Pergamon

Tetrahedron 57 (2001) 3939–3944

TETRAHEDRON

New and efficient synthesis of $CpRe(CO)_3$ substituted steroids

Franck Le Bideau,[a] Alejandro Pérez-Luna,[a] Jérôme Marrot,[b] Marie-Noëlle Rager,[a] Elie Stéphan,[a] Siden Top[a] and Gérard Jaouen[a,*]

[a]*UMR 7576 CNRS, Ecole Nationale Supérieure de Chimie de Paris, 11 rue Pierre et Marie Curie, 75231 Paris Cedex 05, France*
[b]*Université de Versailles Saint-Quentin-en-Yvelines, IREM, bâtiment Lavoisier, 45 av. des Etats-Unis, 78035 Versailles Cedex, France*

Received 21 November 2000; revised 12 February 2001; accepted 26 February 2001

Abstract—Fulvenes generated from steroids have been efficiently engaged in a process implying nucleophilic or basic attack followed by a transmetallation reaction in the presence of $BrRe(CO)_5$ to afford the corresponding $CpRe(CO)_3$ substituted compounds. This new strategy is of relevant interest for the synthesis of new potential radiopharmaceuticals.

1. Introduction

There is a growing interest in the study of new bioorganometallic materials.[1,2] In this field and in connection with studies of new potential radiopharmaceuticals, an efficient route towards $CpRe(CO)_3$ substituted steroids is desirable and we thus focussed our studies in this direction. Taking into account the cost of the organometallic precursor $BrRe(CO)_5$ and in view of a future introduction of radioactive nuclides, we needed a general strategy which allows the introduction of the $CpRe(CO)_3$ unit as late as possible in the synthesis. To this aim, we found that steroids bearing a fulvene group were very attractive precursors for a one-pot synthesis of the desired products.[3] These compounds are easier to prepare and to characterize and more interesting than the corresponding cyclopentadienyl species because they may provide access to a wide variety of products depending on the conditions (basic versus nucleophilic). In this paper, we describe in full detail our synthetic strategy and efforts to achieve the synthesis of this new generation of potential radiopharmaceuticals.

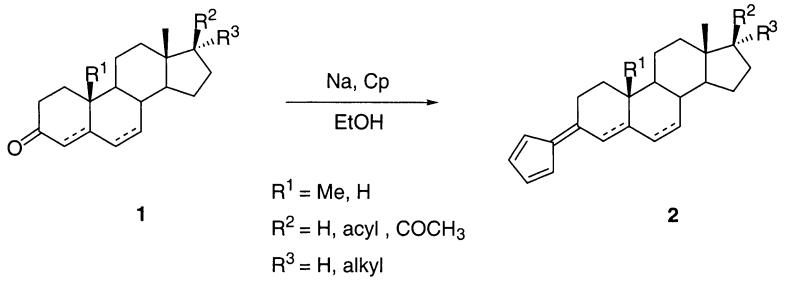
2. Results and discussion

2.1. Fulvene synthesis

Only two general methods for the preparation of steroids substituted by a fulvene group have been reported in the literature. Knox reported the synthesis and a biological study (anabolic properties, anti-ovulatory, anti-androgenic and anti-estrogenic activities) of 3-fulvene androstane, pregnane or nor-derivatives **2**.[4] These compounds were obtained by treating the corresponding 3-keto-androstanes or pregnanes **1** with a solution of cyclopentadiene and sodium in ethanol according to Thiele's method (Scheme 1).[5]

Erker et al. have recently used the Little and Stone method[6] to introduce the fulvene part at the C-16 position of a modified estradiol **3**[7] and at the C-3 position of cholestanone **5**[8] (Scheme 2).

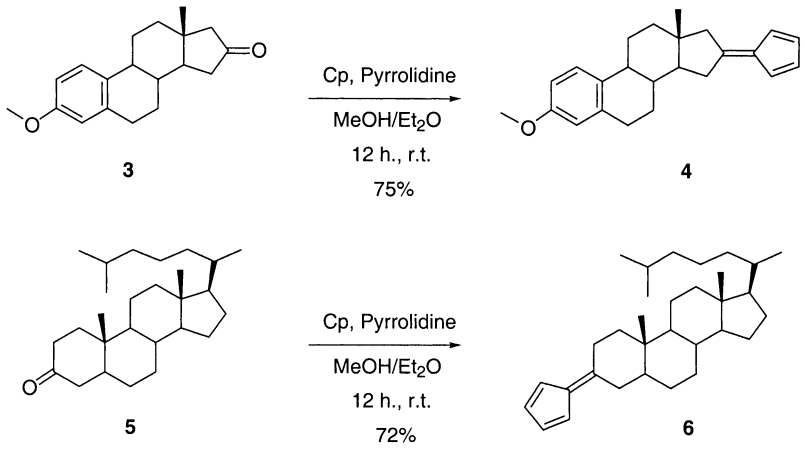
Compounds **4** and **6** are precursors of organometallic



Scheme 1.

