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An expedient synthesis of ferrocene grafted spirooxindolopyrrolizidines via [3+2]-cycloaddition of azomethine ylides

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ABSTRACT

A facile and rapid one-pot synthesis of ferrocene bearing novel spiropyrrolizidines has been accomplished by [3+2]-cycloaddition reaction of various azomethine ylides derived from isatin/5,7-dibromoisatin and L-proline with various ferrocene derivatives as dipolarophile in good yield. The protocol is general and applicable to a wide variety of ferrocenyl derived dipolarophiles. Effect of various solvents on [3+2]-dipolar cycloaddition reaction is also studied.

1. Introduction

Ferrocene, an organometallic compound, was discovered in the early 1950s[1] and since then, there has been enormous growth in the ferrocene chemistry.[2] Ferrocene is now currently employed as a crucial component for redox-active chemical sensors for voltammetric detection of cations[3] as well as anions,[4] metal-containing signaling probes for the detection of estrogen receptors,[5] dinucleotides,[6] and DNA hybridization events,[7] thus opening the way to DNA and gene sensors.[8] Ferrocene materials are used as asymmetric catalysts,[9] liquid crystals,[10] conductive,[11] magnetic,[12] and optical devices,[13] and electron transfer devices.[14] Ferrocene derivatives remain at the forefront of attention offering advantage over other organometallics due to their synthetic versatility, overall thermal and photochemical stability.

Ferrocene substituted organic molecules hold great potential due to their biological activity. Ferrocene derivatives have been used for the treatment of malaria and cancer.[15–18] Many ferrocene based heterocycles are known to exhibit anti-bacterial and anti-fungal properties.[19–21] Hence, there has been renewed interest in the synthesis of ferrocene based heterocycles with potential applications.

The intermolecular [3+2]-cycloaddition reaction of azomethine ylides with olefinic and acetylenic dipolarophiles has resulted in a number of novel heterocyclic scaffolds, which are particularly useful for the creation of diverse chemical libraries of drug-like molecules for biological screening.[22,23] Functionalised pyrrolizidines and oxindoles are the central skeleton for numerous alkaloids and constitute classes of compounds with significant biological activity.[24,25] Spirooxindoles are an important class of naturally occurring substances characterized by highly pronounced biological properties.[26] Recently we have reported bioactivity of some of the spiropyrrolidines.[27]

2. Results and discussion

Only few reports are available on the use of [3+2]-cycloaddition reaction as a tool to synthesize ferrocene based heterocycles that are (a) reaction of nitrile oxide generated from ferrocenecarboxaldehyde oxime with C_{60} affording ferrocenyl-C_{60} adduct,[28] (b) reaction of C_{60} with sarcosine and chiral substituted ferrocenecarboxaldehyde affording chiral ferrocenyl-C_{60} adduct and fullerene-dimer,[29] and (c) reaction of ferrocene derived chiral azomethine ylides (generated via imine tautomerization and complexation with diethylzinc) with a number of electron-deficient dipolarophiles affording some chiral ferrocenyl-substituted pyrrolidine derivatives.[30] It is noteworthy that in all these methods reported, ferrocene derivatives have been used extensively for the generation of 1,3-dipole but they have not been studied as a dipolarophile.

