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Metal-Free Asymmetric Synthesis of Indanes through Chiral Hypervalent Iodine(III)-Mediated Ring Contraction

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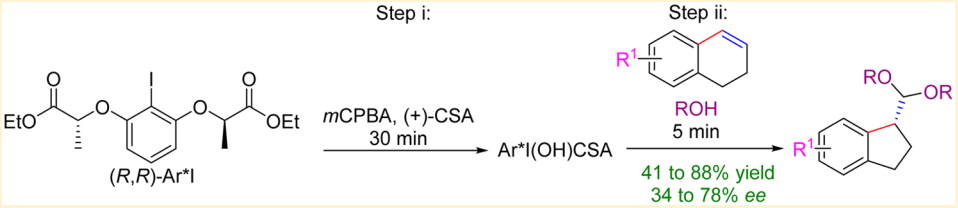
Supporting Information



ABSTRACT: The iodine(III)-mediated asymmetric oxidative rearrangement of 1,2-dihydronaphthalenes was investigated to prepare optically active 1-substituted indanes. The chiral hypervalent iodine species is generated *in situ* from a chiral aryl iodide, prepared in 94% yield in one step. This metal-free protocol was applied to different cyclic alkenes, substituted with oxygen, with nitrogen, or at position 1 with aryl or methyl. Indanes can be isolated as an acetal or alcohol in up to 78% *ee*.

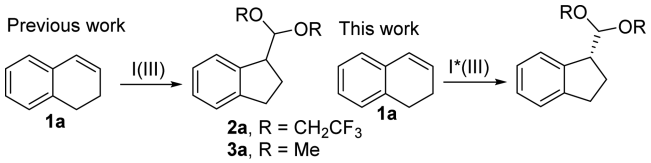
The Indane skeleton occurs in many biologically active natural products[1] and in pharmaceuticals compounds, constituting an important target in organic synthesis and in medicinal chemistry.[2] Indanes are also used as ligands in catalysis.[3] Particularly relevant are efficient methods toward chiral nonracemic 1-substituted indanes, such as ramelteon,[4] rasagiline,[5] and jimscaline.[6]

Hypervalent iodine reagents play a pivotal role in chemical synthesis, including carbon−carbon bond formation, rearrangements, and many functional group transformations.[7] Using chiral hypervalent iodine compounds,[7,8] several organic transformations can be accomplished in enantioselective fashion, such as α-arylation of carbonyl compounds,[9] alkynylation,[10] dearomatization of napthols,[11,12] oxidative cycloetherification and lactonization,[13] diamination of styrenes,[14] and oxyamination.[15] Oxidative rearrangements have been less explored.[16] During the development of our work, Wirth and co-workers reported the asymmetric ring contraction for two substrates using a chiral iodine(III).[17] An acetal of Indane was obtained in 59% enantiomeric excess (*ee*) from 1,2-dihydronaphthalene using the chiral hypervalent iodine, prepared in 5 steps and 62% yield from 2-iodoresorcinol, including an oxidation using Selectfluor. Similarly, the 1,3-disubstituted *trans*-Indane was isolated in 9% *ee*.[17]

Our group developed the ring contraction of 1,2-dihydronaphthalenes synthesizing a variety of indanes.[18−20] Furthermore, new possibilities in total synthesis can be envisioned using a ring contraction approach, as exemplified for (+)-mutisianthol,[21] (±)-indatraline,[19] and (+)-trans-trikentrin A.[22] Motivated by the importance of indanes, we decide to investigate the oxidative rearrangement of nonfunctionalized alkenes in an asymmetric fashion (Scheme 1).

We planned a protocol where the required hypervalent iodine species would be prepared *in situ* from a readily available chiral

Scheme 1. Ring Contraction of 1,2-Dihydronaphthalenes



aryl iodide.[23,24] Thus, iodides **4a−g** were prepared in an expedited manner from 2-iodophenol or 2-iodoresorcinol using as chiral sources the inexpensive natural compounds (−)-menthol and (−)-ethyl lactate (Figure 1).[12,25,26]

The screening was performed by investigating the behavior of **1a** under different conditions. Based on our previous experience,[23] *m*-chloroperoxybenzoic acid (*m*CPBA) in the presence of *p*-toluenesulfonic acid monohydrate ($TsOH·H_2O$) was selected for the *in situ* oxidation of iodobenzenes **4a−g** into the corresponding chiral iodine(III), which would promote the desired oxidative rearrangement. After generation of iodine(III) species, substrate **1a** and water were added. To facilitate purification and analysis, aldehyde **5a** was reduced *in situ* by $NaBH_4$. Two solvent mixtures (1:4 trifluoroethanol/dichloromethane (TFE/DCM) and 1:4 hexafluoroisopropanol/dichloromethane (HFIP/DCM)) were used for testing the iodobenzene derivatives **4a−g**, because either the oxidation of iodobenzene or the ring contraction has been reported in those solvents.[18,27] Chiral aryl iodide **4a** afforded alcohol **6a** in 6−7% *ee*. (Table 1, entries 1 and 2). With menthol based aryl iodides **4b−c** nearly a racemic mixture was obtained (entries 3−6). New amide based "one-arm" **4d−e** proved ineffective (entries 7−10). The desired Indane **6a** was isolated in 49−53% and in 14−15% *ee* with "two-

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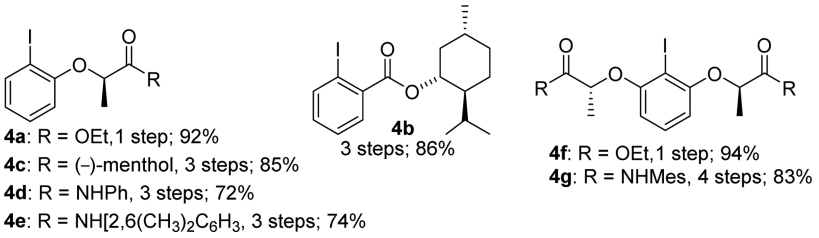
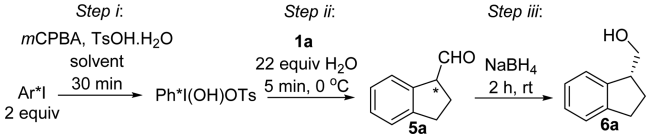


Figure 1. Structures of chiral aryl iodide **4a**–**g**.

Table 1. Screening of Aryl Iodides 4a–g



entry	Ar*I	solvent	**6a** (yield, *ee*)[a]
1	**4a**	HFIP/DCM (1:4)	(43, 7)
2	**4a**	TFE/DCM (1:4)	(41, 6)
3	**4b**	HFIP/DCM (1:4)	(–, 4)
4	**4b**	TFE/DCM (1:4)	(8, 5)
5	**4c**	HFIP/DCM (1:4)	(37, 6)
6	**4c**	TFE/DCM (1:4)	(32, 8)
7	**4d**	HFIP/DCM (1:4)	–
8	**4d**	TFE/DCM (1:4)	–
9	**4e**	HFIP/DCM (1:4)	–
10	**4e**	TFE/DCM (1:4)	–
11	**4f**	HFIP/DCM (1:4)	(49, 15)
12	**4f**	TFE/DCM (1:4)	(53, 14)
13	**4g**	HFIP/DCM (1:4)	(30, 15)
14	**4g**	TFE/DCM (1:4)	(33, 13)

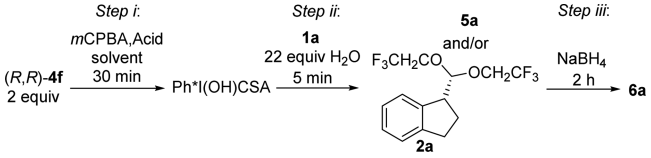
[a]*ee* determined by GC using chiral column.

arm" aryl iodide (*R*,*R*)-**4f** (entries 11–12). A similar *ee*, but lower yield, was observed when the two-arm amide **4g** was used (entries 13–14). Based on the above results, **4f** was selected for additional screening.

Increasing the ratio of the fluorinated solvent (TFE or HFIP) resulted in a lower *ee* (Table 2, entries 1 and 2). Without acid, the ring contraction product was not isolated in pure form (entry 3). When (+)-camphorsulfonic acid (CSA) was used instead of TsOH·H_2O, Indane **6a** was isolated in 54% and 25% *ee* (compare Table 1, entry 11 with Table 2, entry 4). This might be due to the bulky structure of (+)-CSA when compared to TsOH·H_2O. An increasing trend in *ee* was observed by decreasing the ratio of HFIP to DCM from 1:10 to 1:40 (entries 5–7). Using only DCM, ring contraction product was not isolated (entry 8). The desired alcohol **6a** was isolated in 34% yield and 60% *ee* when the temperature was lowered to −78 °C (entry 9). However, using TFE/DCM in a 1:40 ratio, the desired alcohol **6a** was obtained together with acetal **2a** in 58% *ee* and 57% *ee*, respectively (entry 10). Using a higher ratio of TFE to favor the exclusive formation of the acetal, only the acetal **2a** was isolated in 60% yield and 58% *ee* (entry 11). A lower *ee* was observed when a 1:1 mixture of TFE/DCM was used (entry 12). Increasing the ratio of HFIP resulted in a lower *ee* of the product **6a** (entry 13).

