Pergamon

SCIENCE DIRECT®

Tetrahedron Letters 44 (2003) 9317–9320

TETRAHEDRON LETTERS

Novel transformation of 2-substituted alkyl 1-indanone-2-acetates to 6-substituted 3,4-benzotropolones through sequential reduction and oxidation processes using Sm(II) and Ce(IV) salts

Kazuki Iwaya, Mutsuko Tamura, Momoe Nakamura and Eietsu Hasegawa*

Department of Chemistry, Faculty of Science, Niigata University, Ikarashi-2 8050, Niigata 950-2181, Japan

Received 15 August 2003; revised 6 October 2003; accepted 10 October 2003

Abstract—When 2-substituted alkyl 1-indanone-2-acetates **1** were treated with samarium diiodide, 3-substituted 2-hydroxy-2,3-methano-1-oxo-1,2,3,4-tetrahydronaphthalenes **4** were obtained. The reaction is proposed to proceed through a rearrangement initiated by intramolecular ketone–ester coupling. Oxidation of these products **4** or their silyl ethers **13** by ceric(IV) ammonium nitrate involving regioselective bond cleavage of their bicyclo[4.1.0]-rings produced the corresponding benzotropolone derivatives **10**.

Development of effective methods to construct medium-sized rings is an important target in organic synthesis.[1] Among successful ways to achieve this objective is an employment of a cyclization and ring expansion method.[2] We have recently discovered that the reaction of α-ester substituted indanones **I** ($n=1$) with samarium diiodide (SmI_2) promoted intramolecular ketone–ester coupling followed by rearrangement to finally give one-carbon homologated α-hydroxy benzocyclohexenones **II** ($n=1$) (Eq. (1)).[3] Then, we considered that this method was applicable to the synthesis of benzotropolones[4] whose structures are often found in naturally occurring theaflavins.[5] However, the reaction of α-ester substituted tetralones **I** ($n=2$) with SmI_2 did not give the expected α-hydroxy benzocycloheptenones **II** ($n=2$) under the same reaction conditions.[6] In this paper, we would like to report the preliminary results obtained by an exploratory study on an alternative approach to the synthesis of benzotropolones utilizing a two-carbon-homologation methodology as described in Eq. (2). Although the direct transformation of **III** to **IV** was not successful by SmI_2, we finally discovered that sequential reduction and oxidation processes using Sm(II) and Ce(IV) salts, respectively, made such a transformation possible (see below).

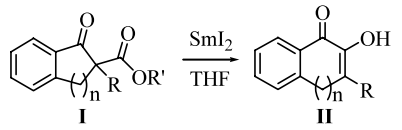
Table 1. Reaction of 2-substituted alkyl 1-indanone-2-acetates **1**, **2**, **3** with SmI_2

Entry	Substrate	R^1	R^2	Conv. (%)	Yield of **4** (%)
1[a]	**1a**	Me	Me	99	48
2[b]	**1a**	Me	Me	98	59
3[c]	**1a**	Me	Me	100	29
4[b]	**1b**	Me	*n*-Pr	98	66
5[b]	**1c**	Me	Allyl	99	67
6[b]	**1d**	Me	$PhCH_2$	84	42
7[a]	**2a**	Et	Me	>95	47
8[a]	**3a**	Ph	Me	93	54

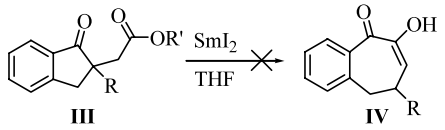
[a] **1a**, **2a** or **3a** was added to 0.10 M SmI_2 solution.
[b] **1** was added to 0.06 M SmI_2 solution.
[c] 0.10 M SmI_2 solution was added to **1a**.

Keywords: γ-keto ester; ketone–ester coupling; samarium diiodide; cyclopropane ring opening; ceric(IV) ammonium nitrate; benzotropolone.
* Corresponding author. Tel.:/fax: +81-25-262-6159; e-mail: ehase@chem.sc.niigata-u.ac.jp

0040-4039/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tetlet.2003.10.083

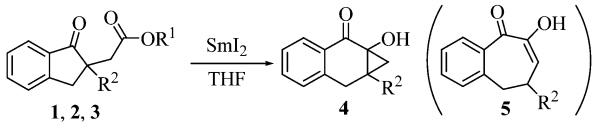


(1)



(2)

