Keywords: Allylic oxidation; TBHP; Chromium; Steroids

Introduction

The oxidation of the B ring in steroidal compounds leads to products exhibiting numerous biological functionalities. Ring B oxidized sterols and steroids have shown anti-cancer activity [1-3]. 7-Ketodehydroepiandrosterone has been shown to improve the memory of mice [4] and 3-acyetyl-7-oxo-DHEA increases the resting metabolism of persons on calorie restrictive diets [5]. 7-Ketopregnenolone has shown anti-cortisone properties [6]. 7-Ketocholesterol has shown some regulatory function in the biosynthesis of cholesterol [7]. Furthermore, B ring oxidized steroidal compounds may be used as synthetic reagents to make other steroidal products, such as a steroidal pyrazoline [8].

Several Δ7 allylic oxidation methods leading to enone formation have been reported and are catalogued in this review. The Δ7 steroidal olefins are very common. Other steroidal olefins, with the exception of Δ5 olefins perhaps, are much less common. As the precursor of steroids, cholesterol's Δ5 moiety is retained until the steroids are enzymatically isomerized [9]. Thus, methods stated in this review have many potential steroidal substrates.

There are three allylic carbons (C4, C7 and C10) to the C5 double bond in a typical steroidal nucleus before isomerization to Δ7. The C10 carbon is a stable quaternary carbon. Thus, allylic oxidation occurs only at C4 and C7, albeit not equally. The C4 carbon is located on the sterically hindered β side with its axial hydrogen extending also in the β direction. On the other hand, the C7 carbon is located on the exposed a side with its axial hydrogen extending further in the α direction [10]. There is also an energetic advantage for C7 oxidation. Resonance originating from C7 oxidation is more energetically favored than resonance originating from C4 oxidation due to delocalization to the tertiary C5 carbon rather than to the secondary C6 carbon. It was calculated that radical oxidation at C7 is favored by ~4.65 kcal/mol over C4 on a two ring system containing the A and B ring moiety of cholesterol [11] (Figure 1). It should be noted as an exception that selenium complexes have been reported to oxidize C4 rather than C7 [12,13].

Steroidal compounds can be fairly resistant to deprotonation, especially within the B ring. Ring strain, that is incurred from the sp3 to sp2 hybridization change (bond angle distortion), is higher than that of non-fused ring systems due to "conformational transmission" [14]. Perhaps this explains why the oxidative methods surveyed in Tables 1-3 occur exclusively through a radical mechanism. With respect to the radical mechanism, it is important to note that tertiary carbons are present on steroidal compounds that can be radically oxidized leading to undesired side products, one in particular being C25 for steroids with side chains [15]. Furthermore, cleavage of the side chain can occur concurrent with allylic oxidation [16].

Protecting the C3 hydroxy group is commonly accomplish by esterification using acetic anhydride to make cholesterol acetate. The authors of this review prefer esterification with benzoyl chloride since cholesterol benzoate products can be more easily isolated with recrystallization in acetone and water than the steroidal acetates. This esterification is necessary because many oxidants and catalysts will convert the C3 hydroxyl group to a ketone [17].

Due to interest in "green" or environmentally benign chemistry, chemists have questioned the ethics of earlier catalysts. Environmental and health concerns have motivated the search for new oxidants and catalysts [18]. From chromium based catalysts, the next phase in steroidal allylic oxidation manifested through more environmentally friendly metallic catalysts that use TBHP as an oxygen donor. Meanwhile, several methods have been reported to give steroidal oxidation without any metal catalysts using as sodium chlorite and sodium hypochlorite [19,20]. Additionally, recoverable heterogeneous catalysts, clay

*Corresponding author: Edward JP, Department of Chemistry and Biochemistry, College of Science and Mathematics, Auburn University, Auburn, Alabama 36849-5319, USA, 179 Chemistry Bldg. Tel: 334-844-4043; Fax: 334-844-6959; E-mail: parisej@auburn.edu

Received February 24, 2016; Accepted March 28, 2016; Published April 02, 2016

Citation: Wendell SG, Edward JP (2016) A Short Review of Methods for the Allylic Oxidation of Δ5 Steroidal Compounds to Enones. J Steroids Horm Sci 7: 171. doi:10.4172/2157-7536.1000171