After the above-mentioned experiments, we selected the conditions of entry 11 for further investigation. When (*S*,*S*)-**4f** (prepared from (+)-ethyl lactate) was used, (−)-**2a** was isolated in similar yield and *ee* (compare entry 1, Table 3 to entry 11, Table 2). After ring contraction, iodide **4f** can be easily recovered

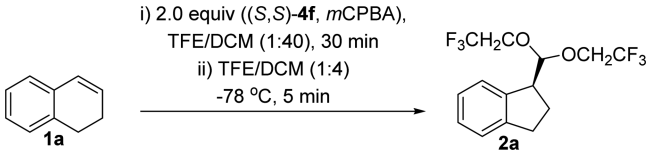
Table 2. Screening of Reaction Conditions



entry	solvent	acid	*T*, °C	product (yield, *ee*)[a]
1	TFE/DCM (1:1)	TsOH·H_2O	0	**6a** (51, 6)
2	HFIP/DCM (1:1)	TsOH·H_2O	0	**6a** (53, 8)
3	TFE/DCM (1:1)	–	0	**6a** (–, 4)[b]
4	HFIP/DCM (1:4)	(+)-CSA	0	**6a** (54, 25)
5	HFIP/DCM (1:10)	(+)-CSA	0	**6a** (47, 31)
6	HFIP/DCM (1:20)	(+)-CSA	0	**6a** (44, 38)
7	HFIP/DCM (1:40)	(+)-CSA	0	**6a** (36, 42)
8	DCM	(+)-CSA	0	–[b]
9	HFIP/DCM (1:40)	(+)-CSA	−78	**6a** (34, 60)
10	TFE/DCM (1:40)	(+)-CSA	−78	**2a** (34, 57), **6a** (20, 58)[c]
11	TFE/DCM (1:40 then 1:4)	(+)-CSA	−78	**2a** (60, 58)[c,d,e]
12	TFE/DCM (1:40 then 1:1)	(+)-CSA	−78	**2a** (62, 46)[c,d,e]
13	TFE/DCM (1:40) then HFIP/DCM (1:10)	(+)-CSA	−78	**6a** (42, 38)[c,d]

[a]*ee* determined for **2a** by HPLC and for **6a** by GC using chiral columns. [b]Complex mixture. [c]No addition of H_2O. [d]Solvent of step i (TFE/DCM,1:40) was removed under reduced pressure. [e]No addition of $NaBH_4$.

Table 3. Asymmetric Ring Contraction of 1a Using (*S*,*S*)-4f



entry	acid	yield, *ee*[a]
1	(+)-CSA	57, 56
2	(*S*,*S*)-**4f** recovered and reused, (+)-CSA	56, 55
3	(−)-CSA	56, 55

[a]*ee* determined by HPLC using chiral column.

in 84% yield. A similar result was obtained using recovered **4f** (entry 2). CSA could be acting as an acid or could also have an influence in the chiral environment. Changes in yield or *ee* were not observed when (−)-CSA was used as an acid (entry 3). These results clearly show that the observed stereoinduction is regulated only by chiral aryl iodide **4f**; i.e., there is no matched/mismatched case.

The scope of the reaction was investigated as shown in Table 4. The ring contraction of the *N*-acetyl alkene **1b** was performed in

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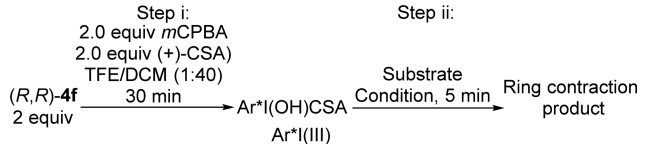
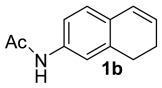
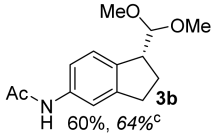
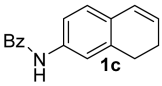
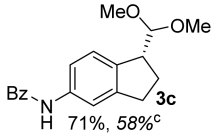
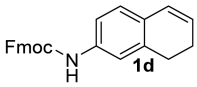
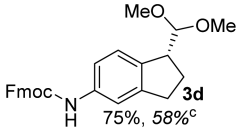
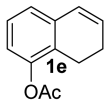
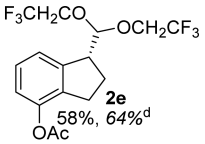
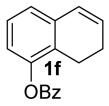
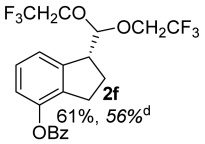
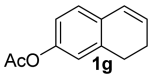
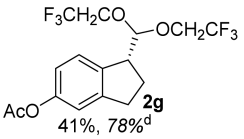
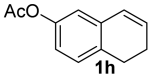
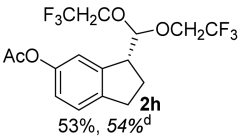
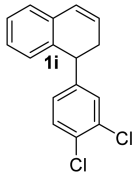
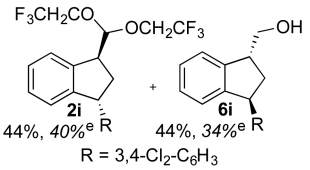
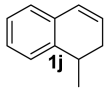
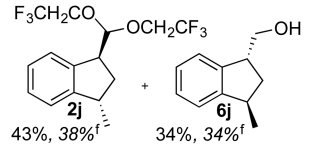
Table 4. Scope of Asymmetric Ring Contraction



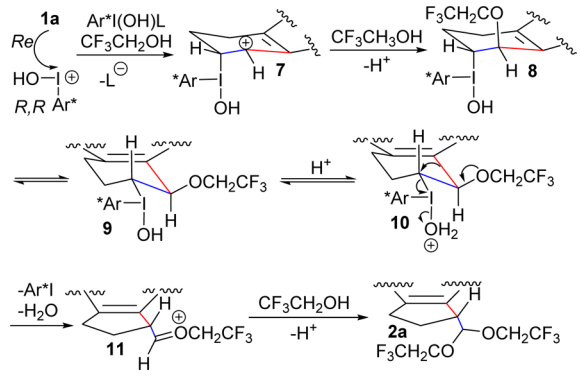
Entry	Substrate	Product (Yield, *ee*)[a,b]
1		 60%, *64%*[c]
2		 71%, *58%*[c]
3		 75%, *58%*[c]
4		 58%, *64%*[d]
5		 61%, *56%*[d]
6		 41%, *78%*[d]
7		 53%, *54%*[d]
8		 44%, *40%*[e] 44%, *34%*[e] R = 3,4-Cl_2-C_6H_3
9		 43%, *38%*[f] 34%, *34%*[f]

[a] *ee* determined by HPLC using chiral column. [b] Solvent of step i (TFE/DCM, 1:40) was removed under reduced pressure. [c] (ii) DCM, 50 equiv MeOH, −78 °C. [d] (ii) TFE/DCM (1:1), −40 °C. [e] (ii) TFE/DCM (1:1), −40 °C; (iii) $NaBH_4$. [f] (ii) TFE/DCM (1:1), −78 °C; (iii) $NaBH_4$.

DCM in the presence of 50 equiv of MeOH to give the desired Indane **3b** in 60% yield and 64% *ee* (entry 1). Under similar reaction conditions, *N*-benzoyl and Fmoc alkenes **1c** and **1d** smoothly undergo ring contraction giving indanes **3c** and **3d** in 71% and 75% yield, respectively, and 58% *ee* (entries 2 and 3). Asymmetric ring contraction was also explored in oxygenated substrates. By generating the iodine(III) species in TFE/DCM (1:40) and performing the ring contraction in TFE/DCM (1:1), Indane **2e** was isolated in 58% yield and 64% *ee* (entry 4). These conditions were extended to other oxygen-containing substrates. Acetal product **2f** was obtained in 61% yield and 56% *ee* when 8-benzoyl alkene **1f** was subjected to oxidative rearrangement conditions (entry 5). The treatment of 7-acetoxy alkene **1g** with **4f** resulted in Indane **2g** in 41% yield and 78% *ee* (entry 6). Similarly, alkene **1h** gave the desired acetal **2h** in good yield and *ee* (entry 7). The reaction of racemic 1-substituted 1,2-dihydronaphthalenes **1i** and **1j** were also investigated. Using TFE/DCM (1:1), the acetal **2i** was isolated together with alcohol **6i** in 88% combined yield and in 34−40% *ee* (entry 8). A very good combined yield of **2j** and **6j** and 34−38% *ee* were also obtained for alkene **1j** at −78 °C (entry 9).

The absolute configuration of indanes was assigned by analogy to that of **6a**, which was determined to be (*R*) by comparison with literature data.[28] A plausible mechanism for asymmetric ring contraction reaction is shown in Scheme 2.[18,19,29,30] Based on the absolute configuration of **6a**,[28] the electrophilic attack of iodine(III) species occurs selectively on the *Re*-face of double-bond-forming benzylic carbocation **7**.[29] Nucleophilic attack of CF_3CH_2OH into **7** gives intermediate **8**. The necessary antiperiplanarity for the rearrangement is achieved via equilibration to its more stable conformational isomer **9**. Migration of the aryl group on **10** gives oxonium **11**. Finally, addition of CF_3CH_2OH leads to acetal **2a**.