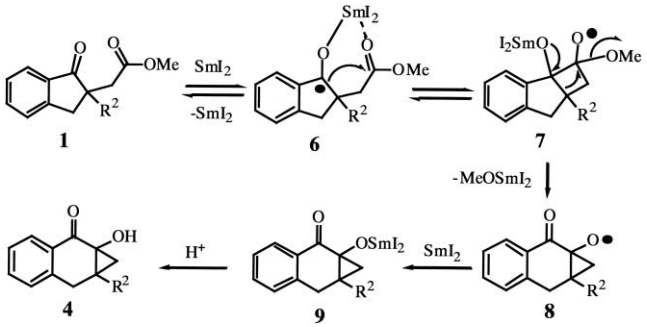
When methyl 2-methyl-1-indanone-2-acetate **1a**[7] was treated with 2.2 equivalents of SmI_2, the expected compound **5a** (R^2 = Me) was not obtained. Instead, a rearrangement product, 2-hydroxy-2,3-methano-3-methyl-1-oxo-1,2,3,4-tetrahydronaphthalene **4a** was isolated in 48% yield (Eq. (3)) (entry 1 in Table 1).[8,9] Modification of the reaction conditions influenced the yield of **4a** to some extent. For example, the yield of **4a** increased under the diluted conditions (entry 2) while the inverse addition in which SmI_2 was added to the solution of **1a** decreased the yield of **4a** (entry 3). Similar rearrangements were also observed for the reaction of other derivatives **1**, **2** and **3** with SmI_2 while the yields of the corresponding products **4** were modest (Table 1).[8] It was then found that the effect of the alkoxy substituent of the ester group (OR^1) on the yield of **4** was rather small (entries 1, 7 and 8).



(3)

On the basis of the above results and those of a related study,[3] a plausible reaction mechanism, represented by **1** and SmI_2, is proposed as shown in Scheme 1. Single electron transfer from SmI_2 to the ketone carbonyl of **1** gives the samarium ketyl radical **6**. Subsequent ketyl radical cyclization onto the ester carbonyl, which might be reversible, gives the cyclobutoxy radical **7**. Then, **7** undergoes ring-opening and re-cyclization liberating methoxy anion and samarium ion ($MeOSmI_2$) to give **8**. The reaction of **8** with another equivalent of SmI_2 giving **9** is followed by hydrolysis to yield **4**. Higher concentration of SmI_2 surrounding **8** should further accelerate the conversion of **8** to **9**, which seems to be consistent with the results presented in Table 1; the yield of **4a** in entry 1 is greater than that in entry 3.

We noticed that the products **4** possess a cyclopropoxy structure which could be opened with certain metal oxidants.[10] Thus, we first attempted to react **4a** with $FeCl_3$ since Fe(III) salts are known as effective reagents

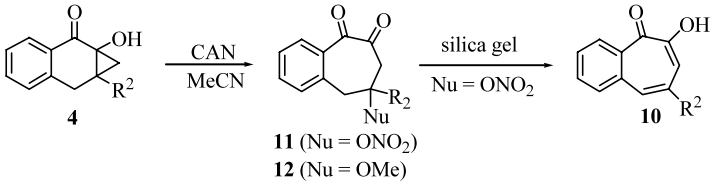


Scheme 1.

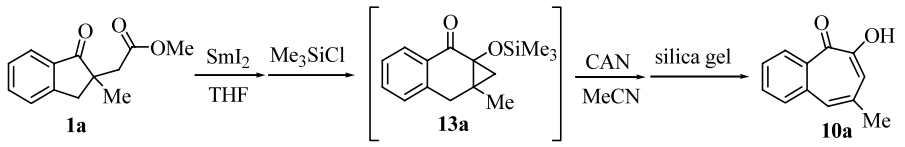
Table 2. Reaction of 3-substituted 1-hydroxy-2,3-methano-1-oxo-1,2,3,4-tetrahydronaphthalenes **4** with CAN

Entry	**4**	R^2	Conv. of **4** (%)	Yield of **10** (%)
1	**4a**	Me	100	47
2	**4b**	*n*-Pr	100	41
3	**4c**	Allyl	100	39
4	**4d**	$PhCH_2$	100	38

