2.4. 2,2-Bis(methoxycarbonyl)-4-vinyl-5,7-dimethyl-1,2,3,4-tetrahydronaphthalene (10d). The reaction of **3d** (181 mg, 0.5 mmol) afforded 103 mg (68%) of **10d**: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.82 (s, 2H), 5.71 (ddd, J=17.3, 10.2, 6.2, 1 Hz), 4.97 (dd, J=10.2, 1.5 Hz, 1H), 4.67 (dd, J=17.3, 1.5 Hz, 1H), 3.83–3.65 (m, 1H), 3.70 (s, 3H) 3.66 (s, 3H), 3.48 (d, J=16.1 Hz, 1H), 3.00 (d, J=16.1 Hz, 1H), 2.54 (dd, J=13.8, 7.2 Hz, 1H), 2.37 (dd, J=13.8, 4.4 Hz, 1H), 2.25 (s, 3H), 2.15 (s, 3H); MS m/z (%) 302 (M$^+$, 99.14), 211 (100); IR (neat) 1730, 1620, 920 cm^{-1}. HRMS calcd for $C_{18}H_{22}O_4$: 302.1518. Found: 302.1538.

4.2.5. 1-Vinyl-3,3-bis(methoxycarbonyl)-1,2,3,4-tetrahydrophenanthrene (10e). The reaction of **3e** (192 mg, 0.5 mmol) afforded 116 mg (72%) of **10e**: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.95 (d, J=8.3 Hz, 1H), 7.72 (d, J=8.0 Hz, 1H), 7.57 (d, J=8.6 Hz, 1H), 7.50–7.35 (m, 2H), 7.24 (d, J=8.6 Hz, 1H), 5.75–5.60 (m, 1H), 5.17 (d, J=15.0 Hz, 1H), 5.13 (d, J=9.6 Hz, 1H), 3.87 (d, J=16.8 Hz, 1H), 3.72 (s, 3H), 3.68–3.54 (m, 1H), 3.59 (s, 3H), 3.35 (d, J=16.8, 1 Hz), 2.60 (dd, J=13.3, 5.9 Hz, 1H), 2.04 (dd, J=13.3, 10.6 Hz, 1); MS m/z (%) 324 (M$^+$, 22.33), 205 (100); IR (neat) 1732, 1610, 910, 820 cm^{-1}. HRMS calcd for $C_{20}H_{20}O_4$: 324.1362. Found: 324.1366.

4.2.6. 2,2-Bis(methoxycarbonyl)-4-methyl-4-vinyl-1,2,3,4-tetrahydronaphthalene (10f). The reaction of **3f** (174 mg, 0.5 mmol) afforded 121 mg (84%) of **10f**: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.20–7.00 (m, 4H), 5.74 (dd, J=17.3, 10.5 Hz, 1H), 4.87 (d, J=10.5 Hz, 1H), 4.48 (d, J=17.3 Hz, 1H), 3.65 (s, 3H), 3.54 (s, 3H), 3.36 (d, J=20.7 Hz, 1H), 2.97 (d, J=20.7 Hz, 1H), 2.46 (d, J=14.2 Hz, 1H), 2.17 (d, J=14.2 Hz, 1H), 1.33 (s, 3H); MS m/z (%) 288 (M$^+$, 16.75), 169 (100) IR (neat) 1737, 1635, 919, 762 cm^{-1}. HRMS calcd for $C_{17}H_{20}O_4$: 288.1362. Found: 288.1365.

4.2.7. 2,2-Bis(methoxycarbonyl)-4,6-dimethyl-4-vinyl-1,2,3,4-tetrahydronaphthalene (10g). The reaction of **3g** (181 mg, 0.5 mmol) afforded 129 mg (85%) of **10g**: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.20–6.90 (m, 3H), 5.82 (dd, J=17.1, 10.4 Hz), 4.95 (d, J=10.4 Hz, 1H), 4.60 (d, J=17.1 Hz, 1H), 3.73 (s, 3H), 3.61 (s, 3H), 3.32 (d, J=16.2 Hz, 1H), 3.08 (d, J=16.2 Hz, 1H), 2.51 (d, J=14.0 Hz, 1H), 2.30 (s, 3H), 2.22 (d, J=14.0 Hz, 1H), 1.26 (s, 3H); MS m/z (%) 364 (M$^+$, 35.76), 245 (100); IR (neat) 1746, 1732, 1635, 918, 826 cm^{-1}. Anal. calcd for $C_{18}H_{22}O_4$: C 71.50, H 7.33. Found: C 71.60, H 7.36.

