

Short Review on Metallocene Complexes: Synthesis, and Biomedical Applications

Islam M. Abdellah^{1,2}, and Mohamed R. Eletmany^{2,3*}

¹Department of Chemistry, Faculty of Science, Aswan University, Aswan, Egypt 81528

²Department of Chemistry, Faculty of Science, South Valley University, Qena, Egypt 83523

³TECS department, North Carolina State University, Raleigh, USA 27606

Corresponding Author: Mohamed R. Eletmany^{2,3*}

Abstract:- Metallocene complexes have gained significant attention in the field of biomedical research due to their versatile chemical properties and potential applications in various the srapeutic areas. This mini review provides a concise overview of recent advancements in the synthesis of metallocene complexes and their emerging roles in biomedical applications. The synthesis of metallocene complexes involves the coordination of transition metals, typically from the ferrocene family, with organic ligands. This process yields compounds with unique structural features, allowing for tailored designs that can be optimized for specific biomedical purposes. The mini review highlights key synthetic methodologies employed in the preparation of metallocene complexes, emphasizing the importance of precision and control in achieving desired molecular structures. In the biomedical context, metallocene complexes have demonstrated promising properties for therapeutic applications. Their ability to interact with biological systems at the molecular level opens avenues for the development of novel drugs, imaging agents, and diagnostic tools. The review explores the potential of metallocene complexes in cancer treatment, antimicrobial activity, and as contrast agents in medical imaging. Finally, the synthesis of metallocene complexes and their biomedical applications represent a burgeoning area of research with the potential to significantly impact healthcare. This mini review serves as a snapshot of the current state of the field, summarizing key developments and paving the way for further exploration of metallocene complexes in the realm of biomedicine.

Keywords:- Metallocene Complexes, Synthesis, Biomedical Applications, Transition Metals, Therapeutic Agents.

I. INTRODUCTION AND GOALS

In recent years, the intersection of inorganic chemistry and biomedical research has witnessed a surge of interest, with the synthesis of metallocene complexes emerging as a focal point in this dynamic and interdisciplinary field. Metallocene, characterized by the bonding of transition metals with organic ligands, presents a unique class of compounds with diverse structural features and intriguing chemical properties [1,2]. The marriage of metal-containing compounds and biomedical sciences has opened new

avenues for the development of innovative therapeutic agents, diagnostic tools, and imaging agents. Metallocene complexes, particularly those derived from the ferrocene family, offer a versatile platform for molecular design, allowing researchers to tailor structures for specific biomedical functions. As such, the controlled synthesis of these complexes has become a critical focal point, requiring precision and innovation to unlock their full potential in the realm of healthcare [3,4]. Specially, metallocene incorporating β -Diketones exhibit a diverse array of applications, spanning from their utilization in metal extraction through chelation processes [5-7] to their incorporation in biomedical contexts, notably as constituents of antibacterial antibiotics [8,9]. Additionally, these compounds find application as ligands in metal complexes, contributing to catalytic processes [10,11].

Platinum, rhodium, iridium, and palladium are among the frequently employed catalytic metals. In the Monsanto process, rhodium compounds serve as catalysts, facilitating the conversion of alcohols into carboxylic acids [12,13]. Additionally, rhodium (I) complexes of β -diketonates find application in the low-temperature hydrogenation of unhindered alkenes [14,15].

Catalytic processes conventionally proceed through a mechanistic sequence, beginning with oxidative addition to the metal facilitated by a compatible substrate. Subsequent stages encompass migration, insertion of a suitable ligand between the metal and the coordinated product, culminating in the reductive elimination of the final product [16,17]. The impact of various substituents on oxidative addition reactions is significant, and this concise review aims to delve into diverse synthetic approaches of the cutting-edge metallocene.

II. SYNTHETIC METHODS OF METALLOCENE

The pursuit of synthesizing metallocene moieties is driven by their significance in a variety of applications and their distinctive chemical properties. Additionally, a detailed analysis of the fundamental chemistry underpinning metallocene derivatives will be incorporated.

