Sequenced Reactions with Samarium(II) Iodide. A Complementary Annulation Process Providing Access to Seven-, Eight-, and Nine-Membered Carbocycles

Gary A. Molander*

Department of Chemistry and Biochemistry, University of Colorado, Boulder, Colorado 80309-0215

Fouzia Machrouhi

Laboratoire de Synthèse Asymétrique, Associé au CNRS, Institut de Chimie Moléculaire d'Orsay, Université Paris-Sud, 91405 Orsay, France

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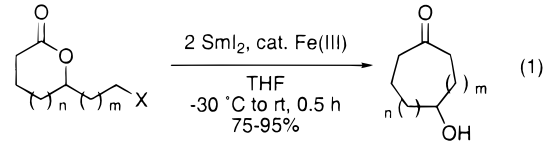
Samarium(II) iodide promotes an efficient one-pot annulation reaction between ω-iodo esters and 2-(ω-chloroalkyl)cycloalkanones. An initial intermolecular carbonyl addition reaction between the iodo ester and the ketone generates a lactone intermediate. The lactone undergoes a subsequent nucleophilic acyl substitution reaction with an organosamarium derived from the chloride. Nickel(II) iodide is an efficient catalyst for the first step of the process, and light is utilized to promote the second step. Seven-, eight-, and nine-membered rings can be accessed by this sequential dianionic process. This annulative approach to carbocycles is complementary to previously reported procedures.

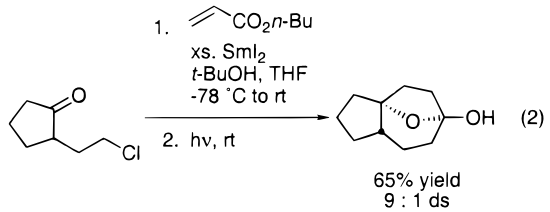
Introduction

Since the first publication on the use of samarium(II) iodide (SmI_2) in organic synthesis,[1] literally hundreds of reports have appeared on the use of this reagent in selective organic synthesis.[2] Although many of the early investigations focused on single transformations, it subsequently became evident that SmI_2 was an ideal reductive coupling agent for sequential processes as well.[3] In addition to its ability to promote a wide array of useful organic reactions (both radical and anionic processes), one of the unique advantages one has in utilizing SmI_2 is the ability to manipulate its reactivity through solvent effects,[4] by the addition of catalysts,[1,5] and even through irradiation of reaction mixtures.[6] This feature greatly facilitates the sequencing of reactions because the reductant can be selectively tuned for each individual step of a multistep process.

Two reports emanating from our laboratories have taken advantage of the singular characteristics of SmI_2 to provide annulative routes to medium-sized carbocycles. Both of these investigations had their genesis in the development of a SmI_2-promoted intramolecular nucleophilic acyl substitution reaction, which provided access to medium-ring compounds via a one-step ring expansion (eq 1).[7] This strategy was employed as one component of more efficient, two-step domino annulations. In one of these sequential processes, (ω-chloroalkyl) ketones were coupled with α,β-unsaturated esters to provide a one-pot synthesis of six- through eight-membered hydroxycycloalkanones (eq 2).[8] An intermolecular ketyl−olefin coupling reaction, generating a lactone, was followed by a nucleophilic acyl substitution reaction to complete the annulation process. An important feature of this transformation was the utilization of light to activate the SmI_2 in the last stage of the two-step process.[6] Consequently, the rapid ketyl−olefin coupling could be carried out selectively, with light facilitating reduction of the chloride to an organosamarium species, thereby permitting the final carbon−carbon bond-forming event. Formation of a lactone is a key step in bringing these domino processes to a successful conclusion, because they provide a rigid template upon which the nucleophilic acyl substitution reaction can be accomplished through five-, six-, or even seven-membered transition structures.[7,9]



(1)



(2)

65% yield
9 : 1 ds

In the second annulative process developed, α,ω-chloroiodoalkanes reacted with keto esters in the presence of SmI_2 to afford seven- through nine-membered

(1) Girard, P.; Namy, J.-L.; Kagan, H. B. *J. Am. Chem. Soc.* **1980**, *102*, 2693.

