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Diastereoselective Synthesis of 2-Arylmethylene-6-hydroxyspiro[4.5]deca-7-ones via $FeCl_3 \cdot 6H_2O$-Catalyzed Spiroannulation/Hydride Transfer of 6-(5-Arylpent-4-yn-1-yl)-7-oxabicyclo[4.1.0]heptan-2-ols

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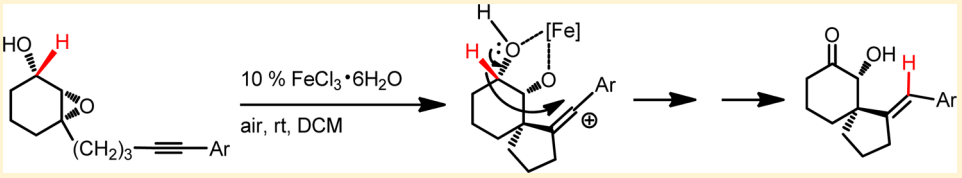
Supporting Information



ABSTRACT: In the presence of a catalytic amount of $FeCl_3 \cdot 6H_2O$, 6-(5-arylpent-4-yn-1-yl)-7-oxabicyclo[4.1.0]heptan-2-ols underwent attack of the pendant acetylene at the iron-activated oxirane to give a vinylic carbocation. Hydride transfer from the carbinol carbon to the newly formed cation center furnished 2-arylmethylene-6-hydroxyspiro[4.5]deca-7-ones in excellent stereoselectivity and good yields.

The spirocarbocyclic skeleton is present in many natural products. Due to the existence of spirocycles possessing useful biological properties, the development of effective methods to all carbon spirocycles has been actively pursued.[1] Many synthetic methods for the construction of such spirocycles involved alkylation via direct substitution[2] or Michael addition,[3] base-induced vinylcyclo-propanol and -butanol rearrangement,[4] pinacol-type rearrangement of cyclic allylic alcohols bearing an aldehyde,[5] or cyclic 2,3-epoxyols,[6] rearrangement of bridged cycles,[7] Nazarov-type spiroannulation of dienones,[8] Diels–Alder cycloaddition of dienes and cyclic enones,[9] transition-metal-based cycloaddition,[10] ene reaction,[11] radical cyclization,[12] and ring closing metathesis of *gem*-dialkenyl molecules.[13] As part of our ongoing investigations on Lewis acid assisted cyclization of cyclic enynols, we recently reported an example of TfOH-catalyzed cycloisomerization of C-3-arylpropargylsulfonamide-tethered 2,3-epoxycyclohexanols at 50 °C in dichloroethane (DCE) for 40 min, producing spiropiperidines in good yields (Scheme 1, eq 1).[14] The reaction started with the TfOH-assisted semipinacol rearrangement to give the ring contraction 2-arylpropargylsulfonamide-tethered cyclopentanecarbaldehyde, which underwent a TfOH-promoted alkyne-aldehyde metathesis via [2 + 2] cycloaddition/[2 + 2] cycloreversion to furnish the spiropiperidines. Surprisingly, when the *N*-tosylpropargyl tether was replaced by an alkynylalkyl group, the Lewis acid catalyzed cycloisomerization reaction of alkynylalkyl-tethered 2,3-epoxycyclohexanols proceeded via a different reaction path (Scheme 1, eq 2). Although intramolecular coupling reaction of alkynes and epoxides has been studied, the reaction required $NiBr_2 \cdot 3H_2O$, $PhMe_2P$, and reducing agent *i*-PrOH at 60 °C.[15] Herein, we report a $FeCl_3 \cdot 6H_2O$-catalyzed spiroannulation/hydride transfer of 6-alkynylalkyl-tethered 7-oxabicyclo[4.1.0]-heptan-2-ols, affording 2-arylmethylene-6-hydroxyspiro[4.5]deca-7-ones in good yields and excellent stereoselectivity under air at room temperature. The spiroannulation may start from attack of the acetylene at the $FeCl_3 \cdot 6H_2O$-activated oxirane to form a carbocation, followed by intramolecular hydride transfer from the carbinol carbon to the newly formed cation center, which furnished 2-arylmethylene-6-hydroxyspiro[4.5]deca-7-ones.

The cyclic *syn* epoxy alcohols **1** tethering a 5-arylpent-4-ynyl moiety at the C-6 position of the ring were prepared from epoxidation of the corresponding 3-(5-arylpent-4-yn-1-yl)-cyclohex-2-enols[16] with 1.2 equiv of *m*-chloroperoxybenzoic acid (*m*-CPBA). To select an optimum reaction protocol for the cycloisomerization of **1a**, various parameters, such as Brønsted and Lewis acids, solvents, and temperatures, were investigated. With acids such as HOTf and $ZnBr_2$ in DCM, **1a** decomposed to give an unidentified crude mixture (Table 1, entries 1 and 2). When reacted with 0.1 equiv of $BF_3 \cdot OEt_2$ in DCM (0.1 M) at room temperature under air for 10 min, **1a** generated the α-hydroxy spirocyclic ketone **2a** as a single stereoisomer in 27% yield (Table 1, entry 3), and none of the semipinacol rearrangement product was obtained. NMR studies have provided the initial evidence for the structural assignment of **2a**. The ^{1}H NMR spectrum of **2a** showed a triplet, centered at δ 6.41, assigned to the vinyl proton; a doublet of doublets, centered at δ 4.39, assigned to the proton at the carbinol carbon; and a doublet, centered at δ 3.60, assigned to the

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Scheme 1. Acid-Catalyzed Cycloisomerization Reaction of C-6-Alkynylalkyl-Tethered 7-Oxabicyclo[4.1.0]heptan-2-ols

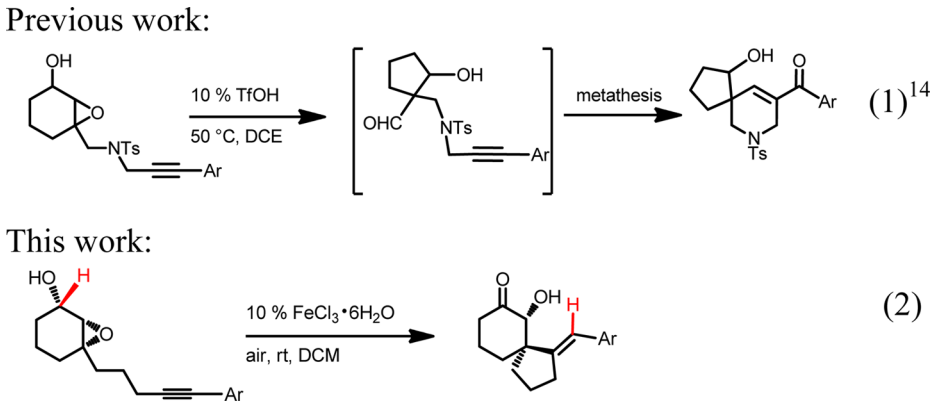
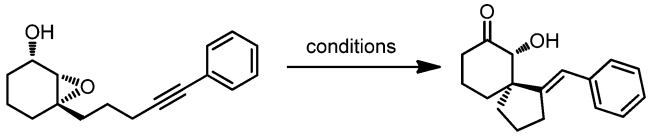


Table 1. Optimization of the Reaction Conditions[a]



1a **2a**

entry	Lewis acid	equiv	solvent	time	yield (%)
1	TfOH	0.1	0.2 M DCM	0.5 h	n.d.[b]
2	$ZnBr_2$	0.5	0.1 M DCM	26 h	n.d.[b]
3	$BF_3{\cdot}OEt_2$	0.1	0.1 M DCM	10 min	27
4	$FeCl_3$	0.5	0.1 M DCM	0.5 h	37
5	$FeCl_3$	2.0	0.1 M DCM	0.5 h	21
6	$FeCl_3$	0.3	0.1 M THF	4.0 h	trace
7	$FeCl_3$	0.5	0.1 M DBE	24 h	trace
8	$FeCl_3$	0.5	0.1 M DCE	3.0 h	31
9	$FeCl_3{\cdot}6H_2O$	0.1	0.1 M DCM	3.0 h	31
10	$FeCl_3{\cdot}6H_2O$	0.3	0.01 M DCM	1.0 h	50
11	$FeCl_3{\cdot}6H_2O$	0.1	0.01 M DCM	3.5 h	57
12	$FeCl_3{\cdot}6H_2O$	0.1	0.01 M THF	24 h	n.r.[c]
13	$FeCl_3{\cdot}6H_2O$	0.1	0.01 M MeCN	24 h	n.r.[c]
14	$AuCl(PPh_3)$/AgOTf	0.05	0.1 M DCM	3 min	8
15	$InCl_3$	0.5	0.1 M DCM	22 h	21
16	AgOTf	0.1	0.1 M DCM	4.0 h	5
17	$SnCl_4$	0.5	0.1 M DCM	3.0 h	29
18	TMSCl	0.3	0.1 M DCM	2.0 h	10
19	$Fe(NO_3)_3{\cdot}9H_2O$	0.1	0.01 M DCM	25 h	n.r.[c]

[a]All reactions were carried out under air at room temperature. [b]Not detected. [c]No reaction.

hydroxyl proton. The ^{13}C NMR spectrum exhibited a signal at δ 211.1 assigned to the carbonyl carbon; a signal at δ 150.8 assigned to the olefinic quaternary carbon; a signal at δ 126.2 assigned to the other olefinic carbon; and a signal at δ 81.3 assigned to the carbinol carbon. The relative stereochemistry of **2a** was proved by NOESY (nuclear Overhauser enhancement spectroscopy) measurements and further secured by X-ray diffraction analysis.[17]

Next, we focused our efforts toward the use of other Lewis acids ($SnCl_4$, $AuCl(PPh_3)$/AgOTf, $InCl_3$, $SnCl_4$, AgOTf, TMSCl, $FeCl_3$, and $FeCl_3{\cdot}6H_2O$), solvents (DCM, DCE, DBE, THF, MeCN, and MeOH), and temperatures. Results of the study are summarized in Table 1. As can be seen from Table 1, subjection of 0.1 equiv of $FeCl_3{\cdot}6H_2O$ to **1a** in DCM at 0.01 M concentration under air at room temperature for 3.5 h produced **2a** in a best isolated yield of 57% (Table 1, entry 11).