Copyright: © 2016 Wendell SG, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.
Substrate: Cholesterol

| Catalysts, Reagents, Solvents and Conditions | TBHP used as Oxidant (Yes/No) | Date Reported | % Yield Reported | Reference # |
|---------------------------------------------|-------------------------------|---------------|-----------------|-------------|
| Rh<sub>2</sub>(cap)<sub>4</sub>, DCM (DCE), r.t, 15 h | Yes | 2009 | 30 | [26] |
| Rh<sub>2</sub>(cap)<sub>4</sub>, DCM (DCE), r.t, 20 h | Yes | 2007 | 63 | [27] |
| NaOCl, DCE, 4°C, 10 h | Yes | 2004 | 68 | [20] |
| CrO<sub>3</sub>/NHPI-activated clay, DCM, r.t, 58 h | No | 2009 | 52 | [21] |
| 2-quinoloxalin salen Cu(II) complex catalyst, Acetonitrile, 70°C, 12 h | Yes | 2010 | 69 | [11] |
| RuCl<sub>3</sub>, Cyclohexane, r.t, 24 h | Yes | 1996 | 51 | [28] |
| VOCl<sub>3</sub>, r.t, 5 days | Yes | 2015 | 45 | [29] |

Table 1: Cholesterol to 7-ketocholesterol.

Substrate: DHEA

| Catalysts, Reagents, Solvents and Conditions | TBHP used as Oxidant (Yes/No) | Date Reported | % Yield Reported | Reference # |
|---------------------------------------------|-------------------------------|---------------|-----------------|-------------|
| Rh<sub>2</sub>(cap)<sub>4</sub>, DCE, 40°C, 20 h | Yes | 2007 | 74 | [27] |
| NaOCl, Ethyl acetate/Tert-butanol (8:2), 4°C, 10 h | Yes | 2004 | 70 | [20] |
| CrO<sub>3</sub>/NHPI-activated clay, DCM, r.t, 58 h | No | 2009 | 67 | [21] |
| BCl<sub>3</sub>, Acetonitrile, 70°C, 28 h | Yes | 2005 | 80 | [30] |
| BCl<sub>3</sub>/K-10, Acetonitrile, 70°C, 11 h | Yes | 2005 | 77 | [30] |
| NaClO<sub>2</sub>, Acetonitrile/Water (2:1), 50°C, 20 h | Yes | 2007 | 65 | [19] |
| NaClO<sub>2</sub>/NHPI, Acetonitrile/Water (2:1), 50°C, 11 h | No | 2007 | 50 | [19] |
| VOCl<sub>3</sub>, r.t, 5 days | Yes | 2015 | 19 | [29] |

Table 2: DHEA to 7-keto DHEA.

Supported and organometallic polymer catalysts, have been reported to yield allylic oxidation products of steroidal compounds [21–23].

**Reported Methods**

The following Tables 1-5 are divided by substrates used in our allylic oxidation reaction with TBHP and vanadium complexes. Reagents, conditions, dates, and isolated yields reported for various steroidal allylic oxidation reactions are displayed. All reagents are listed, with TBHP given a special column (TBHP was mainly, if not exclusively used).

Caution must be taken when comparing the reported yields because there were various methods used to identify "isolated" yields (using HPLC instead of obtaining mass for example) [20], differing standards on purity of the isolated product (i.e., reporting an isolated yield that is 67% pure) [19], differing sampling sizes, and an overall lack of supporting information. Several reported steroidal allylic oxidation reactions have not been included in the tables due to low yields of 7-keto product, such as oxygen irradiation with and without photosensitizer [24] and Gif chemistry [25].

The importance of identifying TBHP usage in allylic oxidation reactions is that those reactions share a similar intermediate. It has been noted, “that different catalysts produce essentially the same mixture of products with the same relative yields suggests that the catalyst is not involved in product-forming steps” [26]. Indeed, tert-butoxide and tert-butyl peroxy radicals are formed through degradation of TBHP by catalysts. Those radicals then oxidize steroidal compounds [19,20,26-33,36].

