A synthesis of ferrocenyl dihydrocoumarin and ferrocenyl dihydroquinolin-2(1*H*)-ones

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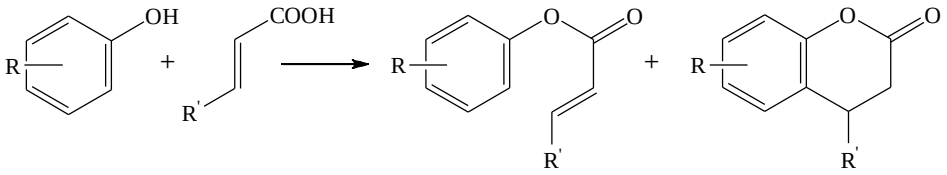
Abstract
A series of phenols have been used to react with ferrocenyl cinnamic acid, and the results of ^{1}H NMR and crystal structures have shown that only resorcinol and 2-naphthalenol can get ring closure products, while the others only get esterified products. This is because resorcinol and 2-naphthalenol have higher electronic density in *ortho*-site of hydroxyl than other phenols used in this work. Ten ferrocenyl dihydroquinolin-2(1*H*)-ones are synthesized by hydroarylation of ferrocenyl acrylic amides in the presence of TFA, and an interpretation is also given to the experimental fact that strong acid can not catalyze hydroarylation of acrylic anilides to dihydroquinolones.

Keywords: Dihydrocoumarin, ferrocenyl, dihydroquinolin-2(1*H*)-ones, DFT

Introduction

4-Aryl-3,4-dihydrocoumarins are of synthetic interest because they are present in a number of natural molecules, such as 4-aryl-3,4-dihydrocounmarins (neoflavonoids),[1] complex falvonoids[2] and tannins.[3] Also, many compounds containing 3,4-dihydrocoumarins rings possess important biological activities; for example, inhibitors of aldose reductase, [4] protein kinases[5] and antiherpetic.[6] In 2008, detailed structure-activity relationships on splitomicin derivatives and their inhibition of recombinant Sirt2 were presented by Jung.[7] 3,4-Dihydroquinolin-2(1*H*)-one skeletons are rarely found in naturally occurring substances, but they possess varied and powerful biological properties;[8-9] for example, they have been proposed as a pharmacophore for norepinephrine transporter(NET) inhibition.[10]

At present, the dihydrocoumarin ring is usually synthesized from phenol and cinnamic acid derivatives.[11-13] This reaction is an atom-economic synthesis and includes esterification and F-C alkylation two steps (Equation 1).



1 **2**

In many cases, esterified product **1** is the main product for Eq. 1. These cases are when (1) the reaction proceeds at low temperature,[14] (2) the acidity of catalyst is not strong enough,[15] (3) there is a strong electron-withdrawing substituent in phenol ring[16]. The effect of spatial obstacle of R' for ring closure is different with the use of different catalyst. Gunnewegh[11] used solid-acid (zeolite H-Beta) as catalyst and found that crotonic acid (R'=methyl) did not react to obtain ring closure product **2**. Jagdale[17] and Kitamura[13] used toluene-4-sulfonic acid or TFA as catalysts, and found substituted cinnamic acids (R'=phenyl) could react with resorcinol to obtain ring closure product **2** easily. In addition, which step proceeds first is still a question in dispute. Ferrocenyl is much bigger than phenyl and it is unknown whether ferrocenyl acrylic acid can react with phenol to obtain dihydrocoumarin. Ferrocenyl has redox activity and it has been used in some anti-tumor drugs [18]. It is possible that dihydrocoumarin, which attaches ferrocenyl, will increase its biological activity.

3,4-Dihydroquinolin-2(1*H*)-one can be prepared in good yield in the presence of acid catalyst by coupling anilines with cinnamic acids prior to hydroarylation[19-20]. The synthesis of dihydroquinolin with attached ferrocenyl has never been reported. It is also unknown whether ferrocenyl will hold back the ring closure of acrylic anilides to dihydroquinolin. In addition, if the two *ortho* positions of an amide group are different, the position which will take place in the ring closure is still a question. In this paper, we use a series of phenols to react with ferrocenyl acrylic acid and want to test whether ferrocenyl can affect ring closure. In order to test the electronic effect on F-C alkylation of acrylic anilide to 3,4-Dihydroquinolin-2(*1H*)-one, we also synthesize a series of 3,4-Dihydroquinolin-2(1*H*)-one.

Results and Discussion

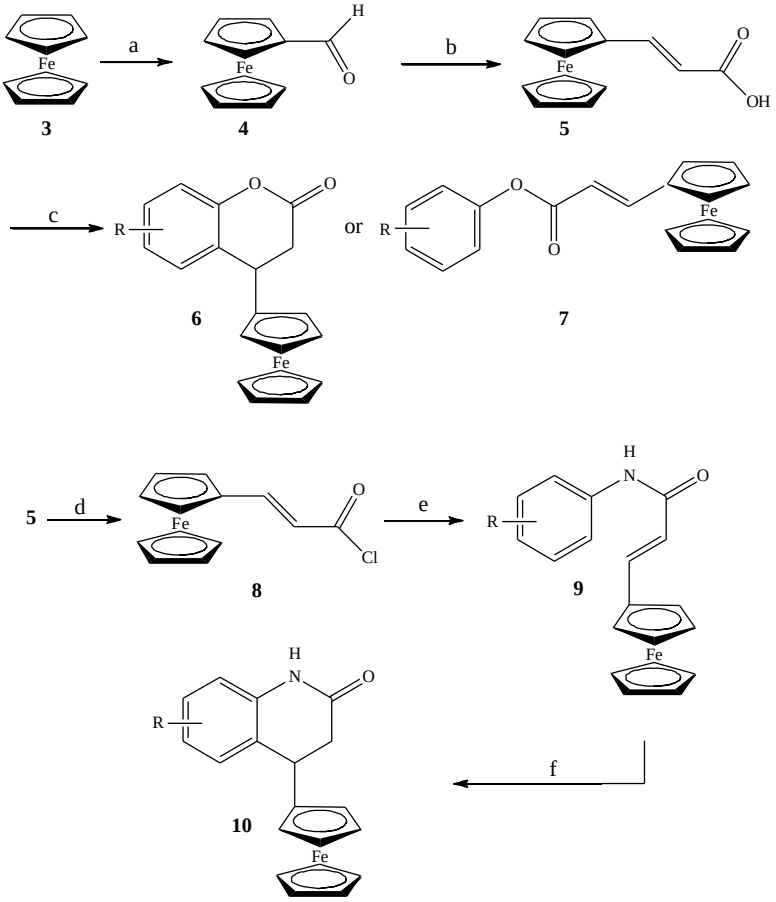
Synthetic route

The synthetic route of this paper is shown as in Scheme 1.