With optimized reaction conditions in hand, we next explored the generality of the spiroannulation/hydride transfer reaction conditions with various substituents on the phenyl ring, and results are shown in Table 2. The phenyl rings bearing one or two methyl groups at the C-3 or C-4 position of the phenyl ring, **2b–d**, were smoothly cyclized to give the desired spirocyclic ketones **2b–d** in 70–80% yields. A phenyl group at the C-4 position of the phenyl group, **1e**, was also efficient, providing a 77% yield of the desired spirocyclic ketone **2e**.[17] Sterically hindered naphthalenyl- or phenanthrenyl-substituted alkynes, **1f** and **1g**, resulted in lower yields of the corresponding products **2f** (46%) and **2g** (45%). Substrate **1h**, with an electron-donating methoxy group at C-3 of the phenyl ring, afforded **2h**[17] in 59% yield. Moving this electron-donating group to C-4, **1i** gave a significant increase in the yield of the desired product **2i** (86%). On the basis of higher yields obtained with a methyl or methoxy group at C-4 of the phenyl

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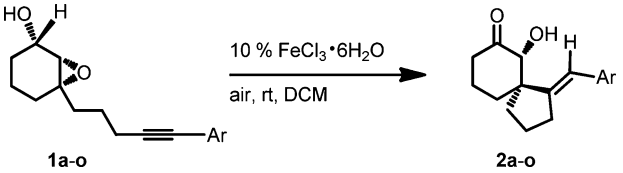
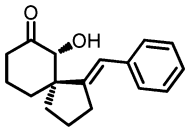
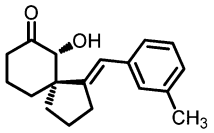
Table 2. Synthesis of 2-Arylmethylene-6-hydroxyspiro[4.5]deca-7-ones from 6-(5-Arylpent-4-yn-1-yl)-7-oxabicyclo[4.1.0]heptan-2-ols and $FeCl_3 \cdot 6H_2O$[a,b,c]



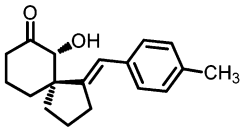
1a-o 2a-o



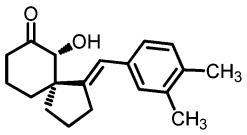
2a,[b] 57%, 3.5 h



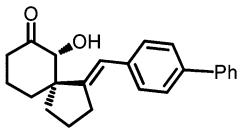
2b, 70%, 3.5 h



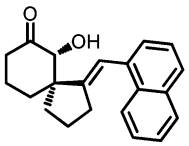
2c,[b] 71%, 3.5 h



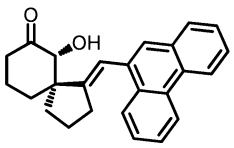
2d,[b] 80%, 0.5 h



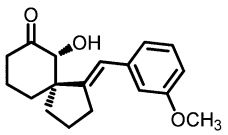
2e,[b] 77%, 1 h



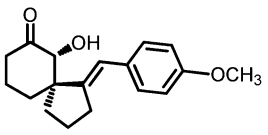
2f, 46%, 3 h



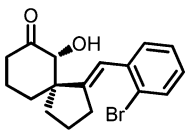
2g, 45%, 3 h



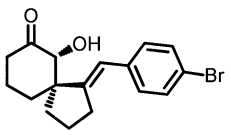
2h,[b] 59%, 2 h



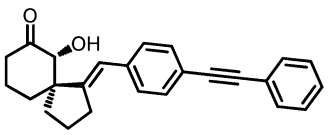
2i, 86%, 1.5 h



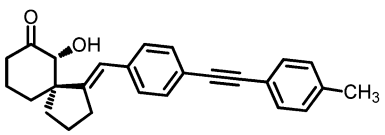
2j, 13%, 24 h



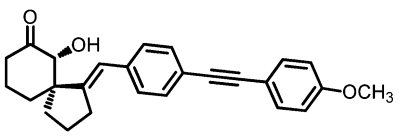
2k, 17%, 24 h



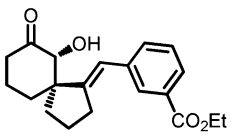
2l, 46%, 4 h



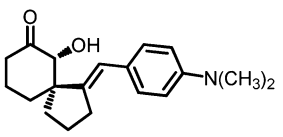
2m, 62%, 1.5 h



2n,[b] 60%, 3 h



2o, 10%, 36 h



2p, n.r.[c]

[a]Reaction conditions: **1** (1.0 equiv), $FeCl_3 \cdot 6H_2O$ (10 mol %), air, room temperature. [b]Structures were confirmed by X-ray diffraction analysis. [c]No reaction.

ring, it may be stated that an electron-donating substituent at the C-4 of the phenyl ring increased the nucleophilicity of the acetylene, which attacked at the iron-activated oxirane more efficiently to give a higher yield of the spirocyclic ketone (see Scheme 2). Moreover, the presence of a bromine atom on the phenyl ring, for example, **1j** and **1k**, was also tolerated and produced the corresponding spirocyclic ketones **2j** and **2k**, albeit in only 13 and 17% yield, respectively. Incorporation of an arylalkynyl moiety at the C-4 position of the phenyl ring, **1l–n**, was also effective and generated the desired spirocyclic ketones **2l–n** in moderate yields (46–62%). Unfortunately, compound **1o** bearing an electron-withdrawing ester group at the C-3 position of the phenyl ring delivered the spirocyclic ketone **2o** in only 10% yield. Moreover, compound **1p**, carrying an amino group at C-4 of the phenyl ring, was recovered

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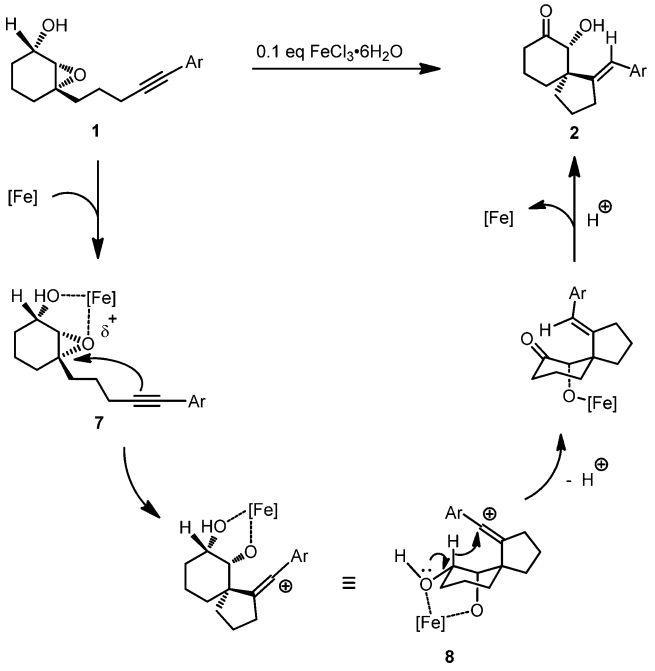
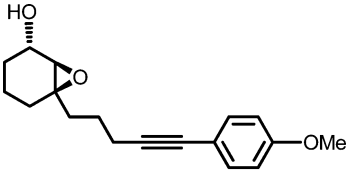
Scheme 2. Suggested Reaction Mechanism for the Formation of 1 to 2



quantitatively when treated with $FeCl_3 \cdot 6H_2O$ under the standard reaction conditions.

The reaction path for the formation of **2a** from **1a** is suggested in Scheme 2. Attack of the pendant acetylene at the iron-activated oxirane **7** gave the vinylic cation **8**. Transfer of the hydride from the carbinol carbon to the proximal cation center led to the spirocyclic ketone **2** after protonation. A similar 1,5-hydride shift in a vinylic cation intermediate has been reported.[18] Moreover, treatment of the diastereomer of **1i**, *anti*-**1i** (Figure 1), with 0.1 equiv of $FeCl_3 \cdot 6H_2O$ resulted in



anti-**1i**

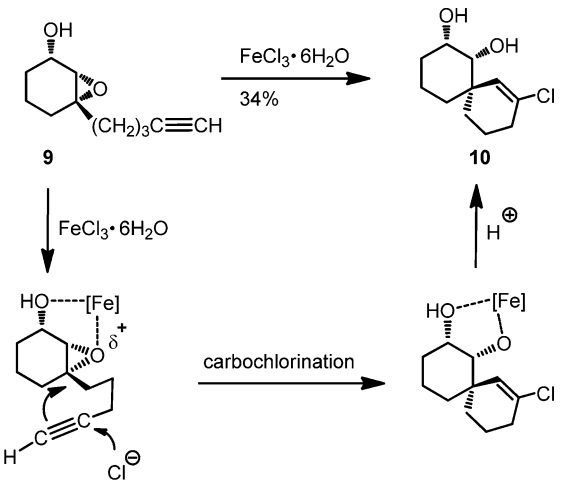
Figure 1. Structure of *anti*-**1i**.

recovering of the starting substrate quantitatively under the standard reaction conditions. Therefore, it is reasonable to state that chelation of both hydroxyl and oxirane oxygens to the iron center to form intermediates **7** and **8** is critical for the spiroannulation/hydride transfer reaction path. It is important to note that the electron-withdrawing effect of the *N*-tosyl group in the alkynylalkyl tether (Scheme 1, eq 1) may reduce the nucleophilicity of the acetylene, and thereby prevented the acetylene from attacking the activated oxirane. Instead, the reaction underwent the acid-promoted semipinacol rearrangement/alkyne-aldehyde metathesis to afford the spiropiperidines.

To provide further insight into the reaction mechanism, a deuterium-labeling experiment was conducted. The deuterated substrate **1c-*d***, with 86% *d*-incorporation (relative to one proton) at the carbinol carbon, was subjected to the opitimized reaction conditions (Scheme 3). The desired compound **2c-*d*** was isolated in 81% yield with 86% *d*-incorporation at the vinylic carbon. Moreover, the deuterium NMR of **2c-*d*** verified the existence of deuterium incorporation at the vinylic position (see the NMR spectra in the Supporting Information for details). Thus, the deuterium-labeling study provided strong evidence to support the hydride transfer mechanism, as suggested above.

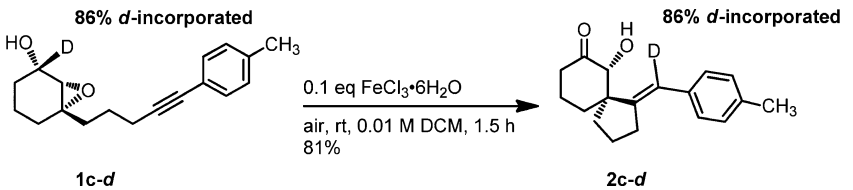
However, no desired spiro hydroxyketone was observed when substrate **9**, having a terminal alkyne, was treated with 0.1 equiv of $FeCl_3 \cdot 6H_2O$ under the same reaction conditions. Instead, carbochlorination of **9** occurred,[16] generating 8-chlorospiro[5.5]undec-7-ene-1,2-diol (**10**)[17] as a single stereoisomer in 34% yield (Scheme 4). Compound **9** failed to

Scheme 4. Carbochlorination of 9



undergo the usual spiroannulation/hydride transfer process, which may be due to the unfavorable formation of a terminal vinylic carbocation. Unfortunately, the use of 1.0 equiv of $FeCl_3 \cdot 6H_2O$ did not improve the yield, and **9** gave **10** in only 23% yield. Moreover, subjection of the methyl-terminated alkyne substrate, **11**, to $FeCl_3 \cdot 6H_2O$ under the standard reaction conditions led to a 24% yield of the spirodiendiol **12** and a 20% yield of the desired spirocyclic ketone **13** (Scheme 5). The formation of **12** may start from attack of the acetylene

Scheme 3. Deuterium-Labeling Study



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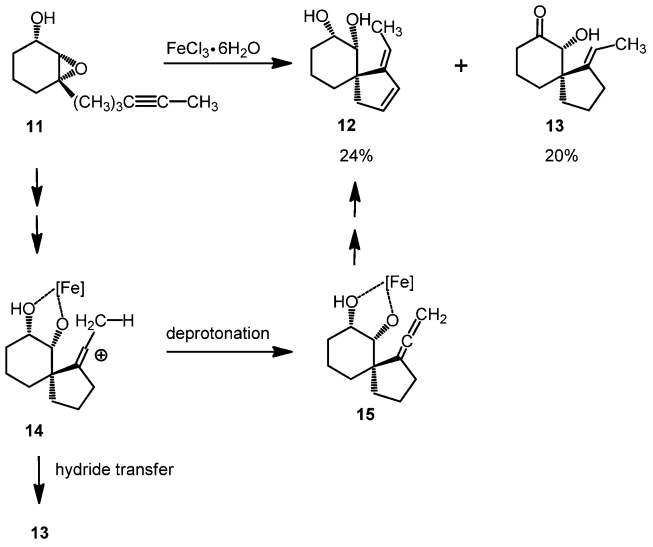
Scheme 5. Cycloisomerization of 11



at the iron-activated oxirane to form the cation intermediate **14**. Deprotonation of the methyl group gave the spiroallene **15**, which underwent double bond migration to afford the spirodiendiol **12**. The (*Z*)-configuration of the exo double bond was confirmed by NOSEY NMR spectroscopy.