Keywords: fulvenes; cyclopentadienyl; rhenium.
* Corresponding author. Tel.: +33-01-43-26-9555; fax: +33-01-43-26-00-61; e-mail: jaouen@ext.jussieu.fr

0040–4020/01/$ - see front matter
PII: S0040-4020(01)00263-0



Scheme 2.

species used as homogeneous Ziegler-type catalysts for stereoselective propene polymerization.

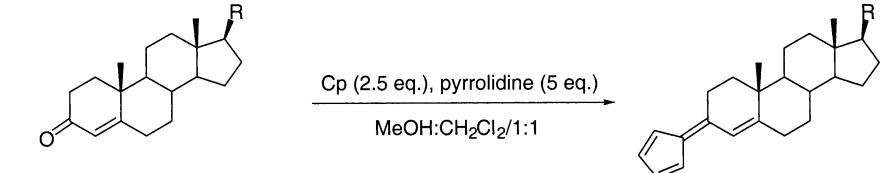
In connection with our interest in new $CpRe(CO)_3$ substituted steroids, we needed an access to the corresponding fulvenes. Cholest-4-en-3-one **7a** was chosen as a model substrate and first submitted to the condition reported by Knox[4] to afford traces of the desired fulvene **8a**. This poor amount of desired product led us to test the second method reported by Erker et al.[7,8] We found that dichloromethane was as good cosolvent as ether used by these authors to overcome the lack of solubility of the starting materials in methanol. These reaction conditions allowed us to obtain the fulvenes **8a**, **8b** and **8c** in good yields (ranging from 66 to 76%) (Scheme 3).

It should be noted that the carbonyl function of the progesterone **7b** in the C-20 position was not transformed probably because of the steric hindrance of the C-18 methyl group. This result was reported by Little and Stone for hindered aldehydes as the major drawback of their method.[6] Using the same conditions as above, compound **10** was formed in 72% yield starting from 5α-androstan-17β-ol-3-one **9** (Scheme 4).

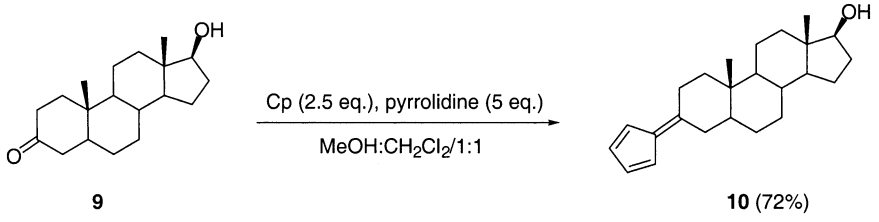
These fulvenes, which are less polar compounds than the corresponding ketones, are easily purified by flash chromatography and can be stored at room temperature for several weeks without modification. It should also be emphasized that since water decreases the yield, reactions have to be carried out in a flame-dried schlenk tube with anhydrous solvents and reactants.

2.2. Formation of the $CpRe(CO)_3$ unit

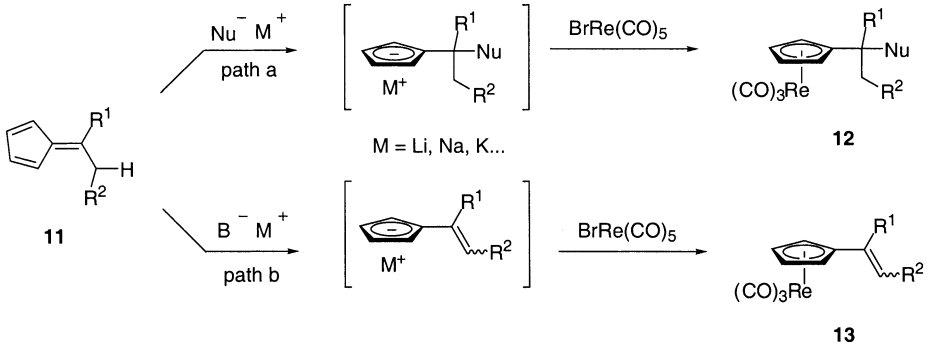
Having found a highly practical route to access steroids bearing a fulvene functionality, we turned our attention on how to have access to the corresponding $CpRe(CO)_3$ substituted compounds. The idea of obtaining a cyclopentadienyl metal unit by reduction of a fulvene through nucleophilic or basic attack was originally developed by Pauson for the synthesis of ferrocene derivatives[9] and substituted cyclopentadienyl derivatives of nickel, cobalt, molybdenum and titanium.[10] The method was afterwards explored for the