4.2.8. 2,2-Bis(methoxycarbonyl)-4-hex-1′(*E*)-enyl-1,2,3,4-tetrahydronaphthalene (10h). The reaction of **3h** (190 mg, 0.487 mmol) afforded 136 mg (85%) of **10h**: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.10–6.90 (m, 4H), 5.56 (dt, J=15.1, 6.7 Hz, 1H), 5.29 (dd, J=15.1, 8.6 Hz, 1H), 3.68 (s, 3H), 3.61 (s, 3H), 3.40–3.34 (m, 1H), 3.34 (dd, J=16.3 Hz, 1H), 3.10 (d, J=16.3 Hz, 1H), 2.50 (ddd, J=13.5, 6.0, 2.2 Hz, 1H), 1.99 (q, J=6.7 Hz, 2H), 1.92 (dd, J=13.5, 11.4 Hz, 2H), 1.34–1.10 (m, 4H), 0.85 (t, J=7.0 Hz, 3H); MS m/z (%) 330 (M$^+$, 3.16), 141 (100); IR (neat) 1737, 1604, 971, 744 cm^{-1}. HRMS calcd for $C_{20}H_{26}O_4$: 330.1831. Found: 330.1864.

4.2.9. 2,2-Bis(methoxycarbonyl)-6-methyl-4-hex-1′(*E*)-enyl-1,2,3,4-tetrahydronaphthalene (10i). The reaction of **1i** (180 mg, 0.446 mmol) afforded 152 mg (99%) of **10i**:

oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.00–6.85 (m, 3H), 5.54 (dt, J=15.1, 6.7 Hz, 1H), 5.26 (dd, J=15.1, 8.7 Hz, 1H), 3.68 (s, 3H), 3.61 (s, 3H), 3.40–3.30 (m, 1H), 3.30 (dd, J=16.0, 1.9 Hz, 1H), 3.05 (d, J=16.0 Hz, 1H), 2.59 (ddd, J=13.6, 6.0, 2.2 Hz, 1H), 2.20 (s, 3H), 2.02 (q, J=6.7 Hz, 2H), 1.89 (dd, J=13.6, 11.3 Hz, 1H), 1.30–1.10 (m, 4H), 0.85 (t, J=7.2 Hz, 3H); MS m/z 344 (M^+, 38.87), 225 (100); IR (neat) 1737, 1604, 971, 744 cm^{-1}. HRMS calcd for $C_{21}H_{28}O_4$: 344.1988. Found: 344.1966.

4.2.10. 2,2-Bis(methoxycarbonyl)-4-(2′-phenylethenyl)-6-methyl-1,2,3,4-tetrahydronaphthalene (10j). The reaction of **3j** (212 mg, 0.5 mmol) afforded 171 mg (94%) of **10j**: white solid; mp 90–91°C (Et_2O–hexanes); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.46–7.40 (m, 2H), 7.40–7.28 (m, 2H), 7.26–7.20 (m, 1H), 7.16–6.90 (m, 3H), 6.58 (d, J=15.6 Hz, 1H), 6.17 (dd, J=15.6, 8.9 Hz, 1H), 3.76 (s, 3H), 3.73 (s, 3H), 3.75–3.60 (m, 1H), 3.43 (d, J=16.2 Hz, 1H), 3.21 (d, J=16.2 Hz, 1H), 2.68 (ddd, J=13.6, 6.1, 2.1 Hz, 1H), 2.27 (s, 3H), 2.12 (dd, J=13.6, 11.0 Hz, 1H),; MS m/z (%) 302 (M^+, 40.94), 242 (100); IR (neat) 1745, 1728, 1614, 971 cm^{-1}. Anal. calcd for $C_{23}H_{24}O_4$: C 75.80, H 6.64. Found: C 75.88, H 6.86.