In conclusion, this report describes a general stereoselective synthesis of 2-arylmethylene-6-hydroxyspiro[4.5]deca-7-ones through $FeCl_3{\cdot}6H_2O$-catalyzed spiroannulation/hydride transfer of 6-(5-arylpent-4-yn-1-yl)-7-oxabicyclo[4.1.0]-heptan-2-ols. A variety of spiro α-hydroxyketones were available stereoselectively using a catalytic amount of the inexpensive, efficient, and environmentally friendly $FeCl_3{\cdot}6H_2O$ at room temperature in the open air.

EXPERIMENTAL SECTION

General Considerations. All $FeCl_3{\cdot}H_2O$-catalyzed cycloisomerization reactions were performed in the open air at ambient temperature. Anhydrous solvents or reaction mixtures were transferred via an oven-dried syringe or cannula. Solvents were predried by molecular sieves and then by passing through an Al_2O_3 column. 6-(5-Arylpent-4-yn-1-yl)-7-oxabicyclo[4.1.0]heptan-2-ols **1** were synthesized by oxidation of 6-(5-arylpent-4-yn)cyclohex-2-enol[15] with MCPBA. Column chromatography was conducted with silica gel 60, hexanes, and ethyl acetate. ^{1}H NMR were recorded at 400 or 500 MHz in $CDCl_3$ with $CHCl_3$ (δ 7.24 ppm) or $(CH_3)_4Si$ (δ 0.00 ppm) as internal standard. ^{13}C NMR spectra were obtained at 100 or 125 MHz in $CDCl_3$ with $CHCl_3$ as internal standard (δ 77.00 ppm). Melting points are uncorrected. Mass spectra were acquired on a spectrometer at an ionization potential of 70 eV and were reported as mass/charge (*m*/*e*) with percent relative abundance. High-resolution mass spectra were obtained with a double-focusing mass spectrometer.

General Procedure for the Synthesis of 1a. To a solution of *t*-butyllithium (15 mmol, 1.6 M in pentane) was added slowly a solution of (5-iodopent-1-yn-1-yl)benzene (2.538 g, 9.4 mmol) in ether (20 mL) over a period of 30 min at −78 °C under N_2. After the reaction mixture was stirring at this temperature for 30 min, 3-ethoxycyclohex-2-en-1-one (1.10 g, 7.85 mmol) in ether (15 mL) was added dropwise at −78 °C under N_2. After 0.5 h, the reaction mixture was allowed to warm to room temperature. The reaction was monitored by TLC, until no trace of enone could be detected. The mixture was quenched with $HCl_{(aq)}$ (35 mL, 2.0 M) at 0 °C for 30 min, followed by stirring at rt for 2 h. The aqueous phase was extracted with ether (3 × 30 mL) and washed with brine (30 mL). The combined organic layers were dried over $MgSO_4$, filtered, and concentrated under reduced pressure to give a crude oil. The oil was purified by flash column over silica gel (3 × 13 cm, 10% ethyl acetate/hexanes) to afforded 3-(5-phenylpent-4-yn-1-yl)cyclohex-2-enone as a light yellow oil (1.220 g, 66%). To a solution of 3-(5-phenylpent-4-yn-1-yl)cyclohex-2-enone (0.370 g, 1.55 mmol) in methanol (15.5 mL) were added $NaBH_4$ (0.070 g, 1.80 mmol) and $CeCl_3{\cdot}7H_2O$ (0.870 g, 2.32 mmol) at 0 °C under air. After the reaction was stirred at room temperature for 30 min, the methanol was removed under reduced pressure. To the reaction mixture were added water and ethyl acetate (1/1). The aqueous phase was extracted with ethyl acetate (3 × 30 mL) and washed with brine (30 mL). The combined organic layers were dried over $MgSO_4$, filtered, and concentrated under reduced pressure to give a crude oil. To the crude product in DCM (15.5 mL) at 0 °C was added *m*CPBA (0.395 g, 2.33 mmol, 70%) portionwise, and the reaction mixture was stirred at 0 °C for 10 min. The reaction mixture was allowed to warm up to room temperature. After being stirred for 3 h, the mixture was quenched with saturated $NaHCO_{3(aq)}$. The resulting mixture was stirred at rt for 30 min. The mixture was extracted with DCM (3 × 30 mL) and washed with brine. The organic layer was dried over $MgSO_4$. The drying agent was removed by filtration, and the resulting solution was concentrated under reduced pressure. The residue was purified by flash chromatography over silica gel (3 × 13 cm, 10% ethyl acetate/hexanes), providing (1*S**,2*S**,6*R**)-6-(5-phenylpent-4-ynyl)-7-oxabicyclo[4.1.0]heptan-2-ol (**1a**) (0.278 g, 1.09 mmol, 70%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39−7.31 (m, 2H), 7.28−7.26 (m, 3H), 4.00 (s, 1H), 3.19 (d, *J* = 2.9 Hz, 1H), 2.45−2.43 (m, 2H), 1.99 (s, 1H), 1.88−1.81 (m, 1H), 1.76−1.68 (m, 5H), 1.58−1.43(m, 3H), 1.30−1.22 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 131.5, 128.2, 127.6, 29.4, 81.2, 66.8, 63.9, 61.2, 36.5, 29.2, 26.8, 24.0, 19.4, 18.1; IR (CH_2Cl_2) 3412, 2942, 2856, 1491, 1442, 848, 758, 693 cm^{-1}; MS (EI) *m*/*e* (%) 256.1 ([M]$^+$, 8), 238.1 (31), 210.1 (22), 128.1 (100), 115.1 (70); HRMS (EI) *m*/*e* calcd for $C_{17}H_{20}O_2$ [M]$^+$ 256.1463, found 256.1466.

(1S,2S*,6R*)-6-(5-m-Tolylpent-4-ynyl)-7-oxabicyclo[4.1.0]-heptan-2-ol (**1b**).* (0.561 g, 0.21 mmol, 81% from 0.821 g, 3.26 mmol of 3-(5-(*m*-tolyl)pent-4-yn-1-yl)cyclohex-2-enone). A yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.21−7.15 (m, 3H), 7.08 (d, *J* = 6.9 Hz, 1H), 4.01−3.98 (m, 1H), 3.19 (d, *J* = 3.1 Hz, 1H), 2.44−2.41 (m, 2H), 2.31 (s, 3H), 2.08 (br s, 1H), 1.87−1.80 (m, 1H), 1.75−1.67 (m, 5H), 1.58−1.42 (m, 3H), 1.30−1.24 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 137.9, 132.2, 128.6, 128.6, 128.1, 123.6, 89.0, 81.3, 66.9, 64.0, 61.3, 36.6, 29.1, 26.8, 24.0, 21.2, 19.4, 18.2; IR (CH_2Cl_2) 3421, 2940, 2864, 1715, 1600, 1448, 784, 692 cm^{-1}; MS (ESI) *m*/*e* (%) 293.1 ([M + Na]$^+$, 100), 288.2 (18); HRMS (ESI) *m*/*e* calcd for $C_{18}H_{22}NaO_2$ [M + Na]$^+$ 293.1517, found 293.1519.

(1S,2S*,6R*)-6-(5-p-Tolylpent-4-ynyl)-7-oxabicyclo[4.1.0]-heptan-2-ol (**1c**).* (0.662 g, 2.45 mmol, 67% from 0.920 g, 3.66 mmol of 3-(5-(*p*-tolyl)pent-4-yn-1-yl)cyclohex-2-enon). A colorless oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.27 (d, *J* = 7.9 Hz, 2H), 7.08 (d, *J* = 7.9 Hz, 2H), 3.99 (br s, 1H), 3.18 (d, *J* = 3.0 Hz, 1H), 2.44−2.41 (m, 2H), 2.33 (s, 3H), 2.04 (d, *J* = 8.3 Hz, 1H), 1.87−1.80 (m, 1H), 1.75−1.67 (m, 5H), 1.59−1.42 (m, 3H), 1.30−1.21 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 137.6, 131.4, 128.9, 120.7, 88.5, 81.2, 66.8, 63.6, 61.2, 36.5, 29.1, 26.8, 24.0, 21.4, 19.4, 18.1; IR (CH_2Cl_2) 3419, 2942, 2863, 1444, 1037, 817 cm^{-1}; MS (EI) *m*/*e* (%) 270.1 ([M]$^+$, 8), 252.2 (18), 237.2 (17), 165.1 (18), 142.1 (100); HRMS (EI) *m*/*e* calcd for $C_{18}H_{22}O_2$ [M]$^+$ 270.1620, found 270.1619.

(1S,2S*,6R*)-6-(5-p-Tolylpent-4-ynyl)-7-oxabicyclo[4.1.0]-heptan-2-ol (**1c-d**).* (0.133 g, 0.49 mmol, 71% from 0.174 g, 0.69 mmol of 3-(5-(*p*-tolyl)pent-4-yn-1-yl)cyclohex-2-enone). A colorless oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.27 (d, *J* = 8.2 Hz, 2H), 7.08 (d, *J* = 8.0 Hz, 2H), 4.00 (s, 86% D), 3.18 (s, 1H), 2.44−2.41 (m, 2H), 2.33 (s, 3H), 2.00 (br s, 1H), 1.87−1.81 (m, 1H), 1.76−1.67 (m, 5H), 1.58−1.43 (m, 3H), 1.29−1.24 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 137.6, 131.4, 128.9, 120.7, 88.5, 81.2, 66.4 (t, J_{CD} = 21.7 Hz, 1C), 63.9, 61.2, 36.5, 29.0, 26.7, 24.0, 21.4, 19.4, 18.1; ^{2}H NMR (76.8 MHz, $CDCl_3$) δ 4.00 (s, ^{1}^{2}H); IR (CH_2Cl_2) 3430, 3027, 2941, 2863, 1510, 1167, 818 cm^{-1}; MS (FAB) *m*/*e* (%) 272.1 ([M + H]$^+$, 37), 254.1 (60), 142.1 (84), 119.1 (74); HRMS (FAB) *m*/*e* calcd for $C_{18}H_{22}{}^2HO_2$ [M + H]$^+$ 272.1761, found 272.1761.

