Cyclization into Hydrindanones Using Samarium Diiodide

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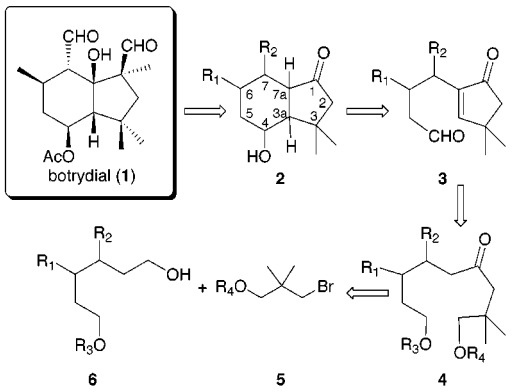
Samarium(II) iodide has been employed to promote vinylogous pinacol coupling reaction of aldehyde onto α,β-unsaturated ketones. The diastereoselectivity of 6-endo products was changed by addition of a proton source and/or HMPA and by the reaction temperature. The cyclization reactions described herein provide a general approach to the syntheses of 3,3-dimethylhydrindanes with a *cis*-relationship between the OH at C-4 and the proton at C-3a with good diastereoselectivity and under mild reaction conditions.

Introduction

Samarium (II) diiodide (SmI_2) is an exceptional reagent for promoting intramolecular reductive cyclization reactions, and the chemistry of this reagent has been well documented in several reviews.[1] Among many synthetic reactions and strategies, carbon−carbon bond formations between aldehydes or ketones and α,β-unsaturated esters are of extreme interest. Most cases are classified as 4-exo,[2] 5-exo-,[3] 6-exo,[4] or 7-exo-Trig[5] type cyclizations. Thus, our interest has been focused on the 6-endo-Trig-type cyclization between aldehydes and enones.

At the same time, we have been interested in total syntheses of compounds having a hydrindane system, such as tamariscol,[6] conocephalenol,[7] isovalerenenol,[8] chiloscyphone,[9] and so on. Botrydial (**1**) is a secondary metabolite of *Botrytis cinerea* and possesses six chiral centers in a hydrindane system.[10] Reductive cyclization using SmI_2 has been a promising method to construct the hydrindane system, although the cis and trans stereochemistry depends on the reaction conditions.[11] Because hydrindanone systems such as **2** could be derived from the corresponding enone aldehyde **3** by an intramolecular reductive cyclization, we have prepared substrates and tested the scope and limitation of this process. This enone aldehyde may be obtained from mono-alcohol **6** and bromide **5** (Scheme 1).

Scheme 1



In electrochemistry, comparison of the half-wave potential of α,β-unsaturated carbonyls with those of the corresponding saturated carbonyls has been extensively studied.[12] The first waves of carbonyl groups, referred to as SCE, are 2.45 V (cyclohexanone), 2.25 V (methyl ethyl ketone), 1.8 V (propionaldehyde), 1.55 V (2-cyclohexen-1-one), 1.5 V (acrolein), and 1.42 V (methyl vinyl ketone), respectively. On the other hand, the reducing characteristics of SmI_2 can be modulated by the addition of catalysts[13] and solvent additives.[14] For example, the oxidation potential of SmI_2, referred to as $Ag/AgNO_3$ electrode, can be changed to between −1.33 V (non

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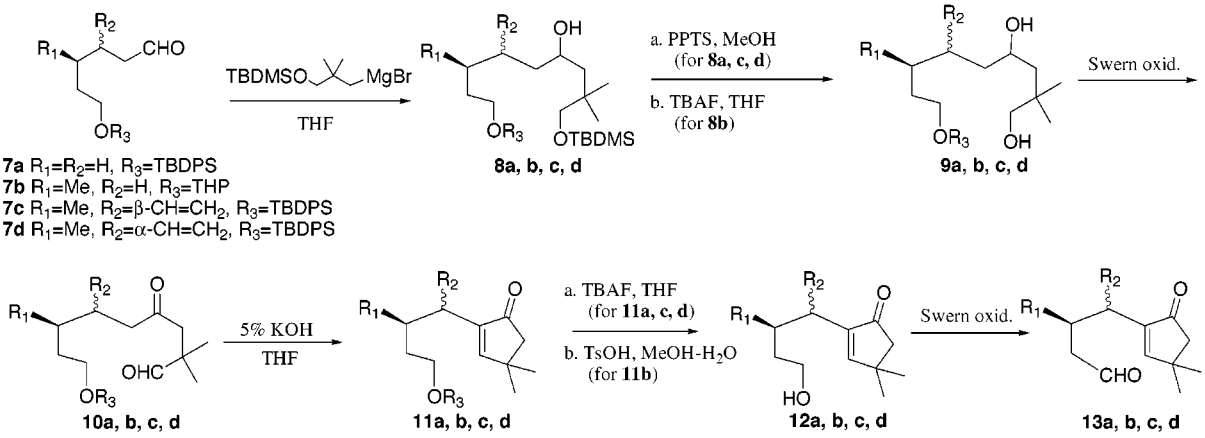
Scheme 2



7a R_1=R_2=H, R_3=TBDPS
7b R_1=Me, R_2=H, R_3=THP
7c R_1=Me, R_2=β-CH=CH_2, R_3=TBDPS
7d R_1=Me, R_2=α-CH=CH_2, R_3=TBDPS

8a, b, c, d **9a, b, c, d** **10a, b, c, d** **11a, b, c, d** **12a, b, c, d** **13a, b, c, d**

additive) and −2.05 V (HMPA 4.0 equiv and more). We are interested in the trend of diastereoselectivity of the reductive cyclization reaction using SmI_2 with various additives.

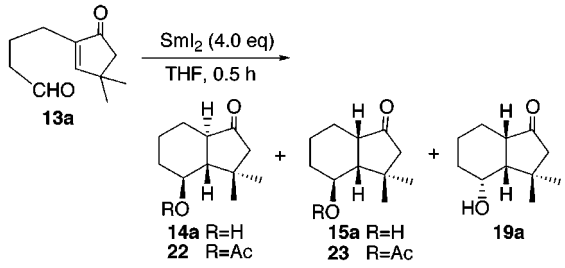
We now report the results on the cyclization processes of compounds having the general structure **3**. Three continuous stereocenters were newly constructed in the reductive annulation. The cis arrangement for the hydroxyl group at C-4 and the juncture proton at C-3a is predominant when the reaction is performed without any additive or in the presence of HMPA. However, addition of a proton source such as MeOH and/or HMPA dramatically changes the product configuration in some cases. The thermodynamic stability between cis and trans hydrindanes has also been studied.

Results and Discussion

Synthesis of Aldehyde 13a, 13b, 13c, and 13d. We chose the simple model **13a**, which was prepared from 1,6-hexanediol via aldehyde **7a** (eight steps, 16% overall yield) as summarized in Scheme 2.[15] Compound **13b** having a *β*-methyl group was prepared from *S*-(−)-citronellol via aldehyde **7b** (eight steps, 28% overall yield) in a similar way. The vinyl group substituted aldehydes **13c** and **13d** were derived from aldehydes **7c** (15 steps, 5% overall yield) and **7d** (15 steps, 1.3% overall yield), respectively (Scheme 2), which were prepared from *S*-(−)-citronellol.[15]

Cyclization with SmI_2. Cyclization reactions were performed in 0.1 mmol scale of the starting material. The amount of SmI_2 employed was 4.0 equiv for simple enone-aldehyde **13a** and 3.0 equiv for methylated enone-aldehyde **13b**. A large amount of SmI_2 (6.0 equiv) was used for vinylated enone-aldehyde **13c** and **13d** considering the reactivity of vinyl group. After the cyclizaton reaction, the cyclyzation products were separated as a mixture of diastereoisomers on silica gel column chromatography. Each diastereoisomer was purified by HPLC, and the structure was determined by mainly using 2D-NMR experiments. The yields were calculated from the mixture of the cyclization products, and the ratios of diastereoisomers were determined on GC-MS analysis (identified on the retention time and the mass fragment pattern).