The choice of acid catalyst

When ferrocenyl acrylic acid **5** reacts with various phenols to generate **6** and **7**, the choice of acid catalyst is important. Seven acid catalysts have been used as catalysts: TsOH (p-CH_3-C_6H_4-SO_3H), TFA (CF_3COOH), c-H_3PO_4 (85%), c-HCl (37%), PPA, c-H_2SO_4 (98%) and H_2SO_4/C (c-H_2SO_4 loaded by activated carbon). Only concentrated sulfuric acid (98%) can catalyze the

reaction well. In ring closure of **9** to **10**, the yield is very low when c-H_2SO_4 is used as catalyst, but TFA can catalyze the reaction well.



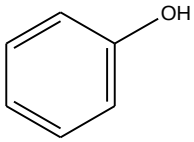
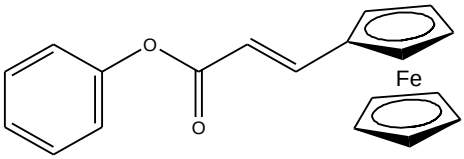
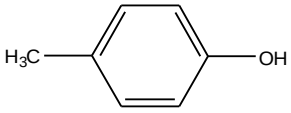
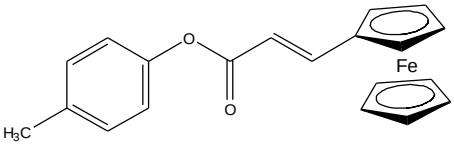
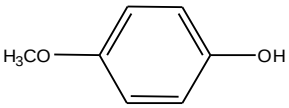
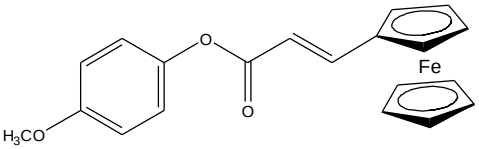
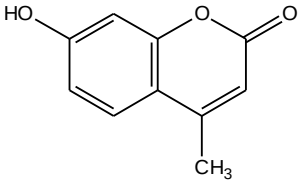
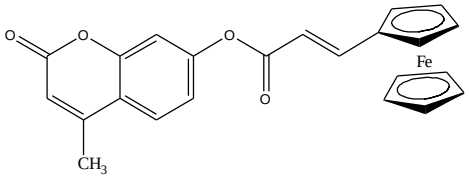
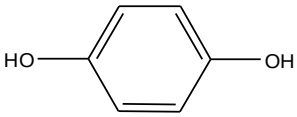
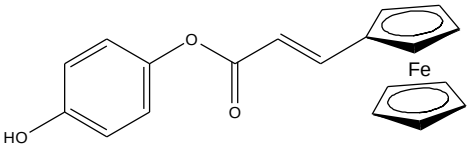
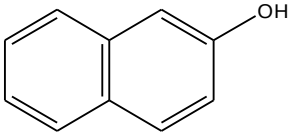
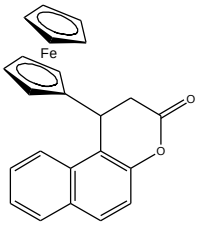
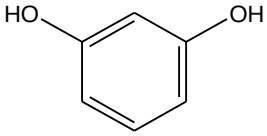
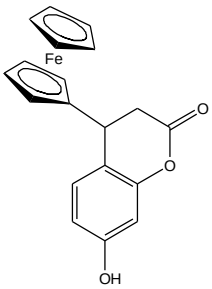
(a) PhN(CH_3)-CHO, $POCl_3$ (b) Propanedioic acid, Pyridine (c) Phenol, H^+ (d) $(COCl)_2$ (e) R(C_6H_4)NH_2 (f) TFA(CF_3COOH)

Scheme 1

Esterified product (7) and ring closure product (6)

Seven phenols have been used to react with **5** in this paper; some of these can form ring closure product **6,** while the others can only form esterification product **7**. We have never obtained products that include both **6** and **7**. The structures of phenols and their corresponding products are shown in Table 1.

Table 1. The reaction of various phenols with ferrocenyl acrylic acid

Entry	Phenol	Product	Time (h)	Yield (%)
1		 **7a**	10	40
2		 **7b**	10	45
3		 **7c**	11	42
4		 **7d**	48	15
5		 **7e**	10	43
6		 **6a**	3	45
7		 **6b**	0.5	50

Why can some phenols lead to ring closure product?

At first, we used phenol, p-cresol, 4-methoxyphenol, umbelliferone and 2-naphthalenol to react with ferrocenyl acrylic acid **5** and found that only 2-naphthalenol produces ring closure product **6a**, while the others only obtain esterified product **7a~7d**. Quantum chemistry calculations show that 2-naphthalenol has the highest π electron density at the *ortho*-position of hydroxyl of all phenols we used. See Table 2.

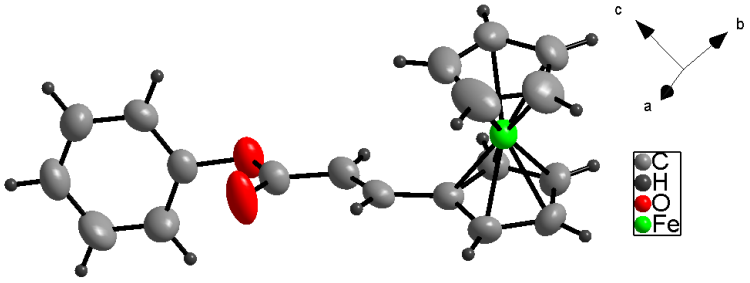
Table 2. The π electron population number in *ortho*-site of hydroxyl of various phenols

Phenols	Phenol	p-Cresol	4-metho xyphenol	Umbelli ferone	2-naphth alenol
Population number	1.063	1.056	1.049	1.064	1.102

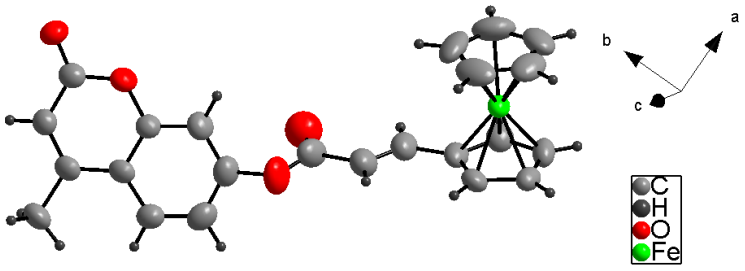
According to table 2, we postulate that phenols which have a large π electron density will obtain the ring closure product when it reacts with ferrocenyl acrylic acid. So, the π electron density at the *ortho*-site of the hydroxyl of hydroquinone and resorcinol were calculated with their values being 1.051 and 1.100, respectively. Experimental result show that resorcinol delivers ring closure product **6b** (by NMR) and hydroquinone delivers the esterified product **7e** (by NMR and crystal structure). This experiment suggests that our postulate is correct.