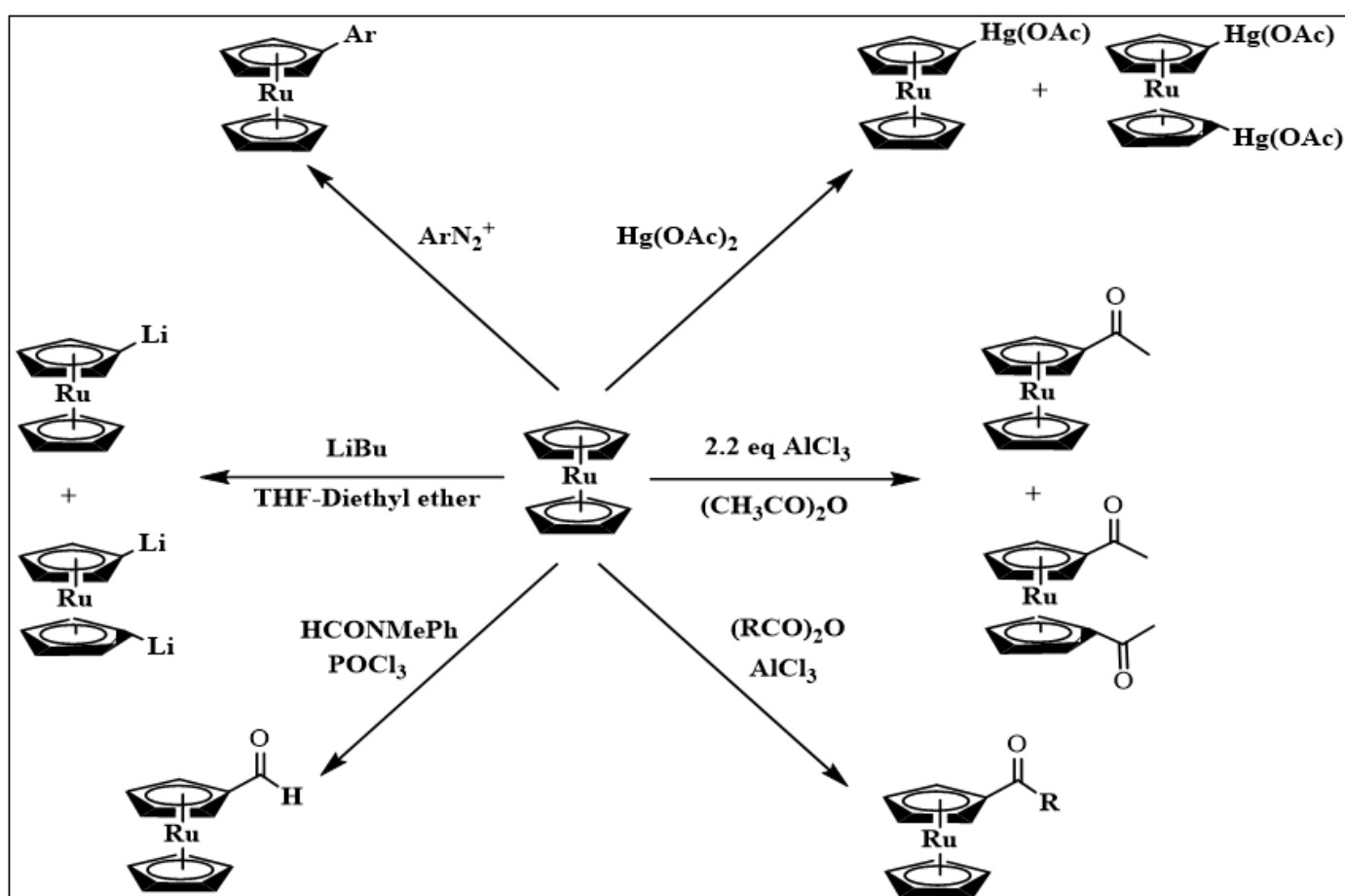
❖ Fundamental of Ruthenocene Chemistry

The extensive organic chemistry associated with ruthenocene, pertinent to this investigation, is elucidated in **Schemes 1** and **2**. **Scheme 1** illustrates the chemical processes governing mono-substitution or di-substitution for ruthenocene, leading to 1 and 1' substituted products. The synthesis of monolithiated and dilithiated ruthenocene species involves the reaction of ruthenocene with n-butyllithium [18-20]. Likewise, monoacetylated and diacetylated derivatives are acquired by reacting ruthenocene with the corresponding anhydride in the presence of aluminum trichloride. Significantly, the 1,1'-diacylation patterns in di-substituted products result from the deactivation of cyclopentadienyl rings following the initial acylation at the 1 position, facilitated by electron-withdrawing and deactivating acyl groups. As a result, the second substitution necessitates occurrence at the 1' position.

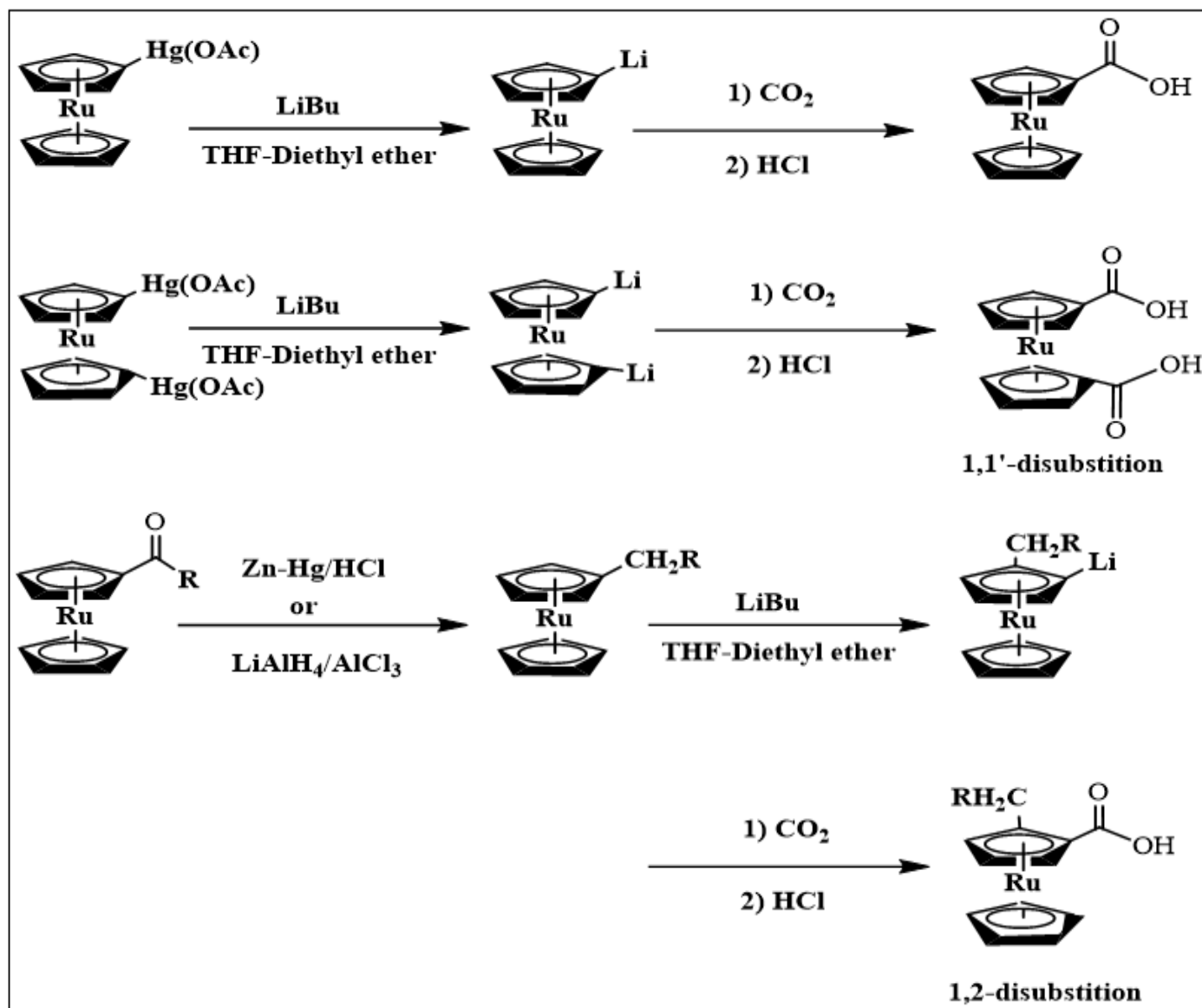
The formation of mercurated products involves the reaction of ruthenocene with mercury acetate in a methanol-ether solution [18-21]. Following separation, the mercurated products can be isolated and subsequently lithiated, leading to the production of pure monolithiated or dilithiated products, as illustrated in Scheme 2. The synthesis of ruthenocene aldehyde involves the reaction of ruthenocene with N-methylformanilide in the presence of phosphorus oxychloride [18,22]. Aryl or alkyl-substituted ruthenocene

derivatives are acquired by reacting ruthenocene with the corresponding diazonium salt [18,23]. Conversely, lithiated ruthenocenes can be transformed into carboxylic acids through a reaction with carbon dioxide followed by hydrochloric acid [20,23], as exemplified in **Scheme 2**. The reduction of carboxylated ruthenocenes to their respective aliphatic chains can be achieved by reacting them with lithium aluminum hydride in the presence of aluminum trichloride [23,24]. Subsequently, conversion to the lithiated product is achievable through reaction with n-butyllithium. In this instance, the substitution pattern is observed to be 1,2, as opposed to 1,1', owing to the activation of the substituted cyclopentadienyl ring by the electron-donating aliphatic group.

Simultaneously, the lithiated forms of ruthenocenes undergo transformation into carboxylic acids through their reaction with carbon dioxide, followed by hydrochloric acid [20,25], as illustrated in Scheme 2. Subsequent reduction of the carboxylated ruthenocenes to their respective aliphatic chains is achieved by subjecting them to lithium aluminum hydride in the presence of aluminum trichloride [18,26]. The ensuing aliphatic products can be reverted to the lithiated state through a reaction with n-butyllithium. In this particular context, the observed substitution pattern is 1,2, in contrast to 1,1', and is ascribed to the activation of the substituted cyclopentadienyl ring by the electron-donating aliphatic group.



Scheme 1 Production of a Diverse of Ruthenocene Precursors (LiBu = n-butyllithium, $\text{Hg}(\text{OAc})_2$ = mercury acetate, ArN_2^+ = aryl or alkyl diazonium salt).



