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Synthesis of functionalized benzannulated compounds

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ABSTRACT

Functionalized indane and naphthalene derivatives have been prepared according to two routes involving a nickel-catalyzed electrochemical arylation of activated olefins as the key step. The first method is a cascade process including the intramolecular nucleophilic addition of the first formed enolate intermediate. In the second method the cascade reaction is prevented by in situ protonation of the enolate, and the cyclization is further conducted chemically. This is an overall more efficient method than the first one, based on the electrochemical process.

1. Introduction

Benzannulated structures are the core of several biological active substances. Particularly, dihydronaphthalene scaffolds such as 1-cyano-2-tetralone and 2-amino-1-cyano-3,4-dihydronaphthalene are involved in the synthesis of analgesic 6,7-benzomorphane,[1] pyrimethamine analogues[2] and are precursors of functionalized naphthalene derivatives possessing pharmaceutical activity.[3] 1,2-Di and 1,2,3-trisubstituted indanes[4] also constitute relevant pharmaceutical scaffolds. Indane 1-acetic acids possess antiinflammatory, analgesic and antipyretic activities,[5] and the moiety has been identified as head group of potent PPAR $\alpha/\gamma/\delta$ pan agonists.[6] *ortho*-Substituted aryl halides are very convenient starting materials from which new fused rings of controlled size can be constructed usually in a one-pot process. These approaches require the activation of the aryl halide by a transition metal catalyst and the organometallic intermediate is then involved in a cyclization process to give the bicyclic compound. Alternatively, nickel[7] or cobalt[8] complexes in the presence of zinc powder as well as palladium complexes[9] have been reported for the carboannulation of disubstituted alkynes with 2-halophenyl-ketones, -aldehydes or (2-halophenyl)malonates to prepare indenes, indenols and indenones. Recently a facile approach to the construction of indenone by intramolecular Heck reaction[10] followed by aerial oxidation of the allylic alcohol has been described. Domino processes involving Heck reaction restricted to allylic or homoallylic alcohols followed by aldol condensation[11] and conjugate addition reaction mediated by cobalt catalysis in the presence of zinc powder followed by cyclocondensation[12] have been reported for the preparation of 1*H*-indenes[11,12] and dihydronaphthalenes.[11]

We have recently investigated a route to medium ring benzannulated lactones through the formation of hydroxyacids, according to Scheme 1.[13] The methodology involves the sequential attachment, *ortho* to each other on a benzene ring, of a tethered carbonyl (ketone) and a tethered ester group, which are later converted into hydroxy and carboxy groups, respectively. One key step is an efficient nickel-catalyzed electrochemical Michael addition, which interestingly does not require functional groups' protection like for the chemical route. Also, the sequence in introducing the first group (i.e., the ketone or the ester) is mostly designed according to the availability (ease of preparation). There is, however, one drawback, which can divert this reaction towards the formation of an unwanted bicyclic product. This is because the organometallic enolate intermediate resulting from the Michael addition can add intramolecularly when there is an electrophile ideally placed on the other chain to allow the formation of C5 and C6 ring. This is notably observed from a carbonyl group (Scheme 2, model I, EWG_1=ester; n=0, 1) or a conjugated double bond (Scheme 2, model II, EWG_1, EWG_2=ester, ketone; n=0, 1). In the previous study[13] it was challenging to avoid such a side reaction. We now want to examine the synthetic potential of this cascade reaction, with the aim of either favouring it or alternatively design the best way to avoid it.

2. Results and discussion

2.1. Syntheses of functionalized five-membered ring annulation

We first investigated the five-membered ring annulation with (*E*)-ethyl 3-(2-bromophenyl)prop-2-enoate **1** and acrylonitrile **2**.

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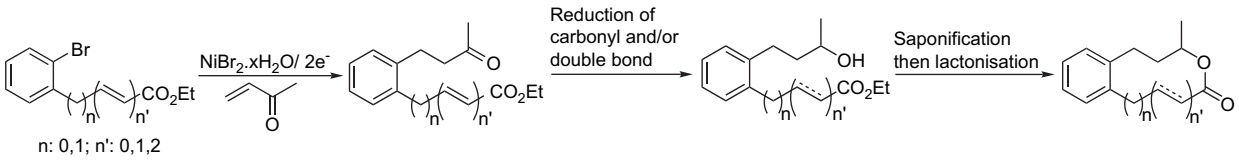
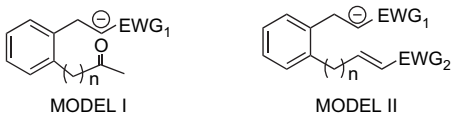


Scheme 1. Concise synthesis of ring benzannulated lactones.