Crystal structures

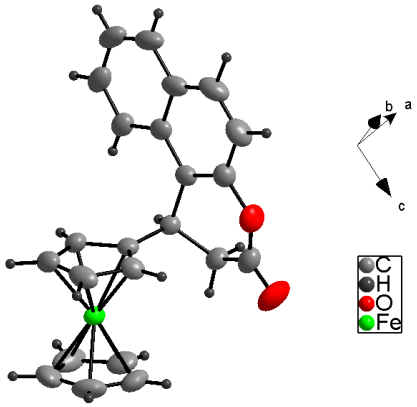
Crystal structures for **6a**, **7a**, **7d**, **7e** were obtained in this research. The molecular structures that come from these crystal structures are shown in Figure 1; the crystal structures can be found in CIF files.



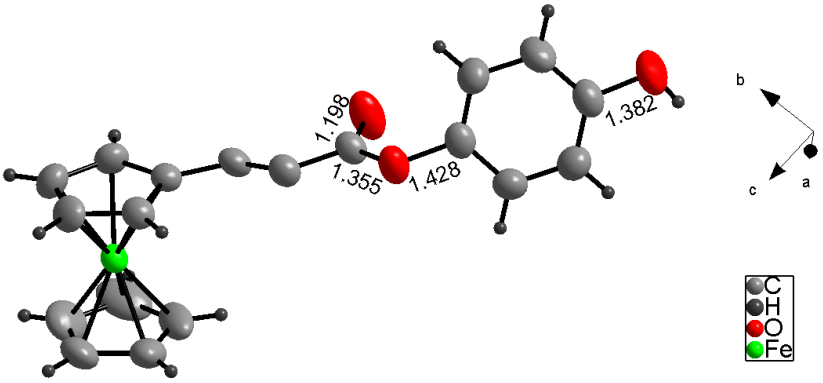
7a (CCDC: 727727)



7d (CCDC: 727726)



6a (CCDC: 727724)



7e (CCDC: 727725)

Figure 1. The molecular structures of some products.

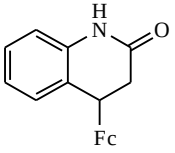
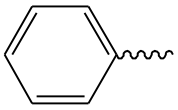
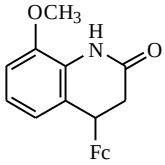
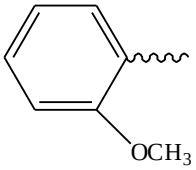
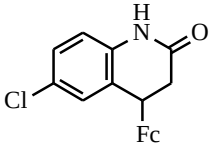
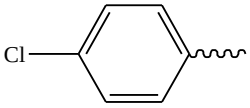
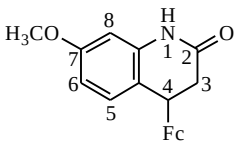
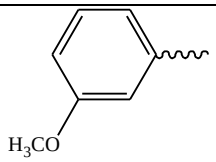
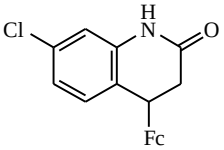
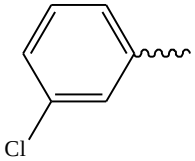
In the three esterified products, the two Cp rings in ferrocenyl are overlapped and parallel. The ferrocenyl, C=C double bond and carbonyl are co-planar, but the phenyl is not co-planar with them because the H atoms of phenyl will be repulsed by the O atom of the carbonyl, and the angles between the plane of phenyl and that of carbonyl are all about 80 ºC. We also find that all C=C double bonds have a *tran*-configuration, which agrees with coupling constants in the double bond (15.6Hz, the coupling constants of H atom in *cis*-double bond is 7~11Hz). In the esterified products, for example **7e** (see Figure 1-**7e**), the O atom connects both with the carbonyl and benzene ring, in which the bond lengths of the two C-O bonds are 0.1355nm and 0.1428nm, respectively. This means the O atom does not conjugate with the benzene ring but conjugates with the carbonyl, C=C double bond and ferrocenyl. In addition, the carbonyl is an electron-withdrawing group, so the substituted Cp ring will be electron-deficient compared with the unsubstituted Cp ring, and the chemical shifts of the four H atoms of the substituted Cp ring occur at 4.46(*m*-site) and 4.54 ppm (*o*-site), while that of the five H atoms of the unsubstituted Cp ring occur in 4.20ppm. In the case of ring closure product **6a**, we can find that the carbonyl does not conjugate with any Cp ring. The chemical environments of the nine H atoms of

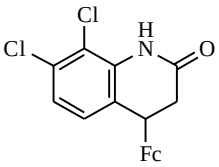
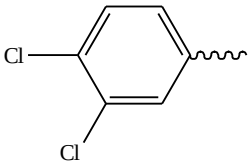
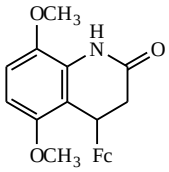
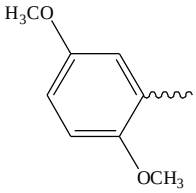
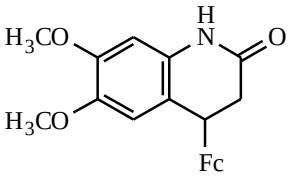
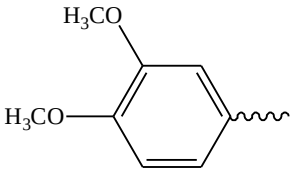
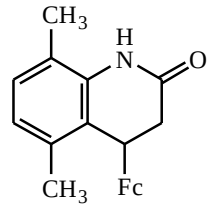
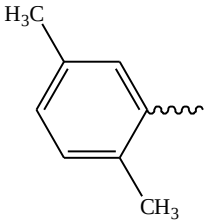
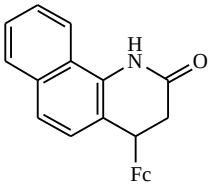
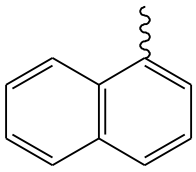
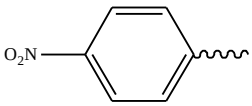
ferrocenyl are almost equal, which means that the peaks of the nine H atoms in the ^{1}H NMR overlap. Finally, our experimental result shows that ring closure products **6a** and **6b** both are yellow powders, while the five esterified products **7a**~**7e** are all red powders.