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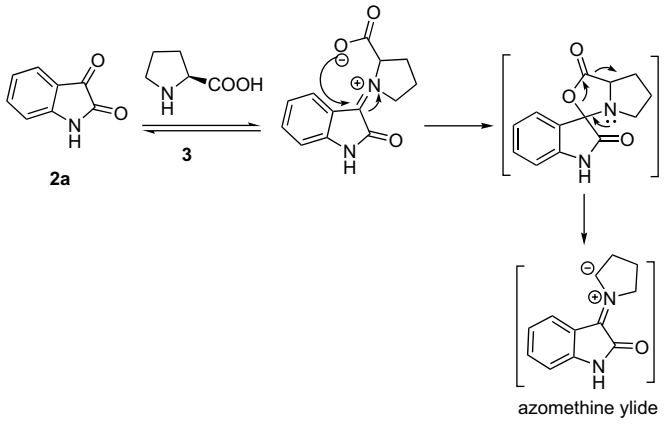
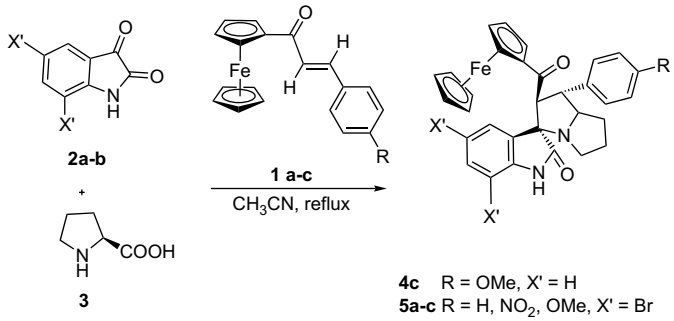
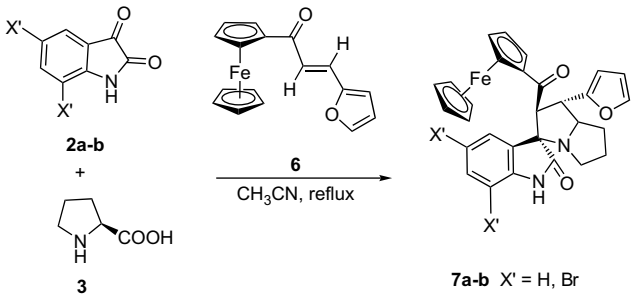


Scheme 1.



Scheme 2.

As part of the ongoing program on synthesis of complex novel spiroheterocycles,[31,32] herein we herein report for the first time, an expeditious and a facile protocol for the synthesis of novel ferrocene grafted monospirooxindolopyrrolizidines. We have explored the reactivity of ferrocene derivatives as efficient dipolarophiles for the synthesis of rare class of ferrocene based spiroheterocycles. The azomethine ylides were generated in situ from isatin **2a**/5,7-dibromoisatin **2b**[33a] and L-proline **3** (Scheme 1) and then trapped with various ferrocene derivatives **1a**–**c**, **6**, **8**, **10a**,**b**, and **12** as dipolarophiles[33b] affording a series of novel ferrocene grafted monospirooxindolopyrrolizidines **4a**/**5a**–**c**, **7**, **9a**,**b**, **11a**,**b**, and **13**. The structure of the ferrocenyl monospiroheterocycles was confirmed through spectral and elemental analysis. The reactions were carried out under two different conditions and the results are shown in Table 1.

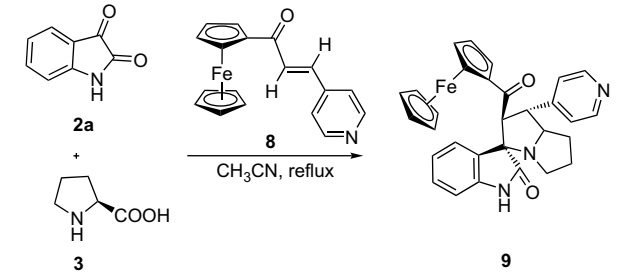


Scheme 3.

Schemes 2–6 suggest one-pot three component reactions involving isatin/5,7-dibromoisatin, L-proline, and various ferrocene derivatives for the synthesis of hitherto unknown novel monospirooxindolopyrrolizidines bearing ferrocene moiety.

A series of novel ferrocene appended spirooxindolopyrrolizidines were synthesized by the reaction of various ferrocene derived dipolarophiles with the azomethine ylide generated from isatin **2a**/5,7-dibromoisatin **2b** and L-proline **3**.

The dipolarophile (**1c**/**1a**–**c**) reacted smoothly with the azomethine ylide generated from isatin **2a**/5,7-dibromoisatin **2b** and L-proline **3** in refluxing acetonitrile, which afforded ferrocenyl spirooxindolopyrrolizidines (**4c**/**5a**–**c**) in good yield (Scheme 2). The formations of the cycloadduct were confirmed by spectral and elemental analysis.



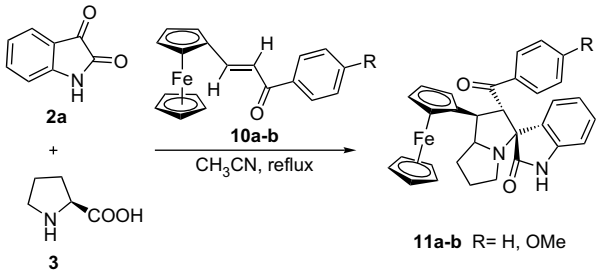
Scheme 4.