All of the reactions in Table 1-5 can be funneled, generally speaking, into two mechanisms. The first mechanism, oxidation through formation of a C7 peroxide, is shared by auto-oxidation, TBHP-metal...
Substrate: Pregnenolone

| Catalysts, Reagents, Solvents and Conditions | TBHP used as Oxidant (Yes/No) | Date Reported | % Yield Reported | Reference # |
|---------------------------------------------|-------------------------------|---------------|------------------|-------------|
| Rh_{(cap)}_4, DCE, 40°C, 20 h | Yes | 2007 | 40 | [27] |
| CrO_3/NHPI-activated clay, DCM, r.t, 58 h | No | 2009 | 54 | [21] |
| 2-Quinoxalinol salen Cu(II) complex catalyst, Acetonitrile, 0°C, 12 h | Yes | 2010 | 53 | [11] |
| VOCl_3, r.t., 5 days | Yes | 2015 | 24 | [29] |

Table 3: Pregnenolone to 7-ketopregnenolone.

Substrate: Cholesteryl Acetate

| Catalysts, Reagents, Solvents and Conditions | TBHP used as Oxidant (Yes/No) | Date Reported | % Yield Reported | Reference # |
|---------------------------------------------|-------------------------------|---------------|------------------|-------------|
| Co(OAc)_2/SiO_2, Benzene, 50°C, 24 h, N_2 | Yes | 2001 | 70 | [22] |
| ZrO_2/SiO_2/Cr(VI), Benzene, r.t, pH 3 | Yes | 1999 | 48 | [31] |
| RuCl_3, Cyclohexane, r.t, 24 h | Yes | 1996 | 51 | [28] |
| Rh_{(cap)}_4, DCE, 40°C, 20 h | Yes | 2007 | 80 | [27] |
| Ti(acac)_3, Benzene, 80°C, 24 h, Ar | Yes | 1981 | 25 | [32] |
| 98% VO(acac)_2, Benzene, 80°C, 24 h, Ar | Yes | 1981 | 26 | [32] |
| Cr(acac)_3, Benzene, 80°C, 24 h, Ar | Yes | 1981 | 52 | [32] |
| Mn(acac)_3, Benzene, 80°C, 24 h, Ar | Yes | 1981 | 11 | [32] |
| Mn(acac)_2, Benzene, 80°C, 24 h, Ar | Yes | 1981 | 10 | [32] |
| Fe(acac)_3, Benzene, reflux, 24 h, Ar | Yes | 1979 | 74 | [32] |
| Co(acac)_2, Benzene, 80°C, 24 h, Ar | Yes | 1981 | 12 | [32] |
| Co(acac)_3, Benzene, 80°C, 24 h, Ar | Yes | 1981 | 43 | [32] |
| Ni(acac)_2, Benzene, 80°C, 24 h, Ar | Yes | 1981 | 38 | [32] |
| Cu(acac)_3, Benzene, 80°C, 24 h, Ar | Yes | 1981 | 83 | [32] |
| Ce(acac)_2, Benzene, 80°C, 24 h, Ar | Yes | 1981 | 24 | [32] |
| Cu(OAc)_2/SiO_2, Benzene, 70°C, 48 h, N_2 | Yes | 2002 | 72 | [23] |
| Cu, Acetonitrile, reflux, 4 h | Yes | 2003 | 79 | [33] |
| Cu/TBAB, DCM, reflux, 4 h | Yes | 2003 | 76 | [33] |
| GrO/Py, Trifluorotoluene, r.t, 31 h, N_2 | Yes | 2006 | 76 | [34] |
| CrO/Py, DCM, r.t, 24 h, N_2 | No | 1969 | 74 | [10] |
| PCC, DCM, 40°C, 66 h | Yes | 2006 | 41 | [34] |
| GrO_2Acetonitrile/Benzene (9:1), reflux, 72 h, N_2 | No | Note | 48 |
| Cr(CO)_6, Acetonitrile, reflux, 15 h | Yes | 1985 | 80 | [35] |
| Mn(OOac)_3, Ethyl Acetate, 40°C, 48 h, N_2 | Yes | 2006 | 87 | [36] |
| NaOCl, DCE, 4°C, 10 h | No | 2004 | 68 | [20] |
| 2-Quinoxalinol salen Cu(II) complex catalyst, Acetonitrile, 70°C, 12 h | Yes | 2010 | 97 | [11] |
| BCl_3, Acetonitrile, 70°C, 22 h | Yes | 2005 | 82 | [30] |
Table 4: Cholesteryl acetate to 7-ketocholesteryl acetate.

