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Synthesis of substituted cyclopentanones from 2-oxabicyclo[3.3.0]oct-6-en-3-one

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Dedicated to Academician Ülo Lille, Professor Emeritus at Tallinn University of Technology, on his 75th birthday

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Abstract. Synthesis of regioisomeric cyclopentanones 3-alkyloxy-2-oxabicyclo[3.3.0]octan-6-one (overall yield up to 34%) and 3-alkyloxy-2-oxabicyclo[3.3.0]octan-7-one (overall yield up to 18%) in four steps, starting from enantiomerically pure (–)-(1*S*,5*R*)-2-oxabicyclo[3.3.0]oct-6-en-3-one is described.

Key words: hydroboration, oxidation, bicyclo[3.3.0]octanones, 9,11-secosterol D-ring.

INTRODUCTION

Substituted cyclopentanes and cyclopentanones are frequently essential parts, starting materials, or intermediates for a number of bioactive compounds (for some recent examples see [1–3]). We study the total chemical synthesis of anti-cancer 9,11-secosterol A (bioactivity: [4]; synthesis: [5–9]). This molecule bears a 1,2,3-substituted cyclopentane fragment as D-ring (Scheme 1).

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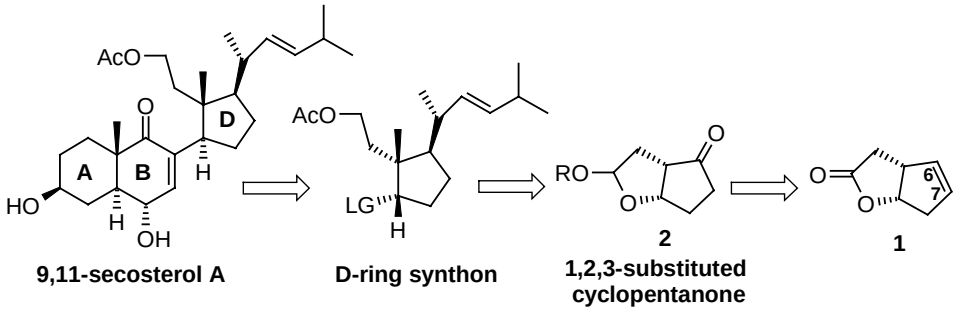


Scheme 1. Retrosynthetic approach to the D-ring of secosterol A.

Chiral 1,2,3-substituted cyclopentanone **2** has an appropriate substitution pattern for the synthesis of 9,11-secosterol D-ring synthon. One possibility of preparing compound **2** is to start from 2-oxabicyclo[3.3.0]oct-6-en-3-one (Grieco lactone) **1** [10], which is a commercially readily available product, in enantiomerically pure form and in multigram scale [11–14]. The derivatives of lactone **1** have been used for the synthesis of a wide variety of natural products (e.g. [15–17]), including some medical preparations [18].

Functionalization of the double bond of lactone **1** could be realized at two positions, either at C6 leading to compound **2** or at C7 leading to regioisomeric compound **3** (Fig. 1).

Different methods exist for the synthesis of these regioisomeric ketones.

The 6-substituted compound **2** (R=Me, R1=H) has been used for the synthesis of pheromone methyl epijasmonate from lactone **1** via epoxidation [19]. Additionally, synthesis of 2-oxabicyclo[3.3.0]octan-3,6-dione **2** (RO,R1=O) was reported along with an approach to sarkomycin A [20]. However, in spite of high enantioselectivity, the yield of the applied microbial Baeyer–Villiger reaction was low.

The regioisomeric 7-substituted ketone **3** (R=Et, R1=H) is a key intermediate for the synthesis of antimicrobial substance halimedatrial [21], which is prepared starting from (*S*)-4-hydroxy-2-cyclopentenone [22]. Also, the synthesis of similarly substituted 7-hydroxy-2-oxabicyclo[3.3.0]octan-3-one was reported [23] starting from bicyclo[2.2.1]hept-5-en-2-one. However, attempts to oxidize 7-hydroxy-2-oxabicyclo[3.3.0]octan-3-one directly to ketone **3** (RO,R1=O) failed.