The IR spectrum of spiro-[2.3′]-5′,7′-dibromooxindole-3-ferrocenoyl-4-(*p*-nitrophenyl)-pyrrolizidine **5b** exhibited peaks at 1675

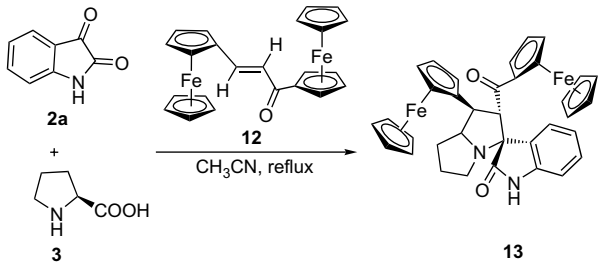
Table 1
[3+2]-Cycloaddition reaction of ferrocene derived dipolarophiles **1a**–**c**/**6**/**8**/**10a**,**b**/**12** with isatin (**2a**)/5,7-dibromoisatin (**2b**), and L-proline (**3**)

Product	R	X′	Acetonitrile/reflux		Toluene/reflux	
			T (h)	Y (%)	T (h)	Y (%)
4c	OMe	H	5.6	60	14	48
5a	H	Br	5.0	70	—	—
5b	NO_2	Br	4.6	78	10	62
5c	OMe	Br	5.4	58	—	—
7a	—	H	4.0	80	—	—
7b	—	Br	4.2	76	—	—
9		H	4.0	78	—	—
11a	H	H	5.2	66	—	—
11b	OMe	H	5.5	62	13	40
13	—	H	5.4	64	16	36

T (h)=time in hour; Y (%)=yield in percentage.



Scheme 5.



Scheme 6.

and 1710 cm^{-1} due to ferrocenoyl and dibromooxindole carbonyl moiety. In the ^1H NMR spectrum of **5b**, six methylene protons of the pyrrolizidine ring exhibited multiplets in the region δ 1.62–1.93 and δ 2.56–2.68. The pyrrolizidine ring proton attached to the *p*-nitrophenyl moiety exhibited a triplet at δ 3.95 (J=10.4 Hz). The pyrrolizidine ring proton attached to the ferrocenoyl moiety appeared as a doublet at δ 4.27 (J=10.4 Hz) whereas the pyrrolizidine –NCH proton exhibited a multiplet in the region δ 4.33–4.38. The ferrocenyl protons exhibited singlets at δ 3.56, 4.22, 4.31, and 4.54. The aromatic protons of the dibromooxindole moiety exhibited singlets at δ 7.19 and 7.37. The other aromatic protons appeared as two doublets at δ 7.74 (J=8.4 Hz) and δ 8.18 (J=8.4 Hz). The –NH proton of the dibromo moiety exhibited a singlet at δ 7.95. The off-resonance decoupled ^{13}C NMR spectra of **5b** added conclusive support to the proposed structure. The spirocarbon resonated at δ 75.84 ppm. The dibromooxindole carbonyl and the carbonyl carbon resonated at δ 176.65 and 196.80 ppm, respectively. These observed chemical shift values confirmed the proposed structure. The formation of the product was confirmed by mass spectral and elemental analysis. The mass spectrum of **5b** showed a peak at *m*/*z* 719 (M^+) and the product **5b** gave satisfactory elemental analysis. Similarly, the formations of the cycloadducts (**4c**/**5a**,**c**) were confirmed by spectral and elemental analysis.