Table 1. Reductive Cyclization of 13a



13a → **14a** R=H / **22** R=Ac + **15a** R=H / **23** R=Ac + **19a**

entry	additives (equiv)	temp (°C)	recovery (%) of **13a**	yield (%) [ratio[a]] **14:15a:19a**
1	−	0	12	77 [47:48:5]
2	−	−78	33	38 [37:33:30]
3	HMPA	0	−	87 [40:52:8]
4	HMPA	−78	−	78 [48:46:6]
5	MeOH (2.0)	0	−	96 [59:14:27]
6	MeOH (2.0)	−78	9	63 [43:11:46]
7	HMPA/MeOH (2.0)	0	−	61 [37:28:35]
8	HMPA/MeOH (2.0)	−78	2	93 [19:9:72]

[a] Ratios were determined by GC analyses.

The results of the reductive cyclization of aldehyde **13a** are shown in Table 1. Without any additive at 0 °C, alcohols **14a** and **15a** were the main products (entry 1). Compound **14a** was purified by recrystallization, but the purification of **15a** from **14a** was not effective. Therefore, the mixture was converted into the corresponding acetates **22** and **23**, which were separated by HPLC, and their stereochemistries were also established by the NOESY experiments.[16] The hydroxyl group at C-4 and the juncture proton at C-3a were cis to each other as revealed by the NOESY spectrum.[16] At −78 °C, the recovery of **13a** increased and the yield of the cyclization products was as low as 38% (entry 2), and the addition of HMPA forced an efficient reaction even at −78 °C (entries 3, 4). However, if a proton source is present, the yield of trans alcohol **19a**[16] was raised (entries 5, 6). In the presence of HMPA and MeOH at −78 °C, **19a** was the main product (entry 8). Although we do not postulate equilibration in the reaction mixture, compound **15a** was subjected to isomerization conditions (K_2CO_3, MeOH), and the equilibration ratio was found to be **14a**:**15a** = 93:7 by GC.[15] Under the equilibration conditions com-

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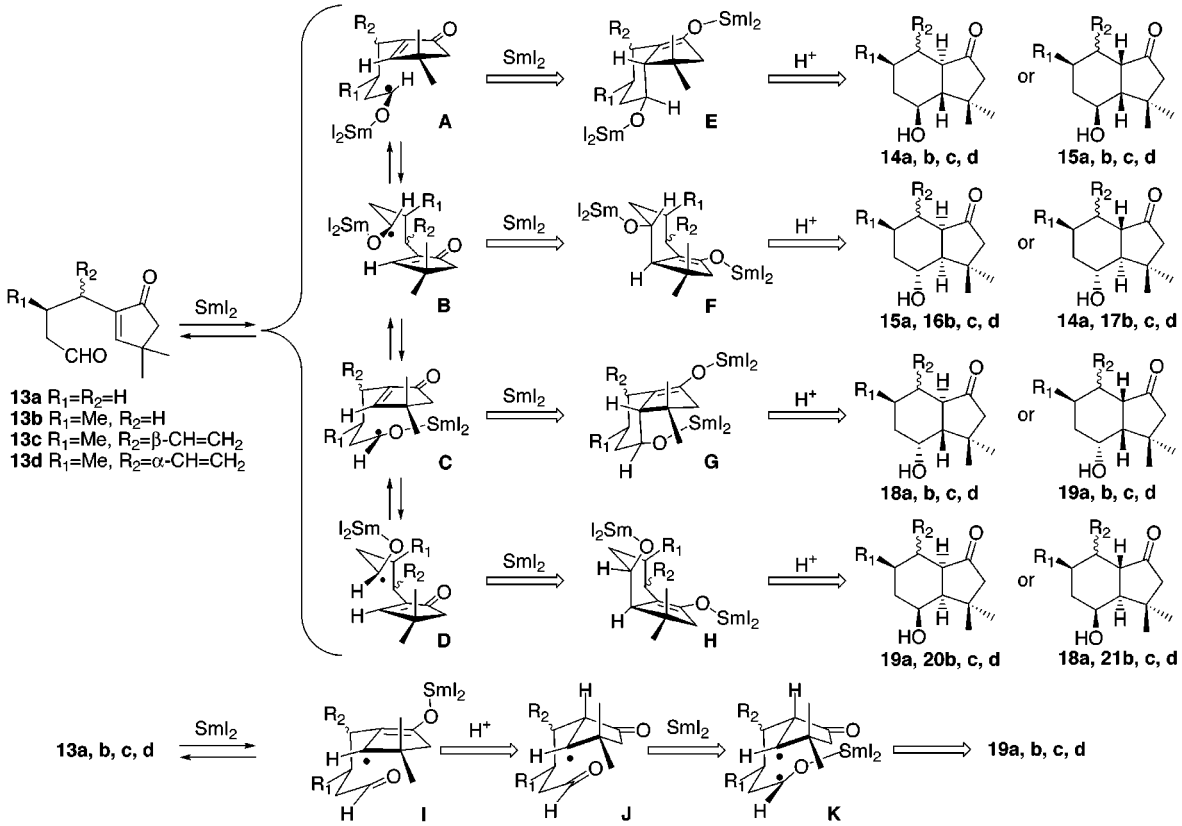
(15) The details are available as Supporting Information.

(16) The full structure was established by the combination of the 2D NMR and NOESY spectroscopy, and the summary of the observed NOE's are shown in the Supporting Information.

Scheme 3



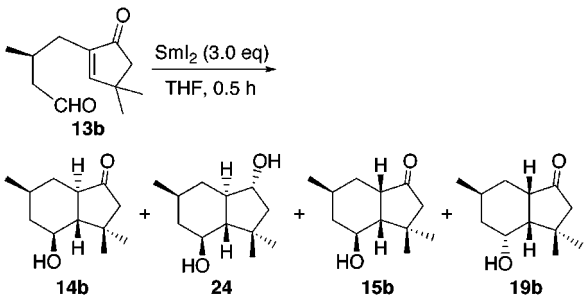
pound **19a** afforded the isomer **18a** (**18a**:**19a** = 21:79),[15] which was not isolated in this cyclization reaction.

Samarium(II) reduces the aldehyde, and the samarium-coordinated species is sterically bulky. Thus, if a proton source is not present, conformation **13a-A** is predominant and the cyclization occurs to lead to cis arrangement for the hydroxyl group at C-4 and the juncture hydrogen at C-3a as observed in compounds **14a** and **15a** (Scheme 3). The reduction of carbonyl groups by SmI_2 proceeds under equilibrium conditions, and the radical coupling and the protonation of samarium enolates are competitive. α,*β*-Unsaturated ketones are reduced more easily than saturated aldehydes electrochemically. Therefore, if a proton source is present, the reduction of the enone moiety of **13a** may be faster. After the enolate **13a-I** is protonated, the samarium(III) attached to the intermediate **13a-K** may interact with the other carbonyl group to provide the trans arrangement between the hydroxyl group at C-4 and the juncture proton at C-3a. This process may be slow, and therefore, in the presence of the proton source, the trans product **19a** predominates at the lower temperature compared to the case at the higher temperature, presumably because of the energetic stability by coordination to both oxygen atoms.

Formation of trans-fused 3,3-dimethylhydrindanes with a cis relationship between the OH at C-4 and the proton at C-3a (e.g., **14a**) should be accessible in yields of approximately 80% by cyclization with SmI_2 (4 equiv) and HMPA (5 equiv) at 0 °C followed by equilibration under basic conditions (K_2CO_3, MeOH) and separation from their *cis*-fused analogues (e.g., **15a**) and other diastereoisomers present in minute quantities (e.g., **18a** and **19a**, less than 8%).