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(1S,2S*,6R*)-6-(5-(3,4-Dimethylphenyl)pent-4-yn-1-yl)-7-oxabicyclo[4.1.0]heptan-2-ol (**1d**).* (0.600 g, 2.12 mmol, 75% from 0.750 g, 2.82 mmol of 3-(5-(3,4-dimethylphenyl)pent-4-yn-1-yl)-cyclohex-2-enone). A yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.17 (s, 1H), 7.12 (d, J = 7.8 Hz, 1H), 7.04 (d, J = 7.7 Hz, 1H), 4.00 (br s, 1H), 3.19 (d, J = 3.1 Hz, 1H), 2.44−2.41 (m, 2H), 2.24 (s, 3H), 2.22 (s, 3H), 1.94 (br s, 1H), 1.88−1.81 (m, 1H), 1.76−1.67 (m, 5H), 1.58−1.42 (m, 3H), 1.29−1.24 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 136. 136.4, 132.6, 129.5, 128.9, 121.0, 88.3, 81.3, 66.8, 64.0, 61.2, 36.5, 29.1, 26.8, 24.0, 19.6, 19.5, 19.4, 18.1; IR (CH_2Cl_2) 3421, 2940, 2864, 1499, 1489, 1037, 820 cm^{-1}; MS (ESI) m/e (%) 307.2 ([M + Na]$^+$, 100); HRMS (ESI) m/e calcd for $C_{19}H_{24}NaO_2$ [M + Na]$^+$ 307.1674, found 307.1677.

(1S,2S*,6R*)-6-(5-(Biphenyl-4-yl)pent-4-ynyl)-7-oxabicyclo-[4.1.0]heptan-2-ol (**1e**).* (0.417 g, 1.25 mmol, 84% from 0.470 g, 1.5 mmol of 3-(5-([1,1′-biphenyl]-4-yl)pent-4-yn-1-yl)cyclohex-2-enon). A yellow solid; mp 100−101 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56 (d, J = 7.3 Hz, 2H), 7.51 (d, J = 8.3 Hz, 2H), 7.45 (d, J = 8.4 Hz, 2H), 7.41 (d, J = 7.8 Hz, 2H), 7.33 (t, J = 7.3 Hz, 1H), 4.02 (br s, 1H), 3.18 (d, J = 2.9 Hz, 1H), 2.46−2.43 (m, 2H), 2.32 (d, J = 7.1 Hz, 1H), 1.86−1.79 (m, 1H), 1.76−1.68 (m, 5H), 1.59−1.42 (m, 3H), 1.28−1.20 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 140.3, 140.3, 131.9, 128.7, 127.4, 126.9, 126.8, 122.7, 90.1, 81.0, 66.9, 63.8, 61.3, 36.5, 28.9, 26.7, 24.9, 19.4, 18.3; IR (CH_2Cl_2) 2421, 3031, 2941, 1446, 842, 765 cm^{-1}; MS (EI) m/e (%) 332.1 ([M]$^+$, 7), 314.2 (10), 204.1 (100), 191.1 (28); HRMS (EI) m/e calcd for $C_{23}H_{24}O_2$ [M]$^+$ 332.1776, found 332.1782.

(1S,2S*,6R*)-6-(5-(Naphthalen-1-yl)pent-4-ynyl)-7-oxabicyclo-[4.1.0]heptan-2-ol (**1f**).* (0.400 g, 1.31 mmol, 83% from 0.455 g, 1.57 mmol of 3-(5-(naphthalen-1-yl)pent-4-yn-1-yl)cyclohex-2-enone). A yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.31 (d, J = 8.2 Hz, 1H), 7.82 (d, J = 8.0 Hz, 1H), 7.77 (d, J = 8.2 Hz, 1H), 7.61 (d, J = 7.1 Hz, 1H), 7.57−7.53 (m, 1H), 7.51−7.47 (m, 1H), 7.38 (t, J = 7.7 Hz, 1H), 3.99 (br s, 1H), 3.20 (d, J = 3.0 Hz, 1H), 2.61−2.55 (m, 2H), 2.21 (br s, 1H), 1.88−1.69 (m, 6H), 1.58−1.42 (m, 3H), 1.27−1.22 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 133.3, 133.0, 129.9, 128.1, 127.9, 126.4, 126.1, 126.0, 125.4, 121.4, 94.4, 79.0, 66.9, 63.8, 61.3, 36.5, 28.7, 26.5, 24.0, 19.6, 18.3; IR (CH_2Cl_2) 3406, 2942, 2862, 2223, 1586, 1396, 801, 775 cm^{-1}; MS (EI) m/e (%) 306.1 ([M]$^+$, 8), 178.1 (100), 165.1 (60), 141.1 (36); HRMS (EI) m/e calcd for $C_{21}H_{22}O_2$ [M]$^+$ 306.1620, found 306.1625.

(1S,2S*,6R*)-6-(5-Phenanthren-9-yl)pent-4-ynyl)-7-oxabicyclo-[4.1.0]heptan-2-ol (**1g**).* (0.468 g, 1.31 mmol, 66% from 0.340 g, 1.01 mmol of 3-(5-(phenanthren-9-yl)pent-4-yn-1-yl)cyclohex-2-enone). A yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.68−8.66 (m, 1H), 8.63 (d, J = 8.2 Hz, 1H), 8.44−8.41 (m, 1H), 7.93 (s, 1H), 7.83 (dd, J = 7.8, 1.1 Hz, 1H), 7.68−7.55 (m, 4H), 4.03−4.00 (m, 1H), 3.23 (d, J = 3.1 Hz, 1H), 2.64−2.62 (m, 2H), 2.04 (br s, 1H), 1.92−1.72 (m, 6H), 1.59−1.44 (m, 3H),1.30−1.25 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 131.4, 131.3, 131.3, 130.0, 130.0, 128.3 (3C), 127.1, 126.9, 126.8, 122.7, 122.5, 120.1, 94.1, 79.3, 66.9, 63.9, 61.3, 36.7, 29.0, 26.8, 24.1, 19.7, 18.1; IR (CH_2Cl_2) 3405, 3061, 2943, 2863, 2221, 1492, 1040, 892 cm^{-1}; MS (EI) m/e (%) 356.2 ([M]$^+$, 16), 228.1 (100), 205.1 (15), 177.1 (11); HRMS (EI) m/e calcd for $C_{25}H_{24}O_2$ [M]$^+$ 356.1776, found 356.1781.

(1S,2S*,6R*)-6-(5-(3-Methoxyphenyl)pent-4-yn-1-yl)-7-oxabicyclo[4.1.0]heptan-2-ol (**1h**).* (0.39 g, 1.36 mmol, 73% from 0.500 g, 1.86 mmol of 3-(5-(3-methoxyphenyl)pent-4-yn-1-yl)cyclohex-2-enone). A yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.19 (t, J = 7.9 Hz, 1H), 6.98 (td, J = 7.9, 1.0 Hz, 1H), 6.92−6.91 (m, 1H), 6.85−6.82 (m, 1H), 4.01−3.98 (m, 1H), 3.79 (s, 3H), 3.19 (d, J = 3.1 Hz, 1H), 2.45−2.42 (m, 2H), 1.94 (br s, 1H), 1.88−1.80 (m, 1H), 1.76−1.67 (m, 5H), 1.53−1.43 (m, 3H), 1.31−1.25 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 159.2, 129.2, 124.7, 124.0, 116.4, 114.1, 89.3, 81.0, 66.9, 63.9, 61.2, 55.2, 36.5, 29.0, 36.7, 23.9, 19.3, 18.2; IR (CH_2Cl_2) 3402, 2940, 1578, 1288, 1044, 853 cm^{-1}; MS (ESI) m/e (%) 309.1 ([M + Na]$^+$, 100), 244.6 (5); HRMS (ESI) m/e calcd for $C_{18}H_{22}NaO_3$ [M + Na]$^+$ 309.1467, found 309.1471.

(1S,2S*,6R*)-6-(5-(4-Methoxyphenyl)pent-4-ynyl)-7-oxabicyclo-[4.1.0]heptan-2-ol (**1i**).* (0.117 g, 0.41 mmol, 45% from 0.243 g, 0.91 mmol of 3-(5-(4-methoxyphenyl)pent-4-yn-1-yl)cyclohex-2-enone). A yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33−7.30 (m, 2H), 6.82−6.79 (m, 2H), 3.99 (br s, 1H), 3.79 (s, 3H), 3.18 (d, J = 3.0 Hz, 1H), 2.43−2.40 (m, 2H), 2.21 (br s, 1H), 1.86−1.79 (m, 1H), 1.75−1.66 (m. 5H), 1.50−1.42 (m, 3H), 1.30−1.21 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 159.0, 132.8, 115.9, 113.8, 87.7, 80.8, 66.9, 63.9, 61.2, 55.2, 36.5, 28.9, 26.7, 24.0, 19.3, 18.2; IR (CH_2Cl_2) 3406, 3032, 2942, 2863, 1487, 842, 764, 698 cm^{-1}; MS (FAB) m/e (%) 287.2 ([M + H]$^+$, 10), 219.2 (18), 204.1 (100), 181.1 (50), 167.1 (49); HRMS (FAB) m/e calcd for $C_{18}H_{23}O_3$ [M + H]$^+$ 287.1647, found 287.1649.

(1R,2S*,6S*)-6-(5-(4-Methoxyphenyl)pent-4-ynyl)-7-oxabicyclo-[4.1.0]heptan-2-ol (anti-**1i**).* To a solution of 3-(5-(4-methoxyphenyl)pent-4-yn-1-yl)cyclohex-2-enone and NaOH (2 M, 0.050 mL, 0.1 mmol) in methanol was added H_2O_2 (35%, 0.388 g, 4 mmol) at 0 °C, and the reaction mixture was stirred at 0 °C until the starting material is consumed (TLC). The reaction mixture was purified by flash chromatography (silica gel, 10% ethyl acetate/hexanes) affording (1S*,6S*)-6-(5-(4-methoxyphenyl)-pent-4-yn-1-yl)-7-oxabicyclo[4.1.0]heptan-2-one as a light yellow oil (0.270 g, 0.95 mmol, 95%). To a solution of (1S*,6S*)-6-(5-(4-methoxyphenyl)pent-4-yn-1- yl)-7-oxabicyclo[4.1.0]heptan-2-one (0.227 g, 0.80 mmol) in methanol (8.0 mL) were added $NaBH_4$ (0.036 g, 0.96 mmol) and $CeCl_3{\cdot}7H_2O$ (0.417 g, 1.12 mmol) at 0 °C under air. After the reaction was stirred at room temperature for 30 min, the methanol was removed under reduced pressure. To the reaction mixture were added water and ethyl acetate (1/1). The aqueous phase was extracted with ethyl acetate (3 × 30 mL) and washed with brine (30 mL). The combined organic layers were dried over $MgSO_4$, filtered, and concentrated under reduced pressure and purified by flash chromatography (silica gel, 9% ethyl acetate/hexanes) to give (1R*,2S*,6S*)-6-(5-(4-methoxyphenyl)pent-4-ynyl)-7-oxabicyclo-[4.1.0]heptan-2-ol as a colorless oil (0.110 g, 0.38 mmol, 48%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.36−7.32 (m, 2H), 6.85−6.82 (m, 2H), 4.08−4.03 (m, 1H), 3.82 (s, 3H), 2.98 (s, 1H), 2.46−2.43 (m, 2H), 1.98−1.87 (m, 2H), 1.79−1.68 (m. 6H), 1.55−1.47 (m, 1H), 1.36−1.28 (m, 1H), 1.24−1.16 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 159.1, 132.9, 116.0, 113.8, 87.9, 80.8, 66.7, 62.1, 61.0, 55.3, 36.1, 30.0, 27.5, 24.1, 19.4, 15.5.