Scheme 2. Two adapted models for the access to bicyclic compounds.

The reaction was conducted in the reaction conditions previously described.[14] In an undivided cell fitted with a stainless steel cathode and a metal rod as the anode, a short pre-electrolysis of (1/1) DMF/acetonitrile (AN) solution containing 1,2-dibromoethane and mixture of Bu_4NBr/Bu_4NI as supporting electrolyte was run at constant current intensity for 15 min at 20 °C. Then, $NiBr_2 \cdot 3H_2O$ (0.1 equiv), **2** (2.5–4 equiv), and **1** were added, and the reaction mixture was heated up to 80 °C before running the electrolysis at constant current intensity (0.5 A dm^{-2}). Two key parameters have been examined: the amount of **2** versus **1**, and the nature of the anode. The results are reported in Table 1. The reaction of **1** with **2** afforded a mixture of four compounds: ethyl cinnamate, which is the reduction product of the aryl bromide derivative, the conjugate addition product **3** and the two diastereoisomeric bicyclic products **4a** and **4b**. Considering that **3** and **4** are formed from the same intermediate, this amounts to an overall yield of up to 85%. In all experiments **3** is formed, even predominantly in several cases. Cis and trans stereoisomers **4** have been separated and their structures have been established on the basis of ^1H and ^{13}C NMR spectra, and mass spectra. Five-membered ring assignment was carried out by heteronuclear multiple bond correlation (HMBC). The stereochemistry of **4a** and **4b** (Fig. 1) has been assigned on the basis of NOESY experiments with the elimination of zero-quantum interference.[15] A sample of **4a** subjected to NOESY experiment displays a correlation between Hc (δ: 3.20 ppm) and distinguishable Ha/Ha′ (δ: 2.73 ppm and 2.89 ppm). This result indicates that Ha/Ha′ and Hc are close to each other, thus ascertaining the trans geometry. The cis geometry of **4b** has been also assigned on the basis of the NOESY experiment not showing any correlation between Ha (δ: 2.94 ppm) and Hc (δ: 3.71 ppm).

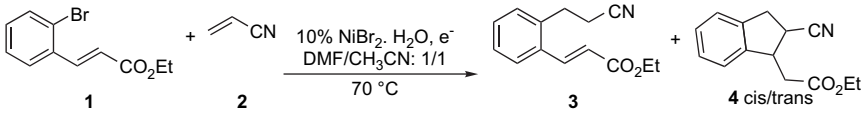
The NOESY experiment of the *trans*-**4** stereoisomer is shown in Fig. 2.

In all runs, and whatever the reaction conditions, the same diastereoisomer ratio of **4** (28/72) has been found from GC analysis, the cis isomer **4b** being the major product. This diastereoselectivity can be explained by a chelation of the two functional groups with the metallic cations (Ni^{2+}, Fe^{2+}), which would occur after the conjugate addition step and drive the cyclization in favour of the cis stereoisomer.

We previously reported that the conjugate addition reaction mediated by nickel catalysis is best performed in the presence of an excess of olefin (2.5 equiv), which plays both as reagent and as ligand to the catalyst. We first tried (Table 1, run 1) to use less than 2.5 equiv of the activated olefin in this reaction because of the presence of the ethenyl group on the side chain of the aryl moiety, which could also ligate to the catalyst. However, decreasing the amount of activated olefin resulted in the decrease of the chemical yield (Table 1, run 1 vs 2) along with a longer reaction time, whereas an amount larger than 2.5 equiv allowed the enhancement of the overall yield of the reaction (Table 1, run 3 vs 2). Compared to nickel and stainless steel, iron as the anode (Table 1, run 3) gives the highest overall yield in **3** plus **4**. With a stainless steel rod (Table 1, run 5) compound **4** is the major product, while use of a nickel anode (Table 1, run 4) is not appropriate, ethyl cinnamate being the main product. These results indicate that a significative amount of iron(II) salts are necessary to promote efficiently the transmetallation reaction and allow the intramolecular reaction. For this reason, iron rod is preferred to stainless steel rod (run 5 vs 3). With nickel rod, the conjugate addition reaction is disrupted (Table 1, run 4). Probably the electroreduction of free nickel(II) salts generated at the anode occurs and affords low valent nickel, which precipitates.