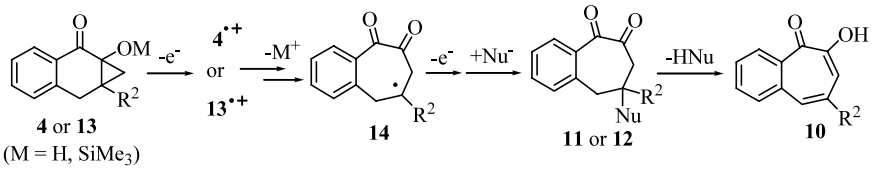
for the related transformations.[10a,c,e] Some consumption of **4a** was observed in MeCN; however, the expected ring opening products were not isolated from the complicated product mixture. On the other hand, **4a** was quantitatively recovered in DMF. Then, we conducted the reaction of **4a** with ceric ammonium nitrate (CAN)[10b] in MeCN to find the formation of 6-methy-3,4-benzotropolone **10a** (Eq. (4)) (entry 1 in Table 2).[11] The same reaction also proceeded in THF to give **10a** (54%). Although ^1H HMR analysis of the reaction mixture of **4a** with CAN suggested the presence of **11a**,[12] **10a** was isolated by silica gel column chromatography (Eq. (4)). As one may expect, when the reaction was conducted in MeOH, the methoxy substituted product **12a**[13] that was stable during column chromatography was isolated. Reactions of other **4** with CAN gave the corresponding **10** in moderate yields (Table 2).[11] It should be noted that the acetate of **4a** prepared by the reaction of **9a** with acetic anhydride was not reactive with CAN. As has been seen in related chemistry,[10a–d] silyloxy cyclopropanes are known to be reactive substrates with metal oxidants. Thus, the reaction mixture of **1a** with SmI_2 was quenched with Me_3SiCl followed by extraction and concentration to give a reaction mixture which was then treated with CAN without further purification (Scheme 2).[14] The overall yield of **10a** (52%) from **1a** in this reaction was better than that (ca. 25%) obtained under the corre sponding stepwise conditions (**1a**→**4a**→**10a**). Again, $FeCl_3$ was found to be ineffective.



(4)



Scheme 2.



Scheme 3.

In Scheme 3, a plausible reaction mechanism is presented. Single electron transfer from **4** or **13** to CAN gives their radical cations. The intermediate **14** possessing tertiary carbon radical is formed through subsequent deprotonation or desilylation and ring-opening while the order of each step could not be easily specified. The reaction of **14** with another equivalent of CAN followed by attack of certain nucleophiles (Nu^-) to the formed carbocation yields the benzocycloheptandione **11** or **12**, depending on the solvents used. If elimination of HNu from these adducts occurs, the following keto–enol tautomerization yields 6-substituted 3,4-benzotropolone **10**.

In conclusion, although the conditions are not fully optimized yet, the results presented above demonstrate that a novel set of reduction and oxidation processes using Sm(II) and Ce(IV) salts, respectively, is effective for the transformation of 2-substituted alkyl 1-indanone-2-acetates to the benzotropolone derivatives via 3-substituted 2-hydroxy-2,3-methano-1-oxo-1,2,3,4-tetrahydronaphthalenes. Studies probing the potential applicability of this methodology to reductive formation and oxidative ring-opening of other cyclopropanols are continuing.[15]

Acknowledgements

This work was supported by Grants-in-Aid for Scientific Research on Priority Areas 'Exploitation of Multi-element Cyclic Molecules' (No. 14044030) as well as Scientific Research C (No. 15550028) from the Ministry of Education, Culture, Sports, Science and Technology, Japan. We thank Professor Toshio Suzuki (Faculty of Engineering, Niigata University) and Professor Masaki Kamata (Faculty of Education of Human Science, Niigata University) for their valuable comments. We also thank Professor Takaaki Horaguchi (Faculty of Science, Niigata University) for his generous assistance.