The reaction of aldehyde **13b** was next investigated and the results are summarized in Table 2. The cis

Table 2. Reductive Cyclization of 13b

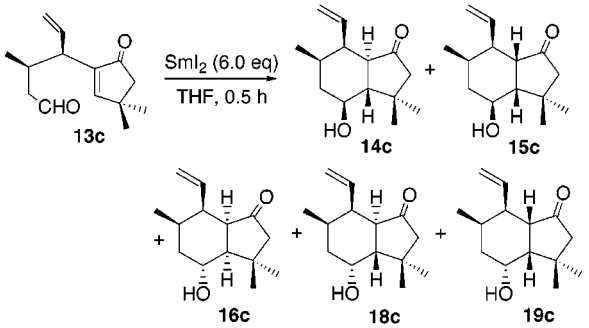


entry	additives (equiv)	temp (°C)	recovery (%) of **13b**	yield (%) [ratio[a]] **14b:24:15b:19b**
1	–	0	11	60 [23:4:60:13]
2	HMPA	0	0	81 [26:11:47:16]
3	MeOH (2.0)	0	28	56 [42:5:36:17]
4	MeOH (25)	−78	18	57 [0:0:0:100]

[a] Ratios were determined by GC analyses.

arrangement for the hydroxyl group at C-4 and the juncture proton at C-3a is also seen in **14b**[16] and **15b**,[16] which were the major products (entries 1, 2). If MeOH (2.0 equiv) was added at 0 °C, the trans-arranged product **19b**[16] was produced in 17% ratio (entry 3). When excess MeOH (25 equiv) as a proton source was added at −78 °C, the stereoselectivity was changed to give **19b** as the sole product, although the total yield was as rather low as 57% (entry 4). Compounds **19b** and **15b** were treated with K_2CO_3 in MeOH to see if there are isomers in the mixture. Compound **19b** afforded the isomer **18b** (**19b**:**18b** = 64:36),[15] which was not produced in the cyclization reaction. Compounds **15b** and **14b** were isomers to each other and the ratio was 17:83.[15] Compound **24**[15] was the

Table 3. Reductive Cyclization of 13c



entry	additives (equiv)	temp (°C)	recovery (%) of **13c**	yield (%) [ratio[a]] **14c:15c:16c:18c:19c**
1	–	0	10	55 [84:10:6:0:0]
2	–	−78	4	66 [85:15:0:0:0]
3	HMPA	0	–	73 [94:6:0:0:0]
4	HMPA	−78	6	59 [91:4:5:0:0]
5	MeOH (25)	0	–	70 [31:2:5:6:56]
6	MeOH (25)	−78	58	30 [17:0:4:3:76]

[a] Ratios were determined by GC analyses.

over-reduction product, whose structure was confirmed by the $NaBH_4$ reduction of **14b**.

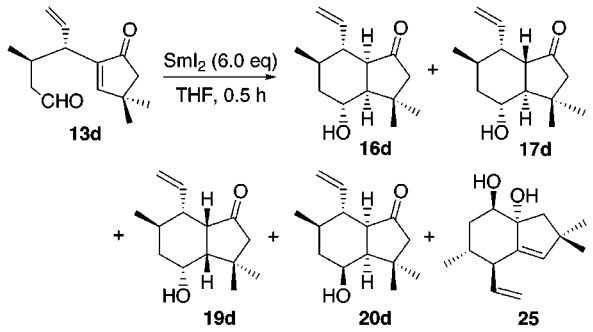
As shown in Scheme 3, in case no additive is present or only HMPA is present, the samarium-coordinated species is much bulkier to adopt the conformation outside the cyclopentane ring to lead to cis stereochemistry for the hydroxyl group at C-4 and the juncture proton at C-3a. The conformation **13b-A** is the most stable due to the equatorial orientation of the methyl substituent. When excess MeOH was added, the reduction of the enone system may be faster, and consequently, intermediate **13b-K** was formed to change the conformation such that the same samarium(III) as a Lewis acid coordinates both the carbonyl groups to lead to trans stereochemistry as in the case of **19b**. Therefore, intermediate **13b-J** or its further reduced species **13b-K** may play an important role under these reaction conditions. These results were almost in accordance with those shown in Table 1.

The vinyl group substituted aldehyde **13c** was next studied (Table 3). Compound **14c** was the major product in entries 1−4, the structure being established by the X-ray analysis,[17] while by addition of excess MeOH (25 equiv) as a proton source, compound **19c**[16] became the major product in entries 5 and 6. Compound **18c**, whose structure was established by X-ray crystallography,[13] was also obtained in minute quantity because of the conformational unstability.

The same mechanism as above can be applied as follows. When no additive is present or only HMPA is present, the samarium-coordinated species is much bulkier to adopt the conformation such that this part protrudes outside the cyclopentane ring to lead to cis stereochemistry for the hydroxyl group at C-4 and the juncture proton at C-3a (Scheme 3). Thus, conformation **13c-A** is more stable due to the methyl and vinyl substitutions. When MeOH was added, the reduction of the enone system may be faster to change the conformation to lead to trans stereochemistry as in the case of **19c** through **13c-J**. The cis product **15c**[16] and the cis but reversed-face selected compound **16c**[16] were produced in minute amounts.

(17) The structure was analyzed by X-ray crystallography. The X-ray data are available in the Supporting Information.

Table 4. Reductive Cyclization of 13d



entry	additives (equiv)	temp (°C)	recovery (%) of **13d**	yield (%) [ratio[a]] **16d:17d:19d:20d:25**
1	–	0	–	68 [58:19:16:7:0]
2	–	−78	–	86 [53:16:21:10:0]
3	HMPA	0	–	52 [30:9:26:21:14]
4	HMPA	−78	–	76 [31:8:32:14:15]
5	MeOH (25)	0	–	83 [49:16:20:15:0]
6	MeOH (25)	−78	3	76 [43:12:38:7:0]

[a] Ratios were determined by GC analyses.

Finally, the diastereoisomer **13d** was subjected to reaction with SmI_2. As shown in Table 4, under any reaction conditions almost the same stereoselectivity was obtained regardless of the presence or absence of a proton source. Thus, compounds **16d**[16] and/or **19d**[16] were obtained as major products. The structures of **17d** and **20d** were completely established by X-ray crystallographic analyses,[13] and the others were determined by the NOESY spectra.[16]

These results may be due to the fact that aldehyde **13d** is conformationally inflexible, and the difference in the conditions did not affect the results (Scheme 3). Actually, there is no product from conformation **13d-A**, which was predominant in three other cases. Only in this case both the carbonyl groups reacted leading to diol **25**.[16] This also shows that the reaction route is diverse in this case, presumably because the stability of each intermediate is almost the same as others.

Conclusion

These results show that 6-endo-Trig type reactions may smoothly proceed to cyclize into hydrindanones by the action of SmI_2, depending on the predominant conformation of the substrate. Unfortunately, the configuration at the C-4 position of compound **19d** differs from that of botrydial (**1**). However, compound **14c** must be a good candidate for construction of botrydial, because the C-7 position could be inverted at a later stage. Therefore, we are currently working along this line to prepare the hydrindane system.

Experimental Section

General. Tetrahydrofuran (THF) was distilled from $LiAlH_4$ under Ar and then redistilled from sodium−benzophenone ketyl prior to use. Samarium metal was purchased from Strem, Inc. and stored under Ar. Iodine was purchased from Aldrich. HMPA was purchased from Aldrich, distilled from CaH_2, and stored over 4 Å molecular sieves under Ar. *t*-BuOH was purchased from Aldrich and was distilled from magnesium and stored over 4 Å molecular sieves under Ar. Commercially available reagents were used without further purification.

Standard benchtop techniques were employed for handling air-sensitive reagents, and all reactions were performed under Ar.

Preparation of the SmI_2 Solution. Samarium metal (496.3 mg, 3.3 mmol) was added under a flow of Ar to an oven-dried, round-bottomed two-necked flask containing a magnetic stirring bar and septum inlet. Diiodomethane (803.5 mg, 3.0 mmol) was added to a vigorously stirred suspension of samarium metal in THF (30 mL). The mixture was stirred vigorously for 3 h at room temperature. The resultant deep blue-green solution was used directly to effect the following reactions.

General Procedure for the Synthesis of Hydrindanones. A solution of SmI_2 in THF was cooled to a fixed temperature, and an enone-aldehyde and an additive in THF were added dropwise slowly. The mixture was stirred at the temperature for 30 min. The reaction was quenched with a saturated aq solution of Rochelle's salt. Organic materials were extracted with diethyl ether, washed with brine, and dried over anhydrous magnesium sulfate. The products were purified by silica gel flash chromatography and HPLC. Gas chromatographic analyses were carried out on a capillary column [HP-20M 25 m × 0.2 mm × 0.2 μm, 50−100 °C (20 °C/min) followed by 100−200 °C (5 °C/min)].