Reaction of 1-ferrocenyl-3-furyl-prop-2-ene-1-one **6** with isatin **2a**/5,7-dibromoisatin **2b** and L-proline **3** in refluxing acetonitrile led to the formation of the spiro-adduct **7a**,**b** as a single product as

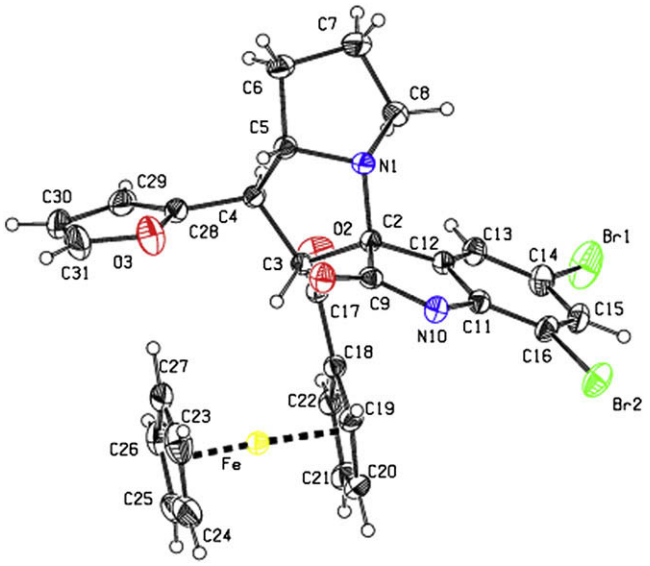


Figure 1. ORTEP diagram of compound **7b**.

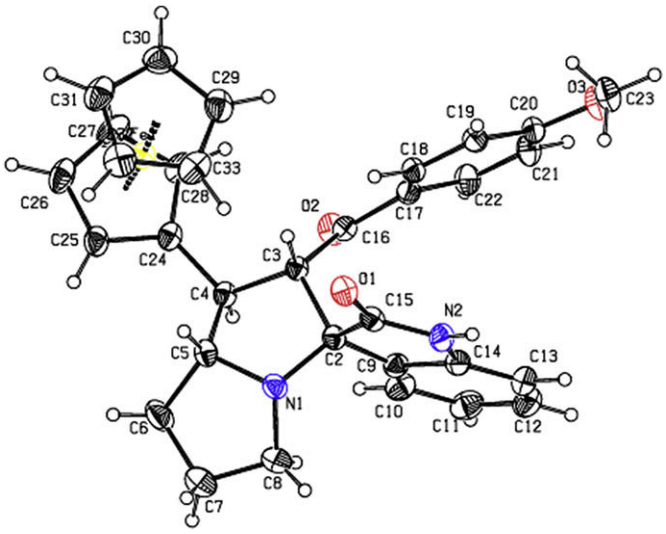


Figure 2. ORTEP diagram of compound **11b**.

evidenced by TLC and spectral analysis. The formation of the cycloadduct **7a**,**b** was confirmed by spectral and elemental analysis (Scheme 3). Finally, the regio- and stereochemical outcome of the cycloaddition reaction was ascertained by the single crystal X-ray analysis of the cycloadduct **7b** (Fig. 1).[33c]

In the similar manner, 1-ferrocenyl-3-pyridyl-prop-2-ene-1-one **8** reacted with the azomethine ylide generated from isatin **2a** and L-proline **3** in refluxing acetonitrile, which afforded spiro-adduct **9** in good yield (Scheme 4).

The dipolarophile, 1-phenyl-3-ferrocenyl-prop-2-ene-1-one derivatives **10a**,**b** reacted smoothly with the azomethine ylide generated from isatin **2a** and L-proline **3** in refluxing acetonitrile and afforded the spiropyrrolizidines **11a**,**b** exclusively in good yield (Scheme 5). The formations of the cycloadducts **11a**,**b** were confirmed by spectral and elemental analysis. The regio- and stereochemical outcome of the cycloaddition reaction was unambiguously ascertained by single crystal X-ray analysis of the cycloadduct **11b** (Fig. 2).[33c] The yields of the cycloadducts are given in Table 1.

It was interesting to note that the cycloadduct **13** has two ferrocene moieties on the pyrrolizidine platform, which was easily synthesized by trapping the azomethine ylide generated from isatin **2a** and L-proline **3** with the unusual dipolarophile **12** (Scheme 6).