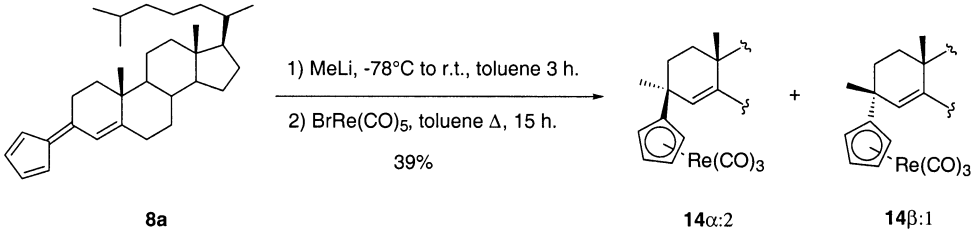
Scheme 3.



Scheme 4.



Scheme 5.



Scheme 6.

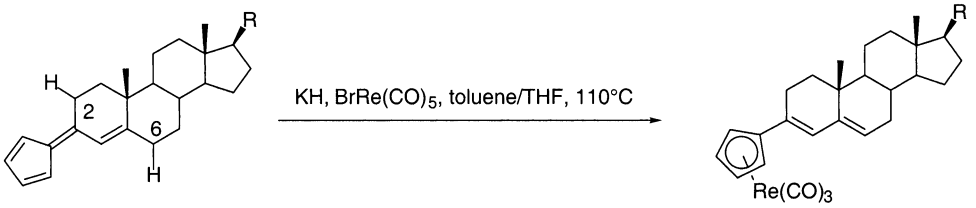
preparation of various cyclopentadienyl units[7,8,11,12] but no example of the synthesis of $CpRe(CO)_3$ substituted compounds was reported. This approach to the desired compounds had therefore to be attempted. The action of a base or a nucleophile on the fulvene part of compound **11** could generate intermediate salts, which could be good precursors of the desired products **12** or **13**, through a transmetallation process in the presence of $BrRe(CO)_5$ (Scheme 5).

According to path a (Scheme 5), fulvene **8a** was treated with MeLi in toluene at −78°C and warmed to room temperature for 3 h. $BrRe(CO)_5$ was then added and the reaction mixture was heated to reflux for 15 h. Under these conditions, two diastereomers **14**α/β were obtained in a 2:1 ratio (according to the ^1H NMR spectra of the mixture) in 39% yield. These diastereomers have different relative configuration at the newly formed stereogenic center (Scheme 6). In that case no compound resulting from the reaction of the MeLi as base was isolated.

The molecular structure (determined by X-ray crystallographic analysis) of the major product **14**α showed that the newly introduced methyl substituent is attached to the α face of the steroid framework.[3]

Fulvenes **8a**, **8b** and **8c** were converted into the corresponding compounds **15a**, **15b** and **15c** in good yields, according to path b (Scheme 5), in the presence of KH and $BrRe(CO)_5$ at 110°C in a mixture of THF and toluene (Scheme 7).

Compound **15a** was crystallized from hexane/CH_2Cl_2 and its molecular structure was determined by X-ray crystallographic analysis (Fig. 1). This product was the result of a proton abstraction in the C-6 position. The structures of **15b** and **15c** were assigned by comparison of their ^1H NMR spectra with that of **15a**, which exhibit similar patterns. It is worth noting that no isomeric product resulting from the deprotonation at the C-2 position was isolated after purification by flash chromatography, although the NMR spectra of the crude reaction mixtures showed small amounts of these species in the case of **15b** and of **15c**.



Scheme 7.