SmI_2 Reduction of 13a. Entry 1: A solution of **13a** (20 mg, 0.11 mmol) in THF (0.8 mL) was treated with SmI_2 (0.1 M, 4.4 mL, 0.44 mmol) at 0 °C according to the general procedure to afford **13a** (2.3 mg) and a mixture (15.6 mg) of **14a**, **15a**, and **19a** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 2: A solution of **13a** (20 mg, 0.11 mmol) in THF (0.8 mL) was treated with SmI_2 (0.1 M, 4.4 mL, 0.44 mmol) at −78 °C according to the general procedure to afford **13a** (6.5 mg) and a mixture (7.7 mg) of **14a**, **15a**, and **19a** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 3: A solution of **13a** (20 mg, 0.11 mmol) and HMPA (0.1 mL, 0.55 mmol) in THF (0.8 mL) was treated with SmI_2 (0.1 M, 4.4 mL, 0.44 mmol) at 0 °C according to the general procedure to afford a mixture (17.6 mg) of **14a**, **15a**, and **19a** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 4: A solution of **13a** (20 mg, 0.11 mmol) and HMPA (0.1 mL, 0.55 mmol) in THF (0.8 mL) was treated with SmI_2 (0.1 M, 4.4 mL, 0.44 mmol) at −78 °C according to the general procedure to afford a mixture (15.8 mg) of **14a**, **15a**, and **19a** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 5: A solution of **13a** (20 mg, 0.11 mmol) and MeOH (7.1 mg, 0.22 mmol) in THF (0.8 mL) was treated with SmI_2 (0.1 M, 4.4 mL, 0.44 mmol) at 0 °C according to the general procedure to afford a mixture (19.4 mg) of **14a**, **15a**, and **19a** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 6: A solution of **13a** (20 mg, 0.11 mmol) and MeOH (7.1 mg, 0.22 mmol) in THF (0.8 mL) was treated with SmI_2 (0.1 M, 4.4 mL, 0.44 mmol) at −78 °C according to the general procedure to afford **13a** (1.8 mg) and a mixture (12.7 mg) of **14a**, **15a**, and **19a** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 7: A solution of **13a** (20 mg, 0.11 mmol), HMPA (0.1 mL, 0.55 mmol), and MeOH (7.1 mg, 0.22 mmol) in THF (0.8 mL) was treated with SmI_2 (0.1 M, 4.4 mL, 0.44 mmol) at 0 °C according to the general procedure to afford a mixture (12.3 mg) of **14a**, **15a**, and **19a** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 8: A solution of **13a** (20 mg, 0.11 mmol), HMPA (0.1 mL, 0.55 mmol), and MeOH (7.1 mg, 0.22 mmol) in THF (0.8 mL) was treated with SmI_2 (0.1 M, 4.4 mL, 0.44 mmol) at −78 °C according to the general procedure to afford **13a** (0.3 mg) and a mixture (18.8 mg) of **14a**, **15a**, and **19a** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

14a and **19a** were purified on HPLC (Nucleosil 50−5, 10ϕ × 250 mm, 30% AcOEt/hexane) and recrystalyzation (hexane−AcOEt). **15a** could not be separated from **14a** (**14a**:**15a** = 1:2).

(3a*R*,4*S*,7a*R*)-4-Hydroxy-3,3-dimethylperhydro-1-indenone (14a). Retention time on GC: 24.7 min; mp 156−159 °C (hexane−AcOEt); FTIR: 3430, 1720 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 1.02−1.10 (1H, m), 1.15 (3H, s), 1.21−1.34 (2H, m), 1.35 (3H, s), 1.37(1H, brd, J = 4.9 Hz), 1.38 (1H, dd, J = 13.7, 9.9 Hz), 1.83−1.88 (1H, m), 1.95 (1H, dddd, J = 13.7, 11.3, 3.3, 1.4 Hz), 1.99−2.06 (2H, m), 2.03 (1H, brd, J = 19.2 Hz), 2.19 (1H, dd, J = 19.2, 1.4 Hz), 3.74 (1H, tt, J = 9.9, 4.7 Hz); ^{13}C NMR (50 MHz, $CDCl_3$) δ 22.3 (CH_3), 24.5 (CH_2), 24.7 (CH_2), 30.8 (CH_3), 36.2 (C), 36.8 (CH_2), 51.7 (CH), 53.8 (CH_2), 57.8 (CH), 72.7 (CH), 217.2 (C); MS (EI) m/z 182 (M^+), (base); HRMS (EI) Calcd for $C_{11}H_{18}O_2$ 182.1307. Found: 182.1279 (M^+).

(3a*R*,4*S*,7a*S*)-4-Hydroxy-3,3-dimethylperhydro-1-indenone (15a): (mixture with **14a**, **14a**:**15a** = 1:2). Retention time on GC: 24.4 min; ^1H NMR (200 MHz, $CDCl_3$) (major peak) δ 1.00−1.40 (3H, m), 1.19 (3H, s), 1.33 (3H, s), 1.51−1.64 (1H, m), 1.80−2.20 (4H, m), 2.13 (2H, br s), 2.78 (1H, brt, J = 7.4 Hz), 3.43 (1H, td, J = 10.5, 4.2 Hz).

(3a*R*,4*R*,7a*S*)-4-Hydroxy-3,3-dimethylperhydro-1-indenone (19a). Retention time on GC: 27.2 min; mp 127−129 °C (hexane−AcOEt); FTIR: 3480, 1720 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 0.83 (1H, br s), 1.17 (3H, s), 1.29−1.35 (1H, m), 1.32 (3H, s), 1.42−1.46 (1H, m), 1.47 (1H, ddd, J = 13.5, 3.8, 1.6 Hz), 1.55−1.64 (1H, m), 1.68−1.74 (1H, m), 1.75 (1H, dd, J = 7.2, 2.7 Hz), 1.98 (1H, dt, J = 18.4, 1.4 Hz), 2.20−2.25 (1H, m), 2.40 (1H, dd, J = 18.4, 0.5 Hz), 2.56 (1H, brt, J = 7.2 Hz), 4.21 (1H, br s); ^{13}C NMR (50 MHz, $CDCl_3$) δ 15.1 (CH_2), 20.7 (CH_2), 24.2 (CH_3), 31.4 (CH_3), 32.5 (CH_2), 35.8 (C), 45.5 (CH), 50.0 (CH), 51.3 (CH_2), 66.6 (CH), 207.7 (C); MS (EI) m/z 182 (M^+), 122 (base); HRMS (EI) Calcd for $C_{11}H_{18}O_2$ 182.1307. Found: 182.1258 (M^+).

Acetylation of 14a and 15a. The mixture (7.3 mg) of **14a** and **15a** (**14a**:**15a** = 1:2)were acetylated using acetic anhydride, DMAP, and pyridine to afford **22** (1.7 mg) and **23** (5.0 mg) after flash chromatography (SiO_2, 15% AcOEt/hexane) and HPLC (Nucleosil 50-5, 4.6ϕ × 250 mm, 10% AcOEt/hexane).

(3a*R*,4*S*,7a*R*)-4-Acetoxy-3,3-dimethylperhydro-1-indenone (22). FTIR: 1640 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 1.05 (3H, s), 1.08−1.12 (1H, m), 1.23 (3H, s), 1.20−1.28 (1H, m), 1.34 (1H, qt, J = 13.7, 3.8 Hz), 1.64 (1H, dd, J = 13.7, 10.4 Hz), 1.86 (1H, dtt, J = 13.7, 3.8, 2.7 Hz), 2.00−2.14 (3H, m), 2.04 (1H, d, J = 19.2 Hz), 2.07 (3H, s), 2.20 (1H, dd, J = 19.2, 1.4 Hz), 4.91 (1H, td, J = 10.4, 4.4 Hz); MS (EI) m/z 224 (M^+), 164 (base); HRMS (EI) Calcd for $C_{13}H_{20}O_3$ 224.1412. Found: 224.1385 (M^+).

(3a*R*,4*S*,7a*S*)-4-Acetoxy-3, 3-dimethylperhydro-1-indenone (23). FTIR: 1740 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 1.07−1.21 (2H, m), 1.09 (3H, s), 1.17 (3H, s), 1.39 (1H, dddd, J = 13.7, 12.6, 6.5, 4.4 Hz), 1.53−1.59 (1H, m), 1.94−1.98 (1H, m), 2.04 (3H, s), 2.09−2.17 (4H, m), 2.84 (1H, brt, J = 6.5 Hz), 4.57 (1H, td, J = 10.2, 4.4 Hz); MS (EI) m/z 224 (M^+), 164 (base); HRMS (EI) Calcd for $C_{13}H_{20}O_3$ 224.1412. Found: 224.1417 (M^+).

Isomerization of 14a and 15a. K_2CO_3(12 mg) was added to a MeOH solution of **14a** and **15a** (**14a**:**15a** = 1:1, 1.9 mg, 0.01 mmol), and the mixture was stirred vigorously and refluxed for 19 h. The organic materials were extracted with diethyl ether, washed with brine, and dried over anhydrous magnesium sulfate. After filtration and evaporation of solvent in vacuo, the mixture (1.8 mg) of **14a** and **15a** (93:7 on GC) was prepared.