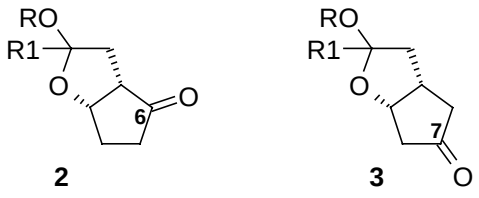
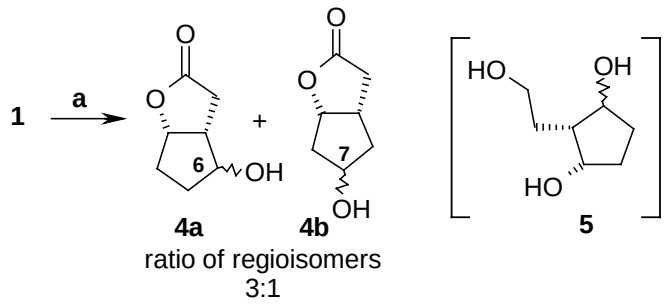


Fig. 1. Regioisomeric 6- and 7-substituted cyclopentanones.

RESULTS AND DISCUSSION

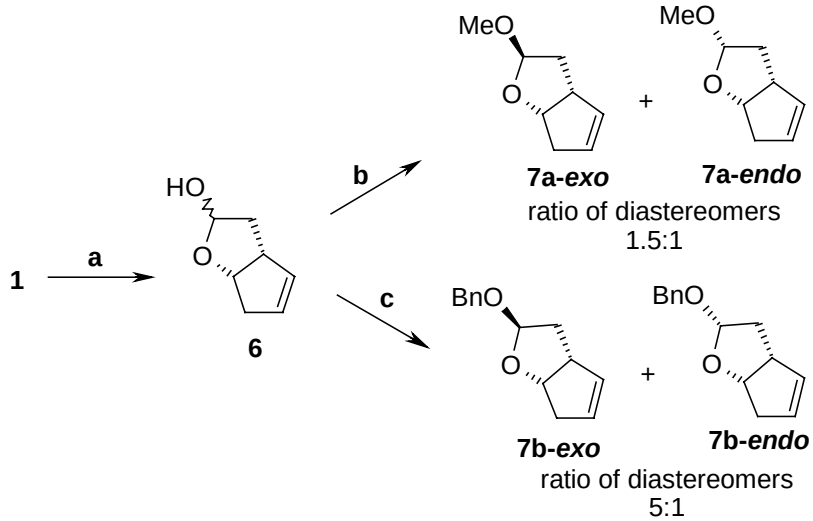
In the light of the information referred to above we made an attempt to obtain diketones **2** and **3** directly from lactone **1** by hydroboration (Scheme 2).



Scheme 2. a: $BH_3{\cdot}SMe_2$, THF, 0 °C followed by H_2O_2, NaOH, and then HCl. Yield **4**: 58%.

The applied hydroboration procedure leads to a chromatographically inseparable mixture of hydroxylated diasereo- and regioisomers **4a** and **4b**, in a ratio of 3 : 1 (determined by NMR). Additionally, the formation of a more polar triol **5** (7%) was detected. The formation of this side product pointed to sensitivity of the lactone carbonyl group towards borane reagent. Moreover, during the oxidative work-up procedure in basic conditions the lactone ring may open and, together with the following relactonization, there is a risk of racemization of **(1*S*, 5*R*, 6*R*)-4a** (the enantiopurity of the other diastereomer **(1*S*, 5*R*, 6*S*)-4a** is not affected).

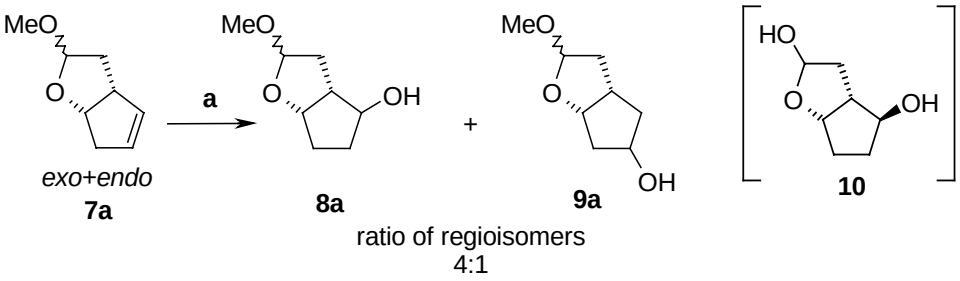
Therefore, lactone was converted to lactol **6** by reducing with diisobutylaluminium hydride and protected as alkylacetals (Scheme 3).