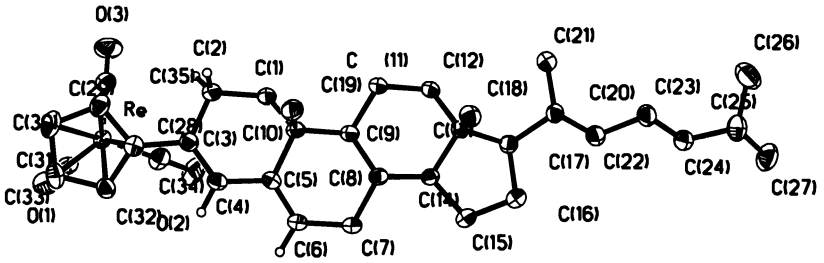
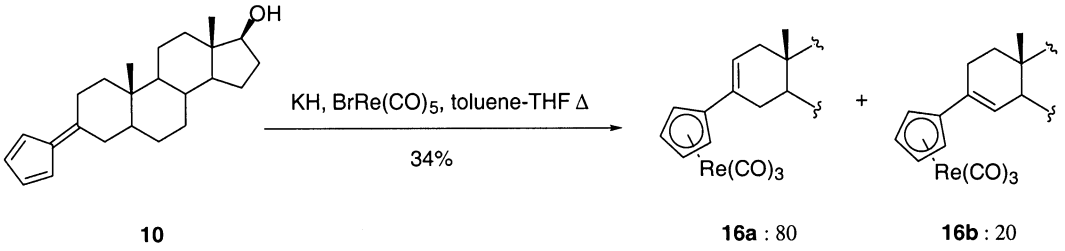


Figure 1. ORTEP structure of **15a** obtained by X-ray crystallographic analysis.



Scheme 8.

Finally, fulvene **10** was transformed under the same conditions into a mixture of isomers **16** (**16a/16b** 4:1), which could not be separated (Scheme 8). The position of the double bond in the major product **16a** was assigned on the basis of (H,H)- and (H,C)-correlated NMR spectroscopy.

The ^{1}H NMR spectra of these conjugated $CpRe(CO)_3$ substituted steroids exhibit three multiplets between 5.6 and 5.2 ppm due to the cyclopentadienyl protons as against three multiplets between 6.7 and 6.4 ppm for the corresponding fulvenes.

3. Conclusions

The results presented above describe a new route to $CpRe(CO)_3$ substituted steroids. Although organic solvents are not the ideal media for the synthesis of radiopharmaceuticals, this efficient method may lead to discovery of new targets of relevant interest in the field of medicinal chemistry. The introduction of the metal carbonyl unit on a steroid in the last step of the synthesis describe here is a crucial point for future developments of potential radiopharmaceuticals. For this reason, fulvenes could be more interesting than the corresponding cyclopentadienes because of the great number of products accessible according to the condition used (basic versus nucleophilic) and their higher stability.

4. Experimental

^{1}H and ^{13}C NMR spectra were recorded on a 200 MHz Bruker AC 200 spectrometer. Chemical shifts are reported in ppm and referenced to the residual proton resonances of the solvent used. Infrared (IR) spectra were recorded by using a BOMEN MB spectrometer. Mass spectra were obtained on NERMAG R1010C apparatus. Melting points were measured on a Büchi B-510 apparatus and are uncorrected. Thin-layer chromatography (TLC) was performed on Merck silica gel 60 F 254. Silica gel Merck Gerudan SI (40–63 μm) was used for column chromatography using the Still method.[13] Elemental analyses were measured at the microanalysis laboratory of the Pierre et Marie Curie University (Paris, France). Optical rotations were measured with a JASCO P-1010 polarimeter. All solvents and reagents were purified when necessary using standard procedures. Anhydrous methanol (99.8%) was purchased from Aldrich and used as received. Reactions were carried out in flame-dried schlenk glassware under inert atmosphere (argon). 4-Cholesten-3-one, pregnenolone and adrenosterone (Aldrich); testosterone, pyrrolidine and progesterone (Acros); 5α-androstan-17β-ol-3-one (Sigma) were used as received.

4.1. General method for the fulvene synthesis

To a solution of steroid (5 mmol) and cyclopentadiene (1 mL, 12 mmol) in 8 mL of $MeOH/CH_2Cl_2$ (1/1), freshly distilled pyrrolidine (2 mL, 24 mmol) was added. The mixture was stirred at room temperature for 20 h, diluted with AcOEt (50 mL), washed with brine (3×25 mL), dried over $MgSO_4$ and concentrated. The obtained residue was purified via flash chromatography.