References

1. Yet, L. *Chem. Rev.* **2000**, *100*, 2963–3007 and the references cited therein.
2. (a) Dowd, P.; Choi, S.-C. *Tetrahedron* **1989**, *45*, 77–90; (b) Roxburg, C. J. *Tetrahedron* **1993**, *49*, 10749–10784; (c) Rousseau, G. *Tetrahedron* **1995**, *51*, 2777–2849; (d) Yet, L. *Tetrahedron* **1999**, *55*, 9349–9403.
3. Iwaya, K.; Nakamura, M.; Hasegawa, E. *Tetrahedron Lett.* **2002**, *43*, 5067–5070.
4. Representative papers for synthesis of benzotropolones. (a) Sato, M.; Tsunetsugu, J.; Ebine, S. *Bull. Chem. Soc. Jpn.* **1972**, *45*, 638–639; (b) Read, G.; Ruiz, V. M. *J. Chem. Soc., Perkin Trans. 1* **1973**, 1223–1224; (c) Friedrichsen, W.; Plug, C. *Tetrahedron Lett.* **1992**, *33*, 7509–7510.
5. (a) Sanderson, G. W. In *Recent Advances in Phytochemistry*; Runeckles, V. C.; Tso, T. C., Eds.; Academic Press: New York, 1972; Vol. 5, pp. 247–316; (b) Lewis, J. R.; Davis, A. L.; Cai, Y.; Davies, A. P.; Wilking, J. P. G.; Pennington, M. *Phytochemistry* **1998**, *49*, 2511–2519.
6. Iriyama, T.; Iwaya, K.; Hasegawa, E. unpublished results.
7. Indanone **1a** was synthesized by the following procedures. Reaction of 1-indanoe (120 mmol) with diethyl carbonate (92.7 ml) and NaH (144 mmol) at reflux temperature provided ethyl 1-indanone-2-carboxylate (85 mmol, 71%). α-Methylation of ethyl 1-indanone-2-carboxylate (20.0 mmol) by CH_3I (80.0 mmol) and NaH (24.0 mmol) gave ethyl 2-methyl-1-indaone-2-carboxylate (20.0 mmol, 100%). Then, decarboxylation of ethyl 2-methyl-1-indaone-2-carboxylate (20.0 mmol) was performed with hydrobromic acid (177.0 mmol) to give 2-methyl-1-indanone (18.6 mmol, 93%). Resulting 2-methyl-1-indanone (18.6 mmol) was treated with methyl bromoacetate (55.8 mmol) and NaH (22.3 mmol) to give **1a** (14.1 mmol, 76%). Physical and spectral data of **1a**: colorless solid, mp 59–60°C; IR (KBr) 1729, 1707 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ 7.79 (d, $J=7.6$ Hz, 1H), 7.60 (dd, $J=7.6$, 7.6 Hz, 1H), 7.46–7.35 (m, 2H), 3.55 (s, 3H), 3.31 (d, $J=17.2$ Hz, 1H), 2.96 (d, $J=17.2$ Hz, 1H), 2.84 (d, $J=16.2$ Hz, 1H), 2.68 (d, $J=16.2$ Hz, 1H), 1.23 (s, 3H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 209.1, 171.6, 152.1, 135.1, 134.8, 127.4, 126.5, 124.3, 51.6, 46.6, 41.3, 40.2, 24.7. Other indanones **1**, **2a** and **3a** were similarly synthesized.