Scheme 3. a: DIBALH, toluene, −78 °C, yield 94%; **b:** MeOH, *p*-TsOH, yield 75%; **c:** BnOH, *p*-TsOH, yield 93%.

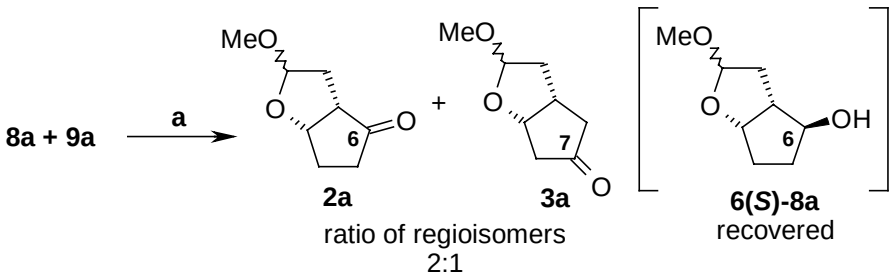
Acetalization of lactol **6** in methanol gave volatile bicyclic methylacetals **7a** as a mixture of *exo*- and *endo*-diastereomers, in a ratio of 1.5 : 1. Additionally, in order to obtain non-volatile and UV-visible compounds, acetalization of lactol **6** with benzylalcohol was carried out. This reaction gave *exo*- and *endo*-benzyllactols **7b** in a ratio of 5 : 1, respectively. Benzyllactols **7b** were separated by chromatography on silica gel.

Next, the hydroboration-oxidation sequence to protected bicycles **7a** and **7b** was performed (Scheme 4).



Scheme 4. a: $BH_3{\cdot}SMe_2$, THF, 0 °C, followed by H_2O_2, NaOH, yield 43%.

The hydroboration of **7a** (diastereomeric mixture) resulted in 6- and 7-hydroxy methylacetals **8a** and **9a**, as a sum of 8 regio- and diastereoisomers (ratio of **8a** and **9a** was 4 : 1), and also 4% of the corresponding 6(*S*)-hydroxyllactol **10**. The last compound is formed due to the cleavage of the protecting methoxy group during the hydroboration procedure. The mixture of 6- and 7-hydroxy methylacetals **8a** and **9a** was oxidized with pyridinium dichlorochromate into 6- and 7-ketones **2a** and **3a**, in a ratio of 2 : 1. Surprisingly, after oxidation 17% of 6(*S*)-hydroxy compound **6(*S*)-8a** was recovered, pointing to the preferable oxidation of **6(*R*)** diastereomer of **8a** (Scheme 5).

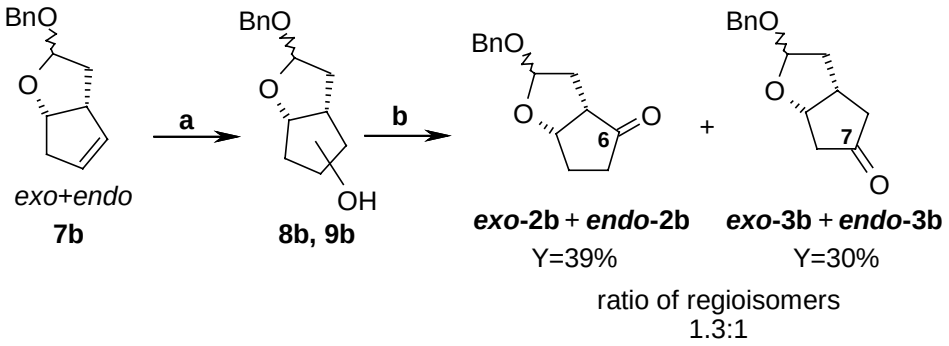


Scheme 5. a: PDC, **2a**+**3a**: yield 24%; **6(*S*)-8a**: yield 17%.

Unfortunately, the regioisomers **2a** and **3a** were chromatographically inseparable. The reaction yields were quite low due to the instability of the methylacetal protecting group towards borane reagent and the problems with handling volatile intermediate compounds.