4.1.1. 4-Cholesten-3-(2,4-cyclopentadien-1-ylidene) 8a. 4-Cholesten-3-one (185 mg, 0.5 mmol) was converted into **8a** according to the general procedure. Purification by flash chromatography (pentane) afforded **8a** as a red solid (137 mg, 66%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 6.65 (m, 1H), 6.55 (m, 2H), 6.5 (m, 2H), 3.00 (dt, J=13.4, 3.8 Hz, 1H), 2.8–0.6 (m, 42H), 1.12 (s, 3H), 0.94 (d, J=6.6 Hz,3H), 0,90 (d, J=6.6 Hz, 6H), 0.71 (s, 3H) ppm; ^{13}C NMR (50 MHz, $CDCl_3$) δ 159.3, 147.2, 138.7, 130.1, 129.6, 121.1, 119.9, 118.8, 56.0, 55.9, 54.1, 42.3, 39.7, 39.4, 38.3, 36.0, 35.7, 33.4, 32.6, 28.1, 27.9, 25.1, 24.1, 23.7, 22.7, 22.5, 21.2, 18.6, 18.0, 11.9 ppm; IR (CH_2Cl_2) 2934, 1601, 1454, 1377, 1367, 1083 cm^{-1}; MS (*m*/*z*) 432, 417, 281, 207, 170, 156, 144, 130, 91, 83; Anal. Calcd for

$C_{32}H_{48}$ (432.6): C 88.82, H 11.18. Found C 86.65, H 11.22; mp 130°C; $[\alpha]_D^{20}=+228.3$ (0.60, CH_2Cl_2).

4.1.2. 4-Pregnene-3-(2,4-cyclopentadien-1-ylidene)-20-one 8b. 4-Pregnene-3,20-dione (1.570 g, 5 mmol) was converted into **8b** according to the general procedure. Purification by flash chromatography (dichloromethane) afforded **8b** as an orange solid (1.390 g, 76%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 6.7–6.6 (m, 1H), 6.6–6.5 (m, 2H), 6.5–6.4 (m, 2H), 3.00 (dt, J=16.2, 4.0 Hz, 1H), 2.8–0.6 (m, 28H), 2.14 (s, 3H), 1.13 (s, 3H), 0.67 (s, 3H) ppm; ^{13}C NMR (50 MHz, $CDCl_3$) δ 209.5, 158.4, 146.6, 139.0, 130.2, 129.7, 121.3, 119.9, 118.8, 63.5, 56.1, 53.9, 43.9, 38.7, 38.3, 36.1, 35.6, 33.2, 32.5, 31.4, 29.6, 25.1, 24.3, 22.7, 21.2, 18.0, 13.2 ppm; IR (KBr) 2927, 2848, 1701, 1616, 1456, 1389 cm^{-1}; MS (*m/z*) 362, 347, 319, 170, 156, 144, 129, 91; Anal. Calcd for $C_{26}H_{34}O$ (362.5): C 86.13, H 9.45. Found C 85.89, H 9.32; mp 161°C; $[\alpha]_D^{20}=+444.1$ (0.76, CH_2Cl_2).

4.1.3. Androstan-3-(2,4-cyclopentadien-1-ylidene)-4-ene-17β-ol 8c. Androstan-4-ene-17β-ol-3-one (146 mg, 0.5 mmol) was converted into **8c** according to the general procedure. Purification by flash chromatography (dichloromethane) afforded **8c** as a red solid (130 mg, 76%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 6.64 (m, 1H), 6.54 (m, 2H), 6.47 (m, 2H), 3.64 (t, J=8.1 Hz; 1H), 3.02 (dt, J=16.3, 3.7 Hz, 1H), 0.8–2.7 (m, 18H), 1.14 (s, 3H), 0.80 (s, 3H) ppm; ^{13}C NMR (50 MHz, $CDCl_3$) δ 158.9, 147.1, 140.0, 130.3, 129.8, 121.4, 120.0, 118.9, 81.8, 54.3, 50.6, 42.9, 38.5, 36.6, 36.2, 35.9, 33.3, 32.2, 30.5, 25.2, 23.4, 20.9, 18.1, 11.1 ppm; IR (CH_2Cl_2) 3608, 3054, 2850–2950, 1606, 1455, 1422, 1370, 895 cm^{-1}; MS (*m/z*) 336, 170, 156, 144, 129, 115, 105, 84; Anal. Calcd for $C_{24}H_{32}O$ (336.5): C 85.66, H 9.59. Found C 85.30, H 9.74; mp 202°C; $[\alpha]_D^{20}=+329.6$ (0.54, CH_2Cl_2).