F-C alkylation of ferrocenyl acrylic amide to ferrocenyl 3,4-dihydroquinolone

Eleven ferrocenyl acrylic anilides have been prepared, and most of them can react smoothly in TFA to provide dihydroquinolones **10** in good yields after only an hour at 30 °C, the results of which are listed in Table 3.

Table 3. The hydroarylation of ferroceneyl acrylic anilides Ar-NH-COCH=CH-Fc

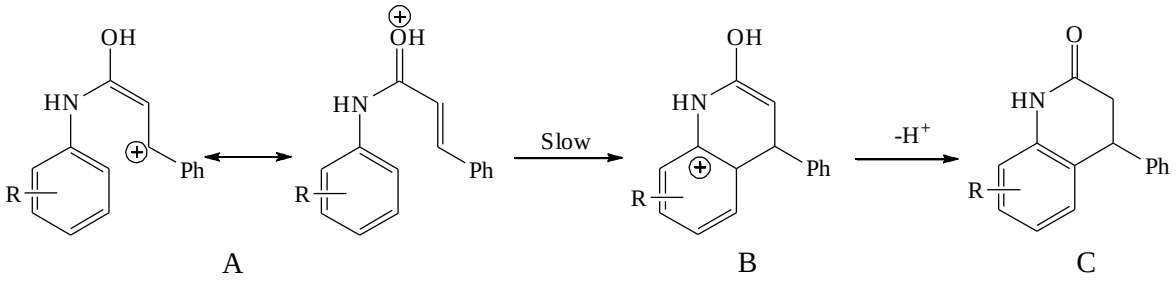
Product	Ar	Time (min)	Yield (%)
 **10a**	 **9a**	45	88
 **10b**	 **9b**	30	90
 **10c**	 **9c**	100	15
 **10d-1**	 **6d**	10	**10d-1** 72 **10d-2** 24
 **10e-1**	 **9e**	40	**10e-1** 71 **10e-2** 23

 **10f**	 **9f**	60	25
 **10g**	 **9g**	10	95
 **10h**	 **9h**	15	96
 **10i**	 **9i**	15	93
 **10j**	 **9j**	10	97
No 3,4-dihydroquinolone product	 **9k**	120	0

The hydroarylation of ferrocenyl acrylic anilides **9** is easier than that of ferrocenyl acrylic esters **7,** and all ferrocenyl acrylic anilides, except of **9k**, can obtain ferrocenyl 3,4-dihydroquinolones in the presence of TFA. The reason is that the amide group (-NHCOCH=CHFc) is a better electron-donating group than the ester group (-OCOCH=CHFc). Electronic factors play an important role in hydroarylation and very strong electron-withdrawing groups make hydroarylation impossible (**9k**). The chlorine atom is a strong electron-withdrawing group for its *meta*-position, so the hydroarylation of **9c** to **10c** is difficult. On the other hand, chorine is a weak electron-withdrawing groups for its *para*-position due to its conjugative effect,

so **9e** can hydroarylate to **10e-1** and **10e-2** easily (the identification of regional isomers, such as **10e-1** and **10e-2**, is based on chemical shifts and coupling constants of H atoms in ^{1}H NMR). Since ferrocenyl 3,4-dihydroquinolones all have an N-H bond which can form an intermolecular hydrogen bond, their melting points are higher than those of ferrocenyl dihydrocoumarin. Finally, we find that all ferrocenyl acrylic amides **9** are red solids and all ferrocenyl 3,4-dihydroquinolones **10** are yellow solids, which suggests that the structures of **9** and **10** are similar to those of **7** and **6**, respectively.

Why cannot strong acid catalyze hydroarylation of acrylic anilides to dihydroquinolones?
Our experiment proves that TFA (CF_3COOH, pka= 0.3) is a good catalyst for the hydroarylation of acrylic anilides to dihydroquinolones, but c-H_2SO_4 (pKa < -7) can not catalyze this reaction. The hydroarylation of acrylic anilide to dihydroquinolone is an electrophilic substitution reaction and its mechanism has been proposed by Tunge[19] as shown in scheme 2.



Scheme 2. The mechanism for hydroarylation proposed by Tunge.

The transition state of A to B has been calculated in this paper (R= -OCH_3) and the structures of reactant A and this transition state are shown in Figure 2.

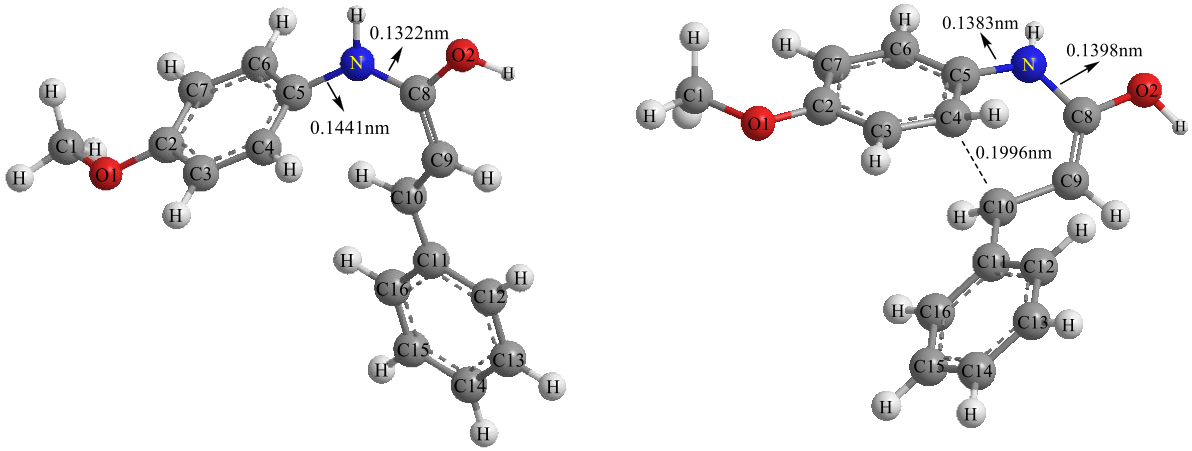


Figure 2. The optimized structures of reactant A and transition state of the reaction of A to B.