Thus, the IR spectrum of the monospirooxindolopyrrolizidine **17** showed peaks at 1664 and 1702 cm^{-1} due to ferrocenoyl and oxindole carbonyl groups. In the ^1H NMR spectrum of **17**, six methylene protons of the pyrrolizidine ring exhibited multiplets in the region δ 1.70–2.04 and δ 2.35–2.59. The pyrrolizidine ring proton attached to the ferrocene moiety exhibited a triplet at δ 3.74 (J=10.3 Hz). The pyrrolizidine ring proton attached to the ferrocenoyl moiety appeared as a doublet at δ 4.26 (J=11 Hz) whereas the pyrrolizidine –NCH proton exhibited a multiplet in the region δ 4.08–4.13. The ferrocenyl protons exhibited singlets at δ 3.86, 4.15, 4.19, 4.24, 4.50, and 4.58. The aromatic protons of the oxindole moiety exhibited multiplets in the region δ 6.62–7.32. The structure of the product was further confirmed through mass spectra of **17**, which showed a molecular ion peak at 624 (M^+). The cycloadduct **17** gave satisfactory elemental analysis. From the Table 1, it is evident that the rate of the reaction and the yields of the products are good in polar solvents (60–80%).

3. Conclusion

In conclusion, we have synthesized a series of hitherto unknown novel ferrocene based monospirooxindolopyrrolizidine heterocycles through [3+2]-cycloaddition of azomethine ylides with unusual ferrocene dipolarophiles under different conditions.

4. Experimental

4.1. General considerations

All melting points were uncorrected. IR spectra were recorded on a SHIMADZU 8300 series FT-IR instrument. ^{1}H NMR spectra were recorded in $CDCl_3$ using TMS as an internal standard on a JEOL GX 400 spectrometer at 400 MHz and on a BRUKER 300 spectrometer at 300 MHz. ^{13}C NMR was recorded on a JEOL GX 400 spectrometer at 100 MHz and on a BRUKER 300 spectrometer at 75 MHz. Mass spectra were recorded on a JEOL DX 303 HF spectrometer. Elemental analysis was carried out on Perkin–Elmer 2400 B instrument. Column chromatography was performed on silica gel (ACME, 100–200 mesh). Routine monitoring of the reactions was made using thin layer chromatography developed on glass plates coated with silica gel-G (ACME) of 0.25 mm thickness and visualized with iodine. For dry experiments, glasswares used were thoroughly dried in a hot air-oven, cooled and assembled under a stream of nitrogen. The organic extracts of crude products were dried over anhydrous $MgSO_4$. Solvents were reagent grade and were purified according to standard procedures. The starting materials ferrocene, isatin and sarcosine were purchased commercially and used as such. Ferrocene based dipolarophiles and 5,7-dibromoisatin were synthesized as per the literature procedures.[33]

4.2. General procedure for the synthesis of ferrocene based spiroheterocycles

A solution of the dipolarophile derived from ferrocene (1 mmol), isatin/5′,7′-dibromoisatin (1 mmol) and L-proline (1 mmol) was refluxed in acetonitrile (10 mL) by using a $CaCl_2$ guard tube, until completion of the reaction as indicated by TLC. The solvent was removed under reduced pressure and the crude product was purified by column chromatography using petroleum ether/ethylacetate (4:1) as eluent followed by recrystallization from methanol. Alternatively, the reactions could also be carried out in toluene using a Dean–Stark apparatus.

4.2.1. Spiro-[2.3′]-oxindole-3-ferrocenoyl-4-(p-methoxyphenyl)-pyrrolizidine ***4c***

Eluent: petroleum ether/ethylacetate (4:1), R_f value: 0.5; mp: 167–169 °C; IR (KBr): 1660, 1706 cm^{-1}; ^{1}H NMR ($CDCl_3$/400 MHz): δ 1.74–2.76 (m, 6H), 3.62 (s, 5H), 3.72 (s, 3H), 3.80–3.90 (m, 1H), 4.18–4.20 (m, 2H), 4.30 (s, 2H), 4.51 (s, 2H), 6.71–7.53 (m, 8H), 8.60 (s, 1H). Mass spectrum *m*/*z*: 546 (M^+). Anal. Calcd for $C_{32}H_{30}N_2O_3Fe$: C, 70.33; H, 5.53; N, 5.12%. Found: C, 70.49; H, 5.36; N, 5.33%.