Scheme 2. A Plausible Mechanism



In conclusion, the asymmetric synthesis of indanes can be accomplished through the ring contraction of 1,2-dihydronaphthalenes mediated by chiral iodine(III) in up to 78% *ee*, which is the highest *ee* for this type of transformation. The rearrangement step occurs in a very short time when compared to the previous protocol (5 min vs 14 h[17]). Ring contraction products are obtained as masked aldehydes, which can be converted into a variety of compounds.[19−22] The hypervalent iodine species is generated *in situ* using readily available MCPBA from chiral aryl iodine **4f**, which is prepared in 94% yield in one step from (−)-ethyl lactate. In the previous work,[17] iodine(III) was prepared in 5 steps using as oxidant the expensive Selectfluor. Furthermore, **4f** can be recovered and reused in an efficient manner. The metal-free oxidative rearrangement of non-functionalized olefins herein reported will be certainly useful in the development of a more efficient version of this reaction.

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EXPERIMENTAL SECTION

All commercially available reagents were used without further purification unless otherwise noted. All solvents used for reactions and chromatography were dried and purified by standard methods.[31] TLC analyses were performed using silica gel 60F 254 precoated plates, with detection by UV-absorption (254 nm) and by spraying with *p*-anisaldehyde and phosphomolybdic acid solutions followed by charring at ∼150 °C for visualization. Flash column chromatography was performed using silica gel 200−400 Mesh. All NMR analyses were recorded using $CDCl_3$, acetone-d_6, and DMSO-d_6 as solvents and TMS as internal standard. Chemical shifts are reported in ppm downfield from TMS with reference to internal solvent. High-performance liquid chromatography (HPLC) analysis was carried out using chiral columns of Daicel CHIRALCEL OD-H (4.6 mm × 25 cm), AS-H (4.6 mm × 25 cm), and chiral Astec Cellulose DMP column (4.6 mm × 25 cm). Gas chromatography analysis (GC) was conducted using a chiral ALPHA DEX 120 fused silica capillary column (30 m × 0.25 mm × 0.25 μm). Specific rotation was measured in CH_3Cl and THF (589 nm, T = 20 °C, 10 mm × 100 mm) with a digital polarimeter. Preparations of substrates **1a**,[18,32] **1b**,[18] **1c**,[18,33] **1e**,[34] **1g**,[35] **1i**,[19,36] and **1j**[19] were performed as reported in literature.

(9*H*-Fluoren-9-yl)methyl (7,8-Dihydronaphthalen-2-yl)carbamate (1d). To a stirred solution of 6-amino-3,4-dihydronaphthalen-1(2*H*)-one (0.484 g, 3.00 mmol) and pyridine (0.29 mL, 3.60 mmol) in anydrous DCM (25 mL) at 0 °C was added a solution of Fmoc-Cl (0.854 g, 3.30 mmol) in anhydrous DCM, and the resulting reaction mixture was allowed to stir at rt. After 1 h the solution was acidified with 1 mol/L HCl. The product was extracted with DCM (3 × 10 mL) and dried over anhydrous Mg_2SO_4.[37] After workup solvent was removed under reduced pressure. The crude product was purified by flash column chromatography (15−25% EtOAc in hexane) giving (9*H*-Fluoren-9-yl)methyl (5-oxo-5,6,7,8-tetrahydronaphthalen-2-yl)carbamate (1.13 g, 2.95 mmol, 98%) as a white solid. Mp: 160.6−161.5. **(9*H*-Fluoren-9-yl)methyl (5-Oxo-5,6,7,8-tetrahydronaphthalen-2-yl)carbamate:** ^{1}H NMR (300 MHz, $CDCl_3$) δ: 2.06−2.15 (m, 2H), 2.62 (t, J = 6.3 Hz, 2H), 2.91 (t, J = 6.0 Hz, 2H), 4.27 (t, J = 6.4 Hz, 1H), 4.57 (d, J = 6.6 Hz, 2H), 6.95 (bs, 1H), 7.14 (dd, J = 8.4, 1.5 Hz, 1H), 7.32 (td, J = 7.6, 1.2 Hz, 1H), 7.37−7.44 (m, 3H), 7.56−7.62 (m, 2H), 7.78 (dt, J = 7.5, 0.9 Hz, 2H), 7.98 (d, J = 8.7 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 23.2 (CH_2), 30.0 (CH_2), 38.9 (CH_2), 47.0 (CH), 67.0 (CH_2), 116.4 (CH), 117.0 (CH), 120.1 (CH), 124.8 (CH), 127.1 (CH), 127.8 (CH), 128.1 (C), 128.7 (CH), 141.3 (C), 142.2 (C), 143.5 (C), 146.3 (C), 152.9 (C), 197.3 (C). HRMS [ESI(+)-TOF] calcd for $[C_{25}H_{21}NO_3 + H]^+$ 384.1600; found 384.1600. IR (film): 3305, 3065, 2946, 2890, 1737, 1665, 1602, 1585, 1537, 1495, 1478, 1450, 1427, 1412, 1350, 1336, 1323, 1287, 1219, 1185, 1164, 1129, 1105 cm^{-1}.

The reaction was performed using (9*H*-fluoren-9-yl)methyl (5-oxo-5,6,7,8-tetrahydronaphthalen-2-yl)carbamate (1.15 g, 3.00 mmol), MeOH (50 mL), and $NaBH_4$ (0.227 g, 6.00 mmol). After workup, solvent was removed under reduced pressure and (9*H*-fluoren-9-yl)methyl (5-hydroxy-5,6,7,8-tetrahydronaphthalen-2-yl)carbamate (1.12 g, 2.91 mmol, 97.0%) was obtained as a white solid and used in the next step without purification. The reaction was performed using (9*H*-fluoren-9-yl)methyl (5-hydroxy-5,6,7,8-tetrahydronaphthalen-2-yl)carbamate (1.12 g, 2.91 mmol), toluene (50 mL), and $TsOH·H_2O$ (cat. few crystals) at 130 °C. The crude product was purified by flash column chromatography (10−30% EtOAc in hexane) giving (9*H*-fluoren-9-yl)methyl (7,8-dihydronaphthalen-2-yl)carbamate (**1d**) (0.890 g, 2.42 mmol, 83%) as a white solid. Mp: 141−142 °C. **(9*H*-Fluoren-9-yl)methyl (7,8-Dihydronaphthalen-2-yl)carbamate (1d):** ^{1}H NMR (300 MHz, $CDCl_3$) δ: 2.25−2.33 (m 2H), 2.77 (t, J = 8.2 Hz, 2H), 4.27 (t, J = 6.6 Hz, 2H), 4.53 (d, J = 6.9 Hz, 2H), 5.95 (dt, J = 9.6, 4.4 Hz, 1H), 6.41 (dt, J = 9.6, 1.6 Hz, 1H), 6.57 (bs, 1H), 6.94 (d, J = 8.1 Hz, 1H), 7.08−7.18 (m, 2H), 7.32 (td, J = 7.4, 1.2 Hz, 2H), 7.38−7.44 (m, 2H), 7.61 (d, J = 7.2 Hz, 2H), 7.61 (d, J = 7.2 Hz, 2H), 7.78 (d, J = 7.5 Hz, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 23.0 (CH_2), 27.7 (CH_2), 47.1 (CH), 66.8 (CH_2), 116.5 (CH), 118.2 (CH), 120.0 (CH), 124.9 (CH), 126.4 (CH), 127.0 (CH), 127.1 (CH), 127.5 (CH), 127.7 (CH), 130.0 (C), 136.1 (C), 136.6 (C), 141.3 (C), 143.7 (C), 153.3 (C). HRMS [ESI(+)-TOF] calcd for $[C_{25}H_{21}NO_2 + H]^+$ 368.1651; found 368.1648. IR (film): 3307, 3030, 2931, 2882, 2826, 1703, 1612, 1585, 1527, 1478, 1465, 1450, 1425, 1326, 1308, 1278, 1219, 1170, 1104 cm^{-1}.