If the bond lengths of C5-N and N-C8 are compared in reactant **A** and the transition state, the following is noted: (1) in reactant **A**, the N atom conjugates with the enol mainly because the positive charge is on C10 atom, so N-C8 bond is a partial double bond and its bond length is 0.1322 nm; (2) in the transition state, the N atom conjugates with the benzene ring mainly because positive charge is on the benzene ring, so C5-N bond is a partial double bond and its bond length is 0.1383 nm. This result indicates that the lone pair of electron on the N atom is very important and it can stabilize the positive charge, no matter if the positive charge is on C10 atom or on benzene ring (C2~C7). The acidity of c-H_2SO_4 is strong enough to protonate the N atom of acrylic anilide and a protonated N atom can not stabilize the positive charge caused by electrophilic attack. Therefore, c-H_2SO_4 can not catalyze hydroarylation of acrylic anilides to dihydroquinolones.

Conclusions

Since the ferrocenyl has large spatial obstacle, the ring closure of phenol and ferrocenyl acrylic acid to ferrocenyl dihydrocoumarin is difficult. Only phenols those have large electronic density in *ortho*-site of the hydroxyl, such as resorcinol and 2-naphthalenol, that can get ring closure product. But the ring closure of ferrocenyl acrylic anilides to ferrocenyl 3,4-dihydroquinolones is easy unless there is a strong electron-withdrawing group in the phenyl ring, the weak electron-withdrawing groups only make the reaction slow but do not hold back it.

Experimental Section

Computational details

All geometry optimizations of reactants and products are performed by means of B3LYP method with Gaussian 03 program and 6-311G(d) basis set for all atoms. The transition states are all obtained from QST3 calculations and are affirmed by calculations of vibration frequency. All calculated details are available from authors.

General. All reagents were commercially available and used as received without further purification. All solvents were distilled and dried before use. Melting points were measured with WRS-1B micromelting apparatus. ^{1}H NMR spectra were recorded on a Bruker spectrometer at 400 MHz, using TMS as internal standard. The chemical shift values are on δ scale and the coupling constants (*J*) are in Hz. Elemental analyses were conducted by the Service Center of Elemental Analysis of Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences. The IR spectra were recorded on Perkin- Elmer 2000 FT-IR spectrometer.

Procedure for the synthesis of esterified product (7) and ring closure product (6)

The compound **4** and **5** are synthesized according to reference[21]. 0.38g Phenol (4.0mmol), 1.03g ferrocenyl acrylic acid **5** (4.0mmol) and 150mL benzene were added into a 250mL round bottom flask, 0.5mL concentrated sulfuric acid was added dropwise under nitrogen, then a water separator was put on the flask. The reaction mixture was stirred at 90 °C in oil bath for about 10h till the detected spot of ferrocenyl acrylic acid on TLC becomes very weak. The reaction mixture was then washed with saturated NaCl solution (30mL×2), dried over anhydrous $MgSO_4$, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel using a mixture of petroleum ether (60~90 °C) and ethyl acetate (8:1, v/v) as an eluent to give phenyl ferrocenyl cinnamate **7a** in 40%.

1,2-Dihydro-1-ferrocenyl-3*H*-naphtho-[2,1*b*]pyran-3-one (6a). Yellow solid, mp 166.1-167.5 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 3.08 (1H, dd, *J* = 6.4 Hz and 16.0 Hz, C-3H$_\alpha$), 3.41 (1H, d, *J* = 6.4 Hz, C-3H$_\beta$), 4.09-4.23 (m ,9H, , Cp-H), 4.69 (1H, d, *J* = 6.0 Hz, C-4H), 7.30-8.11(m, 6H, ArH); IR (KBr): 3096 (Ar-CH), 1715 (C=O), 1626 , 1452 (C=C), 1288, 1160 (Cp C=C), 492, 482 (Fe-Cp); Anal. Calcd. for $C_{23}H_{18}FeO_2$: C, 72.27; H, 4.75. Found: C, 71.95; H, 4.70.

7-Hydroxy-4-ferrocenyl-3,4-dihydrocoumarin (6b). Yellow solid**,** mp 147.8-149.1 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 2.98 (1H, dd, *J* = 6.0 Hz and 16.0 Hz, C-3H$_\alpha$), 3.10 (1H, dd, *J* = 5.6Hz and 16.0 Hz, C-3H$_\beta$), 3.95 (1H, t, *J* = 6.0 Hz, C4-H), 4.02-4.19 (9H, m, Cp-H), 5.80 (1H, br s, OH), 6.59-6.64 (2H, m, *o*-Ar-H of OH), 6.98 (1H, d, *J* = 8.0 Hz, *m*-Ar-H of OH); IR(KBr): 3092 (Ar-CH), 2925 (Saturated C-H), 1734 (C=O), 1623, 1509 (C=C), 1278,1153 (Cp C=C), 492,481,469 (Fe-Cp); Anal. Calcd. for $C_{19}H_{16}FeO_3 \cdot 0.5H_2O$: C, 63.89; H, 4.80. Found: C, 63.63; H, 4.77.

Phenyl ferrocenyl acrylate (7a). Red solid, mp 192.3-193.5 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 4.19 (5H, s, Cp-H), 4.49 (2H, t, *J* = 1.6 Hz, Cp-H), 4.58 (2H, t, *J* = 1.6 Hz, Cp-H), 6.22 (1H, d, *J* = 15.6, = CH-C = O), 7.77 (1H, d, *J* = 16.0, Cp-CH =), 7.18-7.45 (5H, m, C_6H_5); IR(KBr): 3088 (Ar-CH), 1720 (C = O), 1622, 1450 (C = C), 1260, 1142 (Cp C = C), 502, 492 (Fe-Cp); Anal. Calcd. for $C_{19}H_{16}FeO_2$: C, 68.70; H, 4.85. Found: C, 68.75; H, 4.93.

4-Methylphenyl ferrocenyl acrylate (7b) Red solid, mp 134.0-135.2 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 4.21 (5H, s, Cp-H), 4.48 (2H, t, *J* = 1.6 Hz, Cp-H), 4.57 (2H, t, *J* = 1.6 Hz, Cp-H), 6.21 (1H, d, *J* = 15.6, = CH-C = O), 7.76 (1H, d, *J* = 16.0, Cp-CH =), 7.05-7.23 (5H, m, C_6H_5); IR(KBr): 3084 (Ar-CH), 1717 (C = O), 1624, 1508 (C = C), 1247, 1138 (Cp C = C), 499, 482 (Fe-Cp); Anal. Calcd. for $C_{20}H_{18}FeO_2$: C, 69.39; H, 5.24. Found: C, 69.40; H, 5.35.