4.2.11. 4-Hex-1′-enyl-2-(*p*-methylphenylsulfonyl)-1,2,3,4-tetrahydroisoquinlone (10k). The reaction of **3k** (170 mg, 0.396 mmol) afforded 135 mg (92%) of **10k**: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.53 (d, J=8.0 Hz, 2H), 7.13 (d, J=8.0 Hz, 2H), 6.99–6.88 (m, 3H), 6.85–6.76 (m, 1H), 5.45 (dt, J=15.3, 6.7 Hz, 1H), 5.18 (dd, J=15.3, 8.6 Hz, 1H), 4.14 (d, J=15.3 Hz, 1H), 3.92 (d, J=15.3 Hz, 1H), 3.46–3.36 (m, 1H), 3.32 (dd, J=11.0, 4.9 Hz, 1H), 2.77 (dd, J=11.0, 7.3 Hz, 1H), 2.23 (s, 3H), 1.90–1.76 (m, 2H), 1.24–1.02 (m, 4H), 0.71 (t, J=7.3 Hz, 3H); MS m/z 370 (M^++1, 10.74), 129 (100); IR (neat) 3208, 1598, 970, 958, 814 cm^{-1}. Anal. calcd for $C_{22}H_{27}NO_2S$: C 71.51, H 7.36, N 3.79. Found: C 71.51, H 7.49, N 3.89.

4.2.12. (4b*R,8a*S**)-9,9-Bis(methoxycarbonyl)-4b,7,8,8a,9,10-hexahydro-phenanthrene (4b*R**,8a*S**-11a).** The reaction of (1*R**,4*S**)-**9a** (108 mg, 0.3 mmol) afforded 87 mg (97%) of (4b*R**,8a*S**)-**11a**: white solid; mp 77–78°C (Et_2O–hexanes); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.26 (d, J=7.6 Hz, 1H), 7.18–7.05 (m, 3H), 6.26–6.20 (m, 1H), 5.85–5.75 (m, 1H), 3.78 (s, 3H), 3.70 (bs, 1H), 3.62 (s, 3H), 3.41 (d, J=17.2 Hz, 1H), 3.29 (d, J=17.2 Hz, 1H), 2.89 (dd, J=12.3, 4.7 Hz, 1H), 2.26–2.00 (m, 2H), 1.55–1.20 (m, 2H); ^{1}H NMR (75.4 MHz, $CDCl_3$) δ 170.9, 170.7, 137.4, 131.6, 129.0, 128.7, 127.7, 127.2, 126.5, 125.6, 57.6, 52.8, 52.7, 36.9, 35.4, 30.3, 25.5, 21.3; MS m/z (%) 300 (M^+, 6.28), 181 (100); IR (KBr) 1730, 1610, 1500, 760 cm^{-1}. HRMS calcd for $C_{18}H_{20}O_4$: 300.1362. Found: 300.1337.

The reaction of (1*R**,4*R**)-**9a** (108 mg, 0.3 mmol) afforded 81 mg (90%) of (4b*R**,8a*S**)-**11a**.

4.2.13. (4b*R*,8a*S*)-9,9-Bis(methoxycarbonyl)-4b,7,8,8a,9,10-hexahydro-phenanthrene (4b*R*,8a*S*-11a). The reaction of (1*R*,4*S*)-**13a** (80 mg, 98%ee) in TFA/AcOH (3:1) afforded 56 mg (99%) of (4b*R*,8a*S*)-**11a**: 98% ee (HPLC Conditions: Chiralcel AD Column (0.46 cmϕ×25 cm), λ=254 nm, rate: 0.7 mL/min, eluent: *n*-hexane/*iso*-propanol=100:2).