7,8-Dihydronaphthalen-1-yl benzoate (1f). The reaction was performed using 7,8-dihydronaphthalen-1-ol (0.248 g, 1.70 mmol), BzCl (0.22 mL, 0.267 g, 1.90 mmol), and Et_3N (0.51 mL, 0.374 g, 3.70 mmol) in DCM (10 mL).[38] Purification by flash column chromatography (3−4% EtOAc in hexane) gave benzoyl protected alkene **1f** (0.398 g, 1.60 mmol, 94%) as a white solid (mp: 58.1−58.7 °C). **7,8-Dihydronaphthalen-1-yl Benzoate (1f):** ^{1}H NMR (300 MHz, $CDCl_3$) δ: 2.24−2.32 (m, 2H), 2.71 (t, J = 8.4 Hz, 2H), 6.04 (dt, J = 9.6, 4.5 Hz, 1H), 6.49 (dt, J = 9.6, 1.8 Hz, 1H), 6.96 (d, J = 7.5 Hz, 1H), 7.00 (dd, J = 8.1, 1.2 Hz, 1H), 7.17−7.22 (m, 1H), 7.48−7.54 (m, 2H), 7.61−7.66 (m, 1H), 8.21−8.25 (m, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 20.6 (CH_2), 22.3 (CH_2), 120.8 (CH), 123.8 (CH), 126.8 (CH), 127.2 (C), 127.3 (CH), 128.6 (CH), 129.0 (CH), 129.4 (C), 130.1 (CH), 133.5 (CH), 135.7 (C), 148.0 (C), 164.8 (C). LRMS m/z (rel. int.): 250 ($M^{+\bullet}$, 9), 144 (3), 128 (11), 115 (10), 105 (100), 91 (2), 77 (36), 63 (3), 51 (10), 39 (2). HRMS [ESI(+)-TOF] calcd for $[C_{17}H_{14}O_2 + Na]^+$ 273.0891; found 273.0890. IR (film): 3035, 2935, 2887, 2834, 2127, 1735, 1651, 1601, 1583, 1569, 1491, 1451, 1395, 1342, 1314, 1296, 1266, 1247, 1229, 1212 cm^{-1}.

5,6-Dihydronaphthalen-2-yl Acetate (1h). The reaction was performed using 6-methoxy-1,2-dihydronaphthalene[18,39] (0.481 g, 3.00 mmol), NaH (3.12 g, 130 mmol, 60% in mineral oil), and EtSH (6.5 mL, 90 mmol, 30 equiv based on olefin substrate) in DMF (35 mL) at 140 °C. The crude product was purified by flash column chromatography (10−15% ethyl acetate in hexane) giving 5,6-dihydronaphthalen-2-ol (0.351 g, 2.40 mmol, 80%) as a white solid. Mp: 98−99 °C. **5,6-Dihydronaphthalen-2-ol:** ^{1}H NMR (300 MHz, $CDCl_3$) δ: 2.25−2.32 (m, 2H), 2.71 (t, J = 8.1 Hz, 2H), 4.59 (s, 1H), 6.04 (dt, J = 9.6, 4.4 Hz, 1H), 6.38 (dt, J = 9.6, 1.8 Hz, 1H), 6.52 (d, J = 2.7 Hz, 1H), 6.59 (dd, J = 7.8, 2.7 Hz, 1H), 6.96 (d, J = 8.1, Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 23.5 (CH_2), 26.6 (CH_2), 112.9 (CH), 113.1 (CH), 127.5 (CH), 127.7 (C), 128.3 (CH), 129.5 (CH), 135.3 (C), 154.0 (C). LRMS m/z (rel. int.): 146 ($M^{+\bullet}$, 100), 145 (71), 131 (45), 127 (43), 117 (36), 115 (55), 103 (5), 91 (12), 77 (7), 63 (14), 51 (13), 39 (10). HRMS [ESI(+)-TOF]: calcd for $[C_{10}H_{10}O + K]$ 185.0369; found 185.0361. IR (film): 3247, 3027, 2936, 2880, 2851, 2818, 1629, 1614, 1574, 1492, 1477, 1465, 1435, 1426, 1395, 1349, 1327, 1282, 1265, 1215 cm^{-1}.

The reaction was performed using 5,6-dihydronaphthalen-2-ol (0.351 g, 2.40 mmol), DMAP (0.08 g, 0.065 mmol), and Ac_2O (0.9 mL, 9.0 mmol) in Et_3N (10 mL). Purification by flash column chromatography (3−5% EtOAc in hexane) gave 5,6-dihydronaphthalen-2-yl acetate (**1h**) (0.359 g, 1.90 mmol, 85%) as a colorless liquid. **5,6-Dihydronaphthalen-2-yl Acetate (1h):** ^{1}H NMR (300 MHz, $CDCl_3$) δ: 2.27−2.36 (m, 2H), 2.28 (s, 3H), 2.77 (t, J = 8.0 Hz, 2H), 6.06 (m, 1H), 6.41 (dt, J = 9.6, 1.8 Hz, 1H), 6.74 (d, J = 2.4 Hz, 1H), 6.81 (dd, J = 8.1, 2.4 Hz, 1H), 7.08 (d, J = 8.1 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 21.1 (CH_3), 23.2 (CH_2), 26.8 (CH_2), 118.8 (CH), 119.4 (CH), 127.3 (CH), 128.2 (CH), 129.6 (CH), 132.9 (C), 135.3 (C), 149.2 (C), 169.7 (C). LRMS m/z (rel. int.): 188 ($M^{+\bullet}$, 20), 146 (100), 145 (52), 131 (30), 127 (19), 117 (24), 115 (42), 91 (15), 77 (5), 63 (9), 43 (30), 39 (10). HRMS [ESI(+)-TOF]: calcd for $[C_{12}H_{12}O_2 + Na]$ 211.0735; found 211.0724. IR (film): 3034, 2935, 2885, 2831, 1761, 1609, 1575, 1491, 1432, 1369, 1328, 1271, 1210 cm^{-1}.

Preparations of known chiral iodoarene compounds **4a**,[12] **4b**,[26] **4c**,[25] **4f**,[12] and **4g**[12] were performed as reported in literature.

(*R*)-2-(2-Iodophenoxy)-*N*-phenylpropanamide (4d). The reaction was performed using (*R*)-2-(2-iodophenoxy)propanoic acid (0.584 g, 2.00 mmol), DCM (50 mL), aniline (0.233 g, 2.5 mmol), DCC (0.515 g, 2.5 mmol), and DMAP (0.037 g, 0.300 mmol).[40] Purification by silica gel flash column chromatography (10% EtOAc in hexane) gave compound **4d** (0.589 g, 1.87 mmol, 80%) as a white solid. Mp: 128.6−129.3 °C, $[\alpha]^{20}_D$ = −99.3 (c = 0.17, $CHCl_3$). **(*R*)-2-(2-Iodophenoxy)-*N*-phenylpropanamide (4d):** ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.73 (d, J = 6.6 Hz, 3H), 4.91 (q, J = 6.6 Hz, 1H), 6.81 (td, J = 7.5, 1.2 Hz, 1H), 6.87 (dd, J = 8.4, 1.2 Hz, 1H), 7.11−717 (m, 1H), 7.31−7.38 (m, 3H), 7.63−7.67 (m, 2H), 7.82 (dd, J = 7.8, 1,5 Hz, 1H), 8.02 (bs, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 18.3 (CH_3), 75.9 (CH),

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87.5 (C), 113.3 (CH), 119.8 (CH), 124.0 (CH), 124.7 (CH), 129.1 (CH), 129.9 (CH), 137.3 (C), 139.9 (CH), 155.0 (C), 169.1 (C). HRMS [ESI(+)-TOF]: calcd for $[C_{15}H_{14}INO_2 + H]^+$ 368.0147; found 368.0149. IR (film): 3248, 3134, 3059, 2981, 2918, 2850, 1669, 1598, 1582, 1570, 1544, 1498, 1470, 1439, 1376, 1287, 1277, 1246, 1204 cm^{-1}.

(*R*)-2-(2-Iodophenoxy)-*N*-(2,6-dimethylphenyl)propanamide (4e). The reaction was performed using (*R*)-2-(2-iodophenoxy)-propanoic acid (0.876 g, 3.00 mmol), dimethylaniline (0.462 mL, 3.75 mmol), DCC (0.768 g, 3.75 mmol), and DMAP (0.055 g, 0.45 mmol) in DCM (50 mL).[40] Purification by silica gel flash column chromatography (5−20% EtOAc in hexane) gave compound **4e** in (0.970 g, 2.45 mmol, 82%) as white solid. Mp: 171.8−173.2 °C, $[\alpha]^{20}_D = -52.7$ (c = 0.16, $CHCl_3$). **(*R*)-2-(2-Iodophenoxy)-*N*-(2,6-dimethylphenyl)-propanamide (4e):** ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.78 (d, J = 6.6 Hz, 3H), 2.19 (s, 6H), 4.99 (qd, J = 6.6, 0.6 Hz, 1 H), 6.81 (dd, J = 7.5, 1.6 Hz, 1H), 6.92 (dd, J = 8.7, 1.5 Hz, 1H), 7.10 (m, 3H), 7.35 (ddd, J = 8.2, 7.4, 1.6 Hz, 1H), 7.83 (dd, J = 7.8, 1.5 Hz, 1H), 8.07 (bs, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 18.4 (CH_3), 18.7 (CH_3), 75.8 (CH), 87.3 (C), 113.2 (CH), 123.9 (CH), 127.5 (CH), 128.3 (CH), 129.8 (CH), 132.8 (C), 135.4 (C), 139.7 (CH), 155.1 (C), 169.6 (C). HRMS [ESI(+)-TOF]: calcd for $[C_{17}H_{18}INO_2+H]^+$ 396.0460; found 396.0461. IR (film): 3234, 3025, 2990, 2919, 1667, 1593, 1582, 1569, 1538, 1471, 1438, 1372, 1278, 1250, 1231 cm^{-1}.