4.1.4. 5α-Androstan-3-(2,4-cyclopentadien-1-ylidene)-17β-ol 10. 5α-Androstan-17β-ol-3-one (1.162 g, 4 mmol) was converted into **10** according to the general procedure. Purification by flash chromatography (dichloromethane) afforded **10** as a yellow solid (1.010 g, 72%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 6.58 (m, 2H), 6.50 (m, 2H), 3.63 (t, J=7.9 Hz, 1H), 2.98 (bd, J=14.3 Hz, 1H), 2.58 (bd, J=14.0 Hz, 1H), 0.7–2.5 (m, 20H), 0.99 (s, 3H), 0.76 (s, 3H) ppm; ^{13}C NMR (200 MHz, $CDCl_3$) δ 157.9, 139.1, 130.5(2), 119.9, 119.7, 81.8, 54.3, 50.8, 48.3, 42.9, 40.2, 36.6, 36.5, 36.1, 35.4, 31.4, 30.4, 29.4, 28.8, 23.3, 20.7, 12.0, 11.1 ppm; IR (CH_2Cl_2) 3405, 2850–2950, 1635, 1467, 1447, 1370, 1047, 767 cm^{-1}; MS (*m/z*) 338, 323, 310, 171, 157, 145, 131, 117, 105, 91; Anal. Calcd for $C_{24}H_{34}O$ (338.5): C 85.15, H 10.12; found C 80.34, H 9.81; mp 195°C; $[\alpha]_D^{20}=+18.5$ (0.27,CH_2Cl_2).

4.1.5. 4-Cholesten-3β-cyclopentadienyletricarbonylerhenium-3α-methyl 14. MeLi (1.6 M, 150 mL, 0.25 mmol) was added to a solution of fulvene **8a** (80 mg, 0.2 mmol) in toluene (1 mL) at −78°C. The solution was slowly warmed to room temperature (2.5 h) and $BrRe(CO)_5$ (162 mg, 0.4 mmol) was added. The resulting reaction mixture was heated to reflux for 15 h, cooled to room temperature, diluted in CH_2Cl_2 (5 mL), washed with brine (3×5 mL), dried over $MgSO_4$ and concentrated. Purification by flash chromatography (pentane) afforded a mixture of **14**α and **14**β (54 mg, 39%) as a white solid. A sample of **14** was obtained from the mixture by crystallisation (CH_2Cl_2/hexane) for further analysis.

14α: ^{1}H NMR (200 MHz, $CDCl_3$) δ 5.3–5.1 (m, 4H), 5.02 (bs, 1H), 2.2–0.6 (m, 31H), 1.23 (s, 3H), 1.05 (s, 3H), 0.91 (s, 3H) 0.89 (s, 3H), 0.71 (s, 3H) ppm; ^{13}C NMR (50 MHz, $CDCl_3$) δ 194.6, 145.0, 126.7, 122.1, 84.2, 82.8, 81.6, 56.2, 54.3, 42.5, 39.9, 39.5, 37.1, 36.2, 35.9, 35.8, 35.4, 35.0, 34.5, 33.0, 32.5, 29.7, 28.4, 28.2, 28.0, 24.2, 23.8, 22.8, 22.5, 21.5, 19.2, 18.6, 12.0 ppm; IR (KBr) 2932, 2012, 1929, 1467, 1381 cm^{-1}; MS (*m/z*) 718, 703, 690, 661, 628, 427, 415, 119; Anal. Calcd for $C_{36}H_{51}O_3Re$ (718.0): C 60.22, H 7.16. Found C 60.25, H 7.10; mp 195°C.

14β: ^{1}H NMR (200 MHz, $CDCl_3$) δ 5.4–5.2 (m, 2H), 5.2–5.1 (m, 2H), 4.94 (bs, 1H), 2.2–0.6 (m, 46H) ppm; ^{13}C NMR (50 MHz, $CDCl_3$) δ 194.7, 145.8, 125.5, 118.8, 86.7, 83.5, 82.3, 82.0, 56.1, 55.1, 39.9, 39.5, 37.1, 36.0, 35.7, 35.5, 35.3, 35.0, 33.9, 33.0, 32.5, 29.3, 28.4, 28.2, 24.2, 23.8, 22.8, 22.5, 21.6, 19.3, 18.6, 12.0 ppm.