4.2.14. (4b*R,8a*S**)-3-Methyl-9,9-bis(methoxycarbonyl)-4b,7,8,8a,9,10-hexahydro-phenanthrene (4b*R**,8a*S**-11b).** The reaction of (1*R**,4*S**)-**9b** (38 mg, 0.1 mmol) in TFA/AcOH (3:1) afforded 31 mg (99%) of (4b*R**,8a*S**)-**11b**: white solid; mp 87–88°C (Et_2O–hexanes); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.30–6.85 (m, 3H), 6.40–6.20 (m, 1H), 5.95–5.75 (m, 1H), 3.78 (s, 3H), 3.75–3.65 (m, 1H), 3.63 (s, 3H), 3.50–3.40 (m, 2H), 3.10–2.85 (m, 1H), 2.27 (s, 3H), 2.25–1.85 (m, 2H), 1.70–1.30 (m, 2H); ^{13}C NMR (75.4 MHz, $CDCl_3$) δ 171.1, 170.8, 137.3, 136.0, 129.0, 128.8, 128.6, 128.3, 127.3, 126.6, 57.8, 52.82, 52.77, 37.1, 35.5, 30.0, 25.6, 21.5, 21.2; MS m/z (%) 314 (M^+, 6.77), 195 (100); IR (neat) 1736, 1610, 1500, 1196, 1180 cm^{-1}. HRMS calcd for $C_{19}H_{22}O_4$: 314.1518. Found: 314.1517.

4.2.15. (4b*R*,8a*S*)-3-Methyl-9,9-bis(methoxycarbonyl)-4b,7,8,8a,9,10-hexahydro-phenanthrene (4b*R*,8a*S*-11b). The reaction of (1*R*,4*S*)-**13b** (60 mg, 96% ee) in TFA/AcOH (3:1) afforded 42 mg (97%) of (4b*R*,8a*S*)-**11b**: 98% ee (HPLC Conditions: Chiralcel OJ Column (0.46 cmϕ×25 cm), λ=254 nm, rate: 0.7 mL/min eluent: *n*-hexane/*iso*-propanol=80:20).

4.2.16. (4b*R,8a*S**)-3-Methoxy-9,9-bis(methoxycarbonyl)-4b,7,8,8a,9,10-hexahydrophenanthrene (4b*R**,8a*S**-11c).** The reaction of (1*R**,4*S**)-**9c** (100 mg, 0.256 mmol) afforded 80 mg (95%) of (4b*R**,8a*S**)-**11c**: white solid; mp 88–89°C (Et_2O–hexanes). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.03 (d, J=8.4 Hz, 1H), 6.78 (s, 1H), 6.67 (d, J=8.4 Hz, 1H), 6.24–6.15 (m, 1H), 5.85–5.75 (m, 1H), 3.77 (s, 3H), 3.75 (s, 3H), 3.72–3.65 (m, 1H), 3.62 (s, 3H), 3.34 (d, J=17.0 Hz, 1H), 3.19 (d, J=17.0 Hz, 1H), 2.90–2.80 (m, 1H), 2.30–1.90 (m, 2H), 1.50–1.20 (m, 2H); MS m/z (%) 330 (M^+, 8.88), 211 (100); IR (KBr) 1730, 1610, 1500, 1560, 1260, 1230, 1196, 1180 cm^{-1}. Anal. calcd for $C_{19}H_{22}O_5$: C, 69.07, H, 6.71. Found: C, 68.91, H, 6.84.

4.2.17. (4b*R*,8a*S*)-3-Methoxy-9,9-bis(methoxycarbonyl)-4b,7,8,8a,9,10-hexahydro-phenanthrene (4b*R*,8a*S*-11c). The reaction of (1*S*,4*R*)-**13c** (80 mg, 0.177 mmol, 95% ee) in TFA/AcOH (3:1) afforded 54 mg (93%) of (4b*R*,8a*S*)-**11c**. 95% ee (HPLC Conditions: Chiralcel AD Column (0.46 cmϕ×25 cm), λ=254 nm, rate: 0.7 mL/min, eluent: *n*-hexane/*iso*-propanol=100:2).