The benzylprotected lactols **7b** were also subjected to hydroxylation, followed by oxidation of the derived hydroxyl group.

First, oxidative hydroboration of separated *exo*-benzyllactol ***exo*-7b**, with the hydroborane tetrahydrofurane complex used, afforded a mixture of regio- and diasereoisomeric bicyclic alcohols ***exo*-8b** + ***exo*-9b**. These alcohols were oxidized further as a crude mixture with Swern reagent to afford 6-oxo ***exo*-2b** and 7-oxo ***exo*-3b**, which were separately isolated in a ratio of 2 : 1 (overall yield for two steps 55%) (Scheme 6).



Scheme 6. a: 9-BBN, THF, followed by H_2O_2, NaOH, yield 70%; **b:** Swern oxidation, yield 69% (***exo*-2b**: 29%, ***endo*-2b**: 10%, ***exo*-3b**: 24%, ***endo*-3b**: 6%).

Subsequently, oxidative hydroboration of the mixture of *exo*- and *endo*-benzylacetals **7b** with sterically more hindered hydroboration reagent 9-borabicyclo[3.3.1]nonane was performed. This reaction afforded, after subsequent Swern oxidation, four isomeric ketones: ***exo*-2b**, ***endo*-2b**, ***exo*-3b**, and ***endo*-3b**. All four ketones were chromatographically separable and the ratio of regioisomers was 1.3 : 1.

CONCLUSIONS

We may conclude that the best regioselectivity for oxygen insertion into Grieco lactone **1** was achieved by hydroboration of methylacetals **7a** (ratio of regioisomers 4 : 1 in favour to C6 substitution). The use of the bulkier protecting group (Bn) lowered the ratio of regioisomers to 2 : 1 and, additionally, use of bulkier hydroboration reagent 9-BBN lowered the ratio even more, to 1.3 : 1. As a result, using the above-described method, it is possible to synthesize in four steps 3-benzyloxy-2-oxabicyclo[3.3.0]octan-6-ones **2b** with an overall yield of 34% (from **1**, with BH_3·THF) and 3-benzyloxy-2-oxabicyclo[3.3.0]octan-7-ones **3b** with an overall yield of 18% (from **1**, with 9-BBN). These compounds are useful intermediates for secosterol D-ring and for many other valuable compounds.

EXPERIMENTAL

All reactions sensitive to moisture or oxygen were carried out under argon atmosphere and in oven-dried glassware. Commercial reagents were used as received. All solvents were distilled. THF was distilled over Na/benzophenone ketyl prior to use. Full assignment of ^{13}C- and ^{1}H-NMR chemical shifts is based on the 1D and 2D FT NMR spectra on a Bruker AMX 500 instrument. Solvent peaks in ^{13}C- and ^{1}H-NMR were used as chemical shift references. The mass spectra were recorded on a Hitachi M80B spectrometer using electron ionization (EI) at 70 eV or chemical ionization (CI) with isobutane. IR spectra were recorded on a Perkin-Elmer Spectrum BX FT-IR infrared spectrophotometer. Optical rotations were obtained using a Krüss Optronic GmbH Polarimeter P 3002.

6-Hydroxy-2-oxabicyclo[3.3.0]octan-3-one and 7-hydroxy-2-oxabicyclo[3.3.0]octan-3-one (4)

To a solution of 199 mg (1.61 mmol, 1 eq) of (–)-Grieco lactone **1** in 4.5 mL of dry THF under argon atmosphere at 0 °C the solution of 101.5 μL (1.07 mmol, 0.67 eq) of $BH_3{\cdot}SMe_2$ in 1 mL THF was dropwise added. The mixture was stirred for 6 h, then 0.5 mL of 3 M NaOH and 0.5 mL of 30% H_2O_2 were added and stirred additionally for 1 h. The mixture was acidified with 50% solution of HCl and then the saturated solution of Na_2SO_3 (prepared from 0.4 g of Na_2SO_3) was added. The mixture was neutralized with $NaHCO_3$ and dried over $MgSO_4$. Of the total 159 mg of crude product 106 mg was purified on silica gel and 62 mg (58%) of hydroxylated lactones **4**, as a mixture of diastereo- and regioisomers (according to NMR analysis, the ratio of the regioisomers was in favour of 6-hydroxylated lactone ~3 : 1), along with 8 mg (7%) reduced derivative **5** was isolated.