Asymmetric Ring Contraction Reactions Mediated by Chiral I(III) (*R*)-1-(Bis(2,2,2-trifluoroethoxy)methyl)-2,3-dihydro-1*H*-indene (2a). To a stirred solution of Ar*I **4f** (0.872 g, 2.00 mmol) in TFE/DCM (1:40) (17 mL) was added *m*CPBA (77%) (0.448 g, 2.00 mmol) followed by (+)-CSA (0.464 g, 2.00 mmol). The resulting solution was stirred at rt for 30 min. Solvent was removed under reduced pressure. To this reaction mixture TFE/DCM (1:4) (17 mL) was added, and the temperature was lowered to −78 °C, followed by addition of alkene **1a** (0.130 g, 1.00 mmol) (dissolved in 3 mL of TFE/DCM (1:4)). After 5 min the reaction was quenched with saturated solution of $NaHCO_3$, extracted with DCM, washed with brine, and dried over anhydrous $MgSO_4$. The solvent was evaporated under reduced pressure. The crude product was purified by flash column chromatography (2−3%, EtOAc in hexane), giving acetal **2a** (0.196 g, 0.110 mmol, 60%) as a colorless oil in 58% *ee* (Daicel chiral ODH column (25 cm), hexanes/*i*-PrOH = 99.7/0.3, 0.3 mL/min, temp 28 °C, 215 nm; tr (major) = 40.3 min, tr (minor) = 46.4 min), $[\alpha]_D^{20} = +6.5$ (c = 0.35, $CHCl_3$)).

(*R*)-1-(Bis(2,2,2-trifluoroethoxy)methyl)-2,3-dihydro-1*H*-indene (2a).[18] ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.96−2.08 (m, 1H), 2.19−2.31 (m, 1H), 2.83−3.03 (m, 2H), 3.47 (q, J = 9.0 Hz, 1H), 3.86−4.05 (m, 4H), 4.70 (d, J = 8.1 Hz, 1H), 7.15−7.24 (m, 3H), 7.38−7.41 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 27.1, 31.1, 47.1, 61.8 (q, J = 34.8 Hz), 63.3 (q, J = 34.8 Hz), 105.3, 123.7 (q, J = 276.07 Hz), 123.8 (q, J = 276.0 Hz), 124.6, 125.4, 126.4, 127.5, 140.7, 144.5.

(*S*)-1-(Bis(2,2,2-trifluoroethoxy)methyl)-2,3-dihydro-1*H*-indene (2a). The reaction was performed using Ar*I **4f** (Ar*I derived from (+)-ethyl-D-lactate) (0.872 g, 2.00 mmol), *m*CPBA (77%) (0.448 g, 2.00 mmol), and (+)-CSA (0.464 g, 2.00 mmol) in TFE/DCM (1:40) (17 mL). After evaporation of the solvent, TFE/DCM (17 mL) (1:4) was added, followed by addition of alkene **1a** (0.130 g, 1.00 mmol) (dissolved in 3 mL TFE/DCM (1:4)) at −78 °C. After workup solvent was removed under reduced pressure. The crude product was purified by flash column chromatography (3−5% EtOAc in hexane) giving acetal **2a**[18] (0.188 g, 0.57 mmol, 57%) as a colorless oil in 56% *ee* (Sigma-Aldrich chiral Astec Cellulose DMP column (25 cm), hexanes/*i*-PrOH = 99.0/1.0, 0.3 mL/min, temp 28 °C, 215 nm; tr (minor) = 19.7 min, tr (major) = 21.1 min), $[\alpha]_D^{20} = -6.3$ (c = 0.4, $CHCl_3$)).

(*R*)-(2,3-Dihydro-1*H*-inden-1-yl)methanol (6a). To a stirred solution of Ar*I **4f** (0.872 g, 2.00 mmol) in HFIP/CH_2Cl_2 (1:40) (17 mL) was added *m*CPBA (77%) (0.448 g, 2.00 mmol) followed by (+)-CSA (0.464 g, 2.0 mmol). The resulting solution was stirred at rt for 30 min. H_2O (0.4 mL) and alkene **1a** (0.130 g, 1.0 mmol) (dissolved in 3 mL of HFIP/DCM (1:40)) were added at −78 °C. After 2 min, $NaBH_4$ (0.190 g, 5.0 mmol) was added. The reaction stirred for 2 h at rt. The reaction was quenched with a saturated solution of $NaHCO_3$, extracted with DCM (3 × 10 mL), washed with brine (2 × 10 mL), and dried over anhydrous $MgSO_4$. The solvent was evaporated under reduced pressure. The crude product was purified by flash column chromatography (10−20%, EtOAc in hexane), giving alcohol **6a** (0.050 g, 0.34 mmol, 34%) in 60% *ee* as a colorless oil (chiral ALPHA DEX 120 fused silica capillary column (30 m × 0.25 mm × 0.25 μm), tr (major) = 25.7 min, tr (minor) = 26.3 min), $[\alpha]_D^{20} = +8.8$ (c = 1, $CHCl_3$).

(*R*)-(2,3-Dihydro-1*H*-inden-1-yl)methanol (6a).[18] ^{1}H NMR (200 MHz, $CDCl_3$) δ: 1.56 (bs, 1H), 1.85−2.02 (m, 1H), 2.18−2.36 (m, 1H), 2.80−3.10 (m, 2H), 3.30−3.42 (m, 1H), 3.80 (d, J = 6.2 Hz, 2H), 7.15−7.30 (m, 4H). ^{13}C NMR (50 MHz, $CDCl_3$) δ: 28.4, 31.4, 47.5, 66.0, 124.1, 124.7, 126.2, 127.0, 143.8, 144.7.

(*R*)-*N*-(1-(Dimethoxymethyl)-2,3-dihydro-1*H*-inden-5-yl)-acetamide (3b). To a stirred solution of Ar*I **4f** (0.872 g, 2.00 mmol) in TFE/DCM (1:40) (17 mL) was added *m*CPBA (77%) (0.448 g, 2.00 mmol) followed by (+)-CSA (0.464 g, 2.00 mmol). The resulting solution was stirred at rt for 30 min. Solvent was removed under reduced pressure. To this reaction mixture DCM (15 mL) and MeOH (1.7 mL) were added, and the temperature was lowered to −78 °C, followed by addition of alkene **1b** (0.187 g, 1.00 mmol) (dissolved in 3 mL DCM/MeOH (10:1)). After 5 min the reaction was quenched with a saturated solution of $NaHCO_3$, extracted with DCM, washed with brine, and dried over anhydrous $MgSO_4$. The solvent was evaporated under reduced pressure. The crude product was purified by flash column chromatography (30−60%, EtOAc in hexane), giving acetal **3b** (0.149 g, 0.600 mmol, 60%) as a viscous colorless liquid in 64% *ee* (Daicel chiral ASH column (25 cm), hexanes/EtOH:MeOH (1:1) = 95/5, 1.0 mL/min, temp 28 °C, 215 nm; tr (minor) = 15.7 min, tr (major) = 16.7 min), $[\alpha]_D^{20} = +13.1$ (c = 0.59, $CHCl_3$).

(*R*)-*N*-(1-(Dimethoxymethyl)-2,3-dihydro-1*H*-inden-5-yl)-acetamide (3b).[18] ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.93−2.02 (m, 1H), 2.15 (s, 3H), 2.17−2.23 (m, 1H), 2.77−2.97 (m, 2H), 3.37 (s, 3H), 3.39 (m, 1H), 3.42 (s, 3H), 4.27 (d, J = 7.5 Hz, 1H), 7.14 (dd, J = 8.4, 1.8 Hz, 1H), 7.31 (bs, 1H), 7.33 (d, J = 8.1 Hz, 1H), 7.46 (s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 24.5, 27.5, 31.4, 47.0, 52.9, 54.2, 107.2, 116.3, 118.1, 125.7, 136.7, 138.9, 145.8, 168.3.

(*R*)-*N*-(1-(Dimethoxymethyl)-2,3-dihydro-1*H*-inden-5-yl)-benzamide (3c). The reaction was performed using Ar*I **4f** (0.872 g, 2.00 mmol), *m*CPBA (77%) (0.448 g, 2.00 mmol), and (+)-CSA (0.464 g, 2.00 mmol) in TFE/DCM (1:40) (17 mL). After evaporation of the solvent, DCM (15 mL) and MeOH (1.7 mL) were added, followed by addition of alkene **1c** (0.249 g, 1.00 mmol) (dissolved in 3 mL of DCM/MeOH (10:1)) at −78 °C. After workup solvent was removed under reduced pressure. The crude product was purified by flash column chromatography (30−40% EtOAc in hexane) giving acetal **3c** (0.221 g, 0.710 mmol, 71%) as a white solid (mp: 91.5−93 °C) in 58% *ee* (Daicel chiral ASH column (25 cm), hexanes/EtOH:MeOH (1:1) = 92/8, 1.0 mL/min, temp 28 °C, 220 nm; tr (minor) = 25.1 min, tr (major) = 27.5 min) $[\alpha]^{20}_D = +11.2$ (c = 0.28, $CHCl_3$)).