(2) (a) Soderquist, J. A. *Aldrichimica Acta* **1991**, *24*, 15. (b) Molander, G. A. *Chem. Rev.* **1992**, *92*, 29. (c) Sasaki, M.; Collin, J.; Kagan, K. B. *New J. Chem.* **1992**, *16*, 89. (d) Molander, G. A. *Org. React.* **1994**, *46*, 211.

(3) (a) Molander, G. A.; Harris, C. R. *Chem. Rev.* **1996**, *96*, 307. (b) Molander, G. A.; Harris, C. R. *Tetrahedron* **1998**, *54*, 3321.

(4) (a) Inanaga, J.; Ishikawa, M.; Yamaguchi, M. *Chem. Lett.* **1987**, 1485. (b) Ruder, S. M. *Tetrahedron Lett.* **1992**, *33*, 2621. (c) Hasegawa, E.; Curran, D. P. *J. Org. Chem.* **1993**, *58*, 5008. (d) Namy, J.-L.; Colombo, M.; Kagan, H. B. *Tetrahedron Lett.* **1994**, *35*, 1723. (e) Cabri, W.; Candiani, I.; Colombo, M.; Franzoi, L.; Bedeschi, A. *Tetrahedron Lett.* **1995**, *36*, 949. (f) Hamann, B.; Namy, J.-L.; Kagan, H. B. *Tetrahedron* **1996**, *45*, 14225.

(5) (a) Machrouhi, F.; Hamann, B.; Namy, J.-L.; Kagan, H. B. *Synlett* **1996**, 633. (b) Molander, G. A.; McKie, J. A. *J. Org. Chem.* **1991**, *57*, 3132.

(6) (a) Skene, W. G.; Scaiano, J. C.; Cozens, F. L. *J. Org. Chem.* **1996**, *61*, 7918. (b) Ogawa, A.; Sumino, Y.; Nanke, T.; Ohya, S.; Sonoda, N.; Hirao, T. *J. Am. Chem. Soc.* **1997**, *119*, 2745. (c) Ogawa, A.; Ohya, S.; Hirao, T. *Chem. Lett.* **1997**, 275.

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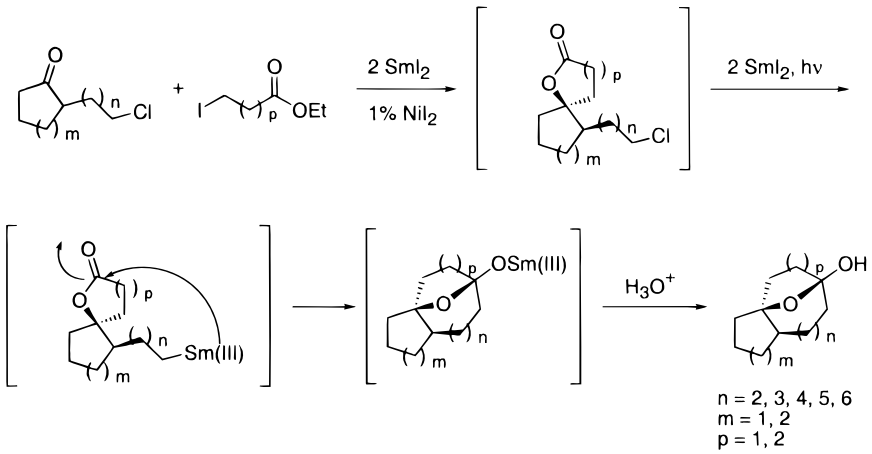
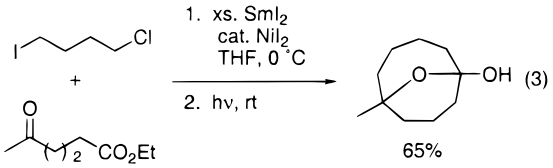
Scheme 1



carbocycles (eq 3). The dihaloalkanes serve as dianionic synthons in the overall transformation, reacting sequentially with the dielectrophilic dicarbonyl substrates. Nickel(II) iodide was utilized as a catalyst in this reaction[5a] to promote the selective intermolecular Barbier-type reaction between the iodide and the ketone of the keto ester, generating a lactone. The second step of the two-step transformation, an intramolecular nucleophilic acyl substitution reaction, was again promoted by light.[6] The combination of the NiI_2 catalyst and light not only permits high selectivity in the two-step transformation, but also alleviates the necessity to employ toxic HMPA as a promoter to enhance the reductive capability of SmI_2.[4a]