(1S,2S*,6R*)-6-(5-(2-Bromophenyl)pent-4-ynyl)-7-oxabicyclo-[4.1.0]heptan-2-ol (**1j**).* (0.215 g, 0.64 mmol, 65% from 0.313 g, 0.99 mmol of 3-(5-(2-bromophenyl)pent-4-yn-1-yl)cyclohex-2-enone). A yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56 (dd, J = 7.9, 1.3 Hz, 1H), 7.41 (dd, J = 7.7, 1.8 Hz, 1H), 7.24 (td, J = 7.9, 1.3 Hz, 1H), 7.12 (td, J = 7.7, 1.7 Hz, 1H), 4.00 (br s, 1H), 3.20 (d, J = 3.2 Hz, 1H), 2.51−2.48 (m, 2H), 2.01−1.95 (m, 1 H), 1.89−1.70 (m, 6H), 1.59−1.43 (m, 3H), 1.31−1.21 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 133.3, 132.3, 128.1, 126.9, 125.8, 125.4, 94.5, 80.0, 66.8, 63.9, 61.2, 36.4, 29.1, 26.8, 23.8, 19.5, 18.1 IR (CH_2Cl_2) 3398, 2939, 2864, 1465, 1026, 755 cm^{-1}; MS (ESI) m/e (%) 359.0 ([M + 2 + Na]$^+$, 95), 357.0 ([M + Na]$^+$, 100); HRMS (ESI) m/e calcd for $C_{17}H_{19}BrNaO_2$[79] [M + Na]$^+$ 357.0466, found 357.0462.

(1S,2S*,6R*)-6-(5-(4-Bromophenyl)pent-4-ynyl)-7-oxabicyclo-[4.1.0]heptan-2-ol (**1k**).* (0.372 g, 1.11 mmol, 74% from 0.432 g, 1.50 mmol of 3-(5-(4-bromophenyl)pent-4-yn-1-yl)cyclohex-2-enone). A yellow solid; mp 54−55 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 (, J = 8.5 Hz, 2H), 7.24 (d, J = 8.4 Hz, 2H), 4.02−3.96 (m, 1H), 3.18 (d, J = 3.1 Hz, 1H), 2.43−2.40 (m, 2H), 2.03−1.99 (m, 1H), 1.88−1.81 (m, 1H), 1.75−1.65 (m, 5H), 1.58−1.42 (m, 3H), 1.31−1.22 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 130.0, 131.4, 122.7, 121.7, 90.7, 80.2, 66.8, 63.8, 61.2, 36.5, 29.1, 26.8, 23.8, 19.4, 18.1; IR (CH_2Cl_2) 3406, 2942, 2863, 1711, 1486, 1070, 1010, 823 cm^{-1}; MS (FAB) m/e (%) 335.1 ([M + H]$^+$, 35), 317.0 (60), 182.9 (85), 154.0 (100), 136.0 (72), 107.1 (39); HRMS (FAB) m/e calcd for $C_{17}H_{20}BrO_2$[79] [M + H]$^+$ 335.0647, found 335.0647.

(1S,2S*,6R*)-6-(5-(4-(Phenylethynyl)phenyl)pent-4-ynyl)-7-oxabicyclo[4.1.0]heptan-2-ol (**1l**).* (0.844 g, 2.37 mmol, 79% from 1.014 g, 3.00 mmol of 3-(5-(4-(phenylethynyl)phenyl)pent-4-yn-1-yl)-cyclohex-2-enone). A yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53−7.51 (m, 2H), 7.45−7.43 (m, 2H), 7.37−7.33 (m, 5H), 4.00 (br s, 1H), 3.19 (d, J = 3.0 Hz, 1H), 2.46−2.43 (m, 2H), 2.08 (br s, 1H),

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1.88−1.84 (m, 1H), 1.75−1.67 (m, 5H), 1.59−1.43 (m, 3H), 1.31−1.22 (m, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 131.6, 131.5, 131.4, 128.4, 128.3, 123.7, 123.1, 122.5, 91.4, 90.8, 89.1, 81.0, 66.9, 63.9, 61.2, 36.5, 29.1, 26.7, 23.9, 19.5, 18.1; IR (CH_2Cl_2) 3473, 2947, 1715, 1509, 1108, 826, 757, 692 cm^{-1}; MS (EI) *m/e* (%) 356.2 ($[M]^+$, 7), 228.1 (100), 193.1 (11), 142.1 (23); HRMS (EI) *m/e* calcd for $C_{25}H_{24}O_2$ $[M]^+$ 356.1766, found 356.1776.

(1S,2S*,6R*)-6-(5-(4-(p-Tolylethynyl)phenyl)pent-4-yn-1-yl)-7-oxabicyclo[4.1.0]heptan-2-ol* (**1m**). (0.126 g, 0.34 mmol, 71% from 0.168 g, 0.477 mmol of 3-(5-(4-(*p*-tolylethynyl)phenyl)pent-4-yn-1-yl)cyclohex-2-enone). A light yellow solid: mp 108−110 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 7.44−7.40 (m, 4H), 7.34 (d, *J* = 8.2 Hz, 2H), 7.15 (d, *J* = 8.0 Hz, 2H), 4.00 (br s, 1H), 3.19 (d, *J* = 3.1 Hz, 1H), 2.47−2.44 (m, 2H), 2.37 (s, 3H), 1.94−1.82 (m, 2H), 1.76−1.70 (m, 5H), 1.56−1.46 (m, 3H), 1.29−1.26 (m, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 138.6, 131.5, 131.5, 131.3, 129.1, 123.5, 122.7, 120.0, 91.3, 91.1, 88.5, 81.0, 66.8, 63.9, 61.2, 36.5, 29.2, 26.8, 23.9, 21.5, 19.5, 18.0 ; IR (CH_2Cl_2) 3358, 2938, 2857, 1516, 1434, 1036, 839 cm^{-1}; MS (ESI) *m/e* (%) 393.2 ($[M + Na]^+$, 100), 367.2 (42), 363.2 (24), 279.1 (12); HRMS (ESI) *m/e* calcd for $C_{26}H_{26}NaO_2$ $[M + Na]^+$ 393.1831, found 393.1834.

(1S,2S*,6R*)-6-(5-(4-((4-Methoxyphenyl)ethynyl)phenyl)pent-4-yn-1-yl)-7-oxabicyclo[4.1.0]heptan-2-ol* (**1n**). (0.280 g, 0.73 mmol, 61% from 0.438 g, 1.19 mmol of 3-(5-(4-((4-methoxyphenyl)ethynyl)-phenyl)pent-4-yn-1-yl)cyclohex-2-enone). A light yellow solid: mp 108−110 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 7.47−7.45 (m, 2H), 7.42 (d, *J* = 8.3 Hz, 2H), 7.34 (d, *J* = 8.3 Hz, 2H), 6.89−6.74 (m, 2H), 4.02−3.98 (m, 1H), 3.82 (s, 1H), 3.19 (d, *J* = 3.0 Hz, 1H), 2.46−2.43 (m, 2H), 2.09 (br s, 1H), 1.88−1.81 (m, 1H), 1.75−1.69 (m, 5H), 1.58−1.43 (m, 3H), 1.31−1.24 (m, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 159.7, 133.0, 131.4, 131.2, 123.3, 122.8, 115.2, 114.0, 91.2, 90.9, 87.8, 81.0, 66.8, 63.9, 61.2, 55.3, 36.5, 29.1, 26.8, 23.9, 19.5, 18.1; IR (CH_2Cl_2) 3402, 2941, 2862, 1654, 1517, 1247, 1031, 833 cm^{-1}; MS (ESI) *m/e* (%) 409.2 ($[M + Na]^+$, 100), 387.2 (11); HRMS (ESI) *m/e* calcd for $C_{26}H_{26}O_3Na$ $[M + Na]^+$ 409.1780, found 409.1773.

Ethyl 3-(5-((1R,5S*,6S*)-5-Hydroxy-7-oxabicyclo[4.1.0]heptan-1-yl)pent-1-yn-1-yl)benzoate* (**1o**). (0.416 g, 1.27 mmol, 82% from 0.435 g, 1.40 mmol of ethyl 3-(5-(3-oxocyclohex-1-en-1-yl)pent-1-yn-1-yl)benzoate). A light yellow oil: ^1H NMR (400 MHz, $CDCl_3$) δ 8.06 (t, *J* = 1.4 Hz, 1H), 7.94 (dt, *J* = 7.9, 1.3 Hz, 1H), 7.55 (dt, *J* = 7.9, 1.3 Hz, 1H), 7.36 (t, *J* = 7.8 Hz, 1H), 4.38 (q, *J* = 7.1 Hz, 2H), 4.03−3.97 (m, 1H), 3.19 (d, *J* = 3.1 Hz, 1H), 2.46−2.43 (m, 2H), 2.02 (d, *J* = 9.6 Hz, 1H),1.89−1.82 (m, 1H), 1.78−1.68 (m, 5H), 1.59−1.43 (m, 3H), 1.40 (t, *J* = 7.1 Hz, 3H), 1.32−1.23 (m, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 166.0, 135.6, 132.6, 130.6, 128.6, 128.3, 124.1, 90.4, 80.3, 66.8, 63.8, 61.2, 61.1, 36.5, 29.1, 26.8, 23.8, 19.4, 18.1, 14.3; IR (CH_2Cl_2) 3424, 2941, 2863, 1720, 1295, 1227, 1105, 755 cm^{-1}; MS (FAB) *m/e* (%) 329.1 ($[M + H]^+$, 43), 311.1 (100), 283.1 (97), 265.1 (53), 177.0 (65); HRMS (FAB) *m/e* calcd for $C_{20}H_{25}O_4$ $[M + H]^+$ 329.1753, found 329.1751.

(1S,2S*,6R*)-6-(Pent-4-yn-1-yl)-7-oxabicyclo[4.1.0]heptan-2-ol* (**9**). (0.935 g, 5.19 mmol, 88% from 0.972 g, 6.00 mmol of 3-(pent-4-yn-1-yl)cyclohex-2-enone). A white oil: ^1H NMR (400 MHz, $CDCl_3$) δ 3.99 (br s, 1H), 3.16 (d, *J* = 3.0 Hz, 1H), 2.24−2.20 (m, 2H), 2.11 (br s, 1H), 1.97 (t, *J* = 2.6 Hz, 1H), 1.85−1.78 (m, 1H), 1.75−1.61 (m, 5H), 1.58−1.51 (m, 2H), 1.48−1.42 (m, 1H), 1.30−1.21 (m, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 83.8, 68.8, 66.9, 63.8, 61.2, 36.3, 29.0, 26.7, 23.6, 18.4, 18.1; IR (CH_2Cl_2) 3414, 3295, 2942, 2864, 2116, 1037, 635 cm^{-1}; MS (FAB) *m/e* (%) 181.1 ($[M + H]^+$, 92), 163.1 (100), 123.1 (87), 121.1 (58); HRMS (FAB) *m/e* calcd for $C_{11}H_{17}O_2$ $[M + H]^+$ 181.1229, found 181.1227.