Major isomer of 4–6(*S*)-OH: ^{13}C NMR (125.7 MHz, $CDCl_3$), δ: 30.44, 31.89, 32.97, 47.12, 78.90, 85.60, 117.28.

^{1}H NMR (500 MHz, $CDCl_3$), δ: 1.78 (m, 2 H), 1.96 (m, 1 H), 2.17 (m, 1 H), 2.31 (d, 1 H), 2.83 (m, 1 H), 2.86 (m, 1 H), 4.12 (bs, 1 H), 5.12 (t, 1 H).

5: ^{13}C NMR (125.7 MHz, $CDCl_3$ + MeOD), δ: 26.56, 32.50 (2 C), 47.58 (2 C), 61.09, 74.81.

^{1}H NMR (500 MHz, $CDCl_3$ + MeOD), δ: 1.56 (m, 1 H), 1.78 (m, 2 H), 1.82 (m, 4 H), 3.64 (t, $J = 2 \times 6.2$ Hz, 2 H), 4.07 (bs, 2 H).

3-Benzyloxy-2-oxabicyclo[3.3.0]oct-6-ene (7b)

A solution of 302 mg (2.38 mmol) of lactol **6**, 269 μL (2.86 mmol) of benzyl-alcohol, and 2 mg of *p*-TsOH in 12 mL of dry toluene was refluxed in Dean-Stark apparatus for 2 h. The saturated solution of $NaHCO_3$ was added. The mixture was extracted with EtOAc and dried over $MgSO_4$. After solvent

evaporation and purification on silica gel, 480 mg (93%) of benzyllactols **7b** (as a mixture of *exo*- and *endo*-isomers, in a ratio of 5 : 1, respectively) were isolated. The diastereoisomers of **7b** were in the first attempt separated with flash chromatography (eluent 2–5% EtOAc in petroleum ether).

7b: MSCI: *m/z* 217(MH^+), 199, 717, 133, 109, 91.

***exo*-7b:** ^{13}C NMR (125.7 MHz, $CDCl_3$), δ: 38.13, 39.10, 48.54, 68.63, 81.12, 103.45, 127.51, 127.92 (×2), 127.93, 128.35 (×2), 133.35, 138.18.

^{1}H NMR (500 MHz, $CDCl_3$), δ: 1.85 (dt, J = 13.2/2 × 5.2 Hz, 1 H), 2.24 (m, 1 H), 2.52 (d, J = 18.2 Hz, 1 H), 2.65 (m, 1 H), 3.43 (m, 1 H), 4.49 (d, J = 11.8 Hz, 1 H), 4.75 (d, J = 11.8 Hz, 1 H), 4.82 (t, J = 2 × 6.3 Hz, 1 H), 5.25 (d, J = 5.3 Hz, 1 H), 5.62 (m, 1 H), 5.63 (m, 1 H), 7.28–7.38 (m, 5 H).

$[\alpha]_D$ = –122.8° (c 0.033, MeOH).

***endo*-7b:** ^{13}C NMR (125.7 MHz, $CDCl_3$), δ: 37.79, 41.72, 48.93, 68.73, 83.35, 103.66, 127.29, 127.67 (×2), 128.08, 128.24 (×2), 133.14, 138.44.

^{1}H NMR (500 MHz, $CDCl_3$), δ: 2.04 (d, J = 13.2 Hz, 1 H), 2.13 (m, 1 H), 2.55 (d, J = 17.5 Hz, 1 H), 2.69 (dd, J = 18.6/6.6 Hz, 1 H), 3.36 (t, J = 2 × 7 Hz, 1 H), 4.41 (d, J = 12.1 Hz, 1 H), 4.70 (d, J = 12.1 Hz, 1 H), 4.90 (t, J = 2 × 6.5 Hz, 1 H), 5.19 (d, J = 5.2 Hz, 1 H), 5.65–5.73 (m, 2 H), 7.25–7.34 (m, 5 H).

$[\alpha]_D$ = +33.1° (c 0.025, MeOH).