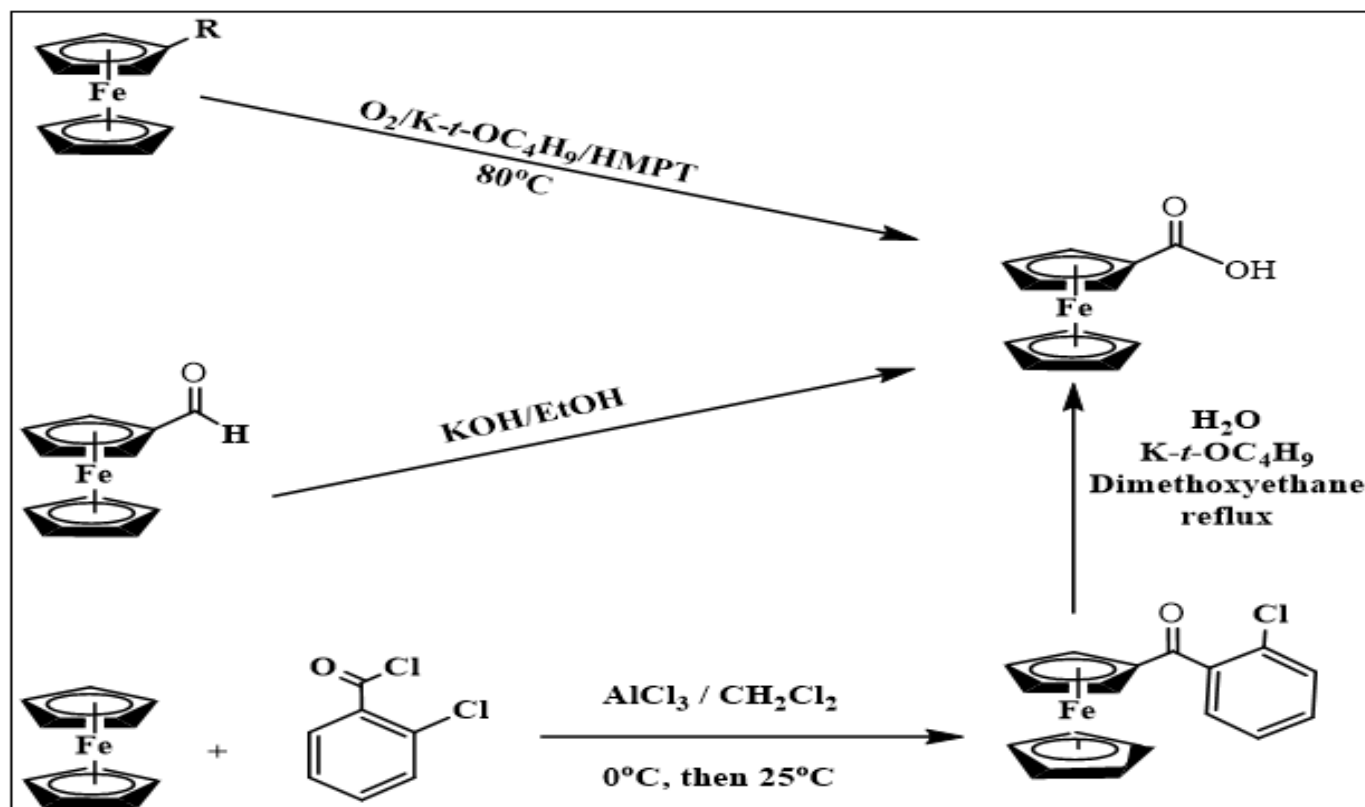
Scheme 2 Generation of Different Substituted Ruthenocene from Precursors in Scheme 1. (LiBu = n-butyllithium, LiAlH₄ = Lithium Aluminum Hydride)

A. Preparation of Metallocene Carboxylic Acids

The generation of β -diketones via a Claisen condensation reaction requires the presence of a metallocene ester and/or an acetyl metallocene. While the lithiation pathway for ruthenocenic acid production is outlined in **Scheme 2**, the synthesis of metallocene carboxylic acids has predominantly been documented for ferrocene. **Scheme 3** delineates three distinct methods employed in the synthesis of ferrocenecarboxylic acid.

Schmitt and Özman conducted the synthesis of ferrocenecarboxylic acid, revealing that the carboxylic acid could be derived from aliphatic-substituted ferrocenes. The yields for these reactions exhibited variation within the range of 25-86%, depending on the nature of the substituent ($R = \text{CH}_2\text{OH}$, CHO , COCH_3 , $\text{CH}_2\text{N}(\text{CH}_3)_2$), when the substituted ferrocene underwent reaction with potassium tert-butoxide in hexamethylphosphoric triamide (HMPT) [27]. An alternative approach to synthesizing ferrocenecarboxylic acid involves the reaction of ferrocene

aldehyde in the presence of potassium hydroxide in ethanol [28,29]. The most commonly employed method for obtaining ferrocenecarboxylic acid is detailed in the Organic Synthesis series [30]. In this process, ferrocene undergoes an initial reaction with 2-chlorobenzoylchloride, yielding 2-chlorobenzoylferrocene, as illustrated in **Scheme 3**. Subsequent reaction with potassium tert-butoxide in the presence of water results in the desired carboxylic acid, with yields ranging from 74-83%. This method was adapted in the current study to obtain ruthenocenoic acid.

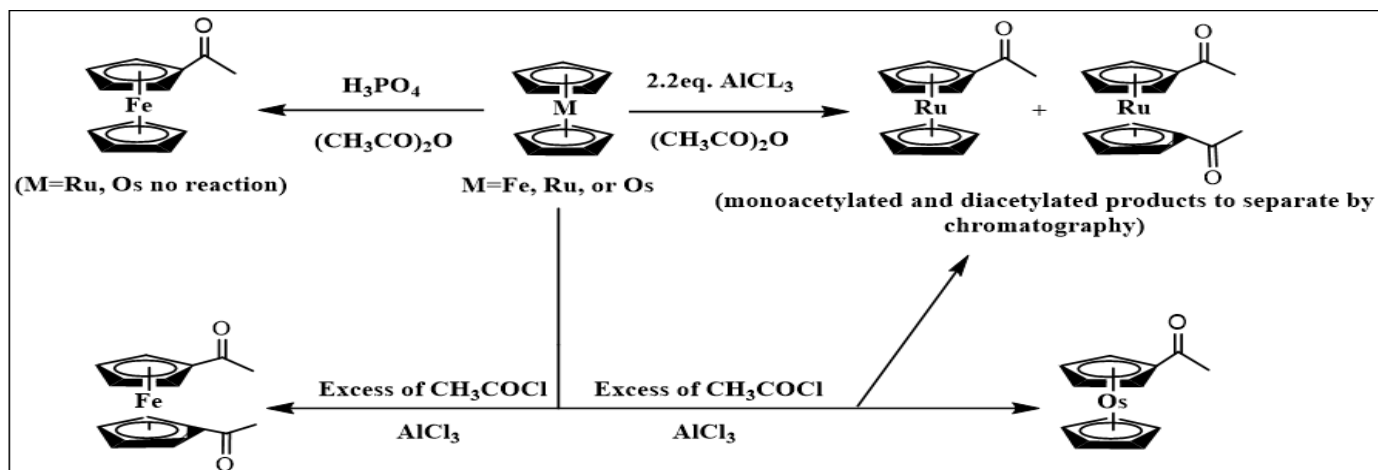


Scheme 3 Production of Ferrocenecarboxylic Acid via Three Different Pathways (K-*t*-OC₄H₉ = Potassium tertiary-butoxide, HMPT= hexamethylphosphoric triamide)