Isomerization of 19a. K_2CO_3 (12 mg) was added to a MeOH (3 mL) solution of **19a** (2.1 mg, 0.012 mmol), and the mixture was stirred vigorously and refluxed for 24 h. The organic materials were extracted with diethyl ether, washed with brine, and dried over anhydrous magnesium sulfate. After filtration and evaporation of solvent in vacuo, the mixture (1.9 mg) of **18a** and **19a** (21:79) was prepared.

SmI_2 Reduction of 13b. Entry 1: A solution of**13b** (20 mg, 0.1 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 3.0 mL, 0.30 mmol) at 0 °C according to the general procedure to afford **13b** (2.2 mg) and a mixture (12.1 mg) of **14b**, **15b**, **19b**, and **24** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 2: A solution of **13b** (20 mg, 0.1 mmol) and HMPA (0.09 mL, 0.50 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 3.0 mL, 0.30 mmol) at 0 °C according to the general procedure to afford a mixture (16.4 mg) of **14b**, **15b**, **19b**, and **24** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 3: A solution of **13b** (20 mg, 0.1 mmol) and MeOH (6.5 mg, 0.2 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 3.0 mL, 0.30 mmol) at 0 °C according to the general procedure to afford **13b** (4.6 mg) and a mixture (11.3 mg) of **14b**, **15b**, **19b**, and **24** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 4: A solution of **13b** (20 mg, 0.1 mmol) and MeOH (79.1 mg, 2.5 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 3.0 mL, 0.30 mmol) at −78 °C according to the general procedure to afford **13b** (3.5 mg) and **19b** (11.5 mg) after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

The mixture of **14b**, **15b**, **19b**, and **24** was separated by HPLC (Nucleosil 50−5, 4.6ϕx250 mm, 30% AcOEt/hexane) and (Cosmosil 50-5, 4.6ϕ × 250 mm, 40% MeOH/H_2O).

(3a*R*,4*S*,6*S*,7a*R*)-4-Hydroxy-3,3,6-trimethylperhydro-1-indenone (14b). Retention time on GC: 25.3 min; mp 132−134 °C (hexane−$CHCl_3$); $[\alpha]^{19}_D$ −78° (*c* 0.84, $CHCl_3$); FTIR: 3450, 1720 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 0.79 (1H, br q, J = 12.1 Hz), 0.98 (3H, d, J = 6.6 Hz), 1.01 (1H, td, J = 12.4, 10.4 Hz), 1.14 (3H, s), 1.34 (1H, br s), 1.34 (3H, s), 1.36 (1H, dd, J = 13.7, 10.4 Hz), 1.49−1.58 (1H, m), 1.97−2.05 (3H, m), 2.05 (1H, dd, J = 19.2, 0.5 Hz), 2.21 (1H, dd, J = 19.2, 1.4 Hz), 3.76 (1H, td, J = 10.4, 4.1 Hz); ^{13}C NMR (50 MHz, $CDCl_3$) δ 21.6 (CH_3), 22.3 (CH_3), 30.8 (CH_3), 31.7 (CH), 33.1 (CH_2), 36.0 (C), 45.8 (CH_2), 51.5 (CH), 54.3 (CH_2), 57.7 (CH), 72.0 (CH), 216.7 (C); MS (EI) *m*/*z* 196 (M^+), 111 (base); HRMS (EI) Calcd for $C_{12}H_{20}O_2$ 196.1463. Found 196.1467 (M^+).

(3a*R*,4*S*,6*S*,7a*S*)-4-Hydroxy-3,3,6-trimethylperhydro-1-indenone (15b). Retention time on GC: 24.4 min; mp 91−93 °C (hexane−$CHCl_3$); $[\alpha]^{21}_D$ +106° (*c* 1.6, $CHCl_3$); FTIR: 3450, 1740 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 0.93 (3H, d, J = 6.6 Hz), 0.93−1.03 (2H, m), 1.18 (3H, s), 1.20−1.26 (1H, m), 1.34 (3H, s), 1.59 (1H, br s), 1.80 (1H, dd, J = 10.0, 7.8 Hz), 1.83 (1H,ddt, J = 12.4, 4.7, 2.2 Hz), 2.11 (2H, s), 2.15 (1H, ddt, J = 13.7, 3.8, 1.9 Hz), 2.80 (1H, td, J = 7.8, 0.8 Hz), 3.45 (1H, td, J = 10.0, 4.0 Hz); ^{13}C NMR (50 MHz, $CDCl_3$) δ 21.9 (CH_3), 27.0 (CH_3), 27.6 (CH), 30.0 (CH_3), 31.2 (CH_2), 36.2 (C), 43.1 (CH_2), 49.7 (CH), 50.4 (CH_2), 53.4 (CH), 69.3 (CH), 218.9 (C); MS (EI) *m*/*z* 196 (M^+), 111 (base); HRMS (EI) Calcd for $C_{12}H_{20}O_2$ 196.1463. Found 196.1469 (M^+).

(3a*R*,4*R*,6*S*,7a*S*)-4-Hydroxy-3,3,6-trimethylperhydro-1-indenone (19b). Retention time on GC: 26.8 min; mp 128−130 °C (hexane-$CHCl_3$); $[\alpha]^{19}_D$ +63° (*c* 1.0, $CHCl_3$); FTIR: 3400, 1725 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 0.90 (3H, d, J = 6.6 Hz), 0.99 (1H, br s), 1.02 (1H, ddd, J = 14.0, 12.4, 6.9 Hz), 1.13 (1H, ddd, J = 13.7, 12.9, 1.6 Hz), 1.17 (3H, s), 1.33 (3H, s), 1.67−1.73 (2H, m), 1.75−1.83 (1H, m), 1.97 (1H, dt, J = 18.0, 1.1 Hz), 2.26 (1H, ddt, J = 14.0, 4.7, 1.6 Hz), 2.40 (1H, d, J = 18.0 Hz), 2.60 (1H, brt, J = 7.4 Hz), 4.21 (1H, br s); ^{13}C NMR (50 MHz, $CDCl_3$) δ 21.0 (CH), 22.2 (CH_3), 24.3 (CH_3), 29.7 (CH_2), 31.5 (CH_3), 35.6 (C), 41.4 (CH_2), 46.3 (CH), 49.9 (CH), 51.5 (CH_2), 67.4 (CH), 218.5 (C); MS (EI) *m*/*z* 196 (M^+), 136 (base); HRMS (EI) Calcd for $C_{12}H_{20}O_2$ 196.1463. Found 196.1444 (M^+).

(1*R*,3a*R*,4*S*,6*S*,7a*R*)-1,4-Dihydroxy-3,3,6-trimethylperhydroindene (24). Retention time on GC: 27.0 min; mp 150−152 °C (hexane−$CHCl_3$); $[\alpha]^{19}_D$ −13° (*c* 0.96, $CHCl_3$); FTIR: 3300 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 0.67 (1H, q, J = 11.8 Hz), 0.91 (1H, td, J = 12.4, 10.4 Hz), 0.96 (3H, d, J = 6.6 Hz), 0.98 (1H, dd, J = 12.4, 10.4 Hz), 1.11 (3H, s), 1.17 (3H, s), 1.37 (1H, dd, J = 13.6, 7.4 Hz), 1.45−1.53 (2H, m), 1.64 (2H, br s), 1.89−1.95 (2H, m), 1.97 (1H, dd, J = 13.6, 9.0 Hz), 3.66 (1H, td, J = 10.4, 4.4 Hz), 3.80 (1H, td, J = 9.0, 7.4 Hz); ^{13}C NMR (50 MHz, $CDCl_3$) δ 21.9 (CH_3), 25.8 (CH_3), 31.6 (CH), 32.5 (CH_3), 37.4 (C), 37.5 (CH_2), 45.6 (CH_2), 49.7 (CH), 51.0 (CH_2), 58.3 (CH), 71.6 (CH), 76.3 (CH); MS (EI) *m*/*z* 198 (M^+), 125 (base); HRMS (EI) Calcd for $C_{12}H_{22}O_2$ 198.1620. Found 198.1637 (M^+).