4.2. General procedure for the preparation of the $CpRe(CO)_3$ substituted steroids

Fulvene (0.25 mmol), KH (12 mg, 0.3 mmol) washed twice with pentane and $BrRe(CO)_5$ (122 mg, 0.3 mmol) in THF/toluene (2 mL/2 mL) were refluxed for 2 h. The reaction mixture was cooled to room temperature and diluted in CH_2Cl_2 (20 mL). The organic layer was washed with brine (2×20 mL), dried ($MgSO_4$), filtered and concentrated.

4.2.1. Cholestan-3-cyclopentadienyletricarbonylerhenium-3,5-diene 15a. 4-Cholesten-3-(2,4-cyclopentadien-1-ylidene) **8a** (108 mg, 0.25 mmol) was converted into **15a** according to the general procedure. Purification by flash chromatography (dichloromethane/pentane=95:5) afforded **15a** as a white solid (118 mg, 67%).

Crystal data for $C_{35}H_{47}O_3Re$: M=701.93, orthorhombic, a=10.525 (2), b=11.477 (2), c=26.102 (2) Å, U=3152.81 (8) Å^3, T=296 K, space group $P2_12_12_1$, Z=4, μ=3.886 mm^{-1}, 21,696 reflections measured, 8160 unique (R_{int}=0.0413) which were used in all calculations. The final wR(F^2) is 0.0511 (all data), R_1=0.0293.

^{1}H NMR (200 MHz, $CDCl_3$) δ 6.26 (sl, 1H), 5.5–5.6 (m, 3H), 5.3–5.2 (m, 2H), 0.9–2.4 (m, 29H), 0.95 (s, 3H), 0.91 (s, 3H), 0.87 (s, 3H), 0.73 (s, 3H) ppm; ^{13}C NMR (50 MHz, $CDCl_3$) δ 194.4, 141.1, 126.7, 126.6, 124.8, 110.7, 84.4, 83.2, 79.8, 79.4, 56.8, 56.1, 48.1, 42.4, 39.7, 39.5, 36.2, 35.8, 34.9, 33.4, 32.0, 31.7, 28.2, 28.0, 24.6, 24.1, 23.8, 22.8, 22.5, 21.0, 19.0, 18.7, 12.0 ppm; IR (KBr) 2850–2950, 2020, 1900, 1466, 822 cm^{-1}; MS (*m/z*) 702, 614, 441; Anal. Calcd for $C_{35}H_{47}O_3Re$: C 59.89, H 6.75. Found C 59.76, H 6.89; mp 180°C; $[\alpha]_D^{20}=-79.3$ (0.58, CH_2Cl_2).

4.2.2. Pregnan-3-cyclopentadienyletricarbonylerhenium-3,5-diene-20-one 15b. 8b (326 mg, 0.9 mmol) was converted into **15b** according the general procedure. Purification by flash chromatography (pentane/ether=80:20) afforded **15b** (45%) as a white solid ^{1}H NMR (200 MHz,

$CDCl_3$) δ 6.23 (bs, 1H), 5.6–5.4 (m, 3H), 5.4–5.2 (m, 2H), 2.55 (t, J=8.8 Hz, 1H), 2.4–0.6 (m, 17H); 2.13 (s, 3H), 0.92 (s, 3H), 0.57 (s, 3H) ppm; ^{13}C NMR (50 MHz, $CDCl_3$) δ 210.0, 194.4, 141.0, 126.5, 126.1, 125.0, 110.5, 84.5, 83.4, 79.8, 79.5, 63.7, 57.0, 47.9, 44.1, 38.8, 34.9, 33.4, 31.9, 31.7, 31.6, 24.6, 24.4, 22.8, 21.0, 13.4 ppm; IR (KBr) 2942–2840, 2013, 1931, 1703 cm^{-1}; $[\alpha]_D$=−35.5 (0.60, CH_2Cl_2).

4.2.3. Androstan-3-cyclopentadienyle tricarbonyle rhenium-3,5-diene-17β-ol 15c. FLB11 (84 mg, 0.25 mmol) was converted into **15e** according to the general procedure. Purification by flash chromatography (pentane/ether=70:30) afforded **15c** as a white solid (70 mg, 46%). ^{1}H NMR (200 MHz, $CDCl_3$) δ 6.25 (s, 1H), 5.53 (m, 3H), 5.34 (m, 1H), 5.30 (m, 1H), 3.67 (t, J=8.0 Hz, 1H), 0.8–2.3 (m, 17H), 0.95 (s, 3H), 0.80 (s, 3H) ppm; ^{13}C NMR (50 MHz, $CDCl_3$) δ 194.3, 141.1, 126.5, 126.1, 124.9, 105.3, 84.4, 83.2, 81.7, 79.7, 79.4, 51.4, 48.1, 42.8, 36.4, 34.9, 33.4, 31.7, 31.5, 30.4, 24.5, 23.2, 20.6, 18.9, 11.0 ppm; IR (CH_2Cl_2) 3615, 2850–2945, 2020, 1930 cm^{-1}; MS (*m/z*) 606, 591, 574, 223, 205, 149, 97; Anal. Calcd for $C_{27}H_{31}O_4$ (605.8): C 53.53, H 5.16. Found C 53.24, H 5.56; mp 195°C; $[\alpha]_D$ −95.8 (0.43, CH_2Cl_2).