B. Synthesis of Acetyl Metalloenes

Acetylation reactions using the Friedel-Crafts method have primarily been conducted on group VIII metallocenes, as depicted in **Scheme 4**. Graham and colleagues determined that the most effective method for acetylating ferrocene involves utilizing 85% *m*-phosphoric acid as the Lewis acid [31,32]. After chromatographic separation, the yield for this reaction reached 71%, and due to the use of the relatively weak Lewis acid, H₃PO₄, only monoacetylation occurs. However, phosphoric acid proves ineffective for acetylating the less reactive ruthenocene. In this case, aluminum trichloride serves as the requisite Lewis acid, given the diminishing reactivity of metallocenes down Group VIII. Remarkably, both diacetylation and

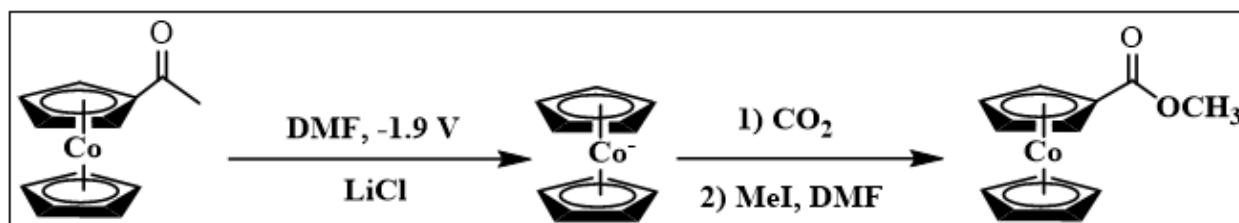
monoacetylation are evident in this situation, attributable to the heightened strength of the Lewis acid involved. The overall yield for this reaction is 67%, and product separation is achieved through column chromatography. An efficient method for acetylating osmocene has been elucidated by Rausch and collaborators, involving the use of acetyl chloride [20]. The documented yield for this reaction stands at 89%, and exclusive monoacetylation is observed for osmocene when using acetyl chloride. In contrast, both monoacetylation and diacetylation are viable for ruthenocene and ferrocene. Diacetylation is secured with an excess of the reagent, while attaining monoacetylation demands precise stoichiometric control.



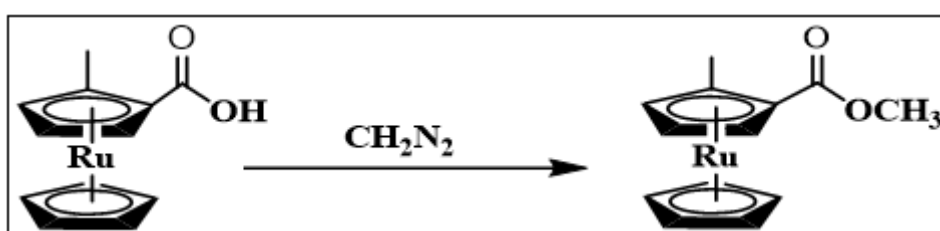
Scheme 4 Acetylation Reactions for Group VIII Metalloenes Necessitate More Severe Conditions for M=Os Compared to M=Ru, while M=Fe Requires the Mildest Conditions.

C. Synthetic Methods of Metallocene Esters

Metallocene esters are conventionally produced through the classical method, involving the reaction of a carboxylic acid with an alcohol in the presence of a catalytic quantity of a mineral acid like H_2SO_4 or HCl . Nevertheless, alternative pathways exist. It has been reported that the cobaltocene ester can be synthesized by reducing cobaltocene to the cobaltocenium anion, followed by its reaction with carbon dioxide in a solution of dimethylformamide/methyl iodide [33, 34], as illustrated in **Scheme 5**. Esterification based on diazomethane is also prevalent, and this method has been employed for the synthesis of the methyl ester of 2-methyl ruthenocenoic acid [35], as illustrated in **Scheme 6**.



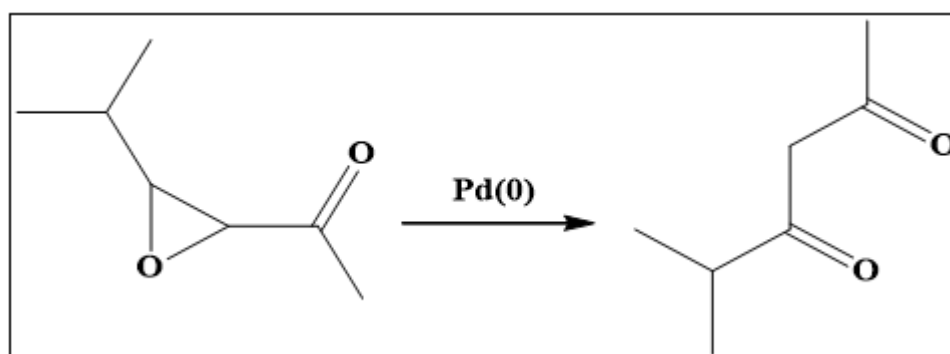
Scheme 5 Synthesis of the Cobaltocene Methyl Ester



Scheme 6 Synthesis of Methyl-Ruthenocene Ester

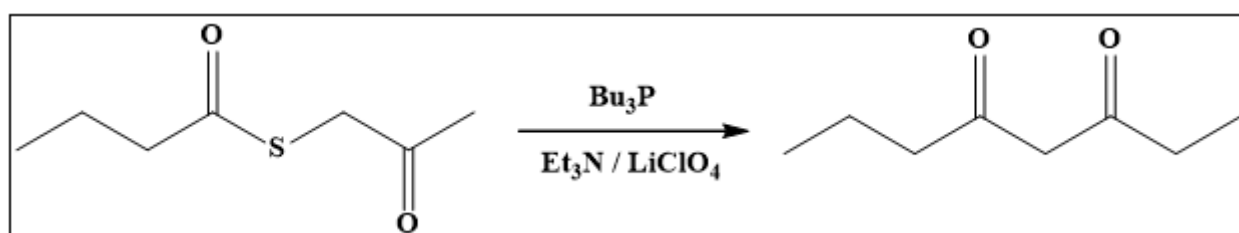
D. Synthesis of β -Diketones

Typically, β -diketones are synthesized *via* Claisen condensation, however, alternative pathways are available. Suzuki *et al.* have presented an alternative method for preparing β -diketones. In their approach, they heat an α,β -epoxy ketone at 80-140°C in toluene with small quantities of $(\text{Ph}_3\text{P})_4\text{Pd}$ and 1,2-bis(diphenylphosphino)ethane. The formation of β -diketones occurs through a pinacol rearrangement [36-39]. The reaction of 2-methyl-3,4-epoxy-5-hexanone under these conditions yields 80% 2-methyl-3,5-hexanedione, as depicted in **Scheme 7**.



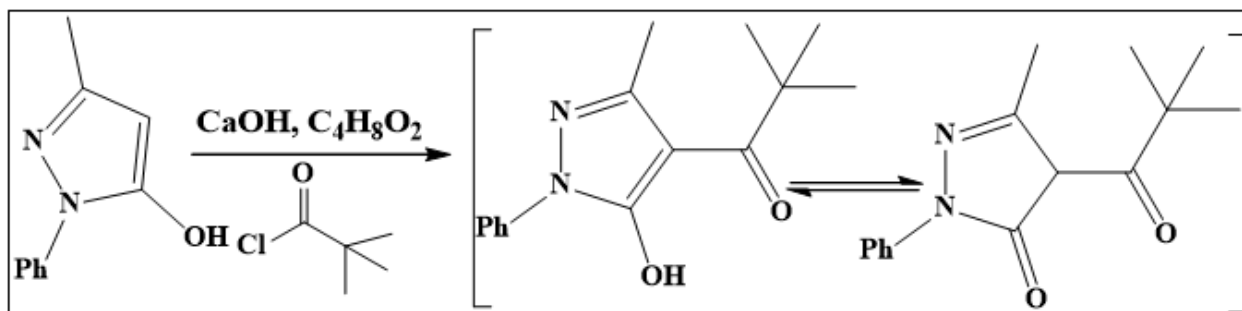
Scheme 7 Synthesis of 2-Methyl-3,5-Hexanedione According to Suzuki Method

Roth and colleagues employed a method involving the conversion of a thioester containing a β keto group in the alkyl position. The production of the β -diketone is achieved by exposing it to a tertiary phosphine in the presence of basic conditions [40, 41]. A reaction yield of 72% was achieved when butyl butanethioate was transformed into octane-3,5-dione, as illustrated in **Scheme 8**.