(*R*)-*N*-(1-(Dimethoxymethyl)-2,3-dihydro-1*H*-inden-5-yl)-benzamide (3c). ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.92−2.04 (m, 1H), 2.15−2.27 (m, 1H), 2.78−2.99 (m, 2H), 3.37−3.47 (m, 1H), 3.38 (s, 3H), 3.42 (s, 3H), 4.29 (d, J = 7.5 Hz, 1H), 7.29 (dd, 8.1, 2.1 Hz, 1H), 7.38 (d, J = 8.4 Hz, 1H), 7.42−7.55 (m, 3H), 7.61 (s, 1H), 7.83−7.86 (m, 2H), 7.93 (bs, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 27.5 (CH_2), 31.4 (CH_2), 46.9 (CH), 52.8 (CH_3), 54.2 (CH_3), 107.1 (CH), 116.6 (CH), 118.5 (CH), 125.6 (CH), 126.9 (CH), 128.5 (CH), 131.5 (CH), 134.9 (C), 136.8 (C), 139.1 (C), 145.7 (C), 165.8 (C). HRMS [ESI(+)-TOF] calcd for $[C_{19}H_{21}NO_3 + Na]^+$ 334.1419; found 334.1408. IR (film): 3307, 3060, 2937, 2830, 1737, 1650, 1601, 1580, 1532, 1493, 1447, 1424, 1374, 1328, 1283, 1248, 1210, 1187, 1154, 1116 cm^{-1}.

(9*H*-Fluoren-9-yl)methyl (*R*)-(1-(Dimethoxymethyl)-2,3-dihydro-1*H*-inden-5-yl)carbamate (3d). The reaction was performed using Ar*I **4f** (0.872 g, 2.00 mmol), *m*CPBA (77%) (0.448 g, 2.00 mmol), and (+)-CSA (0.464 g, 2.00 mmol) in TFE/DCM (1:40) (17 mL). After evaporation of the solvent, DCM (15 mL) and MeOH (1.7 mL) was added, followed by addition of alkene **1d** (0.367 g, 1.00 mmol) (dissolved in 3 mL DCM/MeOH (10:1)) at −78 °C. After workup solvent was removed under reduced pressure. The crude product was purified by flash column chromatography (20−30% EtOAc in hexane) giving acetal **3d** (0.321 g, 0.750 mmol, 75%) as a white solid (mp: 111−112 °C) in 58% *ee*, $[\alpha]^{20}_D = +7.9$ (c = 0.29, $CHCl_3$).

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(9*H*-Fluoren-9-yl)methyl (*R*)-(1-(Dimethoxymethyl)-2,3-dihydro-1*H*-inden-5-yl)carbamate (3d). ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.89−2.01 (m, 1H), 2.12−2.24 (m, 1H), 2.73−2.94 (m, 2H), 3.34−3.43 (m, 1H), 3.35 (s, 3H), 3.40 (s, 3H), 4.22−4.26 (m, 1H), 4.26 (d, J = 7.5 Hz, 1H), 4.51 (d, J = 6.6 Hz, 2H), 6.71 (bs, 1H), 7.04 (d, J = 7.2 Hz, 1H), 7.27−7.32 (m, 4H), 7.36−7.41 (m, 2H), 7.59 (d, J = 7.5 Hz, 2H), 7.76 (d, J = 7.5 Hz, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 27.5 (CH_2), 31.4 (CH_2), 46.8 (CH), 47.0 (CH), 52.8 (CH_3), 54.1 (CH_3), 66.6 (CH_2), 107.1 (CH), 115.0 (CH), 117.0 (CH), 119.9 (CH), 124.8 (CH), 125.6 (CH), 127.0 (CH), 127.6 (CH), 136.6 (C), 138.0 (C), 141.2 (C), 143.7 (C), 145.7 (C), 153.5 (C). HRMS [ESI(+)-TOF] calcd for $[C_{27}H_{27}NO_4+Na]^+$ 452.1832; found 452.1837. IR (film): 3307, 3066, 2942, 2849, 2830, 1730, 1708, 1598, 1538, 1493, 1478, 1450, 1431, 1375, 1326, 1297, 1220 cm^{-1}.

(*R*)-*N*-(1-(Dimethoxymethyl)-2,3-dihydro-1*H*-inden-5-yl)-acetamide (3b). To a stirred solution of **3d** (0.12 g, 0.28 mmol) in dichloromethane (15 mL) was added piperidine (20% v/v) (3 mL). The solution was stirred for 25 min, and the solvent was removed under reduced pressure. The crude product was purified by flash column chromatography (60−70% EtOAc in hexane) giving deprotected acetal (0.050 g, 0.241 mmol, 86%) as a colorless liquid.[41] As deprotected amine acetal was unstable, it was protected with acetyl group. The reaction was performed using deprotected acetal (0.050 g, 0.241 mmol), cat. DMAP, and Ac_2O (0.08 mL, 0.82 mmol) in Et_3N (2 mL).[42] Purification by flash column chromatography (50−60% EtOAc in hexane) gave acetyl protected acetal **3b**[18] (0.054 g, 0.217 mmol, 90%) in 58% *ee* (Daicel chiral ASH column (25 cm), hexanes/EtOH:MeOH (1:1) = 95/5, 1.0 mL/min, temp 28 °C, 215 nm; tr (minor) = 15.7 min, tr (major) = 16.7 min).

(*R*)-1-(Bis(2,2,2-trifluoroethoxy)methyl)-2,3-dihydro-1*H*-inden-4-yl Acetate (2e). The reaction was performed using Ar*I **4f** (0.872 g, 2.00 mmol), *m*CPBA (77%) (0.448 g, 2.00 mmol), and (+)-CSA (0.464 g, 2.00 mmol) in TFE/DCM (1:40) (17 mL). After evaporation of the solvent, TFE/DCM (17 mL) (1:1) was added, followed by addition of alkene **1e** (0.188 g, 1.00 mmol) (dissolved in 3 mL of TFE/DCM (1:1)) at −40 °C. After workup solvent was removed under reduced pressure. The crude product was purified by flash column chromatography (4−5% EtOAc in hexane) giving acetal **2e** (0.223 g, 0.580 mmol, 58%) as a white solid (mp: 59.3−60.5 °C) in 64% *ee* (Daicel chiral ODH column (25 cm), hexanes/*i*-PrOH = 98.0/2.0, 0.4 mL/min, temp 26 °C, 215 nm; tr (major) = 18.3 min, tr (minor) = 21.6 min), $[\alpha]^{20}_D$ = +11.8 (c = 0.28, $CHCl_3$)).

(*R*)-1-(Bis(2,2,2-trifluoroethoxy)methyl)-2,3-dihydro-1*H*-inden-4-yl Acetate (2e). ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.98−2.10 (m, 1H), 2.22−2.32 (m, 1H), 2.30 (s, 3H), 2.70−2.91 (m, 2H), 3.47−3.55 (m, J = Hz, 1H), 3.84−4.07 (m, 4H), 4.71 (d, J = 8.1 Hz, 1H), 6.94 (dt, J = 7.8 Hz, 1H), 7.21 (t, J = 7.8 Hz, 1H), 7.28 (d, J = 7.5 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 20.8 (CH_3), 26.8 (CH_2), 28.1 (CH_2), 47.5 (CH), 61.8 (q, J = 34.8 Hz) (CH_2), 63.3 (q, J = 34.8 Hz) (CH_2), 105.0 (CH), 120.6 (CH), 123.2 (CH), 123.6 (q, J = 276 Hz) (CF_3), 123.7 (q, J = 276 Hz) (CF_3), 128.0 (CH), 136.6 (C), 143.3 (C), 147.1 (C), 168.9 (C). HRMS [ESI(+)-TOF]: calcd for $[C_{16}H_{16}F_6O_4+Na]^+$ 409.0850; found 409.0849. IR (film): 2947, 1764, 1615, 1587, 1468, 1433, 1372, 1281, 1213 cm^{-1}.

(*R*)-1-(Bis(2,2,2-trifluoroethoxy)methyl)-2,3-dihydro-1*H*-inden-4-yl Benzoate (2f). The reaction was performed using Ar*I **4f** (0.872 g, 2.00 mmol), *m*CPBA (77%) (0.448 g, 2.00 mmol), and (+)-CSA (0.464 g, 2.00 mmol) in TFE/DCM (1:40) (17 mL). After evaporation of the solvent, TFE/DCM (17 mL) (1:1) was added, followed by addition of alkene **1f** (0.250 g, 1.00 mmol) (dissolved in 3 mL TFE/DCM (1:1)) at −40 °C. After workup, solvent was removed under reduced pressure. The crude product was purified by flash column chromatography (3−4% ethyl acetate in hexane) giving acetal **2f** (0.272 g, 0.610 mmol, 61%) as a white solid (mp: 77.5−77.9 °C) in 56% *ee*, $[\alpha]^{20}_D$ = +19.4 (c = 0.33, $CHCl_3$).