| Substrate: Cholesteryl Benzoate’ | Catalysts, Reagents, Solvents and Conditions | TBHP used as Oxidant (Yes/No) | Date Reported | % Yield Reported | Reference # |
|----------------------------------|---------------------------------------------|------------------------------|---------------|-----------------|-------------|
| Cholesteryl Benzoate             | PFC, Benzene, reflux, 48 h, N₂              | No                           | 1996          | 88              | [37]        |
|                                  | CrO₂, Acetonitrile/benzene (9:1), reflux, 72 h, N₂ | No                           | Note          | 52              | [35]        |
|                                  | CrO₃/DMP, DCM, -10°C to -20°C, 4 h           | No                           | 1978          | 75              | [38]        |
|                                  | PCC, Benzene, refluxed, 24 h, N₂             | No                           | 1987          | 87              | [39]        |
|                                  | VOCl₃, r.t, 5 days                           | Yes                          | 2015          | 88              | [29]        |

Table 5: Cholesteryl benzoate to 7-ketocholesteryl benzoate.

Figure 2: TBHP and singlet oxygen oxidation’s shared mechanism. 5,6-epoxicholesterol may be a side product.

Figure 3: Suggested mechanism of allylic oxidation by chromium [38].

Figure 4: Hydrogen abstraction in benzophenoneaminocholestene [43].

oxidation, and hypochlorite oxidation. In auto-oxidation, a peroxide is formed via singlet oxygen (ene reaction) at the C5 carbon [24], which rearranges to the C7 position [40,41]. Likewise, TBHP degradation by metal leads to radicals that form a C7 peroxide. Bleach initiates radical formation from TBHP, similar to the metal catalysts [20]. When only sodium chlorite and NHPI are used, NHPI becomes phthalimide N-oxyl (PINO), a radical initiator of molecular oxygen [19]. Those radicals in addition to radicals formed from ClO₂ lead to a C7 peroxide. The C7 peroxide degrades to form a ketone or hydroxyl group [40-42] (Figure 2).

The second mechanism is that of oxidation via chromium reagent. During the first step of the suggested mechanism (Figure 3), there is complexation of chromium and a ligand containing a functional group, imine preferably, such as DMP or pyridine. After complexation, the ligand abstracts the C7 hydrogen leaving a resonating steroidal radical. An oxo group on the chromium complex will terminate the radical, reducing the chromium. Oxidation of the steroid then proceeds in an unspecified manner. It is important to note that the chromium complex may be monomeric [38].

Acetonitrile, benzene, pyridine, DCM, DCE, trifluorotoluene, 1,4-dioxane/water, and cyclohexane were used as solvents in Tables 1-5. Using laser flash photolysis and benzophenoneaminocholestene, it has been shown that the C7 hydrogens are abstracted at a much greater rate (more than double) in DCM than in acetonitrile, dioxane, and
methanol [43] (Figure 4). Thus, the least polar solvents appear to work best for allylic oxidation. This is, however, limited by the solubility of the steroidal substrate.

**Conclusion**

Converting Δ5 steroidal compounds to their corresponding enones is an endeavor that has spanned several decades. The authors of this review suggest that all of the oxidative methods found within this review utilize one of two general mechanisms. One mechanism involves formation of a peroxide at the allylic position and the other achieves oxidation through reduction of a chromium complex. Both mechanisms occur via radical formation. Various solvents were used in the reported methods, but flash photolysis experiments from at least one article indicate that nonpolar solvents may be more effective.