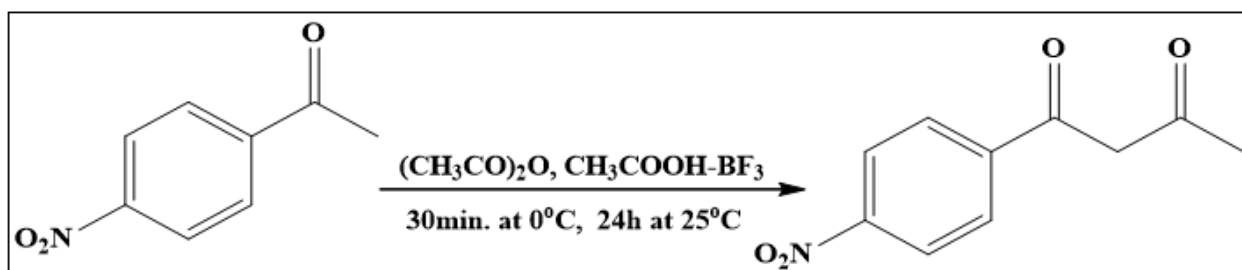
Scheme 8 Synthesis of Octa-3,5-Dione by the Roth Method

Several innovative β -diketones, such as the 4-pivaloyl-3-methyl-1-phenyl-5-pyrazolone complex, have been synthesized by Umetani *et al.* [42,43]. This synthesis involved the condensation reaction of 3-methyl-1-phenyl-5-pyrazolone with pivaloyl chloride in the presence of calcium hydroxide. The yield for this reaction is 19%, as illustrated in **Scheme 9**.



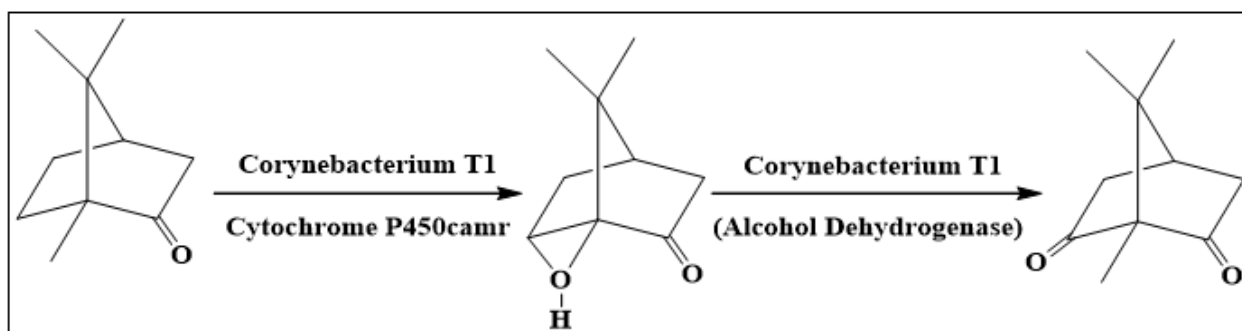
Scheme 9 Synthesis of 4-Pivaloyl -3-Methyl-5-Pyrazolone According to Umetani Method

The synthesis approach for β -diketones, as illustrated by Cravero *et al.*, employs acid-catalyzed condensation [44,45]. *p*-NO₂-benzoylacetone was synthesized by combining a mixture of *p*-NO₂-acetophenone and acetic anhydride with an acetic acid-BF₃ complex, initially at 0°C for 30 minutes, followed by incubation at 25°C for 24 hours. The reaction is depicted in **Scheme 10**.



Scheme 10 Synthesis of P-Nitrobenzoylacetone According to Cravero Method

The advent of enzyme-catalyzed reactions motivated Gunslus and collaborators to clarify the microbial degradation process of camphor by *Corynebacterium T1*. Their observations revealed the degradation pathway yielding the symmetrical β -diketone 2,6-diketocamphane from optically pure camphor [46,47]. This enzymatic degradation is depicted in **Scheme 11**.