4-Methoxyphenyl ferrocenyl acrylate (7c). Red solid, mp 104.5-105.6 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 3.84 (3H, s, CH_3), 4.21 (5H, s, Cp-H), 4.48 (2H, t, *J* = 1.6 Hz, Cp-H), 4.57 (2H, t, *J* = 1.6 Hz, Cp-H), 6.21 (1H, d, *J* = 15.6, = CH-C = O), 7.76 (1H, d, *J* = 16.0, Cp-CH =), 6.93 (2H, m, Ar-H), 7.09 (2H, m, Ar-H); IR(KBr): 3089 (Ar-CH), 2924 (υCH_3), 1719 (C = O), 1626, 1506 (C = C), 1248, 1138 (Cp C = C), 496, 481 (Fe-Cp);

4-Methyl-2-oxo-2*H*-chromen-7yl-ferrocenyl acrylate (7d). Red solid, mp 175.8-176.9 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 2.48 (3H, s, CH_3), 4.24 (5H, s, Cp-H), 4.52 (2H, t, *J* = 1.6 Hz, Cp-H), 4.59 (2H, t, *J* = 1.6 Hz, Cp-H), 6.21 (1H, d, *J* = 15.6, = CH-C = O), 6.30 (1H, s, CH = of

coumarin), 7.18-7.23 (2H, m, C6-H and C8-H), 7.54 (1H, d, *J* = 8.0 Hz, C5-H), 7.81 (1H, d, *J* = 15.6, Cp-CH =); IR(KBr): 3087 (Ar-CH), 1732 (C = O), 1630, 1612, 1497 (C = C), 1233, 1146, (Cp C = C), 482 (Fe-Cp); Anal. Calcd. for $C_{23}H_{18}FeO_4 \cdot 0.5H_2O$: C, 65.27; H, 4.52. Found: C, 65.44; H, 4.46.

4-Hydroxyphenyl ferrocenyl acrylate (7e). Red solid, mp 178.7-179.8 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 4.20 (5H, s, Cp-H), 4.46 (2H, t, *J* = 1.6 Hz, Cp-H), 4.54 (2H, t, *J* = 1.6 Hz, Cp-H), 6.17 (1H, d, *J* = 15.6, = CH-C = O), 6.79 (2H, d, *J* = 8.4 Hz, Ar-H), 7.00 (2H, d, *J* = 8.8 Hz, Ar-H), 7.73 (1H, d, *J* = 15.6, Cp-CH =); IR(KBr): 3312 (OH), 3087 (Ar-CH), 1683 (C = O), 1620, 1508 (C = C), 1190, 1150 (Cp C = C), 499, 481 (Fe-Cp); Anal. Calcd. for $C_{19}H_{16}FeO_3$: C, 65.54; H, 4.63. Found: C, 65.85; H, 5.11.

Procedure for the synthesis of ferrocenyl acrylic amide 6 and ferrocenyl dihydroquionlin-2-one (10)

Intermediate **8** was synthesized according to the document [22]. **8** (1.0 mmol) and aniline (1.0 mmol) were added into a 50mL round bottom flask under nitrogen, then 15ml dried 1,2-dichloroethane and triethylamine (1.0mmol) were subsequently added. The reaction mixture was stirred at 30 °C in water bath till the detected spot of ferrocenyl acryloyl chloride on TLC becomes very weak. The reaction mixture was then washed with diluted hydrochloric acid, diluted NaOH solution and water in turn, dried over anhydrous $MgSO_4$, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel using dichloromethane as an eluent to give the intermediate **9a** in 95%.

9a (0.5 mmol) was added into a 50mL round bottom flask under nitrogen, the 15ml dried 1,2-dichloroethane and 2 ml TFA were added. The reaction mixture was stirred at 30℃ in water bath till the detected spot of the intermediate amide on TLC disappeared. The reaction mixture was washed with NaOH solution (0.5 mol/L) and water, dried over anhydrous $MgSO_4$, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel using a mixture of petroleum ether (60~90 °C) and ethyl acetate (4:1, v/v) as an eluent to give **10a** in 88%.

4-Ferrocenyl-3,4-dihydroquionlin-2-one (10a). Yellow solid, mp 198.6-200.1 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 2.89 (1H, dd, *J* = 7.2 Hz and 16.0 Hz, C-3H$_\alpha$), 3.05 (1H, dd, *J* = 6.0 Hz and 16.0 Hz , C-3H$_\beta$), 4.00 (1H, t, *J* = 6.4 Hz, C4-H), 4.08-4.18 (9H, m, Cp-H), 6.71 (1H, d, *J* = 7.2 Hz, C8-H), 6.97 (1H, t, *J* = 7.6 Hz, C6-H), 7.08(1H, d, *J* = 7.2 Hz, C5-H), 7.16(1H, t, *J* = 7.6 Hz, C7-H), 7.72 (1H, s, N-H); IR(KBr): 3217 (NH), 3073 (Ar-CH), 2986 and 2908 (CH_2 and CH-Fc), 1676 (C = O), 1598, 1504 (C = C), 1383, 1248 (C-N), 1168, 1106 (Cp C = C), 500, 483 (Fe-Cp); Anal. Calcd. for $C_{19}H_{17}FeNO \cdot 0.3H_2O$: C, 67.80; H, 5.27; N, 4.16 . Found: C, 67.68; H, 4.99; N, 3.99.

4-Ferrocenyl-8-methoxyl-3,4-dihydroquionlin-2-one (10b). Yellow solid, mp 174.2-175.3 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 2.85 (1H, dd, *J* = 4.8 Hz and 16.0 Hz, C-3H$_\alpha$), 3.05 (1H, dd, *J* = 4.8 Hz and 16.4 Hz , C-3H$_\beta$), 3.84(3H, s, OCH_3), 3.96 (1H, t, *J* = 6.0 Hz, C4-H), 4.18-4.24 (9H, m, Cp-H), 6.68(1H, d, *J* = 7.6 Hz, C5-H), 6.73(1H, d, *J* = 8.0 Hz, C7-H), 6.91(1H, t, *J* = 7.6 Hz,

C6-H), 7.80 (1H, s, N-H); IR(KBr): 3193 (NH), 3089 (Ar-CH), 2939, 2904, 2851 (OCH_3, CH_2 and CH-Fc), 1679 (C = O), 1594, 1498 (C = C), 1266, 1244(C-N), 1164, 1096 (Cp C = C), 494, 484 (Fe-Cp); Anal. Calcd. for $C_{20}H_{19}FeNO_2$: C, 66.50; H, 5.30; N, 3.88. Found: C, 66.10; H, 5.31; N, 3.70.