8. A typical experiment (entry 2 in Table 1): a THF solution (5.0 mL) of indanone **1a** (0.50 mmol) was added dropwise under N_2 during 0.1 min to the THF solution (17.0 mL) of SmI_2 (1.10 mmol) at room temperature. The reaction mixture was stirred for 30 min followed by quenching with 0.1 M HCl (10 mL), and was stirred under air for 10 min. The resulting mixture was extracted with Et_2O (30 mL×3), and then the organic layer was washed with saturated aqueous $NaHCO_3$, $Na_2S_2O_3$ and NaCl (30 mL), and dried over $MgSO_4$. The residue obtained by the concentration of the extract was separated by column chromatography on silica gel (EtOAc:benzene = 1:10) to give **4a** (0.29 mmol, 59%). Physical and spectral data of **4a**: colorless solid, mp 40–41°C; IR (KBr) 3440, 1658 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ 7.90 (d, J = 7.6 Hz, 1H), 7.48 (dd, J = 7.6, 7.6 Hz, 1H), 7.34 (dd, J = 7.6, 7.6 Hz, 1H), 7.18 (d, J = 7.6 Hz, 1H), 3.15 (s, 2H), 1.52 (s, 3H), 1.27 (d, J = 5.4 Hz, 1H), 1.15 (d, J = 5.4 Hz, 1H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 198.2, 139.4, 133.2, 130.2, 128.5, 127.1, 127.0, 67.7, 36.1, 27.4, 25.1, 18.7. Reactions of other indanones **1**, **2a** and **3a** with SmI_2 and characterizations of the products **4** were performed in the similar manner.
9. Interestingly, in the related aliphatic systems, 1-methyl-5-hydroxybicyclo[3.2.0]heptan-7-one and 1-methyl-6-hydroxybicyclo[4.1.0]heptan-5-one were found to exist as the equilibrium mixture in solution, where the former isomer is more favorable than the latter one: Jung, M.E.; Davidov, P. *Org. Lett.* **2001**, *3*, 627–629. On the contrary, the existence of 1-methyl-5-hydroxy-2,3-benzobicyclo-[3.2.0]heptan-7-one was not confirmed in our benzo-fused system.
10. (a) Ito, Y.; Fujii, S.; Saegusa, T. *J. Org. Chem.* **1976**, *41*, 2073–2074; (b) Paolobelli, A. B.; Gioacchini, F.; Ruzziconi, R. *Tetrahedron Lett.* **1993**, *34*, 6333–6336; (c) Booker-Milburn, K. I.; Thompson, D. F. *J. Chem. Soc., Perkin Trans. 1* **1995**, 2315–2321; (d) Iwasawa, N.; Funahashi, M.; Hayakawa, S.; Ikeno, T.; Narasaka, K. *Bull. Chem. Soc. Jpn.* **1999**, *72*, 85–97; (e) Booker-Milburn, K. I.; Jones, J. L.; Sibley, G. E. M.; Cox, R.; Meadows, J. *Org. Lett.* **2003**, *5*, 1107–1109.
11. A typical experiment (entry 1 in Table 2): an MeCN solution (7.0 mL) of **4a** (0.50 mmol) was added dropwise under N_2 during 0.1 min to the MeCN solution (3.0 mL) of CAN (1.10 mmol) at room temperature. The reaction mixture was stirred for 1 h, and was then quenched with saturated aqueous $NaHCO_3$ (10 mL), and the solution was stirred under air for 10 min. The following extraction procedure was the same as that for SmI_2 reaction (see Ref. 8). The crude mixture was separated by thin-layer chromatography on silica gel (EtOAc:benzene = 1:10) to give **10a** (0.23 mmol, 47%). Physical and spectral data of **10a**: yellow solid, mp 85–98°C (decomp); IR (KBr) 3266, 1638, 1586 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ 8.84 (d, J = 8.2 Hz, 1H), 8.65 (br, 1H), 7.73–7.58 (m, 3H), 7.26 (s, 1H), 7.15 (s, 1H), 2.46 (s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 180.1, 155.3, 138.2, 136.5, 133.7, 132.7, 132.0, 131.9, 130.6, 128.4, 117.9, 27.2. Reactions of other **4** with CAN and characterizations of the products **10** were performed in a similar manner.
12. Physical and spectral data of **11a**: yellow oil; IR (neat) 1729, 1689, 1628 (-ONO_2), 861 (-ONO_2) cm^{-1}; ^1H NMR (200M Hz, $CDCl_3$) δ 7.98 (d, J = 7.5 Hz, 1H), 7.65 (dd, J = 7.5, 7.5 Hz, 1H), 7.50 (dd, J = 7.5, 7.5 Hz, 1H), 7.32 (d, J = 7.5 Hz, 1H), 3.42 (d, J = 15.5 Hz, 1H), 3.36 (d, J = 12.3 Hz, 1H), 3.25 (d, J = 12.3 Hz, 1H), 3.16 (d, J = 15.5 Hz, 1H), 1.87 (s, 1H); ^{13}C NMR (50M Hz, $CDCl_3$) δ 194.6, 190.4, 135.7, 135.0, 133.7, 131.8, 130.1, 128.9, 87.0, 48.6, 42.6, 24.2.
13. Physical and spectral data of **12a**: yellow oil; IR (neat) 1723, 1686 cm^{-1}; ^1H NMR (200 MHz, $CDCl_3$) δ 7.93 (d, J = 7.3 Hz, 1H), 7.58 (dd, J = 7.3, 7.3 Hz, 1H), 7.43 (dd, J = 7.3, 7.3 Hz, 1H), 7.28 (d, J = 7.3 Hz, 1H), 3.26 (s, 1H), 3.17 (d, J = 15.0 Hz, 1H), 3.06 (d, J = 11.9 Hz, 1H), 2.94 (d, J = 15.0 Hz, 1H), 2.80 (d, J = 11.9 Hz, 1H), 1.42 (s, 1H); ^{13}C NMR (50 MHz, $CDCl_3$) δ 197.3, 191.7, 138.3, 134.3, 134.0, 1315, 129.8, 127.8, 74.9, 49.9, 49.3, 44.0, 23.7.
14. To the reaction mixture obtained from **1a** (0.50 mmol) and SmI_2 was added Me_3SiCl (5.0 mmol), and the resulting solution was stirred under air for 20 min followed by ethereal extraction. An MeCN solution (7.0 mL) of the mixture obtained by concentration of the extract was added to a MeCN solution (3.0 mL) of CAN (1.10 mmol) at room temperature. Following procedure was the same as that described in Ref. 11.
15. Latest review of synthesis and reactions of cyclopropanols: Kulinkovich, O. G. *Chem. Rev.* **2003**, *103*, 2597–2632.