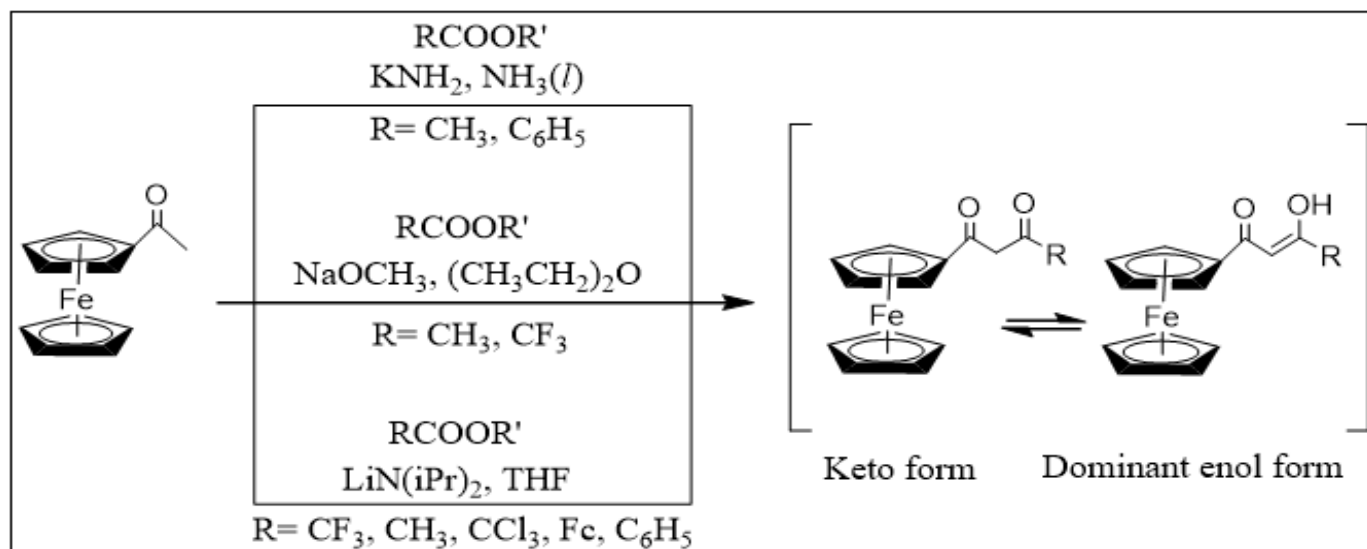


Scheme 11 Synthesis of 2,6-Diketocamphane According to Gunslus Method

E. Synthesis of Metallocene β -Diketones

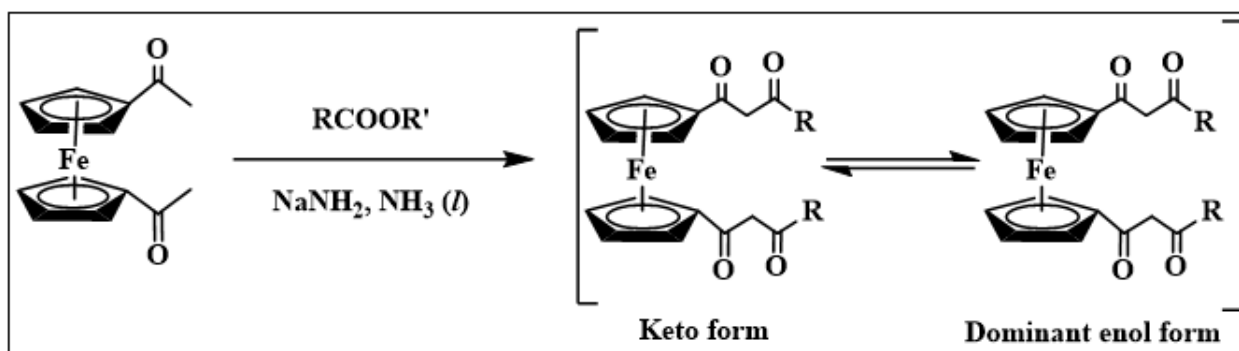
Metallocene-containing β -diketones have been synthesized through Claisen condensation, involving acetylferrocene and corresponding methyl or ethyl esters, in the presence of a potent base, as detailed in **Schemes 12** and **13**. Hauser and collaborators [48] demonstrated an effective strategy for obtaining ferrocene-containing β -diketones by employing potassium amide as the strong base in a mixture of liquid ammonia and ether, as illustrated in Scheme 12. This method yielded 65% for 1-ferrocenylbutane-1,3-dione

(R=CH₃) and 63% for 1-ferrocenyl-3-phenylpropane-1,3-dione (R=C₆H₅). Another approach by Weinmayr utilized sodium methoxide as the base, resulting in a yield of 29% for 1-ferrocenylbutane-1,3-dione (R=CH₃) and 80% for 1-ferrocenyl-4,4,4-trifluorobutan-1,3-dione (R=CF₃), as depicted in Scheme 12 [49]. Cullen and colleagues introduced the hindered base lithium diisopropylamide [50] in the synthesis of 1-ferrocenylbutane-1,3-dione, a method subsequently adopted by Du Plessis *et al.* for the synthesis of various ferrocene-containing β -diketones [51].



Scheme 12 Synthesis of ferrocene-containing β -diketone by Claisen condensation with the use of three different bases. R'=methyl or ethyl, ($\text{LiN}(\text{pr})_2$ = Lithium diisopropylamide)

Hauser's work demonstrated the feasibility of Claisen condensation between bisacetylferrocene and a suitable ester utilizing potassium amide in liquid ammonia [52,53], as depicted in **Scheme 13**. The resulting yields were 72% for 1,1'-bis(1-butan-1,3-dione)ferrocene ($\text{R}=\text{CH}_3$), and 1,1'-bis[1-(3-phenyl)propane-1,3-dione]ferrocene ($\text{R}=\text{C}_6\text{H}_5$) was isolated with a yield of 46%.



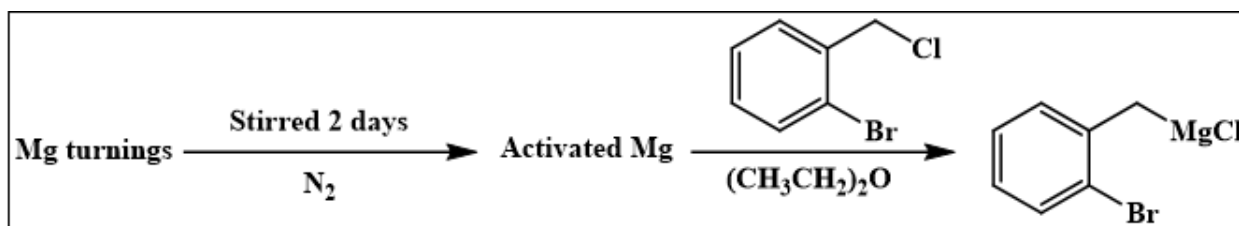
Scheme 13 Synthesis of Ferrocene-Containing bis- β -Diketones. ($\text{R}=\text{CH}_3$, or C_6H_5 , $\text{R}'=\text{CH}_3$, or C_6H_5).

F. Synthesis using Grignard Reagents

Throughout this investigation, the need arose to formulate novel electrolytes for electrochemical applications, necessitating the utilization of Grignard reagents [54]. Grignard reagents have been employed in diverse synthesis reactions, including the formation of alkanes, carboxylic acids, alcohols, and ketones, along with their application in solid-phase synthesis.

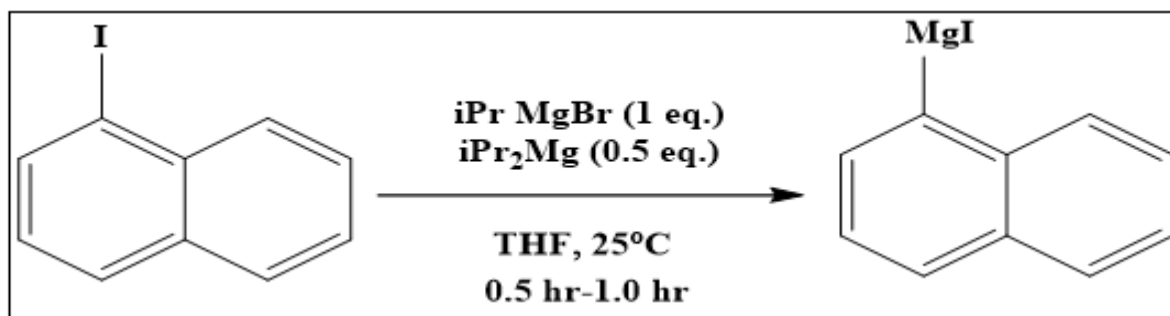
➤ Preparation of Grignard Reagents

Baker and colleagues observed that certain halides did not react with Grignard reagents unless activated magnesium was employed. The activated magnesium underwent a reaction with the halide, resulting in the formation of the Grignard reagent with a yield typically exceeding 90%. In the case of the reaction depicted in **Scheme 14**, the generation of the Grignard reagent achieved 100% yield [55].



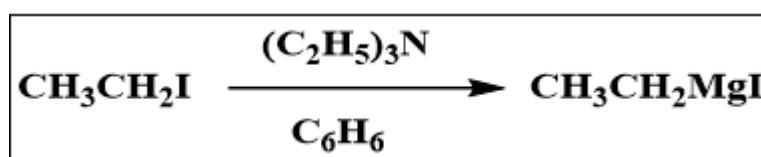
Scheme 14 Generation of a Grignard reagent according to Baker method

Knochel and collaborators discovered that the conversion of iodonaphthalene to its Grignard reagent achieves a 90% conversion when the reagents are reacted with iPrMgBr or iPr_2Mg in THF, as illustrated in **Scheme 15** [56].