Isomerization of 19b. K_2CO_3 (12 mg) was added to a MeOH (3 mL) solution of **19b** (21.0 mg, 0.012 mmol), and the mixture was stirred vigorously and refluxed for 19 h. The organic materials were extracted with diethyl ether, washed with brine, and dried over anhydrous magnesium sulfate. After filtration and evaporation of solvent in vacuo, the mixture (20.9 mg) of **18b** and **19b** (36:64) was prepared. **18b** and **19b** were purified by flash chromatography (SiO_2, 0−40% AcOEt/hexane).

(3a*R*,4*R*,6*S*,7a*R*)-4-Hydroxy-3,3,6-trimethylperhydro-1-indenone (18b). mp 90−92 °C (hexane-$CHCl_3$); $[\alpha]_D^{19}$ −160° (*c* 0.64, $CHCl_3$); FTIR: 3500, 1730 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 0.82 (1H, q, J = 11.6 Hz), 0.94 (3H, d, J = 6.6 Hz), 1.13 (1H, ddd, J = 13.7, 12.6, 2.5 Hz), 1.16 (3H, s), 1.21 (3H, s), 1.28 (1H, br s), 1.38 (1H, dd, J = 14.3, 1.5 Hz), 1.80 (1H, dtd, J = 14.3, 3.6, 1.6 Hz), 1.84−1.93 (1H, m), 2.03 (1H, d, J = 18.6 Hz), 2.14 (1H, dtd, J = 12.9, 3.8, 1.6 Hz), 2.18 (1H, dd, J = 18.6, 1.4 Hz), 2.60 (1H, dddd, J = 14.3, 11.6, 3.8, 1.5 Hz), 4.43 (1H, s); ^{13}C NMR (50 MHz, $CDCl_3$) δ 21.8 (CH_3), 24.6 (CH_3), 26.2 (CH), 28.6 (CH_3), 34.7 (CH_2), 36.6 (C), 43.8 (CH_2), 45.0 (CH), 55.3 (CH_2), 55.5 (CH), 65.8 (CH), 218.7 (C); MS (EI) *m*/*z* 196 (M^+), 163 (base); HRMS (EI) Calcd for $C_{12}H_{20}O_2$ 196.1463. Found 196.1460 (M^+).

Isomerization of 14b. K_2CO_3 (12 mg) was added to a MeOH (3 mL) solution of **14b** (5.5 mg, 0.01 mmol), and the mixture was stirred vigorously and refluxed for 24 h. The organic materials were extracted with diethyl ether, washed with brine, and dried over anhydrous magnesium sulfate. After filtration and evaporation of solvent in vacuo, the mixture (4.5 mg) of **14b** and **15b** (83:17) was prepared.

SmI_2 Reduction of 13c. Entry 1: A solution of **13c** (20 mg, 0.09 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 5.4 mL, 0.54 mmol) at 0 °C according to the general procedure to afford **13c** (2.0 mg) and a mixture (11.1 mg) of **14c**, **15c**, and **16c** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 2: A solution of **13c** (20 mg, 0.09 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 5.4 mL, 0.54 mmol) at −78 °C according to the general procedure to afford **13c** (0.9 mg) and a mixture (13.3 mg) of **14c** and **15c** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 3: A solution of **13c** (20 mg, 0.09 mmol) and HMPA (0.08 mL, 0.45 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 5.4 mL, 0.54 mmol) at 0 °C according to the general procedure to afford a mixture (14.7 mg) of **14c** and **15c** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 4: A solution of **13c** (20 mg, 0.09 mmol) and HMPA (0.08 mL, 0.45 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 5.4 mL, 0.54 mmol) at −78 °C according to the general procedure to afford **13c** (1.1 mg) and a mixture (11.9 mg) of **14c**, **15c**, and **16c** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 5: A solution of **13c** (20 mg, 0.09 mmol) and MeOH (79.1 mg, 2.47 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 5.4 mL, 0.54 mmol) at 0 °C according to the general procedure to afford a mixture (14.1 mg) of **14c**, **15c**, **16c**, **18c**, and **19c** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 6: A solution of **13c** (20 mg, 0.09 mmol) and MeOH (79.1 mg, 2.47 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 5.4 mL, 0.54 mmol) at −78 °C according to the general procedure to afford **13c** (11.6 mg) and a mixture (6.1 mg) of **14c**, **16c**, **18c**, and **19c** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

The mixture of **14c**, **15c**, **16c**, **18c**, and **19c** was separated by HPLC (Develosil 60−10, 20ϕx250 mm, 30% AcOEt/hexane) and recrystalyzation.

(3a*R*,4*S*,6*R*,7*R*,7a*R*)-4-Hydroxy-3,3,6-trimethyl-7-vinylperhydro-1-indenone (14c). Retention time on GC: 31.8 min; mp 113−116 °C (hexane−$CHCl_3$); $[\alpha]^{21}_D$ −107° (*c* 1.6, $CHCl_3$); FTIR: 3450, 1720, 1640 cm^{-1}; ^1H NMR (600 MHz, C_6D_6) δ 0.75 (3H, d, J = 6.9 Hz), 0.80 (3H, s), 0.89 (1H, br s), 0.99 (1H, td, J = 12.6, 10.7 Hz), 1.14−1.20 (1H, m), 1.20 (3H, s), 1.33 (1H, dt, J = 10.2, 4.2 Hz), 1.53 (1H, dd, J = 14.3, 10.2 Hz), 1.72 (1H, dd, J = 18.3, 0.5 Hz), 1.72 (1H, dd, J = 10.2, 1.1 Hz), 1.91 (1H, dd, J = 18.3, 1.4 Hz), 2.63 (1H, dt, J = 9.3, 4.1 Hz), 3.25 (1H, td, J = 10.2, 4.2 Hz), 5.14 (1H, dd, J = 10.2, 4.2 Hz), 5.33 (1H, dd, J = 17.0, 2.5 Hz), 5.51 (1H, dt, J = 17.0, 10.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.1 (CH_3), 21.7 (CH_3), 30.6 (CH_3), 34.8 (CH), 36.0 (C), 41.1 (CH_2), 43.0 (CH), 41.1 (CH_2), 43.0 (CH), 51.3 (CH), 55.3 (CH_2), 55.7 (CH), 72.4 (CH), 120.0

(CH_2), 132.4 (CH), 215.3 (C); MS (EI) *m*/*z* 222 (M^+), 121 (base); HRMS (EI) Calcd for $C_{14}H_{22}O_2$ 222.1620. Found 222.1644 (M^+).

(3a*R*,4*S*,6*R*,7*R*,7a*S*)-4-Hydroxy-3,3,6-trimethyl-7-vinylperhydro-1-indenone (15c). Retention time on GC: 28.8 min; $[\alpha]^{20}_D$ +129° (*c* 1.2, $CHCl_3$); FTIR: 3400, 1740, 1640 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 0.87 (3H, d, J = 6.9 Hz), 1.18 (3H, s), 1.27 (1H, td, J = 12.9, 11.0 Hz), 1.34 (3H, s), 1.39−1.46 (1H, m), 1.54 (1H, br s), 1.56−1.60 (1H, m), 1.93 (1H, dd, J = 10.0, 8.2 Hz), 2.12 (2H, s), 2.75 (1H, dd, J = 8.2, 0.8 Hz), 2.79 (1H, dd, J = 9.1, 4.4 Hz), 3.47 (1H, td, J = 11.0, 5.2 Hz), 5.10−5.13 (2H, m), 5.89 (1H, ddd, J = 15.7, 11.5, 8.8 Hz); ^{13}C NMR (50 MHz, $CDCl_3$) δ 19.3 (CH_3), 27.0 (CH_3), 29.9 (CH), 29.9 (CH_3), 36.2 (C), 38.0 (CH_2), 41.5 (CH), 50.1 (CH_2), 51.1 (CH), 55.3 (CH), 69.6 (CH), 116.8 (CH_2), 136.3 (CH), 217.5 (C); MS (EI) *m*/*z* 222 (M^+), 121 (base); HRMS (EI) Calcd for $C_{14}H_{22}O_2$ 222.1620. Found 222.1622 (M^+).