Then we turned our attention onto the selectivity of the reaction. The formation of **3** can be partly explained by in situ protonation of the enolate species by residual water in the solvent and structural water of nickel catalyst precursor.[14] We could show, by

Table 1
Ni-catalyzed electrochemical Michael addition of **1** onto acrylonitrile[a]



Run	Anode	Acrylonitrile (equiv)	Reaction time	Additive (equiv)	Ratio[b] of **4a**/**4b**	Ratio of **3**/**4**	Yield[c] in **3**	Yield[c] in **4**
1	Fe	1.2	5 h 30 min	None	28/72	56/44	26	18
2	Fe	2.5	3 h 30 min	None	28/72	52/48	37	32
3	Fe	4	3 h 30 min	None	28/72	47/53	42	43
4	Ni	4	7 h	None	27/73	15/85	n.a.	n.a.
5	Stainless steel	4	4 h 20 min	None	29/71	27/73	22	45
6	Fe	4	5 h 30 min	NaH[d] (0.2)	29/71	24/76	14	49
7	Fe	4	2 h 40 min	EtOH (2.5)	31/69	67/33	55	24
8	Fe	4	2 h 40 min	EtOH (5)			60	Traces

[a] *Reaction conditions*. Compound **1**: 7.5 mmol; solvent: DMF/AN (15/15, mL/mL); supporting electrolytes: Bu_4NBr, Bu_4NI; cathode: stainless steel; current intensity: 0.15 A; theoretical reaction time: 2 h 40 min.
[b] Isomer ratio, as determined by GC.
[c] Isolated yield.
[d] Added before electrolysis.

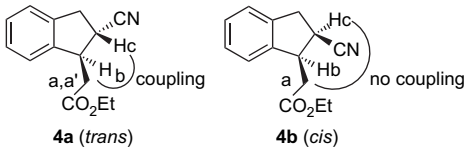


Figure 1. Stereochemistry of **4a** and **4b**.

addition of NaH (0.20 equiv) prior to the electrolysis (Table 1, run 6), that removal of all proton sources favours the formation of **4** over **3**. This methodology has been applied to other models as shown below. Compound **1** was thus added to methylvinylketone **6** (Scheme 3), while **5** was added to ethyl acrylate **7** (Scheme 4).

In these reactions, the uncyclized conjugate addition product is obtained as the main product and the yields in carbocycles are lower than those obtained from **1** and acrylonitrile (Table 1).

To summarize, the cascade cyclocondensation is not easily controlled under the above electrochemical conditions and not fully achieved one pot. We thus attempted to find reaction conditions allowing now to form selectively **3** without **4**, with the aim of performing the cyclization chemically. Some years ago, we have reported[16] that the electrochemical conjugate addition reaction mediated by nickel–dipyridylamine complexes could be conducted in ethanol. We found that the addition of 5 equiv of ethanol as proton source (Table 1, run 8) enables to obtain **3** in 60% isolated yield. Compound **3** was then cyclized in the presence of sodium hydride (2 equiv) at low temperature to give **4** in 56% isolated yield based on **1** (Scheme 5).

2.2. Syntheses of functionalized six-membered ring annulation

Next, we examined the reactivity of 2-bromophenylacetonitrile **12**, 2-bromophenylacetone **13** and ethyl 2-(2-bromophenyl)acetate **14** with activated olefins in order to perform six-membered ring annulation under electrosynthesis conditions. It is worth noting that **12**–**14** are characterized by the presence of acidic hydrogen at the benzylic position and which may interfere with the main process. The reactions are conducted in the same conditions as above. Compounds **12** and **13** have been reacted with methylvinylketone **6**, ethyl acrylate **7** and acrylonitrile **2** under nickel catalysis to get functionalized dihydro and tetrahydronaphthalenes. The results are reported in Table 2. Each reaction led to the formation of the