4.2.2. Spiro-[2.3′]-5′,7′-dibromooxindole-3-ferrocenoyl-4-phenyl-pyrrolizidine ***5a***

Eluent: petroleum ether/ethylacetate (4:1), R_f value: 0.5; mp: 160–162 °C; IR (KBr): 1663, 1708 cm^{-1}; ^{1}H NMR ($CDCl_3$/400 MHz): δ 1.67–2.05 (m, 4H), 2.50–2.61 (m, 2H), 3.83 (s, 5H), 3.99 (t, 1H), 4.24 (s, 1H), 4.29–4.35 (m, 1H), 4.38 (s, 1H), 4.50 (d, *J*=11 Hz, 1H), 4.54 (s, 1H), 4.62 (s, 1H), 6.84–7.46 (m, 5H), 7.20 (s, 1H), 7.34 (s, 1H), 8.18 (s, 1H); ^{13}C NMR (100 MHz): δ 27.13, 30.20, 46.05, 47.88, 62.85, 68.48, 69.09, 69.18, 69.62, 72.72, 73.09, 74.72, 78.59, 103.54, 107.41, 110.62, 115.13, 128.38, 129.68, 134.19, 139.02, 141.73, 152.31, 179.29, 198.46 ppm. Mass spectrum *m*/*z*: 674 (M^+). Anal. Calcd for $C_{31}H_{26}N_2O_2Br_2Fe$: C, 55.22; H, 3.88; N, 4.15%. Found: C, 55.38; H, 3.97; N, 3.98%.

4.2.3. Spiro-[2.3′]-5′,7′-dibromooxindole-3-ferrocenoyl-4-(p-nitrophenyl)-pyrrolizidine ***5b***

Eluent: petroleum ether/ethylacetate (4:1), R_f value: 0.6; mp: 212–214 °C; IR (KBr): 1675, 1710 cm^{-1}; ^{1}H NMR ($CDCl_3$/400 MHz): δ 1.62–1.93 (m, 4H), 2.56–2.68 (m, 2H), 3.56 (s, 5H), 3.95 (t, *J*=10.4 Hz, 1H), 4.22 (s, 1H), 4.27 (d, *J*=10.4 Hz, 1H), 4.31 (s, 2H), 4.32–4.38 (m, 1H), 4.54 (s, 1H), 7.19 (s, 1H), 7.37 (s, 1H), 7.74 (d, *J*=8.4 Hz, 2H), 7.95 (s, 1H), 8.18 (d, *J*=8.4 Hz, 2H); ^{13}C NMR (100 MHz): δ 24.41, 27.23, 45.72, 50.21, 64.25, 66.24, 66.91, 67.02, 69.19, 70.46, 71.02, 72.08, 75.84, 101.23, 112.94, 121.68, 125.67, 127.14, 127.37, 132.11, 136.79, 145.01, 145.76, 176.65, 196.80 ppm. Mass spectrum *m*/*z*: 719.6 (M^+). Anal. Calcd for $C_{31}H_{25}N_3O_4Br_2Fe$: C, 51.77; H, 3.50; N, 5.84%. Found: C, 51.62; H, 3.67; N, 5.98%.

4.2.4. Spiro-[2.3′]-5′,7′-dibromooxindole-3-ferrocenoyl-4-(p-methoxyphenyl)-pyrrolizidine ***5c***

Eluent: petroleum ether/ethylacetate (4:1), R_f value: 0.5; mp: 177–179 °C; IR (KBr): 1666, 1704 cm^{-1}; ^{1}H NMR ($CDCl_3$/300 MHz): δ 1.59–1.92 (m, 4H), 2.54–2.59 (m, 2H), 3.56 (s, 5H), 3.65 (s, 3H), 3.78 (t, *J*=10.5 Hz, 1H), 4.14 (s, 1H), 4.19–4.22 (m, 1H), 4.25 (d, *J*=11 Hz, 1H), 4.27 (s, 1H), 4.38 (s, 1H), 4.52 (s, 1H), 6.83 (d, *J*=8.6 Hz, 2H), 7.23 (s, 1H), 7.36 (s, 1H), 7.44 (d, *J*=8.6 Hz, 2H), 8.29 (s, 1H); ^{13}C NMR (75 MHz): δ 27.03, 29.96, 48.08, 52.18, 55.33, 66.49, 68.93, 69.05, 69.39, 71.55, 72.50, 72.95, 74.76, 78.80, 103.46, 114.31, 115.10, 128.66, 129.42, 129.87, 131.70, 134.14, 139.17, 159.15, 179.62, 199.22 ppm. Mass spectrum *m*/*z*: 704 (M^+). Anal. Calcd for $C_{32}H_{28}N_2O_3Br_2Fe$: C, 54.57; H, 4.00; N, 3.97%. Found: C, 54.73; H, 4.14; N, 3.82%.