A third complementary annulation process was envisioned that would provide access to similar carbocycles from a different set of starting materials. Thus, it seemed that ω-iodo esters and 2-(ω-chloroalkyl)cycloalkanones would react in the presence of SmI_2 to provide medium-membered hydroxycycloalkanones (Scheme 1). Selectivity was assured in the generation of an organosamarium species by reduction of the iodide in the presence of the chloride.[1,2d,10] Utilizing NiI_2 as a catalyst,[5a] an intermolecular Barbier reaction was expected between the iodide of the ester and the ketone of the cycloalkanone, forming the requisite lactone. The ketone was anticipated to react selectively with the organometallic in preference to the ester,[1,9,11] even though the latter would be an intramolecular process. Based upon substantial precedent, high diastereoselectivity in this reaction was virtually guaranteed.[9] Although chlorides are only reluctantly reduced to the corresponding organosamariums in THF,[1,2d,10] it has been demonstrated that visible light activates SmI_2,[6,8,9] facilitating this process. Thus, the lactone would undergo a subsequent nucleophilic acyl substitution reaction with an organosamarium derived from the chloride, providing the desired product.[7−9] Herein we describe our successful efforts to develop this process as a useful annulation strategy for the synthesis of seven-, eight-, and nine-membered hydroxycycloalkanones.

Results and Discussion

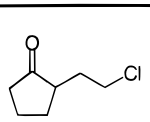
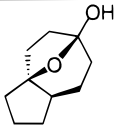
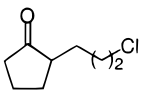
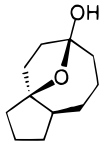
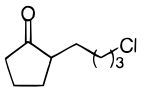
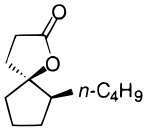
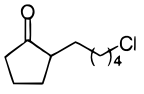
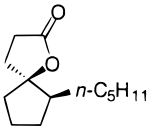
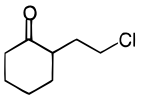
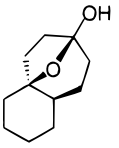
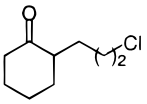
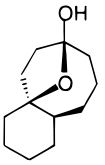
To explore the scope and limitation of the proposed annulation, ethyl 3-iodopropanoate was chosen as the first dipolar synthon, with several 2-(ω-chloroalkyl)-cycloalkanones utilized as partners for the annulation. Six different 2-(ω-chloroalkyl)cycloalkanones were synthesized and, employing the protocol outlined above, paired with the halo ester in the annulation process (Table 1). In the cyclopentanone series, those 2-(ω-chloroalkyl)cycloalkanones that would allow conversion through a six- or seven-membered transition structure for the nucleophilic acyl substitution reaction (substrates **2** and **3**, entries 1 and 2, Table 1) provided good yields of the desired products. As expected, the higher homologues (**4** and **5**) were not able to cyclize for entropic reasons. In these cases, the products isolated were the lactones derived from an intermolecular Barbier reaction followed by simple reduction of the chloride. Appropriately functionalized cyclohexanones (entries 5 and 6, Table 1) reacted analogously to the cyclopentanones. Thus reasonable yields of the seven- and eight-membered annulated products were achieved.

The stereochemistry of the annulation products is determined in the initial carbonyl addition reaction. Stereochemical assignments in the current systems are based upon previous annulation reactions on analogous substrates in which the stereochemically determinant step is the same (i.e., SmI_2-promoted intermolecular carbonyl addition to an α-substituted cycloalkanone).[9] Single-crystal X-ray structure determinations were utilized to assign stereochemistry in the previous effort.