(3a*S*,4*R*,6*R*,7*R*,7a*R*)-4-Hydroxy-3,3,6-trimethyl-7-vinylperhydro-1-indenone (16c). Retention time on GC: 32.0 min; $[\alpha]^{20}_D$ −71° (*c* 0.97, $CHCl_3$); FTIR: 3450, 1730, 1640 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 0.88 (3H, d, J = 7.1 Hz), 1.21 (3H, s), 1.23 (3H, s), 1.41 (1H, br s), 1.54 (1H, ddd, J = 13.7, 7.4, 4.1 Hz), 1.69 (1H, ddd, J = 13.7, 11.5, 4.1 Hz), 1.78−1.83 (1H, m), 2.06 (1H, dd, J = 9.1, 6.5 Hz), 2.16 (1H, dd, J = 18.7, 0.5 Hz), 2.23 (1H, d, J = 18.7 Hz), 2.31 (1H, q, J = 6.6 Hz), 2.57 (1H, dd, J = 9.1, 6.6 Hz), 3.95 (1H, dt, J = 6.5, 4.1 Hz), 5.01 (1H, dt, J = 17.1, 1.4 Hz), 5.10 (1H, ddd, J = 10.2, 1.4, 0.8 Hz), 5.76 (1H, ddd, J = 17.1, 10.2, 7.7 Hz); ^{13}C NMR (50 MHz, $CDCl_3$) δ 20.0 (CH_3), 26.7 (CH_3), 29.8 (CH_3), 30.7 (CH), 36.8 (C), 37.5 (CH_2), 44.6 (CH), 50.7 (CH), 52.1 (CH), 52.6 (CH_2), 64.9 (CH), 115.0 (CH_2), 141.5 (CH), 218.2 (C); MS (EI) *m*/*z* 222 (M^+), 120 (base); HRMS (EI) Calcd for $C_{14}H_{22}O_2$ 222.1620. Found 222.1612 (M^+).

(3a*R*,4*R*,6*R*,7*R*,7a*R*)-4-Hydroxy-3,3,6-trimethyl-7-vinylperhydro-1-indenone (18c). Retention time on GC: 31.6 min; mp 162−170 °C (hexane−AcOEt); $[\alpha]^{20}_D$ −129° (*c* 1.3, $CHCl_3$); FTIR: 3430, 1730, 1645 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 0.85 (3H, d, J = 7.1 Hz), 1.11 (3H, s), 1.23 (3H, s), 1.33 (1H, br s), 1.45 (1H, ddd, J = 14.8, 13.2, 2.5 Hz), 1.62 (1H, dt, J = 14.8, 4.0 Hz), 1.78 (1H, dd, J = 14.0, 1.8 Hz), 1.90 (1H, dd, J = 18.1, 0.6 Hz), 2.05−2.13 (1H, m), 2.11 (1H, dd, J = 18.1, 1.6 Hz), 2.78−2.83 (2H, m), 4.44 (1H, br q, J = 2.5 Hz), 5.14 (1H, dd, J = 10.3, 2.2 Hz), 5.18 (1H, ddd, J = 17.0, 2.2, 0.8 Hz), 5.63 (1H, ddd, J = 17.0, 10.3, 9.6 Hz); ^{13}C NMR (50 MHz, $CDCl_3$) δ 19.2 (CH_3), 24.0 (CH_3), 28.2 (CH_3), 28.8 (CH), 36.6 (C), 39.4 (CH_2), 44.3 (CH), 48.9 (CH), 49.0 (CH), 55.7 (CH_2), 65.7 (CH), 120.0 (CH_2), 132.1 (CH), 217.5 (C); MS (EI) *m*/*z* 222 (M^+), 189 (base); HRMS (EI) Calcd for $C_{14}H_{22}O_2$ 222.1620. Found 222.1611 (M^+).

(3a*R*,4*R*,6*R*,7*R*,7a*S*)-4-Hydroxy-3,3,6-trimethyl-7-vinylperhydro-1-indenone (19c). Retention time on GC: 32.9 min; $[\alpha]^{20}_D$ +52.6° (*c* 1.7, $CHCl_3$); FTIR: 3500, 1740, 1650 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 0.84 (3H, d, J = 6.9 Hz), 0.95 (1H, br s), 1.18 (3H, s), 1.34 (3H, s), 1.41−1.45 (2H, m), 1.82 (1H, dd, J = 7.7, 3.0 Hz), 1.98 (1H, dt, J = 18.5, 1.4 Hz), 2.00−2.08 (1H, m), 2.42 (1H, d, J = 18.5 Hz), 2.54 (1H, br d, J = 7.7 Hz), 2.86 (1H, dd, J = 9.2, 4.9 Hz), 4.21 (1H, br t, J = 3.0 Hz), 5.08 (1H, dd, J = 10.2, 1.8, 1.4 Hz), 5.10 (1H, ddd, J = 16.9, 1.8, 0.8 Hz), 5.86 (1H, ddd, J = 16.9, 10.2, 9.2 Hz); ^{13}C NMR (50 MHz, $CDCl_3$) δ 19.4 (CH_3), 23.0 (CH), 24.3 (CH_3), 31.5 (CH_3), 35.6 (C), 36.9 (CH_2), 40.2 (CH), 47.4 (CH), 50.9 (CH_2), 52.2 (CH), 67.5 (CH), 116.1 (CH_2), 137.2 (CH), 217.1 (C); MS (CI) *m*/*z* 223 $(M + 1)^+$, 163 (base), 135, 121, 109, 93, 81; HRMS (CI) Calcd for $C_{14}H_{23}O_2$ 223.1698. Found 223.1705 $(M + H)^+$.

SmI_2 Reduction of 13d. Entry 1: A solution of **13d** (20 mg, 0.09 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 5.4 mL, 0.54 mmol) at 0 °C according to the general procedure to afford a mixture (13.7 mg) of **16d**, **17d**, **19d**, and **20d** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 2: A solution of **13d** (20 mg, 0.09 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 5.4 mL, 0.54 mmol) at −78 °C according to the general procedure to afford a mixture (17.4 mg) of **16d**, **17d**, **19d**, and **20d** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 3: A solution of **13d** (20 mg, 0.09 mmol) and HMPA (0.08 mL, 0.45 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 5.4 mL, 0.54 mmol) at 0 °C according to the general procedure to afford a mixture (10.5 mg) of **16d**, **17d**, **19d**, **20d**, and **25** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 4: A solution of **13d** (20 mg, 0.09 mmol) and HMPA (0.08 mL, 0.45 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 5.4 mL, 0.54 mmol) at −78 °C according to the general procedure to afford a mixture (15.3 mg) of **16d**, **17d**, **19d**, **20d**, and **25** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 5: A solution of **13d** (20 mg, 0.09 mmol) and MeOH (79.1 mg, 2.47 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 5.4 mL, 0.54 mmol) at 0 °C according to the general procedure to afford a mixture (16.8 mg) of **16d**, **17d**, **19d**, and **20d** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

Entry 6: A solution of **13d** (20 mg, 0.09 mmol) and MeOH (79.1 mg, 2.47 mmol) in THF (1.0 mL) was treated with SmI_2 (0.1 M, 5.4 mL, 0.54 mmol) at −78 °C according to the general procedure to afford **13d** (0.6 mg) and a mixture (15.4 mg) of **16d**, **17d**, **19d**, and **20d** after flash chromatography (SiO_2, 0−40% AcOEt/hexane).

The mixture of **16d**, **17d**, **19d**, **20d**, and **25** was separated by HPLC (Develosil 60−10, 20ϕ × 250 mm, 30% AcOEt/hexane) and recrystalyzation.

(3a*S*,4*R*,6*R*,7*S*,7a*R*)-4-Hydroxy-3,3,6-trimethyl-7-vinylperhydro-1-indenone (16d). Retention time on GC: 31.1 min; $[\alpha]^{20}_D$ −91° (*c* 1.1, $CHCl_3$); FTIR: 3400, 1730, 1640 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 0.87 (3H, d, J = 7.1 Hz), 1.20 (3H, s), 1.22 (3H, s), 1.53 (1H, ddd, J = 13.7, 7.4, 4.0 Hz), 1.70 (1H, ddd, J = 13.7, 7.7, 4.0 Hz), 1.71 (1H, br s), 1.77−1.84 (1H, m), 2.07 (1H, dd, J = 9. 1, 6.0 Hz), 2.16 (1H, dd, J = 18.7, 0.6 Hz), 2.23 (1H, d, J = 18.7 Hz), 2.29 (1H, dt, J = 13.7, 6.6 Hz), 2.57 (1H, dd, J = 9.1, 7.2 Hz), 3.95 (1H, ddd, J = 7.4, 6.0, 4.0 Hz), 5.01 (1H, dt, J = 17.3, 1.4 Hz), 5.09 (1H, ddd, J = 10.3, 1.4, 0.8 Hz), 5.76 (1H, ddd, J = 17.3, 10.3, 7.2 Hz); ^{13}C NMR (50 MHz, $CDCl_3$) δ 20.0 (CH_3), 26.6 (CH_3), 29.7 (CH_3), 30.6 (CH), 36.8 (C), 37.5 (CH_2), 44.7 (CH), 50.6 (CH), 52.2 (CH), 52.6 (CH_2), 64.7 (CH), 144.9 (CH_2), 141.4 (CH), 218.4 (C); MS (EI) *m*/*z* 222 (M^+), 120 (base); HRMS (EI) Calcd for $C_{14}H_{22}O_2$ 222.1620. Found 222.1612 (M^+).