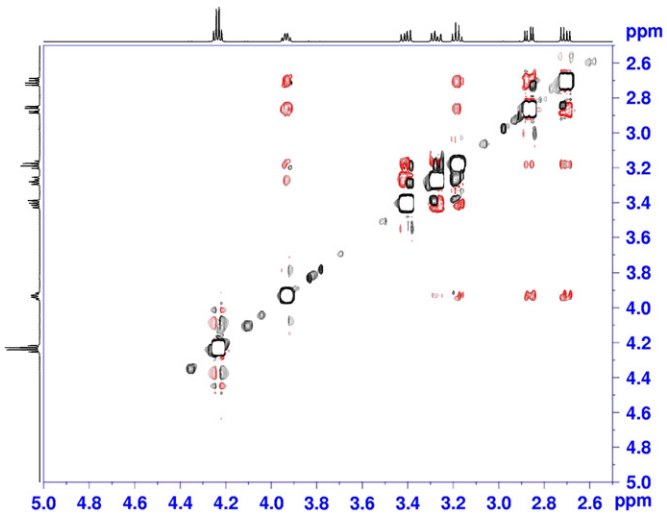
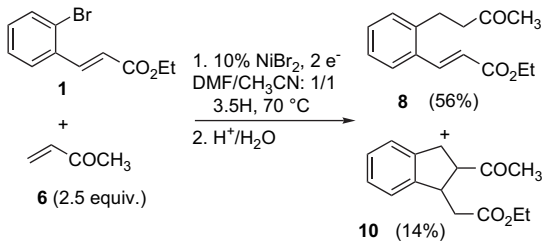
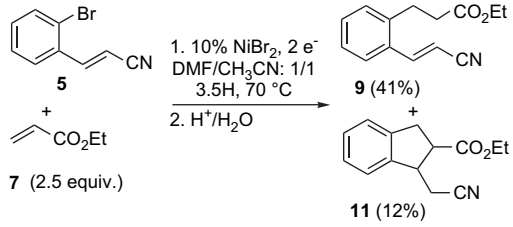


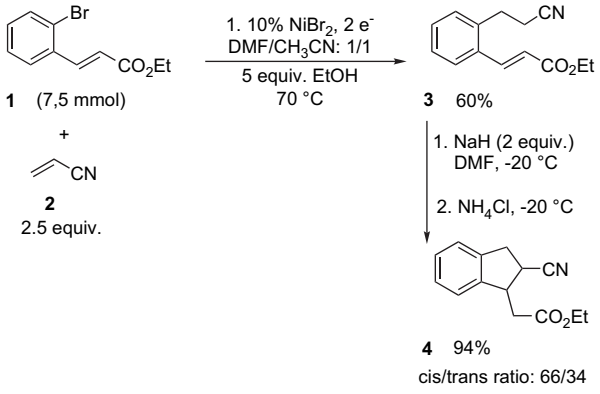
Figure 2. NOESY experiment of the *trans*-**4** stereoisomer.



Scheme 3.



Scheme 4.



Scheme 5. A two step-reaction for the preparation of **4**.

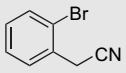
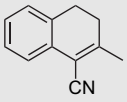
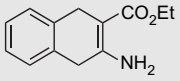
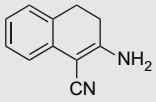
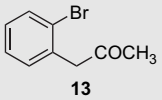
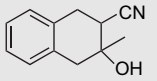
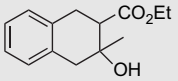
bicyclic product either as dihydro- or tetrahydronaphthalene, indicating that intramolecular trapping of the enolate species occurred, though in low yields. The formation of compounds **17**, **21** and **22** is explained by a direct trapping of the enolate intermediate by the electrophilic group (CN, CO) located on the opposite chain of the aryl halide. The formation of **15** and **19** is explained by the involvement of the enolate species in a transprotonation reaction with the benzylic methylene to give the most stable carbanion before the cyclization, as depicted in Scheme 6 for **19**.

There is a third outcome for the enolate species, which accounts for the low yields obtained in the conjugate addition and the bicyclic compounds. Indeed the enolate species also promotes the alkylation at the benzylic position to give by-products. Thus, in the reaction of 2-bromophenylacetonitrile **12** with acrylonitrile **2**, side products **23** and **24**[17] have been identified (Scheme 7).

Thus, in order to avoid the formation of undesired alkylated compounds we decided to add some ethanol to the medium as proton source. This afforded several changes. Firstly, alkylated side products were avoided. Also, in the reaction of 2-bromoacetophenone **13** with acrylonitrile, **21** was obtained in 67% isolated yield (Scheme 8).