**References**

1. Carvalho JF, Silva MM, Moreira JN, Simões S, Sá e Melo ML (2010) Sterols as anticancer agents: synthesis of ring-B oxygenated steroids, cytotoxic profile, and comprehensive SAR analysis. J Med Chem 53: 7632-7638.
2. Parish EJ, Chittrakorn S, Luu B, Schmidt G, Ourisson G (1989) Studies of the oyster inhibition of tumor cell growth. Steroids 53: 579-596.
3. de Medina P, Paillasse MR, Ségalà G, Khaloufi F, Brillouet S, et al. (2011) Importance of cholesterol and oxysterols metabolism in the pharmacology of tamoxifen and other AEBs ligands. Chim Phys Lipsid 164: 432-437.
4. Shi J, Schulze S, Lardy HA (2000) The effect of 7-oxo-DHEA acetate on memory in young and old C57BL/6 mice. Steroids 65: 124-129.
5. Zenk JL, Frestedt JL, Kuskowski MA (2007) HUM5007, a novel combination of thermogenic compounds, and 3-acetyl-7-oxo-dehydroyiandrosterone: each increases the resting metabolic rate of overweight adults. J Nutr Biochem 18: 629-634.
6. Marshall CW, Ray RE, Laos I, Riegel B (1957) 7-Keto Steroids. II. Steroidal Syntheses and Anti-tumor Evaluation of B-ring substituted steroidal pyrazoline derivatives. Steroids 78: 1263-1272.
7. Kandutsch AA, Chen HW (1973) Inhibition of sterol synthesis in cultured mouse cells by Talpha-hydroxycholesterol, Tbeta-hydroxycholesterol, and 7-ketoscholesterol. J Biol Chem 248: 8408-8417.
8. Shamsuzzaman, Khaman H, Mashrai A, Sherwani A, Owais M, et al. (2013) Synthesis and anti-tumor evaluation of 2-ring substituted steroidal pyrazoline derivatives. Steroids 78: 1263-1272.
9. Ghayee KY, Auchs RJ (2007) Basic concepts and recent developments in human steroid hormone biosynthesis. Rev Endocr Metab Disord 8: 289-300.
10. Dauben WG, Lorber ME, Fullerton DS (1969) Oxidation of Olefins with Chromium Trioxide-Pyridine Complex. J Org Chem 34: 3587-3592.
11. Li Y, Wu X, Lee TB, Isbell EK, Parish EJ, et al. (2010) An effective method for allylic oxidation of Delta5-steroids using tert-butyl hydroperoxide. J Org Chem 75: 1807-1810.
12. Barton DHR, Crich D (1985) Oxidation of Olefins with 2-Pyridinesulfenyl Imidhydride. Tetrahedron 41: 4359-4364.
13. Crich D, Zou Y (2004) Catalytic allylic oxidation with a recyclable, fluorocyclic seleniumic acid. Org Lett 6: 775-777.
14. Barton DHR, Head AJ, May PJ (1957) Long-range Effects in Alicyclic Systems. Part II. The Rates of Condensation of Some Triphenylketones with Benzaldehyde. J Chem Soc (Resumed) pp: 935-944.
15. Parish E, Aikara N, Boos T, Kizito S (1998) Methodology and Synthetic Studies on the Remote Functionalization of Steroid Side Chains. Rec Res Devol Org Chem 2: 95-105.
16. Takano S, Sato S, Ogasawara K (1985) Simple Synthesis of 38, 24-Dihydroxycholest-5-en-Tone by Oxidative Cleavage of the Side Chain of Cholesterol. Chem Lett 14: 1265-1266.
17. Parish EJ, Kizito SA, Qiu Z (2004) Review of chemical syntheses of 7-keto-delta5-steroids. Lipids 39: 801-804.
18. Salvador Jar, Silva,RM, Moreira VM (2006) Catalytic Oxidative Processes in Steroid Chemistry: Allylic Oxidation, 8-Selective Epoxidation, Alcohol Oxidation and Remote Functionalization Reactions Current Organic. Curr Org Chem 10: 2227-2257.
19. Silvestre SM, Salvador Jar (2007) Allylic and Benzylidane Oxidation Reactions with Sodium Chlorite. Tetrahedron 63: 2439-2445.
20. Marwan P, Marwan A, Lardy HA (2004) An Economical and Green Approach for the Oxidation of Olefins to Enones. Green Chem 6: 570-577.
21. Liu J, Zhu HY, Cheng XH (2009) CrO3/NH2PF Adsorbed on Activated Clay: A New Supported Reagent for Allylic Selective Oxidation of 5-Sterols. Synthetic Communications 39: 1076-1083.