(3a*S*,4*R*,6*R*,7*S*,7a*S*)-4-Hydroxy-3,3,6-trimethyl-7-vinylperhydro-1-indenone (17d). Retention time on GC: 30.3 min; mp 93−98 °C (hexane−$CHCl_3$); $[\alpha]^{20}_D$ +177° (*c* 0.97, $CHCl_3$); FTIR: 3450, 1730, 1640 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 1.06 (3H, d, J = 7.4 Hz), 1.12 (3H, s), 1.34 (3H, s), 1.63−1.71 (3H, m), 1.73 (1H, dd, J = 14.0, 10.2 Hz), 1.97 (1H, d, J = 19.5 Hz), 2.12−2.17 (1H, m), 2.17 (1H, dd, J = 19.5, 1.6 Hz), 2.34 (1H, ddd, J = 14.3, 4.5, 1.4 Hz), 2.62 (1H, brt, J = 4.5 Hz), 3.95 (1H, td, J = 10.3, 4.5 Hz), 5.11 (1H, dt, J = 10.7, 1.4 Hz), 5.14 (1H, dt, J = 17.3, 1.4 Hz), 5.79 (1H, ddd, J = 17.3, 10.7, 6.5 Hz); ^{13}C NMR (50 MHz, $CDCl_3$) δ 19.9 (CH_3), 21.1 (CH_3), 30.6 (CH_3), 33.7 (CH), 36.2 (C), 38.7 (CH_2), 42.0 (CH), 50.2 (CH), 52.4 (CH), 55.1 (CH_2), 69.3 (CH), 116.8 (CH_2), 137.1 (CH), 217.2 (C); MS (EI) *m*/*z* 222 (M^+), 93 (base); HRMS (EI) Calcd for $C_{14}H_{22}O_2$ 222.1620. Found 222.1622 (M^+).

(3a*R*,4*R*,6*R*,7*S*,7a*S*)-4-Hydroxy-3,3,6-trimethyl-7-vinylperhydro-1-indenone (19d). Retention time on GC: 31.8 min; $[\alpha]^{19}_D$ −32° (*c* 0.26, $CHCl_3$); FTIR: 3500, 1720, 1640 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 0.84 (3H, d, J = 6.3 Hz), 0.96 (1H, br s), 1.20 (3H, s), 1.23 (1H, ddd, J = 14.0, 11.8, 1.6 Hz), 1.29 (3H, s), 1.67 (1H, dd, J = 7.1, 2.2 Hz), 1.79 (1H, ddd, J = 14.0, 4.1, 3.0 Hz), 1.84−1.93 (2H, m), 1.95 (1H, dt, J = 18.4, 1.4 Hz), 2.31 (1H, d, J = 18.4 Hz), 2.76 (1H, ddd, J = 6.9, 5.8, 1.1 Hz), 4.19 (1H, br s), 5.01 (1H, ddd, J = 17.0, 2.4, 1.1 Hz), 5.03 (1H, dd, J = 10.2, 2.4 Hz), 6.58 (1H, ddd, J = 17.0, 10.2, 9.6 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.3 (CH_3), 24.6 (CH_3), 31.7 (CH), 35.3 (C), 42.4 (CH_2), 50.0 (CH), 51.6 (CH), 52.0 (CH_2), 52.2 (CH), 67.5 (CH), 114.9 (CH_2), 141.0 (CH), 216.4 (C); MS (EI) *m*/*z* 222 (M^+), 121 (base); HRMS (EI) Calcd for $C_{14}H_{22}O_2$ 222.1620. Found 222.1612. (M^+).

(3a*S*,4*S*,6*R*,7*S*,7a*R*)-4-Hydroxy-3,3,6-trimethyl-7-vinylperhydro-1-indenone (20d). Retention time on GC: 35.6 min; mp 93−98 °C (hexane−$CHCl_3$); $[\alpha]^{19}_D$ −34° (*c* 0.75, $CHCl_3$); FTIR: 3450, 1730, 1640 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$) δ 0.90 (3H, d, J = 6.6 Hz), 1.05 (1H, br s), 1.15 (1H, ddd, J =

15.0, 9.6, 1.7 Hz), 1.16 (3H, s), 1.26 (3H, s), 1.40−1.47 (1H, m), 1.86 (1H, dd, J = 9.1, 1.7 Hz), 2.00 (1H, dt, J = 18.6, 1.1 Hz), 2.12 (1H, ddd, J = 15.0, 7.8, 5.8 Hz), 2.26 (1H, dt, J = 11.5, 8.8 Hz), 2.40 (1H, d, J = 18.6 Hz), 2.47 (1H, td, J = 8.8, 1.7 Hz), 4.28 (1H, dt, J = 5.7, 1.7 Hz), 5.11 (1H, dd, J = 10.2, 1.9 Hz), 5.18 (1H, ddd, J = 17.2, 1.9, 0.8 Hz), 5.59 (1H, ddd, J = 17.2, 10.2, 8.8 Hz); ^{13}C NMR (50 MHz, $CDCl_3$) δ 20.7 (CH_3), 25.2 (CH_3), 30.3 (CH), 31.7 (CH_3), 35.8 (C), 42.0 (CH_2), 45.0 (CH_2), 48.6 (CH), 51.2 (CH), 52.2 (CH_2), 67.8 (CH), 115.7 (CH_2), 142.0 (CH), 220.2 (C); MS (EI) m/z 222 (M^+), 163 (base); HRMS (EI) Calcd for $C_{14}H_{22}O_2$ 222.1620. Found 222.1638 (M^+).

(4*S*,5*R*,7*R*,7a*R*,)-7,7a-Dihydroxy-2,2,5-trimethyl-4-vinyl-1,4,5,6,7,7a-hexahydro-2*H*-indene (25). Retention time on GC: 24.9 min; $[\alpha]^{20}_D$ −54° (c 0.58, $CHCl_3$); FTIR: 3400, 1720, 1690, 1940 cm^{-1}; ^{1}H NMR (600 MHz, $CDCl_3$) δ 0.92 (3H, d, J = 6.6 Hz), 1.08 (3H, s), 1.15 (3H, s), 1.37 (1H, br s), 1.50−1.58 (2H, m), 1.63 (1H, d, J = 14.3 Hz), 1.76 (1H, dt, J = 14.6, 3.6 Hz), 1.90 (1H, ddd, J = 14.6, 12.6, 2.2 Hz), 2.35 (1H, d, J = 14.3 Hz), 2.49 (1H, ddd, J = 11.0, 9.2, 1.9 Hz), 3.70 (1H, br s), 5.08 (1H, ddd, J = 17.0, 2.1, 0.5 Hz), 5.15 (1H, dd, J = 10.2, 2.1 Hz), 5.32 (1H, d, J = 1.9 Hz), 5.64 (1H, ddd, J = 17.0, 10.2, 9.2 Hz); ^{13}C NMR (50 MHz, $CDCl_3$) δ 20.0 (CH_3), 29.1 (CH_3), 30.6 (CH), 31.4 (CH_3), 37.0 (CH_2), 42.8 (C), 47.6 (CH), 49.9 (CH_2), 71.3 (CH), 85.6 (C), 116.8 (CH_2), 138.9 (CH), 139.1 (CH), 141.9 (C); MS (EI) m/z 222 (M^+), 189 (base); HRMS (EI) Calcd for $C_{14}H_{22}O_2$ 222.1620. Found 222.1612 (M^+).

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Supporting Information Available: Experimental procedure for compounds **13a**, **13b**, **13c**, **13d**, and **26**−**35**, data of X-ray crystallography, and photocopies of ^{1}H NMR spectra for **7a**−**35**. This material is available free of charge via the Internet at http://pubs.acs.org.

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