3-Methoxy-2-oxabicyclo[3.3.0]octan-6-ol (8a) and 3-methoxy-2-oxabicyclo[3.3.0]octan-7-ol (9a)

The synthesis was carried out analogously to the procedure of hydroboration of Grieco lactone **1**, only without addition of HCl. The obtained alcohols were extracted with EtOAc before drying over $MgSO_4$. From 0.99 mmol (138 mg) of methyllactol **7** 67 mg (43%) of the mixture of alcohols **8a** and **9a** (4 : 1, in favour of 6-OH), along with 6 mg (4%) hydroxylactols **3*R*,6*S*-10** and **3*S*,6*S*-10** were isolated.

Major isomer 3*S*,6*S*-8a: ^{13}C NMR (125.7 MHz, $CDCl_3$), δ: 32.05, 33.31, 37.76, 51.42, 54.2, 79.79, 85.84, 106.10.

^{1}H NMR (500 MHz, $CDCl_3$), δ: 1.65 (m, 1 H), 1.82 (m, 1 H), 1.89 (m, 1 H), 2.06 (m, 1 H), 2.20 (m, 1 H), 2.25 (m, 1 H), 2.53 (m, 1 H), 3.28 (s, 3 H), 4.24 (m, 1 H), 4.78 (t, 1 H), 4.96 (d, 1 H).

3*R*,6*S*-8a: ^{13}C NMR (125.7 MHz, $CDCl_3$), δ: 30.13, 31.91, 37.67, 50.60, 54.15, 78.94, 83.15, 105.64.

^{1}H NMR (500 MHz, $CDCl_3$), δ: 1.5 (m, 1 H), 1.65 (m, 1 H), 1.81 (m, 1 H), 1.83 (m, 1 H), 2.03 (m, 1 H), 2.20 (dd, 1 H), 2.73 (m, 1 H), 3.30 (s, 3 H), 4.06 (m, 1 H), 4.70 (t, 1 H), 4.99 (d, 1 H).

3*R*,6*S*-10: ^{13}C NMR (125.7 MHz, $CDCl_3$), δ: 30.18, 31.87, 38.23, 50.36, 78.83, 83.58, 99.25.

^{1}H NMR (500 MHz, $CDCl_3$), δ: 1.52 (m, 1 H), 1.65 (d, J = 13.2 Hz, 1 H), 1.83 (m, 2 H), 2.05 (m, 1 H), 2.22 (dd, J = 9.9/13.2 Hz, 1 H), 2.80 (q, J = 3 × 8.2 Hz,

1 H), 4.06 (d, J = 3.5 Hz, 1 H), 4.87 (t, J = 2 × 6.2 Hz, 1 H), 5.54 (d, J = 4.8 Hz, 1 H).
3*S*,6*S*-10: ^{13}C NMR (125.7 MHz, $CDCl_3$), δ: 32.07, 33.24, 38.40, 51.70, 79.71, 85.63, 99.55.
^{1}H NMR (500 MHz, $CDCl_3$), δ: 1.59 (m, 1 H), 1.85 (m, 1 H), 1.90 (m, 1 H), 2.10 (m, 1 H), 2.28 (m, 2 H), 2.54 (t, J = 2 × 8.5 Hz, 1 H), 4.28 (m, 1 H), 4.74 (t, J = 6.1 Hz, 1 H), 5.47 (bd, J = 2/4.8 Hz, 1 H).

3-Methoxy-2-oxabicyclo[3.3.0]octan-6-one (2a) and 3-methoxy-2-oxabicyclo[3.3.0]octan-7-one (3a)