(1S,2S*,6R*)-6-(Hex-4-yn-1-yl)-7-oxabicyclo[4.1.0]heptan-2-ol* (**11**). (0.579 g, 2.97 mmol, 74% from 0.705 g, 4.00 mmol of 3-(hex-4-yn-1-yl)cyclohex-2-enone). A light yellow oil: ^1H NMR (400 MHz, $CDCl_3$) δ 4.01−3.97 (m, 1H), 3.16 (d, *J* = 3.1 Hz, 1H), 2.17−2.13 (m, 2H), 2.00 (br s, 1H), 1.85−1.79 (m, 1H), 1.77 (t, *J* = 2.5 Hz, 3H), 1.73−1.64 (m, 3H), 1.61−1.42 (m, 5H), 1.30−1.21 (m, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 78.5, 76.1, 66.8, 64.0, 61.2, 36.5, 29.1, 26.7, 24.2; IR (CH_2Cl_2)3421, 2943, 2863, 1443, 1065, 845 cm^{-1}; MS (APCI) *m/e* (%) 195.1 ($[M + H]^+$, 100), 177.1 (18); HRMS (APCI) *m/e* calcd for $C_{12}H_{19}O_2$ $[M + H]^+$ 195.1385, found 195.1383.

General Experimental Procedure for $FeCl_3·6H_2O$-Catalyzed Cycloisomerization of 6-(5-Arylpent-4-yn-1-yl)-7-oxabicyclo-[4.1.0]-heptan-2-ols. *Synthesis of (5R*,6R*,E)-1-Benzylidene-6-hydroxyspiro[4.5]decan-7-one* (**2a**). To a solution of 6-(5-phenylpent-4-yn-1-yl)-7-oxabicyclo[4.1.0]heptan-2-ol (**1a**) (0.17 g, 0.67 mmol) in DCM (67 mL) was added $FeCl_3·6H_2O$ (18 mg, 0.067 mmol) at room temperature under air. After complete consumption of the starting material (3.5 h), the reaction mixture was quenched with H_2O (50 mL). The resulting mixture was extracted with ether (3 × 30 mL). The organic phase was dried over $MgSO_4$, filtered, and concentrated under reduced pressure. Purification of the residue by flash column chromatography (7% ethyl acetate/hexanes) over silica gel gave **2a** (98 mg, 0.38 mmol, 57%) as a white solid: mp 116−117 °C; ^1H NMR (500 MHz, $CDCl_3$) δ 7.36−7.31 (m, 4H), 7.18 (tt, *J* = 13.9, 1.7 Hz, 1H), 6.41 (t, *J* = 2.5 Hz, 1H), 4.39 (dd, *J* = 3.7, 1.2 Hz, 1H), 3.60 (d, *J* = 3.9 Hz, 1H), 2.71−2.67 (m, 2H), 2.59−2.55 (m, 1H), 2.51−2.44 (m, 1H), 2.06−2.01 (m, 1H), 1.92−1.60 (m, 6H), 1.40−1.35 (m, 1H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 211.1, 150.8, 138.2, 128.5, 128.1, 126.2, 121.2, 81.3, 57.1, 39.0, 36.5, 32.3, 29.4, 24.2, 23.3; IR (CH_2Cl_2) 3475, 2946, 2831, 1714, 1108, 874, 697 cm^{-1}; MS (EI) *m/e* (%) 256.2 ($[M]^+$, 65), 238.2 (46), 183.1 (100), 141.1 (68), 129.1 (28); HRMS (EI) *m/e* calcd for $C_{17}H_{20}O_2$ $[M]^+$ 256.1463, found 256.1465. Crystals suitable for X-ray diffraction analysis were grown from CH_2Cl_2 and hexanes.[17]

(5R,6R*,E)-6-Hydroxy-1-(3-methylbenzylidene)spiro[4.5]decan-7-one* (**2b**). The crude residue obtained from the reaction of **1b** (0.28 g, 1 mmol) with $FeCl_3·6H_2O$ (28 mg, 0.1 mmol) was purified by flash column chromatography to give **2b** (0.19 g, 0.70 mmol, 70%) as a yellow oil: ^1H NMR (400 MHz, $CDCl_3$) δ 7.22−7.15 (m, 3H), 7.00 (d, *J* = 7.4 Hz, 1H), 6.38 (t, *J* = 2.4 Hz, 1H), 4.38 (d, *J* = 2.4 Hz, 1H), 3.60 (d, *J* = 3.7 Hz, 1H), 2.71−2.67 (m, 2H), 2.59−2.54 (m, 1H), 2.52−2.46 (m, 1H), 2.34 (s, 3H), 2.07−2.00 (m, 1H), 1.95−1.60 (m, 6H), 1.40−1.36 (m, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 211.1, 150.5, 138.1, 137.6, 129.3, 128.0, 127.0, 125.5, 121.2, 81.3, 57.1, 39.0, 36.5, 32.3, 29.4, 24.4, 23.3, 21.5; IR (CH_2Cl_2) 3455, 2949, 2875, 1717, 144.1, 1104 cm^{-1}; MS (APCI) *m/e* (%) 271.2 ($[M + H]^+$, 100), 253.2 (13); HRMS (APCI) *m/e* calcd for $[M + H]^+$ $C_{18}H_{23}O_2$ 271.1698, found 271.1692.

(5R,6R*,E)-6-Hydroxy-1-(4-methylbenzylidene)spiro[4.5]decan-7-one* (**2c**). The crude residue obtained from the reaction of **1c** (0.14 g, 0.5 mmol) with $FeCl_3·6H_2O$ (14 mg, 0.050 mmol) was purified by flash column chromatography to give **2c** (0.10 g, 0.36 mmol, 71%) as a white solid: mp 97−99 °C; ^1H NMR (500 MHz, $CDCl_3$) δ 7.25 (d, *J* = 8.1 Hz, 2H), 7.13 (d, *J* = 8.0 Hz, 2H), 6.37 (t, *J* = 2.4 Hz, 1H), 4.37 (s, 1H), 3.59 (d *J* = 2.9 Hz, 1H), 2.67−2.65 (m, 2H), 2.58−2.54 (m, 1H), 2.50−2.42 (m, 1H), 2.33 (s, 3H), 2.04−2.00 (m, 1H), 1.90−1.60 (m, 6H), 1.39−1.35 (m, 1H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 211.1, 149.7, 135.8, 135.4, 128.8, 128.4, 121.0, 81.3, 57.1, 38.9, 36.5, 32.3, 29.4, 24.4, 23.3, 21.1; IR (CH_2Cl_2) 3477, 2945, 2871, 1714, 1385, 1313, 1108, 876 cm^{-1}; MS (EI) *m/e* (%) 270.2 ($[M]^+$, 70), 252.2 (21), 197.1 (100), 155.1 (51), 105.4 (68); HRMS (EI) *m/e* calcd for $C_{18}H_{22}O_2$ $[M]^+$ 270.1620, found 270.1617. Crystals suitable for X-ray diffraction analysis were grown from CH_2Cl_2 and hexanes.[17]

(5R,6R*,E)-6-Hydroxy-1-(4-methylbenzylidene)spiro[4.5]decan-7-one* (**2c-*d***). The crude residue obtained from the reaction of **1c-*d*** (59 mg, 0.22 mmol) with $FeCl_3·6H_2O$ (5.9 mg, 0.022 mmol) was purified by flash column chromatography to give **2c-*d*** (48 mg, 0.18 mmol, 81%) as a white solid: mp 102−104 °C; ^1H NMR (500 MHz, $CDCl_3$) δ 7.25 (d, *J* = 8.1 Hz, 2H), 7.13 (d, *J* = 7.9 Hz, 2H), 6.37 (t, *J* = 2.4 Hz, 86% D), 4.37 (dd, *J* = 3.8, 1.3 Hz, 1H), 3.59 (d, *J* = 3.9 Hz, 1H), 2.71−2.65 (m, 2H), 2.56−2.54 (m, 1H), 2.50−2.43 (m, 1H), 2.33 (s, 3H), 2.05−2.01 (m, 1H), 1.90−1.60 (m, 6H), 1.39−1.35 (m, 1H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ 211.2, 149.6, 135.8, 135.4, 128.9, 128.4, 120.7 (t, $J_{C\text{-}D}$ = 23.8 Hz, 1C), 81.3, 57.1, 39.0, 36.5, 32.3, 29.4, 24.5, 23.3, 21.1; IR (CH_2Cl_2) 3476, 2944, 2871, 1714, 1107, 820 cm^{-1}; MS (EI) *m/e* (%) 271.1 ($[M]^+$, 86), 253.2 (20), 242.2 (15), 198.1 (100), 156.1 (58), 106.1 (69); HRMS (EI) *m/e* calcd for $C_{18}{}^1H_{21}{}^2HO_2$ $[M]^+$ 271.1683, found 271.1685.

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(5R,6R*,E)-1-(3,4-Dimethylbenzylidene)-6-hydroxyspiro[4.5]-decan-7-one (**2d**).* The crude residue obtained from the reaction of **1d** (0.23 g, 0.85 mmol) with $FeCl_3{\cdot}6H_2O$ (23 mg, 0.085 mmol) was purified by flash column chromatography to give **2d** (0.19 g, 0.66 mmol, 80%) as a white solid: mp 108−110 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.12 (s, 1H), 7.09 (s, 2H), 6.34 (t, J = 2.4 Hz, 1H), 4.37 (dd, J = 3.8, 1.1 Hz, 1H), 3.58 (d J = 3.8 Hz, 1H), 2.69−2.65 (m, 2H), 2.58−2.53 (m, 1H), 2.50−2.45 (m, 1H), 2.25 (s, 3H), 2.24 (s, 3H), 2.06−1.97 (m, 1H), 1.90−1.58 (m, 6H), 1.39−1.34 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 211.2, 149.5, 136.1, 135.8. 134.5. 129.9. 129.4. 125.9. 121.1. 81.3. 57.1. 39.0. 36.5. 32.3. 29.4 24.4. 23.3. 19.8. 19.4; IR (CH_2Cl_2) 34.75, 29.42, 28.70, 1715, 1443, 1107 cm^{-1}; MS (APCI) m/e (%) 285.2 ([M + H]$^+$, 100), 267.2 (13); HRMS (APCI) m/e calcd for $C_{19}H_{25}O_2$ [M + H]$^+$ 285.1855, found 285.1849. Crystals suitable for X-ray diffraction analysis were grown from CH_2Cl_2 and hexanes.[17]