4.2.5. Spiro-[2.3′]-oxindole-3-ferrocenoyl-4-furyl-pyrrolizidine ***7a***

Eluent: petroleum ether/ethylacetate (4:1), R_f value: 0.5; mp: 140–142 °C; IR (KBr): 1665, 1708 cm^{-1}; ^{1}H NMR ($CDCl_3$/400 MHz): δ 1.25–2.69 (m, 6H), 3.82 (s, 5H), 4.03 (s, 1H), 4.06–4.10 (m, 1H), 4.32 (s, 1H), 4.37 (s,1H), 4.46–4.58 (m, 1H), 5.96 (s, 1H), 6.09 (s, 1H), 6.70–7.48 (m, 4H), 7.41 (s, 1H), 8.52 (s, 1H); ^{13}C NMR (100 MHz): δ 27.15, 30.20, 46.08, 47.91, 63.09, 68.57, 69.05, 69.33, 69.68, 72.69, 73.10, 74.68, 78.69, 107.39, 110.65, 115.14, 128.43, 129.79, 134.20, 138.95, 141.77, 152.45, 179.01, 198.55 ppm. Mass spectrum *m*/*z*: 506.8 (M^+). Anal. Calculated for $C_{29}H_{26}N_2O_3Fe$: C, 68.78; H, 5.17; N, 5.53%. Found: C, 68.56; H, 5.31; N, 5.72%.

4.2.6. Spiro-[2.3′]-5′,7′-dibromooxindole-3-ferrocenoyl-4-furyl-pyrrolizidine ***7b***

Eluent: petroleum ether/ethylacetate (2:1), R_f value: 0.5; mp: 183–184 °C; IR (KBr): 1668, 1703 cm^{-1}; ^{1}H NMR ($CDCl_3$/300 MHz): δ 1.71–2.05 (m, 4H), 2.58–2.60 (m, 2H), 3.84 (s, 5H), 3.98 (t, 1H), 4.30 (s, 1H), 4.33–4.36 (m, 1H), 4.40 (s, 1H), 4.49 (d, *J*=11 Hz, 1H), 4.54 (s, 1H), 4.63 (s, 1H), 5.94 (s, 1H), 6.30 (s, 1H), 7.19 (s, 1H), 7.40 (s, 1H), 7.82 (s, 1H); ^{13}C NMR (75 MHz): δ 27.15, 30.20, 46.08, 47.91, 63.09, 68.57, 69.05, 69.33, 69.68, 72.69, 73.10, 74.68, 78.69, 107.39, 110.65, 115.14, 128.43, 129.79, 134.20, 138.95, 141.77, 152.45, 179.09, 198.55 ppm. Mass spectrum *m*/*z*: 664 (M^+). Anal. Calcd for $C_{29}H_{24}N_2O_3Br_2Fe$: C, 52.44; H, 3.64; N, 4.21%; Found: C, 52.62; H, 3.84; N, 4.04%.

4.2.7. Spiro-[2.3′]-5′,7′-dibromooxindole-3-ferrocenoyl-4-pyridyl-pyrrolizidine ***9***

Eluent: petroleum ether/ethylacetate (2:1), R_f value: 0.6; mp: 144–146 °C; IR (KBr): 1674, 1706 cm^{-1}; ^{1}H NMR ($CDCl_3$/300 MHz): δ 1.61–1.93 (m, 4H), 2.55–2.62 (m, 2H), 3.59 (s, 5H), 3.80 (t, 1H), 4.21 (s, 1H), 4.22–4.44 (m, 1H), 4.28 (d, *J*=8.3 Hz, 1H), 4.33 (s, 2H), 4.53 (s, 1H), 7.19 (s, 1H), 7.36 (s, 1H), 7.16–7.17 (m, 2H), 7.45–7.50 (m, 2H), 8.56 (s, 1H); ^{13}C NMR (75 MHz): δ 20.85, 21.41, 52.51, 57.50, 57.81, 62.96, 71.46, 78.46, 108.68, 121.84, 125.72, 125.93, 126.80, 128.09,

128.45, 128.73, 132.79, 133.98, 139.46, 143.51, 175.28, 195.07 ppm. Mass spectrum *m*/*z*: 676.4 (M^+). Anal. Calcd for $C_{30}H_{26}N_3O_2Br_2Fe$: C, 53.28; H, 3.87; N, 6.21%. Found: C, 53.49; H, 4.04; N, 6.02%.