Utilizing 2-(ω-chloroalkyl)cycloalkanones known to function well in the annulation process, three reactions were performed employing ethyl 4-iodobutanoate as the dipolar synthon (Table 2). Whereas the intermediate for the iodopropanoate is a readily formed butyrolactone, use of the iodobutanoate required formation of a valerolac-

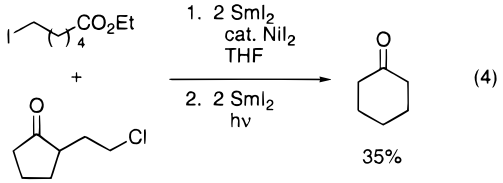
(7) (a) Molander, G. A.; McKie, J. A. *J. Org. Chem.* **1993**, *58*, 7216. (b) Molander, G. A.; Harris, C. R. *J. Am. Chem. Soc.* **1995**, *117*, 3705. (c) Molander, G. A.; Harris, C. R. *J. Org. Chem.* **1998**, *63*, 4374.
(8) Molander, G. A.; Sono, M. *Tetrahedron* **1998**, *54*, 9289.
(9) Molander, G. A.; Alonso-Alija, C. *J. Org. Chem.* **1998**, *63*, 4366.
(10) Ogawa, A.; Nanke, T.; Takami, N.; Sumino, Y.; Ryu, I.; Sonoda, N. *Chem. Lett.* **1994**, 379.
(11) (a) Molander, G. A.; Etter, J. B.; Zinke, P. W. *J. Am. Chem. Soc.* **1987** *109*, 453. (b) Otsuba, K.; Kawamura, K.; Inanaga, J.; Yamaguchi, M. *Chem. Lett.* **1987**, 1487. (c) Csuk, R.; Hu, Z.; Abdou, M.; Kratky, C. *Tetrahedron* **1991**, *47*, 7037.

Table 1. Sequential SmI_2-Promoted Carbonyl Addition/ Nucleophilic Acyl Substitution Reactions Between Ethyl 3-Iodopropanoate (1) and Chloroketone Substrates

entry	substrate	product	% isoltd yield
1	 **2**	 **11**	71
2	 **3**	 **12**	62
3	 **4**	 **13**	68
4	 **5**	 **14**	81
5	 **6**	 **15**	75
6	 **7**	 **16**	43

tone. Rapid formation of a lactone was assumed to be crucial for the success of the process, as unfavorable entropic factors were anticipated to prevent intramolecular nucleophilic acyl substitution on the ethyl ester. Because the organosamariums generated would have a limited lifetime in the presence of the various electrophiles present in the reaction mixture, the overall success of the endeavor seemed incumbent on the ability of the substrates to rapidly form the required lactone. In the event, all of the substrates led to quite good yields of the annulated products. Even a nine-membered ring could be accessed (entry 2, Table 2), which again required transformation through a seven-membered transition structure. Although we have no explanation for the success in this reaction manifold, we note that similar results had been achieved in our earlier study.[9]

The ethyl 4-iodobutanoate synthon represents the practical limit of halo ester substrates that can be utilized in this annulation. Attempts at utilizing ethyl 6-iodohexanoate, for example, led to none of annulation product (eq 4). The lack of annulation product in this case has been ascribed to intramolecular nucleophilic acyl substitution of the iodo ester itself, providing cyclohexanone and byproducts resulting therefrom.



(4)

Conclusions

A SmI_2-promoted annulation process has been developed that is complementary to two previously reported procedures for the construction of medium-membered carbocycles. Substrates for this reaction are readily available ω-iodo esters and 2-(ω-chloroalkyl)cycloalkanones. The reaction brings these two dipolar synthons together in an intermolecular Barbier-type process, which results in the formation of lactone intermediates. A subsequent intramolecular nucleophilic acyl substitution reaction completes the process. Seven-, eight-, and even nine-membered rings constituting a variety of substitution patterns can thus be readily accessed in high yields and with excellent diastereoselectivities. The difficulties normally associated with the construction of medium-sized rings[12] makes this a valuable approach to these structural motifs.