(5R,6R*,E)-1-(Biphenyl-4-ylmethylene)-6-hydroxyspiro[4.5]-decan-7-one (**2e**).* The crude residue obtained from the reaction of **1e** (0.12 g, 0.35 mmol) with $FeCl_3{\cdot}6H_2O$ (10 mg, 0.035 mmol) was purified by flash column chromatography to give **2e** (0.09 g, 0.27 mmol, 77%) as a white solid: mp 179−180 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61−7.56 (m, 4H), 7.44−7.40 (m, 4H), 7.34−7.32 (m, 1H), 6.43 (t, J = 2.2 Hz, 1H), 4.39 (d, J = 3.7 Hz, 1H), 3.62 (d, J = 3.8 Hz, 1H), 2.75−2.70 (m, 2H), 2.58−2.53 (m, 1H), 2.49−2.41 (m, 1H), 2.04−2.02 (m, 1H), 1.91−1.61 (m, 6H), 1.40−1.35 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 211.0, 151.1, 140.8, 138.7, 137.3, 128.9, 128.7, 127.1, 126.9, 126.7, 120.7, 81.2, 57.2, 28.9, 36.4, 32.4, 29.4, 24.4, 23.2; IR (CH_2Cl_2) 3482, 3027, 2944, 1714, 1108, 443, 699 cm^{-1}; MS (EI) m/e (%) 332.2 ([M]$^+$, 76), 259.1 (45), 181.1 (100), 152.1 (67); HRMS (EI) m/e calcd for $C_{23}H_{24}O_2$ [M]$^+$ 332.1776, found 332.1774. Crystals suitable for X-ray diffraction analysis were grown from CH_2Cl_2 and hexanes.[17]

(5R,6R*,E)-6-Hydroxy-1-(naphthalen-1-ylmethylene)spiro[4.5]-decan-7-one (**2f**).* The crude residue obtained from the reaction of **1f** (0.15 g, 0.5 mmol) with $FeCl_3{\cdot}6H_2O$ (14 mg, 0.050 mmol) was purified by flash column chromatography to give **2f** (0.07 g, 0.23 mmol, 46%) as a white solid: mp 105−107 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.05−8.03 (m, 1H), 7.84−7.82 (m, 1H), 7.73−7.71 (m, 1H), 7.51−7.45 (m, 2H), 7.44−7.40 (m, 2H), 6.89 (s, 1H), 4.47 (s, 1H), 3.68 (br s, 1H), 2.58−2.51 (m, 1H), 2.50−2.37 (m, 3H), 2.05−1.97 (m, 2H), 1.84−1.67 (m, 4H), 1.57−1.47 (m, 1H), 1.43−1.36 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 211.1, 152.8, 135.4, 133.5, 131.7, 128.3, 126.8, 126.0, 125.7, 125.5, 125.2, 124.6, 118.2, 81.4, 56.3, 38.8, 36.5, 32.0, 29.5, 24.1, 23.3; IR (CH_2Cl_2) 3461, 3047, 2945, 2870, 2369, 1712, 1391, 1107, 782 cm^{-1}; MS (EI) m/e (%) 306.2 ([M]$^+$, 100), 259.2 (13), 233.2 (70), 191.1 (55), 165.1 (61), 141.1 (58); HRMS (EI) m/e calcd for $C_{21}H_{22}O_2$ [M]$^+$ 306.1620, found 306.1621.

(5R,6R*,E)-6-Hydroxy-1-(phenanthren-9-ylmethylene)spiro[4.5]-decan-7-one (**2g**).* The crude residue obtained from the reaction of **1g** (0.34 g, 0.95 mmol) with $FeCl_3{\cdot}6H_2O$ (26 mg, 0.095 mmol) was purified by flash column chromatography to give **2g** (0.15 g, 0.42 mmol, 45%) as a yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.72 (d, J = 7.9 Hz, 1H), 8.67 (d, J = 8.0 Hz, 1H), 8.10 (dd, J = 7.9, 1.0 Hz, 1H), 7.84 (dd, J = 7.8, 1.2 Hz, 1H), 7.67−7.57 (m, 5H), 6.91 (t, J = 2.6 Hz, 1H), 4.56 (d, J = 3.8 Hz, 1H), 3.72 (t, J = 3.9 Hz, 1H), 2.64−2.50 (m, 4H), 2.61−2.08 (m, 2H), 1.94−1.74 (m, 4H), 1.60−1.44 (m, 1H), 1.48−1.42 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 211.1, 153.2, 140.0, 131.7, 131.3, 130.3, 129.7, 128.4, 126.7.126.6, 126.5, 126.3, 126.2, 125.4, 122.9, 122.5, 118.6, 81.5, 56.3, 39.0, 36.6, 32.0, 29.6, 24.2, 23.4; IR (CH_2Cl_2) 3478, 3061, 2947, 2872, 1715, 1608, 1377, 1108, 898, 746 cm^{-1}; MS (APCI) m/e (%) 357.2 ([M + H]$^+$, 100), 195.2 (57) 163.1 (22), 122.0 (18); HRMS (APCI) m/e calcd for [M + H]$^+$ $C_{25}H_{25}O_2$ 357.1855, found 357.1854.

(5R,6R*,E)-6-Hydroxy-1-(3-methoxybenzylidene)spiro[4.5]-decan-7-one (**2h**).* The crude residue obtained from the reaction of **1h** (0.28 g, 0.98 mmol) with $FeCl_3{\cdot}6H_2O$ (26 mg, 0.098 mmol) was purified by flash column chromatography to give **2h** (0.16 g, 0.57 mmol, 59%) as a white solid: mp 100−102 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.24 (t, J = 8.0 Hz, 1H), 6.95 (d, J = 7.7 Hz, 1H), 6.90 (s, 1 H), 6.75 (dd, J = 8.2, 2.4 Hz, 1H), 6.39 (t, J = 2.2 Hz, 1H), 4.39 (d, J = 3.1 Hz, 1H), 3.81 (s, 3H), 3.61 (d, J = 3.8 Hz, 1H), 2.72−2.68 (m, 2H), 2.60−2.55 (m, 1H), 2.52−2.47 (m, 1H), 2.07−2.02 (m, 1H), 1.92−1.60 (m, 6H), 1.41−1.36 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 211.1, 159.4, 151.1, 139.6, 129.0, 121.2, 121.1, 114.0, 111.9, 81.2, 57.1, 55.2, 38.9, 36.5, 32.4, 29.4, 24.4, 23.3; IR (CH_2Cl_2) 3470, 2946, 2874, 1714, 1596, 1443, 1158, 1107 cm^{-1}; MS (APCI) m/e (%) 287.2 ([M + H]$^+$, 100), 269.2 (30); HRMS (APCI) m/e calcd for $C_{18}H_{23}O_3$ [M + H]$^+$ 287.1647, found 287.1640. Crystals suitable for X-ray diffraction analysis were grown from CH_2Cl_2 and hexanes.[17]

(5R,6R*,E)-6-Hydroxy-1-(4-methoxybenzylidene)spiro[4.5]-decan-7-one (**2i**).* The crude residue obtained from the reaction of **1i** (76 mg, 0.27 mmol) with $FeCl_3{\cdot}6H_2O$ (7.0 mg, 0.027 mmol) was purified by flash column chromatography to give **2i** (66 mg, 0.23 mmol, 86%) as a white solid: mp 90−91 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30−7.27 (m, 2H), 6.88−6.85 (m, 2H), 6.34 (t, J = 2.3 Hz,, 1H), 4.36 (d, J = 3.7 Hz, 1H), 3.80 (s, 3H), 3.60 (d, J = 3.8 Hz, 1H), 2.67−2.63 (m, 2H), 2.58−2.53 (m, 1H), 2.49−2.41 (m, 1H), 2.04−1.99 (m, 1H), 1.93−1.60 (m, 6H), 1.38−1.34 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 211.1, 157.9, 148.4, 131.0, 129.6, 120.5, 113.5, 81.2, 57.0, 55.2, 38.9, 36.5, 32.1, 29.4, 24.4, 23.2; IR (CH_2Cl_2) 3473, 2945, 1607, 1510, 1248, 1178, 1107, 1712, 1034, 827 cm^{-1}; MS (EI) m/e (%) 286.1 ([M]$^+$, 100), 213.1 (72), 171.1 (21), 121.1 (53); HRMS (EI) m/e calcd for $C_{18}H_{22}O_3$ [M]$^+$ 286.1569, found 286.1574.

(5R,6R*,E)-6-Hydroxy-1-(2-bromobenzylidene)spiro[4.5]decan-7-one (**2j**).* The crude residue obtained from the reaction of **1j** (0.21 g, 0.63 mmol) with $FeCl_3{\cdot}6H_2O$ (17 mg, 0.063 mmol) was purified by flash column chromatography to give **2j** (27 mg, 0.08 mmol, 13%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56 (d, J = 7.9 Hz, 1H), 7.40 (dd, J = 76 1.0 Hz, 1H), 7.27 (t, J = 7.4 Hz, 1H), 7.06 (td, J = 7.7, 1.3 Hz, 1H), 6.57 (s, 1H), 4.41 (d, J = 2.8 Hz, 1H), 3.62 (d, J = 3.7 Hz, 1H), 2.60−2.50 (m, 4H), 2.09−1.97 (m, 2H), 1.84−1.17 (m, 4H), 1.60−1.55 (m, 1H), 1.43−1.37 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 210.9, 152.8, 137.8, 132.4, 129.9, 127.8, 126.9, 124.3, 120.6, 81.4, 56.8, 38.9, 36.2, 32.0, 29.3, 24.4, 23.4; IR (CH_2Cl_2) 3429, 2939, 1711, 1430, 1261, 1022, 753 cm^{-1}; MS (APCI) m/e (%) 377.1 ([M + H +2]$^+$, 95), 335.1 ([M + H]$^+$, 100); HRMS (APCI) m/e calcd for $C_{17}H_{20}{}^{79}BrO_2$ [M + H]$^+$ 335.0647, found 335.0648.

(5R,6R*,E)-1-(4-Bromobenzylidene)-6-hydroxyspiro[4.5]decan-7-one (**2k**).* The crude residue obtained from the reaction of **1k** (0.17 g, 0.5 mmol) with $FeCl_3{\cdot}6H_2O$ (13 mg, 0.050 mmol) was purified by flash column chromatography to give **2k** (28 mg, 0.08 mmol, 17%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43 (d, J = 8.5 Hz, 2H), 7.20 (d, J = 8.5 Hz, 2H), 6.34 (s, 1H), 4.36 (d, J = 3.8 Hz, 1H), 3.62 (d, J = 3.8 Hz, 1H), 2.65−2.55 (m, 3H), 2.51−2.43 (m, 1H), 2.07−2.02 (m, 1H), 1.90−1.61 (m, 6H), 1.41−1.36 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 210.9, 153.9, 137.2, 131.2, 130.1, 120.2, 119.9, 81.1, 57.2, 38.9, 36.4, 32.3, 29.4, 24.4, 23.2; IR (CH_2Cl_2) 3457, 2946, 2874, 1714, 1488, 1249, 1108, 1009, 824, 736 cm^{-1}; MS (EI) m/e (%) 334.1 ([M]$^+$, 81), 318.1 (41), 261.1 (98), 182.2 (95), 165.1 (100), 141.1 (60), 128.2 (43); HRMS (EI) m/e calcd for $C_{17}H_{19}{}^{79}BrO_2$ [M]$^+$ 334.0568, found 334.0564.