4-Ferrocenyl-6-chloro-3,4-dihydroquionlin-2-one (10c). Yellow solid, mp 186.6-187.2 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 2.87 (1H, dd, *J* = 6.8 Hz and 16.0 Hz, C-3H$_\alpha$), 3.03 (1H, dd, *J* = 6.0 Hz and 16.0 Hz , C-3H$_\beta$), 3.98 (1H, t, *J* = 6.4 Hz, C4-H), 4.10-4.20 (9H, m, Cp-H), 6.64 (1H, d, *J* = 8.4 Hz, C8-H), 7.06 (1H, d, *J* = 1.6 Hz, C5-H), 7.11(1H, dd, *J* = 2.4 Hz and 8.4 Hz, C7-H), 7.52 (1H, s, N-H); IR(KBr): 3199 (NH), 3089 (Ar-CH), 3055 (Ar-CH), 2949 (CH_2), 1675 (C = O), 1604, 1487 (C = C), 1372, 1278(C-N), 1176, 1104 (Cp C = C), 484, 461 (Fe-Cp); Anal. Calcd. for $C_{19}H_{16}ClFeNO \cdot 1.8H_2O$: C, 57.33; H, 4.96; N, 3.52. Found: C, 57.51; H, 4.78; N, 3.39.

4-Ferrocenyl-7-methoxyl-3,4-dihydroquionlin-2-one (10d-1). Yellow solid, mp 212.7-214.2 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 2.85 (1H, dd, *J* = 6.4 Hz and 16.0 Hz, C-3H$_\alpha$), 3.01 (1H, dd, *J* = 6.0 Hz and 16.0 Hz , C-3H$_\beta$), 3.76(3H, s, OCH_3), 3.94 (1H, t, *J* = 6.0 Hz, C4-H), 4.08-4.19 (9H, m, Cp-H), 6.26 (1H, d, *J* = 2.0 Hz, C8-H), 6.50 (1H, dd, *J* = 2.4 Hz and 8.4 Hz, C6-H), 6.97 (1H, t, *J* = 8.4 Hz, C5-H), 7.59 (1H, s, N-H); IR (KBr): 3195 (NH), 3096 (Ar-CH), 2996, 2936, 2969, 2928 (OCH_3, CH_2 and CH-Fc), 1683 (C = O), 1592, 1491 (C = C), 1372, 1284(C-N), 1166, 1128 (Cp C = C), 487, 449 (Fe-Cp); Anal. Calcd. for $C_{20}H_{19}FeNO_2 \cdot 0.4H_2O$: C, 65.20; H, 5.42; N, 3.80. Found: C, 65.15; H, 5.02; N, 3.78.

4-Ferrocenyl-5-methoxyl-3,4-dihydroquionlin-2-one (10d-2). Yellow solid, mp 236.5-237.7 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 2.85 (1H, dd, *J* = 6.8 Hz and 16.0 Hz, C-3H$_\alpha$), 3.06 (1H, d, *J* = 15.6 Hz , C-3H$_\beta$), 3.94(3H, s, OCH_3), 4.09-4.34 (9H, m, Cp-H), 4.40(1H, d, *J* = 6.4 Hz, C4-H), 6.33(1H, d, *J* = 7.6 Hz, C8-H), 6.59(1H, d, *J* = 8.4 Hz, C6-H), 7.11(1H, t, *J* = 8.0 Hz, C7-H), 7.53 (1H, s, N-H); IR (KBr): 3176 (NH), 3074, 3005 (Ar-CH), 2932, 2886, 2833 (OCH_3, CH_2 and CH-Fc), 1683 (C = O), 1599, 1510 (C = C), 1279, 1232(C-N), 1166, 1103 (Cp C = C), 481, 460 (Fe-Cp); Anal. Calcd. for $C_{20}H_{19}FeNO_2$: C, 66.50; H, 5.30; N, 3.88 . Found: C, 66.21; H, 4.91; N, 3.80.

4-Ferrocenyl-7-chloro-3,4-dihydroquionlin-2-one (10e-1). Yellow solid, mp 198.8-200.3 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 2.88 (1H, dd, *J* = 6.8 Hz and 16.0 Hz, C-3H$_\alpha$), 3.03 (1H, dd, *J* = 6.0 Hz and 16.0 Hz , C-3H$_\beta$), 3.98(1H, t, *J* = 6.4 Hz, C4-H),4.06-4.18 (9H, m, Cp-H), 6.73(1H, d, *J* = 2.0 Hz, C8-H), 6.92(1H, dd, *J* = 2.0 Hz and 8.0 Hz, C6-H), 6.99(1H, d, *J* = 8.4 Hz, C7-H), 7.61 (1H, s, N-H); IR (KBr): 3183 (NH), 3090, (Ar-CH), 2956, 2888, (OCH_3, CH_2 and CH-Fc), 1684 (C = O), 1584, 1485 (C = C), 1365, 1239 (C-N), 1157, 1107 (Cp C = C), 481, 451 (Fe-Cp); Anal. Calcd. for $C_{19}H_{16}ClFeNO$: C, 62.41; H, 4.41; N, 3.83 . Found: C, 62.54; H, 4.47; N, 3.72.

4-Ferrocenyl-5-chloro-3,4-dihydroquionlin-2-one (10e-2). Yellow solid, mp >250 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 2.89 (1H, dd, *J* = 6.8 Hz and 16.4 Hz, C-3H$_\alpha$), 3.15 (1H, d, *J* = 16.4 Hz , C-3H$_\beta$), 4.06-4.44 (9H, m, Cp-H), 4.48(1H, d, *J* = 6.4 Hz, C4-H), 6.60 (1H, dd, *J* = 2.4 Hz and 6.4, C6-H), 7.04-7.09 (2H, m, C7-H and C8-H), 7.72 (1H, s, N-H); IR (KBr): 3195 (NH), 3085, 3058 (Ar-CH), 2979, 2912, (OCH_3, CH_2 and CH-Fc), 1689(C = O), 1582, 1466 (C = C), 1376,

1251 (C-N), 1168, 1105 (Cp C = C), 481, 456(Fe-Cp); Anal. Calcd. for $C_{19}H_{16}ClFeNO \cdot 0.3H_2O$: C, 61.50; H, 4.51; N, 3.77. Found: C, 61.55; H, 4.34; N, 3.63.