To a suspension of 106.5 mg (0.28 mmol) of PDC in 1 mL of CH_2Cl_2 the solution of 30 mg (0.19 mmol) of the mixture of alcohols **8a** + **9a** was drop-wise added. The reaction mixture was stirred at RT for 2 days and filtered through celite. After solvent evaporation and purification on silica gel 7 mg (24%) of regioisomeric ketones **2a** + **3a**, in a ratio of 2 : 1 in favour of 6-oxo isomer **2a**, along with 5 mg (17%) of recovered alcohol **6(*S*)-8a** were isolated.
2a: ^{13}C NMR (125.7 MHz, $CDCl_3$), δ: 28.35, 35.21, 38.32, 49.97, 53.95, 82.71, 104.64, 220.38.
^{1}H NMR (500 MHz, $CDCl_3$), δ: 2.15 (m, 1 H), 2.16 (m, 1 H), 2.26 (m, 1 H), 2.28 (m, 1 H), 2.33, (bd, J = 13.3 Hz, 1 H), 2.56 (m, 1 H), 2.66 (bt, 1 H), 3.27 (s, 3 H), 4.91 (t, J = 2 × 5.9 Hz, 1 H), 4.98 (d, J = 4.8 Hz, 1 H).
3a: ^{13}C NMR (125.7 MHz, $CDCl_3$), δ: 37.85, 40.82, 43.94, 44.49, 54.99, 78.89, 105.81, 217.32.
^{1}H NMR (500 MHz, $CDCl_3$), δ: 2.02 (m, 1 H), 2.03 (m, 1 H), 2.25 (bd, J = 13.6 Hz, 1 H), 2.52 (bd, 2 H), 2.57 (d, J = 19.3 Hz, 1 H), 2.99 (m, 1 H), 3.38 (s, 3 H), 4.75 (t, J = 2 × 3.6 Hz, 1 H), 5.13 (dd, J = 2.1/5.3 Hz, 1 H).

3-Benzyloxy-2-oxabicyclo[3.3.0]octan-6-ol (*exo*-8b) and 3-benzyloxy-2-oxabicyclo[3.3.0]octan-7-ol (*exo*-9b)

To a 0.3 M solution of 96 mg (0.44 mmol) of *exo*-benzyllactol ***exo*-7b** in dry THF at 0 °C under argon atmosphere 296 μL (0.27 mmol) of BH_3 (1 M solution in THF) was added. The mixture was stirred at 0 °C for 3 h. Then 250 μL of 3 M NaOH solution was added, followed by 250 μL of 30% H_2O_2, and stirred for 15 min at RT. After extraction with Et_2O, drying over $MgSO_4$, and evaporation of solvents, 101 mg of crude alcohols was isolated.
GC-MS: *m/z* 234 (M^+), 212, 194, 167, 152, 105, 91, 77.
GC-MS: *m/z* 234 (M^+), 176, 170, 147, 127, 109, 91.

3-Benzyloxy-2-oxabicyclo[3.3.0]octan-6-one (*exo*-2b) and 3-benzyloxy-2-oxabicyclo[3.3.0]octan-7-one (*exo*-3b)

To a 0.2 M solution of 55 μL (0.63 mmol) of $(COCl)_2$ in dry CH_2Cl_2 a 3.3 M solution of 97 μL (1.37 mmol) of DMSO in CH_2Cl_2 was added at −78 °C and

stirred for 30 min. Then the 0.2 M solution of 101 mg (0.43 mmol) of crude alcohols of benzyllactols **8b** + **9b** in CH_2Cl_2 was added. The mixture was stirred for 1 h, and then 300 μL (2.15 mmol) of Et_3N was added and the reaction mixture was warmed to the RT. Next 10 mL of H_2O was added, extracted with CH_2Cl_2, and dried over $MgSO_4$. After purification on silica gel 39 mg (37%) of ketone ***exo*-2b** and 18 mg (18%) of ketone ***exo*-3b** were isolated.

***exo*-2b:** MS: *m/z* 232(M^+), 125, 107, 91.

^{13}C NMR (125.7 MHz, $CDCl_3$), δ: 25.50, 34.87, 37.39, 50.89, 69.14, 80.27, 103.85, 127.65, 127.84 (×2), 128.38 (×2), 137.70, 220.46.

^{1}H NMR (500 MHz, $CDCl_3$ + C_6D_6), δ: 2.13 (m, 1 H), 2.26–32.35 (m, 4 H), 2.43 (m, 1 H), 2.79 (m, 1 H), 4.48 (d, J = 11.8 Hz, 1 H), 4.74 (d, J = 11.8 Hz, 1 H), 4.86 (t, J = 2 × 4.8 Hz, 1 H), 5.25 (dd, J = 2/4.8 Hz, 1 H), 7.27–7.38 (m, 5 H).