(5R,6R*,E)-6-Hydroxy-1-(4-(phenylethynyl)benzylidene)spiro-[4.5]decan-7-one (**2l**).* The crude residue obtained from the reaction of **1l** (0.14 g, 0.4 mmol) with $FeCl_3{\cdot}6H_2O$ (11 mg, 0.040 mmol) was purified by flash column chromatography to give **2l** (66 mg, 0.18 mmol, 46%) as a white solid: mp 179−181 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.57−7.50 (m, 4H), 7.37−7.35 (m, 5H), 6.42 (t, J = 2.3 Hz, 1H), 4.40 (d, J = 3.7 Hz, 1H), 3.66 (d, J = 3.8 Hz, 1H), 2.74−2.71 (m, 2H), 2.62−2.53 (m, 1H), 2.54−2.45 (m, 1H), 2.09−2.04 (m, 1H), 1.94−1.70 (m, 6H), 1.44−1.39 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 211.0, 152.1, 138.2, 131.5, 131.4, 128.4, 128.3, 128.1, 123.4, 120.8, 120.8, 89.7, 89.4, 81.2, 57.3, 38.9, 36.4, 32.5, 29.4, 24.4, 23.2; IR (CH_2Cl_2) 3477, 2945, 1714, 1385, 1313, 2871, 1108, 876 cm^{-1}; MS (EI) m/e (%) 356.2 ([M]$^+$, 100), 283.2 (36), 241.1 (23), 191.1 (48), 142.1 (32); HRMS (EI) m/e calcd for $C_{25}H_{24}O_2$ [M]$^+$ 356.1776, found 356.1776.

(5R,6R*,E)-6-Hydroxy-1-(4-(p-tolylethynyl)benzylidene)spiro-[4.5]decan-7-one (**2m**).* The crude residue obtained from the reaction of **1m** (0.11 g, 0.28 mmol) with $FeCl_3{\cdot}6H_2O$ (8.0 mg, 0.028 mmol) was purified by flash column chromatography to give **2m** (66 mg, 0.19

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mmol, 62%) as a white solid: mp 170−171 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48 (d, J = 8.2 Hz, 2H), 7.42 (d, J = 8.0 Hz, 2H),7.33 (d, J = 8.2 Hz, 2H), 7.15 (d, J = 8.0 Hz, 2H), 6.40 (t, J = 2.5 Hz, 1H), 4.39 (d, J = 3.7 Hz, 1H), 3.63 (d, J = 3.8 Hz, 1H), 2.73−2.68 (m, 2H), 2.61−2.55 (m, 1H), 2.52−2.44 (m, 1H), 2.37 (s, 3H), 2.08−2.03 (m, 1H), 1.92−1.63 (m, 6H), 1.42−1.37 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 210.9, 152.0, 138.3, 138.1, 131.5, 131.3, 129.1, 128.4, 121.0, 120.9, 120.3, 89.8, 89.0, 81.2, 57.3, 38.9, 36.4, 32.5, 28.4, 24.5, 23.3, 21.5; IR (CH_2Cl_2) 3455, 2943, 2866, 1712, 1516, 1342, 1107, 817 cm^{-1};MS (ESI) m/e (%) 393.2 ([M + Na]$^+$, 100), 360.3 (10), 266.2 (10); HRMS (EI) m/e calcd for $C_{26}H_{26}NaO_2$ [M + Na]$^+$ 393.1831, found 393.1823.

(5R,6R*,E)-6-Hydroxy-1-(4-((4-methoxyphenyl)ethynyl)benzylidene)spiro[4.5]decan-7-one (**2n**).* The crude residue obtained from the reaction of **1n** (0.15 g, 0.39 mmol) with $FeCl_3{\cdot}6H_2O$ (11 mg, 0.039 mmol) was purified by flash column chromatography to give **2n** (91 mg, 0.24 mmol, 60%) as a white solid: mp 173−175 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.47 (d, J = 8.6 Hz, 4H), 7.32 (d, J = 8.3 Hz, 2H), 6.89−6.86 (m, 2H), 6.40 (t, J = 2.5 Hz, 1H), 4.39 (d, J = 3.5 Hz, 1H), 3.83 (br s, 3H), 3.63 (d, J = 3.6 Hz, 1H), 2.73−2.68 (m, 2H), 2.60−2.56 (m, 1H), 2.52−2.45 (m, 1H), 2.07−2.02 (m, 1H), 1.92−1.63 (m, 6H), 1.42−1.37 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 211.0, 159.6, 151.9, 137.9, 133.0, 131.2, 128.4, 121.2, 120.9, 115.5, 114.0, 89.6, 88.4, 81.2, 57.3, 55.3, 38.9, 36.4, 32.5, 29.4, 24.5, 23.3; IR (CH_2Cl_2) 3451, 2941, 1711, 1599, 1513, 1248, 1026, 832 cm^{-1};MS (ESI) m/e (%) 409.2 ([M + Na]$^+$, 700), 334.2 (40), 229.1 (70), 143.1 (60); HRMS (EI) m/e calcd for $C_{26}H_{26}NaO_3$ [M + Na]$^+$ 409.1780, found 409.1783. Crystals suitable for X-ray diffraction analysis were grown from CH_2Cl_2 and hexanes.[17]

Ethyl 3-((E)-((5R,6R*)-6-Hydroxy-7-oxospiro[4.5]decan-1-ylidene)methyl)-benzoate (**2o**).* The crude residue obtained from the reaction of **1o** (0.11 g, 0.34 mmol) with $FeCl_3{\cdot}6H_2O$ (9.0 mg, 0.034 mmol) was purified by flash column chromatography to give **2o** (11 mg, 0.03 mmol, 10%) as a yellow oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03 (s, 1H), 7.86 (td, J = 7.8, 1.3 Hz, 2H), 7.36 (d, J = 7.7 Hz, 1H), 7.39 (t, J = 7.7 Hz, 1H), 6.43 (t, J = 2.3 Hz, 1H), 4.47−4.35 (m, 3H), 3.64 (d, J = 3.8 Hz, 1H), 2.73−2.69 (m, 2H), 2.61−2.51 (m, 1H), 2.53−2.46 (m, 1H), 1.93−1.64 (m, 6H), 1.42−1.38 (m, 1H), 1.40 (t, J = 7.7 Hz, 3H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 210.9, 166.7, 152.2, 138.4, 132.6, 130.4, 129.6, 128.1, 127.2, 120.4, 81.2, 60.9, 57.2, 38.9, 36.4, 32.3, 29.4, 24.4, 23.3, 14.3; IR (CH_2Cl_2) 3473, 2946, 2872, 1715, 1282, 1205, 1107, 1025 cm^{-1}; MS (EI) m/e (%) 328.2 ([M]$^+$, 13), 299.2 (36), 253.2 (45), 149.1 (100), 141.1 (18); HRMS (EI) m/e calcd for $C_{20}H_{24}O_4$ [M]$^+$ 328.1675, found 328.1678.

(1R,2S*,6S*)-8-Chlorospiro[5.5]undec-7-ene-1,2-diol (**10**).* The crude residue obtained from the reaction of **9** (0.20 g, 1.13 mmol) with $FeCl_3{\cdot}6H_2O$ (30 mg, 0.11 mmol) was purified by flash column chromatography to give **10** (84 mg, 0.47 mmol, 34%) as a colorless solid: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.81 (s, 1H), 3.91−3.87 (m, 1H), 3.57 (d, J = 1.8 Hz, 1H), 2.30 (td, J = 6.4, 1.6 Hz, 2H), 2.07 (br s, 1H), 1.86−1.79 (m, 3H), 1.75−1.60 (m, 4H), 1.45−1.49 (m, 2H), 1.43−1.37 (m, 1H), 1.27−1.21 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 134.8, 128.2, 74.9, 68.9, 42.1, 33.1, 32.3, 30.2, 28.7, 19.2, 18.6; IR (CH_2Cl_2) 3421, 3301, 2942, 2866, 1713, 1647, 1449, 1059, 869, 758, 642 cm^{-1}; MS (ESI) m/e (%) 217.1 ([M + 2 − H]$^-$, 31), 215.1 ([M − H]$^-$, 100), 195.0 (11); HRMS (ESI) m/e calcd for $C_{11}H_{16}ClO_2{}^{35}$ [M − H]$^-$ 215.0839, found 215.0832. Crystals suitable for X-ray diffraction analysis were grown from CH_2Cl_2 and hexanes.[17]

(5S,6R*,7S*,Z)-1-Ethylidenespiro[4.5]dec-2-ene-6,7-diol (**12**).* The crude residue obtained from the reaction of **11** (0.39 g, 2.0 mmol) with $FeCl_3{\cdot}6H_2O$ (54 mg, 0.20 mmol) was purified by flash column chromatography to give **12** (93 mg, 0.48 mmol, 24%) and **13** (76 mg, 0.40 mmol, 20%). Compound **12** a colorless oil: ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.70 (ddd, J = 9.9, 5.0, 2.5 Hz, 1H), 5.16−5.13 (m, 1H), 5.12−5.08 (m, 1H), 4.08−4.04 (m, 1H), 3.56 (m, 1H), 2.36−2.3 (m, 4H), 2.15−2.09 (m, 1H), 1.90 (d, J = 7.4 Hz, 1H), 1.81−1.75 (m, 3H), 1.58 (td, J = 6.4, 1.6 Hz, 3H), 1.40−1.33 (m, 1H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ 146.9, 131.8, 124.0, 119.5, 71.5, 66.2, 54.9, 35.3 29.3, 27.8, 21.5, 14.6; IR (CH_2Cl_2) 3421, 3301, 2942, 2866, 1713, 1647, 1449, 1059, 869, 758, 642 cm^{-1}; MS (ESI) m/e (%) 217.1 ([M + Na]$^+$, 13), 177.1 (3); HRMS (ESI) m/e calcd for $C_{12}H_{18}NaO_2$ [M + Na]$^+$ 217.1204, found 217.1200.

(5R,6R*,E)-1-Ethylidene-6-hydroxyspiro[4.5]decan-7-one (**13**).* Compound **13** a colorless oil: ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.44−5.38 (m, 1H), 4.23 (dd, J = 3.9, 1.3 Hz, 1H), 3.56 (d, J = 3.9 Hz, 1H), 2.55−2.49 (m, 1H), 2.45−2.30 (m, 3H), 2.00−1.93 (m, 1H), 1.69 (dt, J = 6.6, 1.5 Hz, 3 H), 1.78−1.52 (m, 6H), 1.34−1.29 (m, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 211.5, 148.4, 114.9, 81.2, 55.5, 39.0, 36.5, 30.0, 29.6, 23.5, 23.2, 14.9; IR (CH_2Cl_2) 3471, 2942, 2871, 1713, 1641, 1442, 1108, 805 cm^{-1}; MS (APCI) m/e (%) 195.1 ([M + H]$^+$,100), 177.1 (11); HRMS (ESI) m/e calcd for $C_{12}H_{19}O_2$ [M + H]$^+$ 195.1385, found 195.1380.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

NMR spectra for compounds **1a−o**, **2a−o**, **2c-*d***, and **9−13**, and X-ray crystallographic information files for compounds **2a**, **2c−e**, **2h**, **2n**, and **10**. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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