Experimental Section

Reagents. Tetrahydrofuran (THF) was distilled immediately prior to use from benzophenone ketyl under Ar. Samarium metal was stored under an inert atmosphere. Nickel(II) iodide (NiI_2) and iodine were purchased from Aldrich Chemicals. Hexamethylphosphoramide (HMPA) was purchased from Aldrich Chemicals and was distilled from CaH_2 at 10^{-2} mmHg and stored over 4 Å molecular sieves under Ar. Standard benchtop techniques were employed for handling air-sensitive reagents,[13] and all of the reactions were carried out under Ar.

Preparation of the SmI_2 Solution. Samarium metal (519 mg, 3 mmol) was added under a flow of argon to an oven-dried, two-necked Schlenk flask containing a magnetic stirring bar and a septum inlet. Iodine (761 mg, 3 mmol) was added to a vigorously stirred suspension of samarium metal in THF (30 mL). The mixture was stirred vigorously for 2 h at room temperature. The resultant deep blue-green solution was used directly to effect the sequential reactions.

General Procedure for the Synthesis of Hydroxy Cycloalkanones. To the SmI_2 (3 mmol) in THF at room temperature was added NiI_2 (1 mol %). After stirring for 5 min, a solution of the halo ketone (0.5 mmol) and iodo ester (0.5 mmol) in 5 mL of THF was added in a Barbier-type procedure. The mixture was stirred for 90 min. After the starting material was consumed and the intermediate lactone was formed (TLC analysis), the reaction mixture was irradiated with visible light (250 W krypton lamp) for 8 h, while the temperature was maintained below 25 °C. The resultant mixture was quenched with a saturated aqueous solution of Rochelle's salt.[14] The mixture was extracted several times with diethyl ether, and

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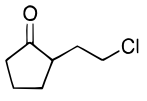
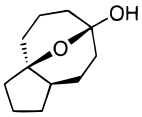
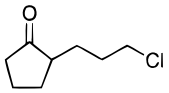
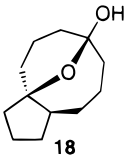
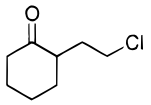
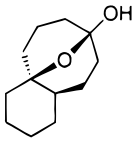
(13) Brown, H. C. *Organic Syntheses via Boranes*; Wiley: New York, 1975.

(14) Schwaebe, M.; Little, R. D. *J. Org. Chem.* **1996**, *61*, 3240.

Table 2. Sequential SmI_2-Promoted Carbonyl Addition/Nucleophilic Acyl Substitution Between Ethyl 4-Iodobutanoate (8) and Chloroketone Substrates

entry	substrate	product	% isolated yield
1	 **2**	 **17**	71
2	 **3**	 **18**	80
3	 **6**	 **19**	67

the organic extracts were washed with brine and dried over anhydrous magnesium sulfate. The products were purifed by silica gel flash chromatography.

1-Hydroxy-11-oxatricyclo[6.2.1.0^{4,8}]undecane (11)[8] was prepared from **2** (81.25 mg, 0.5 mmol) and ethyl 3-iodopropanoate (**1**, 114 mg, 0.5 mmol) according to the general procedure described above to afford, after flash chromatography (30% ethyl acetate:hexanes), **11** (59.7 mg, 71% yield) as a single diastereomer as determined by GC: ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.87 (bs, 1H), 1.98−2.14 (m, 2H), 1.43−1.94 (m, 13H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 106.4, 91.9, 43.0, 34.8, 33.4, 32.6, 30.9, 28.1, 21.6, 21.1; IR (neat) 3394, 1735, 1097 cm^{-1}; LRMS (EI$^+$) *m*/*z* 169 (33), 81 (100), 40 (81). Anal. Calcd for $C_{10}H_{16}O_2$: C, 71.39; H, 9.58. Found: C, 71.27; H, 9.58.