***exo*-3b:** MS: *m/z* 232(M^+), 188, 141, 125, 108, 92, 91.

^{13}C NMR (125.7 MHz, $CDCl_3$), δ: 37.86, 40.83, 43.93, 44.43, 69.21, 79.02, 103, 86, 127.64, 127.86 (×2), 128.39 (×2), 137.82, 217.27.

^{1}H NMR (500 MHz, $CDCl_3$ + C_6D_6), δ: 2.00–2.06 (m, 2 H), 2.35 (m, 1 H), 2.54 (d, J = 3.9 Hz, 2 H), 2.58 (dd, J = 9.9/19.3 Hz, 1 H), 3.01 (m, 1 H), 4.50 (d, J = 12.0 Hz, 1 H), 4.76 (d, J = 12.0 Hz, 1 H), 4.81 (q, J = 5.9/2 × 3.7 Hz, 1 H), 5.34 (dd, J = 5.3/1.8 Hz, 1 H), 7.28–7.38 (m, 5 H).

3-Benzyloxy-2-oxabicyclo[3.3.0]octan-6-one (2b) and 3-benzyloxy-2-oxabicyclo[3.3.0]octan-7-one (3b)

To a 0.7 M solution of 261 mg (1.07 mmol) of 9-BBN in dry THF 154 mg (0.71 mmol) of benzyllactols **7b** was added under argon atmosphere. After stirring for 5 h at RT 286 mg (1.1 mmol) of 9-BBN was added and the mixture was stirred for 60 h. Then 0.5 mL of 3 M solution of NaOH was added at 0 °C, followed by 0.5 mL of 30% H_2O_2, and stirred for 20 min at RT. After extraction with Et_2O, drying over $MgSO_4$, evaporation of solvents, and purification on silica gel, 117 mg (70%) of alcohols of benzyllactols, as a mixture of regio- and diastereoisomers, was isolated. Then Swern oxidation of alcohols was performed as described above and 39 mg (29%) of ***exo*-2b**, 11 mg (10%) of ***endo*-2b**, 27 mg (24%) of ***exo*-3b**, and 7 mg (6%) of ***endo*-3b** were isolated.

***endo*-2b:** ^{13}C NMR (125.7 MHz, $CDCl_3$), δ: 28.43, 35.41, 38.34, 50.11, 68.14, 82.89, 102.64, 127.34 (×2), 127.47, 128.36 (×2), 137.58, 220.17.

^{1}H NMR (500 MHz, $CDCl_3$), δ: 2.2–2.3 (m, 4 H), 2.41 (d, J = 13.1 Hz, 1 H), 2.53 (m, 1 H), 2.70 (dd, J = 9.2/6.1 Hz, 1 H), 4.46 (d, J = 11.8 Hz, 1 H), 46.8 (d, J = 11.8 Hz, 1 H), 4.94 (t, J = 2 × 5.5 Hz, 1 H), 5.17 (d, J = 4.8 Hz, 1 H), 7.22–7.38 (m, 5 H).

***endo*-3b:** ^{13}C NMR (125.7 MHz, $CDCl_3$), δ: 37.47, 40.24, 44.00, 46.75, 69.18, 81.65, 104.34, 127.60, 127.93 (×2), 128.37 (×2), 137.64, 217.69.

^{1}H NMR (500 MHz, $CDCl_3$), δ: 2.09 (d, J = 13.4 Hz, 1 H), 2.24 (m, 1 H), 2.53–2.60 (m, 4 H), 3.05 (p, J = 4 × 7.9 Hz, 1 H), 4.39 (d, J = 11.8 Hz, 1 H), 4.68 (d, J = 11.8 Hz, 1 H), 4.89–4.93 (m, 1 H), 5.25 (d, J = 5.2 Hz, 1 H), 7.27–7.36 (m, 5 H).

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Asendatud tsüklopentanoonide süntees 2-oksabitsüklo[3.3.0]okta-6-een-3-oonist

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On esitatud asendatud tsüklopentanoonide 3-alkoksü-2-oksabitsüklo[3.3.0]okta-6-ooni (summaarne saagis kuni 34%) ja 3-alkoksü-2-oksabitsüklo[3.3.0]okta-7-ooni (summaarne saagis kuni 18%) neljaetapiline süntees, lähtudes enantiomeerselt puhtast (–)-(1*S*,5*R*)-2-oksabitsüklo[3.3.0]okta-6-een-3-oonist.