4.2.18. (4b*R,8a*S**)-1,4-Dimethyl-9,9-bis(methoxycarbonyl)-4b,7,8,8a,9,10-hexahydro-phenanthrene (4b*R**,8a*S**-11d).** The reaction of (1*R**,4*S**)-**9d** (64 mg) in TFA/AcOH (3:1) afforded 53 mg (98%) of a mixture of (4b*R**,8a*S**)-**11d** (*cis*) and *trans* isomer (*cis*/*trans*>90:10). (4b*R**,8a*S**)-**11d**: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.86 (s, 1H), 6.78 (s, 1H), 5.90–5.80 (m, 2H), 3.90 (bs, 1H), 3.80 (s, 3H), 3.55 (s, 3H), 3.36 (d, J=14.8 Hz, 1H), 3.18 (d, J=17.2 Hz, 1H), 3.12–3.05 (m, 1H), 2.35 (s, 3H), 2.36 (s, 3H), 2.20–2.00 (m, 2H), 1.30–1.05 (m, 2H); MS m/z (%) 328 (M^+, 30.39), 209 (100); IR, 1730, 1610, 1250 cm^{-1}. HRMS calcd for $C_{20}H_{24}O_4$ 328.1675. Found: 328.1654.

4.2.19. (4b*R*,8a*S*)-1,4-Dimethyl-9,9-bis(methoxycarbonyl)-4b,7,8,8a,9,10-hexahydro-phenanthrene (4b*R*,8a*S*-11d). The reaction of (1*S*,4*R*)-**13d** (80 mg, 97% ee) in TFA/AcOH (3:1) afforded 56 mg (97%) of a mixture

of (4b*R*,8a*S*)-**11d** (*cis*) and *trans* isomer (*cis*/*trans*>90:10). (4b*R*,8a*S*)-**11d**: 97% ee (HPLC conditions: Chiralcel OJ Column (0.46 cmϕ×25 cm), λ=254 nm, rate: 0.7 mL/min, eluent: *n*-hexane/*iso*-propanol=95:5).

4.3. Synthesis of 14 and its annulation to 10a

4.3.1. Dimethyl 2-(4′-hydroxy-but-2-enyl)-2-benzylmalonate (14). A solution of dimethyl 2-benzyl-malonate **4a** (3.330 g, 15 mmol) in THF was treated with NaH (60%, 0.600 g, 15 mmol) for 10 min under Ar. 4-Chloro-but-2-en-1-ol (1.704 g, 16 mmol) in THF was added and the mixture was stirred for overnight. After the usual work-up, the residue was purified through column chromatography on silica gel afforded 3.466 g (79%) of **14**: liquid; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.32–7.18 (m, 3H), 7.10–7.01 (m, 2H), 5.76–5.60 (m, 2H), 4.10 (d, *J*=5.1 Hz, 2H), 3.71 (s, 6H), 3.22 (s, 2H), 2.54 (d, *J*=6.0 Hz, 2H); MS *m*/*z* (%) 275 (M^+-OH, 40.63), 91 (100); IR (neat) 3429, 1735, 974, 703 cm^{-1}. Anal. calcd for $C_{16}H_{20}O_5$: C 65.74, H 6.90. Found: C 65.58, H 6.64.

The reaction of **14** (146 mg, 0.5 mmol) in TFA/AcOH (3:1) afforded 54 mg (39%) of **10a**.

The reaction of **14** (146 mg, 0.5 mmol) in TFA:$(CF_3CO)_2O$ (4:1) afforded 72 mg (53%) of **10a**.

Acknowledgements

Financial support from the Major State Basic Research Development Program (Grant G2000077500), the National Natural Science Foundation of China, Chinese Academy of Sciences, Shanghai Municipal Committee of Science and Technology are greatly appreciated. Shengming Ma is the recipient of 1999 Qiu Shi Award for Young Scientific Workers issued by Hong Kong Qiu Shi Foundation of Science and Technology (1999–2003).