(*R*)-1-(Bis(2,2,2-trifluoroethoxy)methyl)-2,3-dihydro-1*H*-inden-4-yl Benzoate (2f). ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.99−2.11 (m, 1H), 2.20−2.32 (m, 1H), 2.76−2.97 (m, 2H), 3.54 (q, J = 8.1 Hz, 1H), 3.85−4.09 (m, 4H), 4.74 (d, J = 8.1 Hz, 1H), 7.10 (dt, J = 7.8, 1.2 Hz, 1H), 7.26 (t, J = 7.8 Hz, 1H), 7.33 (d, J = 7.8 Hz, 1H), 7.48−7.54 (m, 2H), 7.64 (tt, J = 7.5, 1.5 Hz, 1H), 8.18−8.22 (m, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 26.8 (CH_2), 28.2 (CH_2), 47.6 (CH), 61.9 (q, J = 34.8 Hz) (CH_2), 63.4 (q, J = 34.8 Hz) (CH_2), 105.1 (CH), 120.7 (CH), 123.2 (CH), 123.69 (q, J = 276 Hz) (CF_3), 123.74 (q, J = 276 Hz) (CF_3), 128.1 (CH), 128.6 (CH), 129.4 (C), 130.2 (CH), 133.6 (CH), 136.8 (C), 143.4 (C), 147.4 (C), 164.5 (C). HRMS [ESI(+)-TOF] calcd for $[C_{21}H_{18}F_6O_4+Na]^+$ 471.1007; found 471.1012. IR (film): 3067, 2948, 1738, 1602, 1585, 1469, 1453, 1423, 1383, 1279, 1230, 1168, 1134 cm^{-1}.

(*R*)-1-(Bis(2,2,2-trifluoroethoxy)methyl)-2,3-dihydro-1*H*-inden-4-yl Acetate (2e). To a stirred solution of acetal **2f** (0.130 g, 0.29 mmol) in methanol (15 mL) was added a solution of K_2CO_3 (0.040 g, 0.29 mmol) in H_2O (0.12 mL). The reaction mixutre was stirred for 3 h. The reaction was diluted with water (5 mL), neutralized with 10% HCl, and extracted with DCM (3 × 5). The extract was then washed with water (5 mL) and brine (2 × 5 mL) and dried over anhydrous $MgSO_4$. The solvent was evaporated under reduced pressure. The crude product was purified by flash column (10−15%, EtOAc in hexane) giving phenolic acetal (0.10 g, 0.29 mmol, 96%) as a colorless oil.[43] The phenolic acetal was protected with an acetyl group. The reaction was performed using deprotected acetal (0.10 g, 0.29 mmol), cat. DMAP, and Ac_2O (0.096 mL, 0.986 mmol) in Et_3N (2 mL).[18] Purification by flash column chromatography (3−4% EtOAc in hexane) gave acetyl protected acetal **2e** (0.105 g, 0.272 mmol, 94%) in 56% *ee* (Daicel chiral ODH column (25 cm), hexanes/*i*-PrOH = 98.0/2.0, 0.4 mL/min, temp 26 °C, 215 nm; tr (major) = 18.3 min, tr (minor) = 21.6 min).

(*R*)-1-(Bis(2,2,2-trifluoroethoxy)methyl)-2,3-dihydro-1*H*-inden-5-yl Acetate (2g). The reaction was performed using Ar*I **4f** (0.872 g, 2.0 mmol), *m*CPBA (77%) (0.448 g, 2.00 mmol) and (+)-CSA (0.464 g, 2.00 mmol) in TFE/DCM (1:40) (17 mL). After evaporation of the solvent, TFE/DCM (17 mL) (1:1) was added, followed by addition of alkene **1g** (0.188 g, 1.00 mmol) (dissolved in 3 mL TFE/DCM (1:1)) at −40 °C. After workup solvent was removed under reduced pressure. The crude product was purified by flash column chromatography (4−5% ethyl acetate in hexane) giving acetal **2g** (0.158 g, 0.410 mmol, 41%) as colorless viscous liquid in 78% *ee* (Sigma-Aldrich chiral Astec Cellulose DMP column (25 cm), hexanes/*i*-PrOH = 99.0/1.0, 0.4 mL/min, temp 28 °C, 215 nm; tr (major) = 45.3 min, tr (minor) = 49.8 min), $[\alpha]^{20}_D$ = +13.5 (c = 0.58, $CHCl_3$).

(*R*)-1-(Bis(2,2,2-trifluoroethoxy)methyl)-2,3-dihydro-1*H*-inden-5-yl Acetate (2g). ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.97−2.09 (m, 1H), 2.21−2.33 (m, 1H), 2.28 (s, 3H), 2.82−3.01 (m, 2H), 3.43 (q, J = 7.8 Hz, 1H), 3.86−4.08 (m, 4H), 4.68 (d, J = 8.4 Hz, 1H), 6.87 (dd, J = 8.4, 2.2 Hz, 1H), 6.94 (s, 1H), 7.38 (d, J = 8.1 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 21.0 (CH_3), 27.4 (CH_2), 31.1 (CH_2), 46.4 (CH), 61.6 (q, J = 34.8 Hz) (CH_2), 63.3 (q, J = 34.8 Hz) (CH_2), 105.1 (CH), 117.8 (CH), 119.7 (CH), 123.6 (q, J = 276 Hz) (CF_3), 123.7 (q, J = 276 Hz) (CF_3), 126.1 (CH), 138.3 (C), 146.1 (C), 150.3 (C), 169.7 (C). LRMS m/z (rel. int.): 386 ($M^{+\bullet}$, 4), 344 (7), 245 (7), 211 (14), 175 (8), 145 (6), 133 (100), 115 (7), 105 (11), 83 (11), 77 (6), 43 (19). HRMS [ESI(+)-TOF]: calcd for $[C_{16}H_{16}F_6O_4+Na]^+$ 409.0850; found 409.0851. IR (film): 2953, 1761, 1610, 1592, 1485, 1460, 1431, 1372, 1282, 1216, 1163, 1134, 1103 cm^{-1}.

(*R*)-3-(Bis(2,2,2-trifluoroethoxy)methyl)-2,3-dihydro-1*H*-inden-5-yl Acetate (2h). The reaction was performed using Ar*I **4f** (0.872 g, 2.00 mmol), *m*CPBA (77%) (0.448 g, 2.00 mmol) and (+)-CSA (0.464 g, 2.00 mmol) in TFE/DCM (1:40) (17 mL). After evaporation of the solvent, TFE/DCM (17 mL) (1:1) was added, followed by addition of alkene **1h** (0.188 g, 1.00 mmol) (dissolved in 3 mL TFE/DCM (1:1)) at −40 °C. After workup solvent was removed under reduced pressure. The crude product was purified by flash column chromatography (4−5% ethyl acetate in hexane) giving acetal **2h** (0.204 g, 0.530 mmol, 53%) as white solid (MP: 61.2−62.1 °C) in 54% *ee* (Sigma-Aldrich chiral Astec Cellulose DMP column (25 cm), hexanes/*i*-PrOH = 99.0/1.0, 0.4 mL/min, temp 26 °C, 215 nm; tr (major) = 28.5 min, tr (minor) = 31.3 min) $[\alpha]^{20}_D$ = +4.7 (c = 0.48, $CHCl_3$)).

(*R*)-3-(Bis(2,2,2-trifluoroethoxy)methyl)-2,3-dihydro-1*H*-inden-5-yl Acetate (2h). ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.98−2.09 (m, 1H), 2.21−2.33 (m, 1H), 2.28 (s, 3H), 2.79−2.99 (m, 2H), 3.46 (q, J = 7.8 Hz, 1H), 3.85−4.06 (m, 2H), 4.69 (d, J = 8.4 Hz, 1H), 6.91 (ddd,

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J = 8.1, 2.1, 0.3 Hz, 1H), 7.10 (d, J = 1.8 Hz, 1H), 7.20 (d, J = 8.1 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 21.1 (CH_3), 27.5 (CH_2), 30.6 (CH_2), 61.7 (q, J = 34.8 Hz) (CH_2), 63.5 (q, J = 34.8 Hz) (CH_2), 105.1 (CH), 118.9 (CH), 120.9 (CH), 123.6 (q, J = 276 Hz) (CF_3), 123.7 (q, J = 276 Hz) (CF_3), 125.1 (CH), 142.0 (C), 142.2 (C), 149.5 (C), 169.8 (C). LRMS m/z (rel. int.): 386 ($M^{+\bullet}$, 2), 344 (25), 287 (7), 244 (8), 211 (100), 145 (17), 133 (92), 115 (15), 105 (17), 83 (29), 77 (12), 43(43). HRMS [ESI(+)-TOF]: calcd for $[C_{16}H_{16}F_6O_4+Na]^+$ 409.0850; found 409.0864. IR (film): 2919, 2850, 1760, 1610, 1591, 1540, 1484, 1459, 1429, 1372, 1281, 1214 cm^{-1}.