4.2.4. Compounds 16a and 16b. Compound **10** (85 mg, 0.25 mmol) was converted into **16a** and **16b** according to the general procedure. Purification by flash chromatography (pentane/ether=60:40) afforded **16a** and **16b** as a mixture of diastereomers (white solid) (52 mg, 34%). IR (CH_2Cl_2) 3357, 2809–2975, 2026, 1959, 1909, 1443 cm^{-1}; MS (*m/z*) 608, 518, 388, 360, 330, 149, 81; Anal. Calcd for $C_{27}H_{33}O_4$ (607.76): C 53.36, H 5.47. Found C 52.75, H 5.57

Major isomer: **5α-Androstan-3-cyclopentadienyle tricarbonyle rhenium-2-ene-17β-ol 16a.** ^{1}H NMR (200 MHz, $CDCl_3$) δ 5.98 (dl, J=5.27, 1H), 5.45 (m, 2H), 5.31 (q, J=2.2 Hz, 1H), 5.26 (q, J=2.2 Hz, 1H), 3.64 (t, J=8.1 Hz, 1H), 0.6–2.2 (m, 20H), 0.75 (s, 6H) ppm; ^{13}C NMR (50 MHz, $CDCl_3$) δ 194.4, 126.6, 124.4, 110.9, 84.0, 83.1, 81.2, 79.4, 79.1, 53.7, 50.8, 42.7, 41.2, 39.9, 36.5, 35.4, 34.5, 31.7, 31.1, 30.3, 28.3, 23.2, 20.5, 11.7, 10.9 ppm.

Minor isomer: **5α-Androstan-3-cyclopentadienyle tricarbonyle rhenium-3-ene-17β-ol.** ^{13}C NMR (50 MHz, $CDCl_3$) δ 129.9, 126.3, 110.5, 82.9, 80.1, 53.2, 46.3, 43.1, 35.3, 34.0, 31.5, 27.3, 25.1, 20.7, 12.2, 11.2 ppm.

References

1. Jaouen, G.; Top, S.; Vessières, A.; Alberto, R. *J. Organomet. Chem.* **2000**, *600*, 23–36.
2. Special issue dedicated to bioorganometallic chemistry: *J. Organomet. Chem.* **1999**, *589*.
3. Le Bideau, F.; El Kaloun, B.; Haquette, P.; Kernbach, U.; Marrôt, J.; Stephan, E.; Top, S.; Vessières, A.; Jaouen, G. *J. Chem. Soc., Chem. Commun.* **2000**, 211–212.
4. Knox, L. H. US Patent 3066155 (CL. 260-397.3).
5. Thiele, J. *Chem. Ber.* **1900**, *33*, 666–672.
6. Stone, K. J.; Little, R. D. *J. Org. Chem.* **1984**, *49*, 1849–1853.
7. Erker, G.; Mollenkopf, C.; Grehl, M.; Schönecker, B. *Chem. Ber.* **1994**, *127*, 2341–2345.
8. Erker, G.; Mollenkopf, C. *J. Organomet. Chem.* **1994**, *483*, 173–181.
9. Knox, G. R.; Pauson, P. L. *J. Chem. Soc.* **1961**, 4610–4615.
10. Knox, G. R.; Munro, J. D.; Pauson, P. L.; Smith, G. H.; Watts, W. E. *J. Chem. Soc.* **1961**, 4619–4624.
11. Macomber, D. W.; Hart, W. P.; Raush, J. *J. Am. Chem. Soc.* **1982**, *104*, 884–886.
12. Abbenhuis, H. C. L.; Burckhardt, V.; Gramlich, V.; Togni, A.; Albinati, A.; Müller, B. *Organometallics* **1994**, *13*, 4481–4493.
13. Still, W. C.; Khan, M.; Mitra, A. J. *J. Org. Chem.* **1978**, *43*, 2923–2925.