References

1. (a) Kuramoto, M.; Yamada, K.; Shikano, M.; Yazawa, K.; Arimoto, H.; Okamura, T.; Uemura, D. *Chem. Lett.* **1997**, 885–886. (b) *Dictionary of Natural Products*, Chapman & Hall, 1994, Vol. 1; pp 812–813. (c) Palmer, D. C.; Strauss, M. J. *Chem. Rev.* **1977**, *77*, 1–92. (d) Shiotani, S.; Kometani, T.; Mitsuhashi, K.; Nozawa, T.; Kurobe, A.; Futsukaichi, O. *J. Med. Chem.* **1976**, *19*, 803–806.
2. For radical cyclization, see: (a) Citterio, A.; Fancelli, D.; Finzi, C.; Pesce, L.; Santi, R. *J. Org. Chem.* **1989**, *54*, 2713–2718. (b) Shundo, R.; Nishiguchi, I.; Matsubara, Y.; Hirashima, T. *Tetrahedron* **1991**, *47*, 831–840.
3. For carbopalladation, see: (a) Takemoto, T.; Sodeoka, M.; Sasai, H.; Shibasaki, M. *J. Am. Chem. Soc.* **1993**, *115*, 8477–8478. (b) Gaudin, J. M. *Tetrahedron Lett.* **1991**, *32*, 6113–6116. (c) O'connor, B.; Zhang, Y.-T.; Negishi, E.; Luo, F.-T.; Cheng, J.-W. *Tetrahedron Lett.* **1988**, *29*, 3903–3906. (d) Wang, R.-T.; Chou, F.-L.; Luo, F.-T. *J. Org. Chem.* **1990**, *55*, 4846–4849.
4. For Pd-catalyzed cyclization of 2-(6′-trimethylsilyl-4′-hexenyl)phenyl iodide, see: Tietze, L. F.; Schimpf, R. *Angew. Chem. Int. Ed. Engl.* **1994**, *33*, 1089–1091.
5. For acylpalladation, see: (a) Tour, J. M.; Negishi, E. *J. Am. Chem. Soc.* **1985**, *107*, 8289–8291. (b) Negishi, E.-I.; Copėret, C.; Ma, S.; Mita, T.; Sugihara, T.; Tour, J. M. *J. Am. Chem. Soc.* **1996**, *118*, 5904–5918.
6. (a) Olah, G. A.; Krishnamurti, R.; Prakash, G. K. S. *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon: Oxford, 1991; Vol. 3, pp 293–339 Chapter 1.8. (b) Roberts, R. M.; Khalaf, A. A. *Friedel–Crafts Alklation Chemistry. A Centry of Discovery*; Marcel Dekker: New York, 1984. (c) *Friedel–Crafts and Related Reactions*; Olah, G. A., Ed.; Wiley: New York, 19631965; Vols. 1–4.
7. For acid-catalyzed cyclization of 4-phenyl-1-alkanols at a very high temperature yielding benzocyclic compounds with a low selectivity, see: (a) Khalaf, A. A.; Roberts, R. M. *J. Org. Chem.* **1969**, *34*, 3571–3574. (b) Khalaf, A. A.; Roberts, R. M. *J. Org. Chem.* **1972**, *37*, 4227–4235.
8. Ma, S.; Zhang, J. *Tetrahedron Lett.* **2002**, *43*, 3435–3438.
9. Trost, B. M.; Shi, Y. *J. Am. Chem. Soc.* **1993**, *115*, 12491–12509.
10. Babler, J. H.; Buttner, W. J. *Tetrahedron Lett.* **1976**, 239–242.
11. Colobert, F.; Genet, J. P. *Tetrahedron Lett.* **1985**, *26*, 2779–2782.
12. Bäckvall, J. E.; Nyström, J. E.; Nordberg, R. E. *J. Am. Chem. Soc.* **1985**, *107*, 3676–3686.
13. Crystal data for (4bR^*,8aS^*)-**11c**: $C_{19}H_{22}O_5$, M_w=330.37, triclinic, space group *P*-1, μ(Mo K_α) 0.093 mm^{-1}, R_1=0.0659, *wR*1=0.1408, *a*=9.721(5) Å, *b*=13.201(7) Å, *c*=13.494(7) Å, α=90.000(8)°, β=80.202(10)°, γ=90.000(9)°, *V*=1706.5(15) $Å^3$, *T*=293(2) K, *Z*=4, reflections collected/unique 7551/6044 (R_{int}=0.0846), no observation ($I>2.0\sigma(I)$) 2647, parameters 576 CCDC 178671.
14. Trost, B. M.; Tanimori, S.; Dunn, P. T. *J. Am. Chem. Soc.* **1997**, *119*, 2735–2736.