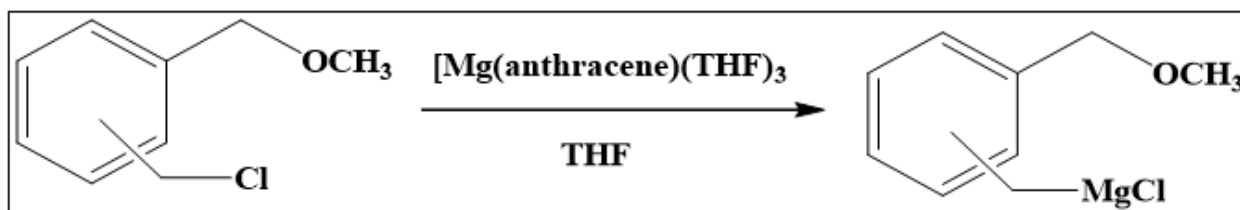
Scheme 15 Preparation of a Grignard reagent according to Knochel method

Traditionally, Grignard reagents have been synthesized in ether solvents. However, Ashby & Reed demonstrated that Grignard reagents could be generated in hydrocarbon solvents with the use of a tertiary amine as a complexing agent [57]. In benzene, the general yield for these formation reactions exceeded 80%. **Scheme 16** depicts the formation of the iodoethane Grignard reagent with a yield of 97%.



Scheme 16 Formation of a Grignard reagent in benzene according to Ashby & Reed method

In recent years, the $[Mg(\text{anthracene})(\text{THF})_3]$ complex has found application in the synthesis of Grignard reagents, particularly for compounds with non-activated phenyl rings or containing ether groups [58]. These reactions typically yield above 90%. **Scheme 17** illustrates a representative reaction of this kind.



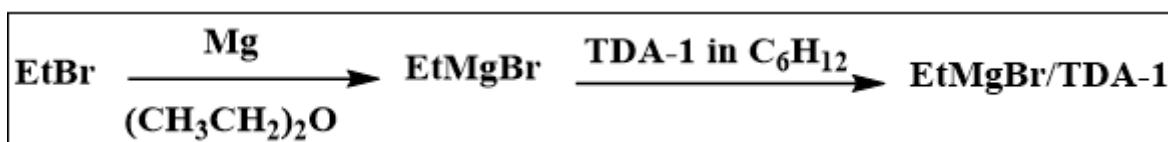
Scheme 17 Formation of a Grignard Benzylic Compound Following Gallagher Method

➤ *Stabilizing Grignard Reagents*

Grignard reagents are highly reactive and prone to react with both water and oxygen. Consequently, their preparation is carried out in an anhydrous nitrogen atmosphere. Due to their inherent instability, these reagents are typically utilized promptly after formation, and storage is not feasible [59]. Nonetheless, methods exist to stabilize Grignard reagents for future use. Generally, Grignard reagents exhibit reduced reactivity at lower temperatures toward various functional groups, allowing for in-situ

maintenance with a lower risk of undesirable side reactions [56].

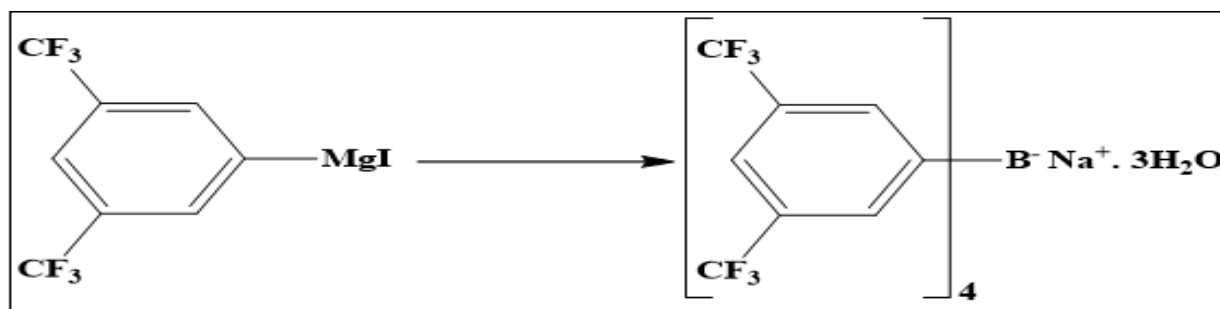
Boudin and colleagues showcased the stabilization of Grignard reagents in a powdered form by chelating a Grignard reagent in solution with a tertiary amine [60]. The stabilized Grignard reagent, as illustrated in **Scheme 18**, is formed with a yield of 72% when ethane bromide is initially reacted with magnesium and then with TDA-1 ($[N(\text{CH}_2\text{CH}_2\text{OCH}_2\text{CH}_2\text{OCH}_3)_3]$).



Scheme 18 Formation of a Solid Stabilized Grignard Reagent

➤ *Reaction of Grignard Reagents with Boron Compounds*

In this investigation, our aim was to generate sodium borate salts for the subsequent production of diverse electrolytes. Nishida demonstrated the formation of sodium tetrakis[3,5-bis(trifluoromethyl)-phenyl]borate by reacting the Grignard reagent 3,5-bis(trifluoromethyl)phenyl-magnesium iodide with an ethereal solution of boron trifluoride [61].



Scheme 19 Formation of Sodium Tetrakis[3,5-bis(trifluoromethyl)-phenyl]Borate.

G. Medicinal Attributes of Metal Complexes

➤ Anti-Cancer Characteristics

• Cisplatin, the Pioneering Molecule

Since its accidental discovery in 1965 by Rosenberg, Van Camp, and Krigas, Cisplatin has been widely utilized in cancer treatment due to its observed efficacy in inhibiting bacterial growth [62], as illustrated in **Figure 1**. Subsequently, numerous studies have investigated the efficacy of cisplatin against various cancers, its cytotoxicity, its distribution in the body, the mechanism through which it destroys cancer cells, and optimal dosage concentrations [62, 63].

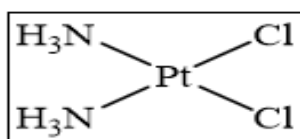


Fig 1 Structure of Cisplatin

Despite being a cornerstone in cancer treatment, cisplatin is associated with a range of side effects. Notably, it promotes the formation of lung adenomas, and resistance to the drug can develop in recurrent cell lines. Fortunately, the sustained efficacy of cisplatin is maintained when it is employed synergistically with other drugs, ensuring its ongoing utilization today [64]. The simultaneous administration of other drugs has helped alleviate some of the adverse effects associated with cisplatin [65]. Addressing the resistance of certain cancer cell lines involves exploring alternative platinum coordination compounds that share structural similarities with cisplatin [66,67], such as carboplatin. Nevertheless, even these next-generation platinum drugs exhibit substantial side effects, underscoring the global priority to discover new cancer drugs.

• Usage of Rhodium and Ruthenium Drugs in Cancer Therapy

Exploration of alternative metals to platinum for cancer treatment has been undertaken. Giraldi *et al.* [68] highlighted early ruthenium and rhodium complexes that showed efficacy comparable to cisplatin. Particularly, the [(acetylanato)(cycloocta-1,5-diene)rhodium] complex demonstrated less histological damage than cisplatin. The complex acetylacetonate-1,5-cyclooctadiene rhodium (I), depicted in **Figure 2**, bears similarity to the ruthenocene compounds synthesized in this study.