4-Ferrocenyl-7,8-dichloro-3,4-dihydroquionlin-2-one (10f). Yellow solid, mp 175.3-176.5 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 2.89 (1H, dd, *J* = 6.0 Hz and 16.0 Hz, C-3H$_\alpha$), 3.04 (1H, dd, *J* = 5.6 Hz and 16.4 Hz , C-3H$_\beta$), 3.99(1H, t, *J* = 6.4 Hz, C4-H), 4.09-4.21 (9H, m, Cp-H), 6.92 (1H, d, *J* = 8.0 Hz, C6-H), 7.05 (1H, d, *J* = 8.0 Hz, C5-H), 7.84 (1H, s, N-H); IR (KBr): 3195 (NH), 3132, 3049 (Ar-CH), 2937, 2842, (OCH_3, CH_2 and CH-Fc), 1686(C = O), 1592, 1459 (C = C), 1351, 1272 (C-N), 1150, 1105 (Cp C = C), 478, 445(Fe-Cp); Anal. Calcd. for $C_{19}H_{15}Cl_2FeNO$: C, 57.04; H, 3.78; N, 3.50 . Found: C, 57.08; H, 3.36; N, 3.24.

4-Ferrocenyl-5,8-dimethoxyl-3,4-dihydroquionlin-2-one (10g). Yellow solid, mp 242.1-243.5 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 2.82 (1H, dd, *J* = 7.2 Hz and 16.4 Hz, C-3H$_\alpha$), 3.02 (1H, d, *J* = 16.4 Hz , C-3H$_\beta$), 3.77 (3H, s, OCH_3 on C8), 3.86 (3H, s, OCH_3 on C5), 4.07-4.36 (10H, m, Cp-H and C4-H), 6.45 (1H, d, *J* = 8.8 Hz, C6-H), 6.63 (1H, d, *J* = 8.8 Hz, C7-H), 7.74 (1H, s, N-H); IR (KBr): 3196 (NH), 3080 (Ar-CH), 2991, 2929, 2829 (OCH_3, CH_2 and CH-Fc), 1674(C = O), 1604, 1503 (C = C), 1383, 1262 (C-N), 1186, 1093 (Cp C = C), 483, 443(Fe-Cp); Anal. Calcd. for $C_{21}H_{21}FeNO_3 \cdot 0.2H_2O$: C, 63.88; H, 5.46; N, 3.55. Found: C, 63.62; H, 5.28; N, 3.40.

4-Ferrocenyl-6,7-dimethoxyl-3,4-dihydroquionlin-2-one (10h). Yellow solid, mp 187.4-188.8 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 2.79 (1H, d, *J* = 15.2 Hz, C-3H$_\alpha$), 2.99 (1H, d, *J* = 15.6 Hz , C-3H$_\beta$), 3.80 (3H, s, OCH_3 on C6), 3.84 (3H, s, OCH_3 on C7), 4.15-4.25 (10H, m, Cp-H and C4-H), 6.28 (1H, s, C8-H), 6.62 (1H, s, C5-H), 7.50 (1H, s, N-H); IR (KBr): 3202 (NH), 3093 (Ar-CH), 2989, 2840 (OCH_3, CH_2 and CH-Fc), 1668(C = O), 1623, 1520 (C = C), 1381, 1276 (C-N), 1200, 1104 (Cp C = C), 495, 478(Fe-Cp); Anal. Calcd. for $C_{21}H_{21}FeNO_3 \cdot 0.3H_2O$: C, 63.59; H, 5.49; N, 3.53. Found: C, 63.29; H, 5.07; N, 3.25.

4-Ferrocenyl-5,8-dimethyl-3,4-dihydroquionlin-2-one (10i). Yellow solid, mp 226.3-227.5 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 2.16 (3H, s, CH_3 on C8), 2.45 (3H, s, CH_3 on C5), 2.85 (1H, dd, *J* = 6.4 Hz and 16.4 Hz, C-3H$_\alpha$), 3.11 (1H, d, *J* = 16.0 Hz , C-3H$_\beta$), 4.07-4.19 (10H, m, Cp-H and C4-H), 6.77 (1H, d, *J* = 7.6 Hz, C6-H), 6.90 (1H, d, *J* = 7.6 Hz, C7-H), 7.35(1H, s, N-H); IR (KBr): 3219 (NH), 3080 (Ar-CH), 2938, 2887 (OCH_3, CH_2 and CH-Fc), 1668(C = O), 1580, 1502 (C = C), 1381, 1232 (C-N), 1200, 1105 (Cp C = C), 475, 454(Fe-Cp); Anal. Calcd. for $C_{21}H_{21}FeNO \cdot 0.4H_2O$: C, 68.83; H, 6.00; N, 3.82. Found: C, 68.61; H, 5.52; N, 3.84.

4-Ferrocenyl-3,4-dihydrobenzo[*h*]quinolin-2-one (10j). Yellow solid, mp >250 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 3.02 (1H, dd, *J* = 5.2 Hz and 15.6 Hz, C-3H$_\alpha$), 3.16 (1H, dd, *J* = 6.4 Hz and 16.0 Hz, C-3H$_\beta$), 4.12-4.20 (10H, m, Cp-H and C4-H), 7.29 (1H, d, *J* = 8.4 Hz, Ar-H), 7.46-7.56 (3H, m, Ar-H), 7.73(1H, d, *J* = 8.4 Hz, Ar-H), 7.81(1H, d, *J* = 8.0 Hz, Ar-H), 8.20(1H, s, N-H); IR (KBr): 3215 (NH), 3092 (Ar-CH), 2930, 2895 (OCH_3, CH_2 and CH-Fc), 1678(C = O), 1571, 1519 (C = C), 1372, 1289 (C-N), 1190, 1103 (Cp C = C), 485, 452(Fe-Cp); Anal. Calcd. for $C_{23}H_{19}FeNO$: C, 72.46; H, 5.02; N, 3.67. Found: C, 72.15; H, 4.72; N, 3.62.

***N*-4(nitrophenyl)-3-ferrocenylacrylamide (9k).** Red solid, mp 217.3-218.5 °C. ^{1}HNMR (400 MHz, $CDCl_3$): δ 4.19 (5H, s, Cp-H), 4.47 (2H, s, Cp-H), 4.53 (2H, s, Cp-H), 6.11 (1H, d, *J* =

14.8, = CH-C = O), 7.37 (1H, s, N-H), 7.70 (1H, d, *J* = 14.8, Cp-CH =), 7.78 (2H, d, *J* = 8.8 Hz, Ar-H), 8.23(2H, d, *J* = 8.8 Hz, Ar-H); IR (KBr): 3374 (NH), 3096 (Ar-CH), 2971, 2923 (OCH_3, CH_2 and CH-Fc), 1672(C = O), 1619(COCH = CHFc), 1596, 1503 (C = C of Ar), 1341, 1247 (C-N), 1536, 1407 (N = O), 1189, 1107 (Cp C = C), 483, 473(Fe-Cp); Anal. Calcd. for $C_{19}H_{16}FeN_2O_3 \cdot 0.1H_2O$: C, 60.37; H, 4.32; N, 7.41. Found: C, 60.20; H, 4.30; N, 7.18.

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