22. Salvador Jar, Clark JH (2001) The Allylic Oxidation of Unsaturated Steroids by tert-Butyl Hydroperoxide Using Homogenous and Heterogenous Cobalt Acetate. Chem Comm pp: 33-34.
23. Salvador Jar, Clark JH (2002) The Allylic Oxidation of Unsaturated Steroids by tert-Butyl Hydroperoxide Using Surface Functionalised Silicon Supported Metal Catalysts. Green Chem 4: 352-356.
24. Kulig MJ, Smith LL (1973) Sterol metabolism. XXXV. Cholesterol oxidation by singlet molecular oxygen. J Org Chem 38: 3639-3642.
25. Barton DHR, Bovin J, Hill CH (1986) Functionalisation of Saturated Hydrocarbons. Part 6. Selective Oxidation of Steroids and Related Compounds. J Chem Soc Perkin Trans pp: 1797-1804.
26. McLaughlin EC, Choi H, Wang K, Chichu G, Doyle MP (2009) Allylic Oxidations catalyzed by dirhodium caprolactamate via aqueous tert-butyl hydroperoxide: the role of the tert-butylperoxy radical. J Org Chem 74: 730-738.
27. Choi H, Doyle MP (2007) Optimal TBHP allylic oxidation of Delta5-steroids catalyzed by dirhodium caprolactamate. Org Lett 9: 5349-5352.
28. Miller RA, Li W, Humphrey GR (1996) A Ruthenium Catalyzed Oxidation of Steroidal Alkenes to Enones. Tetrahedron Lett 37: 3429-3432.
29. Gnaginger WS, Parish EJ (2015) Allylic oxidation of steroidal olefins by vanadyl acetylacetonate and tert-butyl hydroperoxide. Steroids 101: 103-109.
30. Salvador Jar, Silvestre SM (2005) Bismuth-Catalyzed Allylic Oxidation Using t-Butyl Hydroperoxide. Tetrahedron Lett 46: 2581-2584.
31. Baptista LHS, Sousa IM, Gushikem Y, Aleixo AM (1999) Chromium (VI) Adsorbed on SiO2/ZrO2, a New Supported Reagent for Allylic Oxidations. Tetrahedron Lett 40: 2695-2698.
32. Kinmura M, Muto T (1981) The Reactions of Cholesteryl Acetate with tert-Butyl Hydroperoxide and Molybdenum Complexes. Chem Pharm Bull 29: 35-42.
33. Ansenou ES, Koutsourea AI, Frousteris MA, Nikolaropoulos SS (2003) Optimization of the allylic oxidation in the synthesis of 7-keto-delta5-steroidal substrates. Steroids 68: 407-414.
34. Frousteris MA, Koutsourea AI, Nikolaropoulos SS, Rahia A, Muzart J (2006) Improved Chromium-Catalyzed Allylic Oxidation of 5-Steroids with t-Butyl Hydroperoxide. J Mol Catal A: Chem 250: 70-74.
35. Pearson AJ, Chen YS, Han GR, Hsu SY, Ray T (1985) A New Method for the Oxidation of Alkenes to Enones. An Efficient Synthesis of 5-Oxo Steroids. J Chem Soc, Perkin Trans pp: 267-273.
36. Shing TK, Yeung YY, Su PL (2006) Methyl manganese(III) acetyl catalyzed allylic oxidation: application to simple and complex alkenes. Org Lett 8: 3149-3151.
37. Parish EJ, Sun H, Kizito SA (1996) Allylic Oxidation of 5-Steroids with Pyridinium Fluorochromate. J Chem Res pp: 544.
38. Salmon WG, Barta MA, Havens JL (1978) Allylic Oxidation with 3,5-Dimethylpyrazole. Chromium Trioxide Complex. Steroidal 5-7-Ketones. J Org Chem 43: 2057-2059.
39. Parish EJ, Wei TY, Livant P (1987) A facile synthesis and carbon-13 nuclear magnetic resonance spectral properties of 7-ketocholesterol benzaldehyde. Lipids 22: 760-763.
40. Smith LL, Teng JJ, Kulig MJ, Hill FL (1973) Sterol metabolism. 23. Cholesterol oxidation by radiation-induced processes. J Org Chem 38: 1763-1765.
41. Tai CY, Chen YC, Chen BH (1999) Analysis, Formation, and Inhibition of Cholesterol Oxidation Products in Foods: An Overview (Part 1). J Food Drug Anal 7: 243-257.
42. Kinmura M, Muto Toshiki (1979) On the Reaction of Cholesteryl Acetate with tert-Butyl Hydroperoxide in the Presence of Trit(acetylacetonato)iron(III). Chem Pharm Bull 27: 109-112.
43. Andreu I, Palumbo F, Tilocca F, Morera IM, Boscá F, et al. (2011) Solvent effects in hydrogen abstraction from cholesterol by benzenophenone triplet excited state. Org Lett 13: 4096-4099.