4.2.8. Spiro-[2.3′]-oxindole-3-benzoyl-4-ferrocenyl-pyrrolizidine **11a**

Eluent: petroleum ether/ethylacetate (4:1), R_f value: 0.5; mp: 137–139 °C; IR (KBr): 1675, 1708 cm^{-1}; ^1H NMR ($CDCl_3$/400 MHz): δ 1.81–1.99 (m, 3H), 2.26–2.34 (m, 1H), 2.60–2.65 (m, 2H), 3.68 (t, 1H), 3.92 (s, 1H), 4.07 (s, 1H), 4.11 (s, 2H), 4.26 (s, 5H), 4.30–4.33 (m, 1H), 4.95 (d, *J*=11 Hz, 1H), 6.59–7.54 (m, 11H), 8.88 (s, 1H); ^{13}C NMR (100 MHz): δ 27.96, 32.52, 45.27, 47.80, 64.65, 66.70, 67.61, 68.57, 70.61, 73.99, 89.31, 110.23, 122.14, 125.20, 127.85, 127.93, 128.28, 129.29, 133.06, 137.13, 140.75, 181.53, 197.69 ppm. Mass spectrum *m*/*z*: 516 (M^+). Anal. Calcd for $C_{31}H_{28}N_2O_2Fe$: C, 72.10; H, 5.46; N, 5.42%. Found: C, 72.31; H, 5.63; N, 5.21%.

4.2.9. Spiro-[2.3′]-oxindole-3-(p-methoxybenzoyl)-4-ferrocenyl-pyrrolizidine **11b**

Eluent: petroleum ether/ethylacetate (4:1), R_f value: 0.5; mp: 151–152 °C; IR (KBr): 1670, 1706 cm^{-1}; ^1H NMR ($CDCl_3$/400 MHz): δ 1.79–2.32 (m, 4H), 2.58–2.64 (m, 2H), 3.66 (t, 1H), 3.76 (s, 3H), 3.96 (s, 1H), 4.10 (s, 1H), 4.15 (s, 2H), 4.24 (s, 3H), 4.28–4.32 (m, 1H), 4.93 (d, *J*=10.5 Hz, 1H), 6.58–7.52 (m, 10H), 8.86 (s, 1H). Mass spectrum *m*/*z*: 546 (M^+). Anal. Calcd for $C_{31}H_{28}N_2O_2Fe$: C, 70.33; H, 5.53; N, 5.12%. Found: C, 70.49; H, 5.72; N, 4.94%.

4.2.10. Spiro-[2.3′]-oxindole-3-ferrocenoyl-4-ferrocenyl-pyrrolizidine **13**

Eluent: petroleum ether/ethylacetate (4:1), R_f value: 0.5; mp: 160–162 °C; IR (KBr): 1664, 1702 cm^{-1}; ^1H NMR ($CDCl_3$/300 MHz): δ 1.70–2.04 (m, 4H), 2.35–2.59 (m, 2H), 3.74 (t, *J*=10.3 Hz, 1H), 3.86 (s, 5H), 4.08–4.13 (m, 1H), 4.15 (s, 2H), 4.19 (s, 5H), 4.24 (s, 2H), 4.26 (d, *J*=11 Hz, 1H), 4.50 (s, 2H), 4.58 (s, 2H), 6.62–7.32 (m, 4H), 7.87 (s, 1H). Mass spectrum *m*/*z*: 624 (M^+). Anal. Calcd for $C_{35}H_{32}N_2O_2Fe_2$: C, 67.33; H, 5.16; N, 4.48%. Found: C, 67.19; H, 5.29; N, 4.64%.

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Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2009.01.044.

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