(1*S*,3*R*)-1-(Bis(2,2,2-trifluoroethoxy)methyl)-3-(3,4-dichlorophenyl)-2,3-dihydro-1*H*-indene (2i) and ((1*R*,3*R*)-3-(3,4-Dichlorophenyl)-2,3-dihydro-1*H*-inden-1-yl)methanol (6i). To a stirred solution of Ar*I **4f** (0.872 g, 2.00 mmol) in TFE/DCM (1:40) (17 mL) was added *m*CPBA (77%) (0.448 g, 2.00 mmol) followed by (+)-CSA (0.464 g, 2.00 mmol). The resulting solution was stirred at rt for 30 min. Solvent was removed under reduced pressure. To this reaction mixture TFE/DCM (1:1) (17 mL) was added, and the temperature was lowered to −40 °C, followed by addition of alkene **1i** (0.275 g, 1.00 mmol) (dissolved in 3 mL of TFE/DCM (1:1)). After 5 min, $NaBH_4$ (5 equiv) (0.189 g, 5.00 mmol) was added to this reaction mixture. The reaction was stirred for 2 h at rt. The reaction was quenched with saturated solution of $NaHCO_3$, extracted with DCM, washed with brine, and dried over anhydrous $MgSO_4$. The solvent was evaporated under reduced pressure. The crude product was purified by flash column chromatography (2−20%, EtOAc in hexane), giving acetal **2i** (0.21 g, 0.44 mmol, 44%) in 40% *ee* (Sigma-Aldrich chiral Astec Cellulose DMP column (25 cm), hexanes/*i*-PrOH = 99.0/1.0, 0.5 mL/min, temp 28 °C, 220 nm; tr (major) = 10.8 min, tr (minor) = 15.2 min) as a colorless oil $[\alpha]_D^{20}$ = +1.8 (c = 0.50, $CHCl_3$) and alcohol **6i** (0.128 g, 0.440 mmol, 44%) in 34% *ee* (Daicel chiral ASH column (25 cm), hexanes/EtOH:MeOH (1:1) = 98.0/2.0, 0.5 mL/min, temp 28 °C, 220 nm; tr (major) = 30.3 min, tr (minor) = 32.9 min) as a colorless oil, $[\alpha]_D^{20}$ = +1.6 (c = 0.33, $CHCl_3$).

(1*S*,3*R*)-1-(Bis(2,2,2-trifluoroethoxy)methyl)-3-(3,4-dichlorophenyl)-2,3-dihydro-1*H*-indene (2i). ^{1}H NMR (300 MHz, $CDCl_3$) δ: 2.11−2.21 (m, 1H), 2.57−2.66 (m, 1H), 3.56−3.63 (m, 1H), 3.82−4.08 (m, 4H), 4.41 (t, J = 8.1 Hz, 1H), 4.73 (d, J = 7.8 Hz, 1H), 6.93−6.99 (m, 2H), 7.20 (d, J = 2.1 Hz, 1H), 7.24−7.29 (m, 2H), 7.35 (d, J = 9.0 Hz, 1H), 7.43−7.45 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 37.5 (CH_2), 46.4 (CH), 49.0 (CH), 62.0 (q, J = 34.9 Hz) (CH_2), 63.9 (q, J = 34.7 Hz) (CH_2), 105.1 (CH), 123.62 (q, J = 276 Hz) (CF_3), 123.66 (q, J = 276 Hz) (CF_3), 125.2 (CH), 125.9 (CH), 127.3 (CH), 127.5 (CH), 128.3 (CH), 129.8 (CH), 130.5 (CH), 132.6 (C), 141.0 (C), 145.3 (C), 146.0 (C). Anal. Calcd for $C_{20}H_{16}Cl_2F_6O_2$: C, 50.76; H, 3.41. Found: C, 50.55; H, 3.43. IR (film): 3077, 2943, 1590, 1561, 1469, 1421, 1401, 1280, 1167, 1133 cm^{-1}.

((1*R*,3*R*)-3-(3,4-Dichlorophenyl)-2,3-dihydro-1*H*-inden-1-yl)methanol (6i). ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.66 (bs, 1H), 2.14−2.24 (m, 1H), 2.47−2.55 (m, 1H), 3.44−3.52 (m, 1H), 3.80 (d, J = 6.3 Hz, 2H), 4.42 (t, J = 7.8 Hz, 1H), 6.95−7.00 (m, 2H), 7.18−7.28 (m, 3H), 7.35 (d, J = 8.4 Hz, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 39.3 (CH_2), 46.5 (CH), 49.2 (CH), 65.9 (CH_2), 124.4 (CH), 125.2 (CH), 127.3 (CH), 127.4 (CH), 127.7 (CH), 129.8 (CH), 130.2 (C), 130.4 (CH), 132.4 (C), 143.9 (C), 145.9 (C), 146.1 (C). HRMS [ESI(+)-TOF]: calcd for $[C_{16}H_{14}Cl_2O+K]^+$ 331.0059; found 331.0043. IR (film): 3392, 3067, 3022, 2929, 2868, 1736, 1589, 1560, 1468, 1398, 1373, 1324, 1246 cm^{-1}.

(1*S*,3*S*)-1-(Bis(2,2,2-trifluoroethoxy)methyl)-3-methyl-2,3-dihydro-1*H*-indene (2j) and ((1*R*,3*S*)-3-Methyl-2,3-dihydro-1*H*-inden-1-yl)methanol (6j). The reaction was performed using Ar*I **4f** (0.872 g, 2.00 mmol), *m*CPBA (77%) (0.448 g, 2.00 mmol), and (+)-CSA (0.464 g, 2.00 mmol) in TFE/DCM (1:40) (17 mL). After evaporation of the solvent, TFE/DCM (17 mL) (1:1) was added, followed by addition of alkene **1j** (0.144 g, 1.00 mmol) (dissolved in 3 mL of TFE/DCM (1:1)) at −78 °C. After 5 min, $NaBH_4$ (5 equiv) (0.189 g, 5.00 mmol) was added to this reaction mixture. Solvent was removed under reduced pressure. The crude product was purified by flash column chromatography (3−15% ethyl acetate in hexane) giving acetal **2j** (0.147 g, 0.430 mmol, 43%) in 38% *ee* (Sigma-Aldrich chiral Astec Cellulose DMP column (25 cm), hexanes/*i*-PrOH = 99.5/0.5, 0.5 mL/min, temp 28 °C, 220 nm; tr (major) = 11.3 min, tr (minor) = 15.7 min) as a colorless oil, $[\alpha]_D^{20}$ = +6.7 (c = 0.57, $CHCl_3$), and alcohol **6j** (0.055 g, 0.34 mmol, 34%) in 34% *ee* (Daicel chiral ASH column (25 cm), hexanes/EtOH:MeOH (1:1) = 99.0/1.0, 0.5 mL/min, temp 28 °C, 220 nm; tr (major) = 25.3 min, tr (minor) = 33.7 min) as a colorless oil, $[\alpha]_D^{20}$ = +1.5 (c = 0.23, $CHCl_3$).

(1*S*,3*S*)-1-(Bis(2,2,2-trifluoroethoxy)methyl)-3-methyl-2,3-dihydro-1*H*-indene (2j).[18] ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.26 (d, J = 6.9 Hz, 3H), 1.76−1.86 (m, 1H), 2.27−2.36 (m, 1H), 3.27 (sext, J = 7.2 Hz, 1H), 3.46 (sext, J = 4.2 Hz, 1H), 3.82−4.05 (m, 4H), 4.64 (d, J = 8.4 Hz, 1H), 7.15−7.28 (m, 3H), 7.35 (d, J = 6.9 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 20.5 (CH_3), 35.9 (CH_2), 37.6 (CH), 45.9 (CH), 61.5 (q, J = 34.7 Hz) (CH_2), 63.8 (q, J = 34.7) (CH_2), 105.0 (CH), 123.6 (q, J = 276 Hz) (CF_3), 123.5 (CH), 123.8 (q, J = 276 Hz) (CF_3), 125.8 (CH), 126.6 (CH), 127.8 (CH), 140.3 (C), 149.2 (C).

((1*R*,3*S*)-3-Methyl-2,3-dihydro-1*H*-inden-1-yl)methanol (6j). ^{1}H NMR (300 MHz, $CDCl_3$) δ: 1.27 (d, J = 6.9 Hz, 3H), 1.62 (bs, 1H), 1.77−1.87 (m, 1H), 2.16−2.24 (m, 1H), 3.22−3.38 (m, 2H), 3.71 (d, J = 6.6 Hz, 2H), 7.14−7.27 (m, 4H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 20.4 (CH_3), 37.5 (CH_2), 37.7 (CH), 46.2 (CH), 66.1 (CH_2), 123.6 (CH), 124.3(CH), 126.3 (CH), 127.2 (CH), 143.4 (C), 149.2 (C). HRMS [ESI(+)-TOF]: calcd for $[C_{11}H_{14}O+Na]^+$ 185.0942; found 185.0938. LRMS m/z (rel. int.): 162 ($M^{+\bullet}$, 12), 144 (11), 132 (11), 131 (100), 129 (30), 115 (24), 91 (29), 77 (7), 63 (5), 51 (6), 39 (4).

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.5b02803.

NMR spectra, HPLC and GC chromatograms (PDF)

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Notes

The authors declare no competing financial interest.

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Dedicated with deep respect to Prof. R. A. Pilli on the occasion of his 60th birthday.

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