1-Hydroxy-12-oxatricyclo[7.2.1.0^{5,9}]dodecane (12)[8] was prepared from **3** (88.25 mg, 0.5 mmol) and ethyl 3-iodopropanoate (**1**, 114 mg, 0.5 mmol) according to the general procedure described above to afford, after flash chromatography (30% ethyl acetate: hexanes), **12** (56.5 mg, 62% yield) as a single diastereomer as determined by GC: ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.52 (bs, 1H), 1.27−2.22 (m, 17H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 107.6, 91.2, 51.4, 40.6, 38.9, 35.4, 34.0, 31.3, 24.8, 24.2; IR (neat) 3390, 1458, 1071 cm^{-1}; LRMS (EI$^+$) *m*/*z* 182 (59), 94 (100), 43 (58). Anal. Calcd for $C_{11}H_{18}O_2$: C, 72.48; H, 9.96. Found: C, 72.68; H, 9.96.

6-Butyl-1-oxatricyclo[4.4]nonan-2-one (13) was prepared from **4** (95.25 mg, 0.5 mmol) and ethyl 3-iodopropanoate (**1**, 114 mg, 0.5 mmol) according to the general procedure described above to afford, after flash chromatography (25% ethyl acetate:hexanes), **13** (66.2 mg, 68% yield) as a single diastereomer as determined by GC: ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.58−2.68 (m, 2H), 1.15−2.30 (m, 15H), 0.95 (t, J = 6.9 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 171.4, 95.4, 49.2, 39.8, 30.4, 29.8, 29.7, 27.7, 22.9, 21.2, 14.1; IR (neat) 1770, 1163, 1017 cm^{-1}; LRMS (EI$^+$) *m*/*z* 196 (43), 110 (100), 43 (39). Anal. Calcd for $C_{12}H_{20}O_2$: C, 73.41; H, 10.28. Found: C, 73.39; H, 10.25.

6-Pentyl-1-oxatricyclo[4.4]nonan-2-one (14) was prepared from **5** (102.25 mg, 0.5 mmol) and ethyl 3-iodopropanoate (**1**, 114 mg, 0.5 mmol) according to the general procedure described above to afford, after flash chromatography (25% ethyl acetate:hexanes), **14** (85.6 mg, 81% yield) as a single diastereomer as determined by GC: ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.50−2.64 (m, 2H), 1.18−2.25 (m, 17H), 0.90 (t, J = 6.9 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 177.2, 95.8, 49.1, 39.4, 32.1, 29.8, 29.7, 29.4, 28.2, 28.0, 22.5, 21.3, 14.1; IR (neat) 1765, 1664, 1013 cm^{-1}; LRMS (EI$^+$) *m*/*z* 210 (52), 110 (100), 43 (25). Anal. Calcd for $C_{13}H_{22}O_2$: C, 74.23; H, 10.55. Found: C, 74.25; H, 10.70.

1-Hydroxy-12-oxatricyclo[7.2.1.0^{4,9}]dodecane (15)[8] was prepared from **6** (80.25 mg, 0.5 mmol) and ethyl 3-iodopropanoate (**1**, 114 mg, 0.5 mmol) according to the general procedure described above to afford, after flash chromatography (30% ethyl acetate:hexanes), **15** (69.25 mg, 75% yield) as a single diastereomer as determined by GC: mp 104 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.85 (bs, 1H), 1.40−2.07 (m, 11H), 1.12−1.35 (m, 4H), 0.90−1.05 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 104.3, 83.5, 42.6, 37.5, 36.7, 35.5, 29.9, 29.5, 26.7, 25.7, 23.4; IR (neat) 3372, 1435, 1332, 1116, 1015 cm^{-1}; LRMS (EI$^+$) *m*/*z* 182 (81), 136 (54), 134 (100), 43 (30). Anal. Calcd for $C_{11}H_{18}O_2$: C, 72.48; H, 9.96. Found: C, 72.68; H, 9.96.