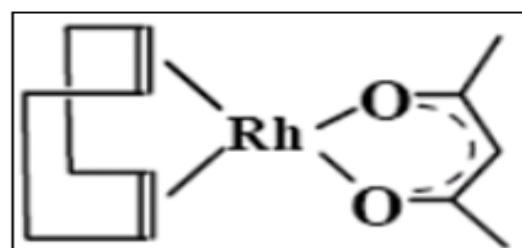
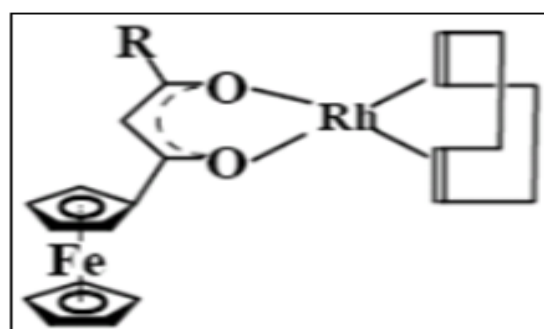


Fig 2 Acetylacetonate-1,5-Cyclooctadiene Rhodium (I) Chemical Structure.

The examination involved subjecting the β -diketone featuring ferrocene, portrayed in Figure 3 as a counterpart to the depicted complex in Figure 2, to assessments against HeLa (a responsive human cervix epithelial carcinoma cell line), CoLo (an inherently multi-drug resistant human colon adenocarcinoma cell line), and COR (a responsive human lung large cell carcinoma cell line). In specific cases, these complexes exhibited a twofold increase in effectiveness in eradicating cancer cells compared to cisplatin. Furthermore, they demonstrated the capability to distinguish between cancer cells and healthy cells at a ratio of 8:1.[69]

Fig 3 Structure of the Ferrocene-Containing β -Diketone Complexes Analogous to that of Fig 2. (R= CF₃, CH₃, CCl₃, C₆H₅).

Subsequent investigations into the novel ruthenocene analogues synthesized in this study may reveal additional advantageous effects conferred by the ruthenocene center in the treatment of cancer with such complexes. While various rhodium- and ruthenium-containing complexes have been employed in the fight against cancer, recent advancements in organometallic compounds with ruthenium as the central metal have proven noteworthy. The development of new antineoplastic ruthenium compounds [70] has demonstrated their ability to mitigate cytotoxicity induced by other chemotherapeutic drugs [71,72].

- *Ruthenocene Compounds in Oncological Applications*

In the realm of cancer therapy, the radiopharmaceutical acetyl-(Ru)-ruthenocene [73] has been utilized to explore the binding affinity of acetyl ruthenocene for the adrenal glands in mice. Synthesized by heating acetyl ferrocene with ^{103}Ru -ruthenium trichloride, this labeled compound was found to specifically target the areas of the adrenal gland associated with androgen and glucocorticoid syntheses [73]. Subsequent investigations delved into the modulation of acetyl ruthenocene localization through hormone control. Notably, it was revealed that by regulating hormones, the in vivo targeting of acetyl ruthenocene could be precisely manipulated [74].

- *Ferrocene Compounds in Oncological Applications*

In tackling the challenges associated with poor solubility in chemotherapy, an innovative approach involves the conjugation of ferrocene derivatives with water-soluble polymers. Notably, it was observed that a water-soluble polymeric drug exhibited comparable effectiveness with fewer drug units compared to its monomeric counterpart [75], as illustrated in Figure 4. The study unveiled the pivotal roles of both the spacer length between the ferrocene drug and the polymer backbone, and the formal reduction potential of the ferrocenyl group in influencing drug activity. Enhanced anticancer activity was discerned with longer spacers and lower ferrocenyl formal reduction potentials [76-107].

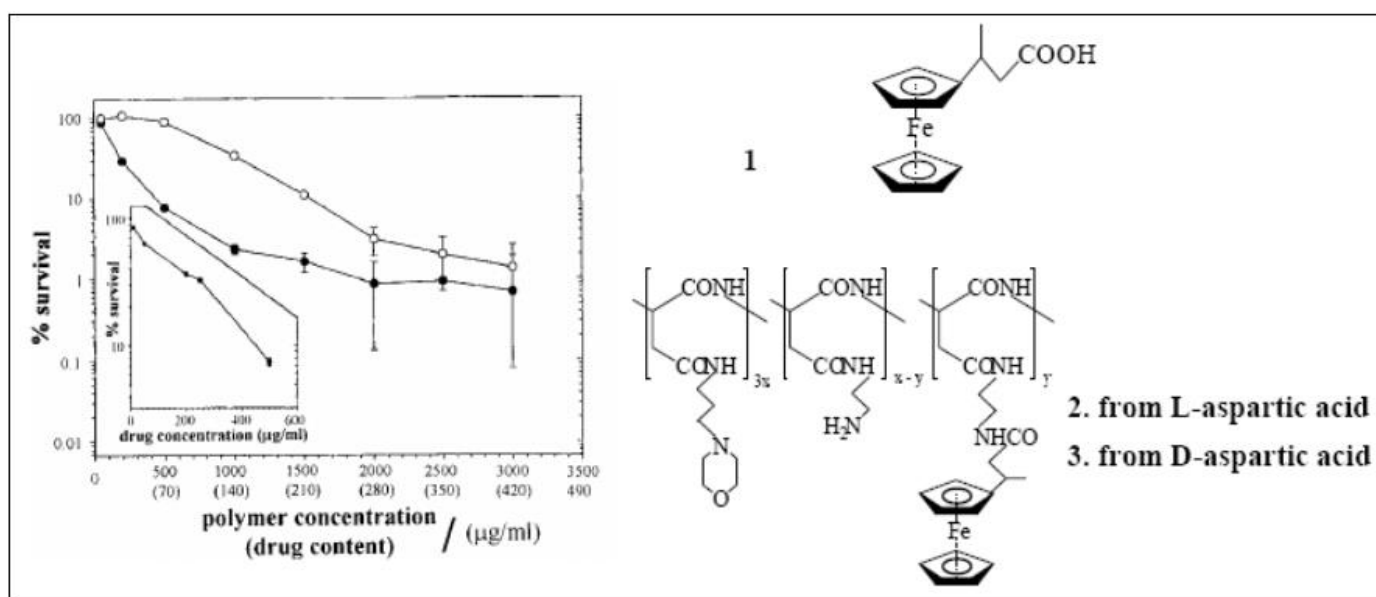


Fig 4 % Survival of Murine EMT-6-Cells after 24 Hours of Incubation with Ferrocene Derivatives 1 (insert), 2 and 3. [77]

III. CONCLUSION

In conclusion, this short review provides a comprehensive snapshot of the current state of research on metallocene complexes, focusing on their synthesis and emerging roles in biomedical applications. The controlled synthesis of metallocene complexes, particularly those derived from the ferrocene family, has been highlighted as a critical aspect, emphasizing precision and innovation to unlock their full potential in healthcare. The diverse synthetic approaches discussed, ranging from Claisen condensation to the use of Grignard reagents, showcase the versatility in creating these compounds. The exploration of metallocene-containing β -diketones, metallocene carboxylic acids, esters, and other derivatives further enriches our understanding of the chemical landscape of these complexes. In the field of biomedical applications, metallocene complexes exhibit promising properties for therapeutic interventions. Their ability to interact with biological systems at the molecular level opens avenues for the development of novel drugs, imaging agents, and diagnostic tools. The review delves into specific areas such as cancer treatment, antimicrobial activity, and the use of metallocene complexes as contrast agents in medical imaging.

The review underscores the significance of metallocene complexes as a burgeoning area of research with the potential to significantly impact healthcare. The discussed advancements in synthesis methodologies and biomedical applications lay the foundation for further exploration and innovation in the field. As researchers continue to unravel the potential of metallocene complexes, the door is opened for the development of next-generation therapeutic agents and diagnostic tools that could revolutionize the landscape of biomedicine.

Conflict of Interest:- The authors affirm that they do not have any competing interests.

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