1-Hydroxy-13-oxatricyclo[8.2.1.0^{5,10}]tridecane (16)[8] was prepared from **7** (87.03 mg, 0.5 mmol) and ethyl 3-iodopropanoate (**1**, 114 mg, 0.5 mmol) according to the general procedure described above to afford, after flash chromatography (15% ethyl acetate:hexanes), **16** (42.10 mg, 43% yield) as a single diastereomer as determined by GC: mp 72 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 3.08 (bs, 1H), 1.13−2.20 (m, 19H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 107.8, 84.2, 44.7, 42.4, 40.4, 40.3, 36.2, 30.5, 28.7, 25.8, 23.2, 18.9; IR (neat) 3390, 1453, 1335, 1115, 1011 cm^{-1}; LRMS (EI$^+$) *m*/*z* 197 (76), 196 (64), 108 (100), 43 (37). Anal. Calcd for $C_{12}H_{20}O_2$: C, 73.41; H, 10.28. Found: C, 73.53; H, 10.37.

1-Hydroxy-12-oxatricyclo[6.3.1.0^{4,8}]dodecane (17) was prepared from **2** (81.25 mg, 0.5 mmol) and ethyl 4-iodobutanoate (**8**, 121 mg, 0.5 mmol) according to the general procedure described above to afford, after flash chromatography (30% ethyl acetate:hexanes), **17** (65.54 mg, 71% yield) as a single diastereomer as determined by GC: ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.47 (bs, 1H), 1.98−1.82 (m, 2H), 1.80−1.30 (m, 15H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 96.4, 84.2, 42.1, 40.4, 36.7, 33.7, 33.4, 32.8, 32.0, 24.5, 22.5, 20.3; IR (neat) 3390, 1451, 1335, 1116 cm^{-1}; LRMS (EI$^+$) *m*/*z* 182 (30), 96 (57), 94 (100), 43 (43). Anal. Calcd for $C_{11}H_{18}O_2$: C, 72.49; H, 9.95. Found: C, 72.28; H, 10.07.

13-Oxatricyclo[7.3.1.0^{1,5}]tridecan-9-ol (18) was prepared from **3** (88.25 mg, 0.5 mmol) and ethyl 4-iodobutanoate (**8**, 121 mg, 0.5 mmol) according to the general procedure described above to afford, after flash chromatography (15% ethyl acetate: hexanes), **18** (78.33 mg, 80% yield) as a single diastereomer as determined by GC: mp 76 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.97 (bs, 1H), 1.28−1.15 (m, 19H); ^{13}C NMR (75 MHz, $CDCl_3$)

δ 98.7, 85.8, 45.7, 43.2, 40.8, 40.5, 37.0, 31.1, 30.0, 27.3, 23.5, 19.2; IR (neat) 3390, 1440, 1312, 1116 cm^{-1}; LRMS (EI^+) *m*/*z* 196 (89), 108 (100), 43 (58). Anal. Calcd for $C_{12}H_{20}O_2$: C, 73.41; H, 10.28. Found: C, 73.27; H, 10.15.

1-Hydroxy-13-oxatricyclo[7.3.1.0^{4,9}]tridecane (19) was prepared from **6** (80.25 mg, 0.5 mmol) and ethyl 4-iodobutanoate (**8**, 121 mg, 0.5 mmol) according to the general procedure described above to afford, after flash chromatography (15% ethyl acetate:hexanes), **19** (66.0 mg, 67% yield) as a single diastereomer as determined by GC: mp 117 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.65 (bs, 1H), 2.37−2.33 (m, 1H), 2.13−2.10 (m, 1H), 1.87−1.85 (m, 1H), 1.81−1.59 (m, 8H), 1.45−1.18 (m, 7H), 1.15−0.99 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 100.9, 75.7, 43.5, 37.5, 36.2, 36.0, 32.6, 31.7, 28.5, 27.5, 25.8, 21.3, 21.2; IR (neat) 3398, 1448, 1312, 1107, 1010 cm^{-1}; LRMS (EI^+) *m*/*z* 196 (43), 167 (64), 108 (100), 81 (72), 43 (83). Anal. Calcd for $C_{12}H_{20}O_2$: C, 73.43; H, 10.27. Found: C, 73.52; H, 10.23.

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Supporting Information Available: Complete experimental details for the synthesis of all of the substrates used in this research. This material is available free of charge via the Internet at http://pubs.acs.org.

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