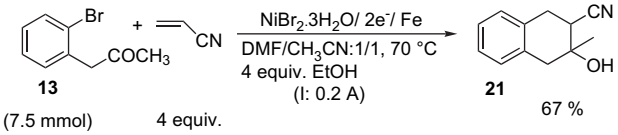
With **12** and **14** as substrates, the enolate intermediates were protonated by ethanol (1–4 equiv) and the conjugate addition products were obtained in good yield as shown in Table 3.

Table 2
Preparation of dihydro and tetrahydronaphthalenes by conjugate addition–cyclization[a]

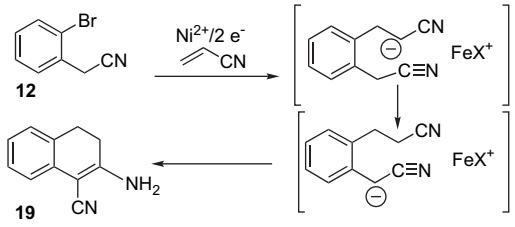
Run	Ar–Br	EWG	Reaction time	Bicyclic product No.	Yield[c] in bicyclic product	Conjugate addition product No.	Yield[c] in conjugate addition product
1	 **12**	$COCH_3$	4 h 30 min	 **15**	13	**16**	34
2	**12**	CO_2Et	4 h 30 min	 **17**	20	**18**	8
3	**12**	CN	4 h 10 min	 **19**	9	**20**	10
4[b]	 **13**	CN	6 h 30 min	 **21**	23		None
5	**13**	CO_2Et	7 h	 **22**	30		None

[a] *Reaction conditions*. Aryl bromide: 7.5 mmol; activated olefin: 2.5 equiv; solvent: DMF/AN (15/15, mL/mL); supporting electrolyte: Bu_4NBr, Bu_4NI; cathode: stainless steel; anode: iron (runs 1–3) or stainless steel (runs 4–5) rod; current intensity: 0.20 A; theoretical reaction time: 2 h.
[b] Addition of acrylonitrile (4 equiv).
[c] Isolated yield %.

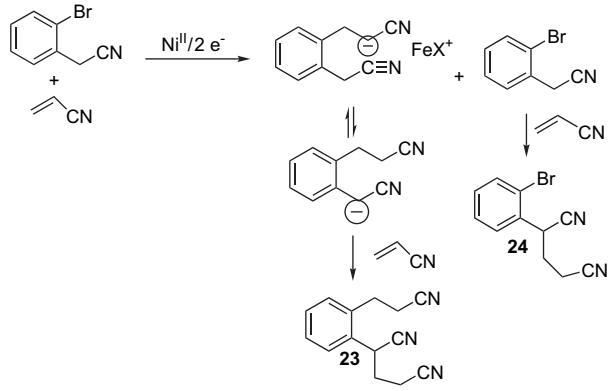
The conjugate addition products are obtained in 48–62% isolated yield. The by-product is the reduction product of the aryl bromide derivative. The release of iron(II) ions as Lewis acid by the oxidation of the anode accounts for the enhancement of the acidity of ethanol. The conjugate addition products undergo cyclization in the presence of sodium ethylate (1.04 equiv) in ethanol to give dihydro and tetrahydronaphthalenes (Fig. 3). The overall yields in carbocycle from *ortho*-substituted aryl halides **12**–**14** are in 33–43% range. The two-step procedure appears to be the most convenient way to obtain the naphthalene derivatives. Compounds **19**, **20** and **27** are intermediates for the preparation of bridged



Scheme 8.

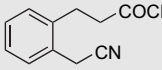
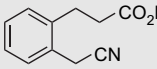
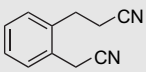
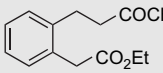


Scheme 6. Formation of compound **19**.

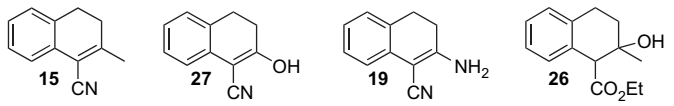


Scheme 7. Alkylation at benzylic position.

Table 3
Nickel-catalyzed electrochemical conjugate addition in the presence of ethanol

Run[a]	ArylBr No.	EWG No.	EtOH (equiv)	Product Formula and No.	Yield (%)
1	**12**	**6**	2	 **16**	50
2	**12**	**7**	1–4	 **18**	48
3	**12**	**2**	1	 **20**	62
4	**14**	**6**	3	 **25**	48

[a] *Reactions conditions*. Aryl bromide: 7.5 mmol; activated olefin: 2.5 equiv; $NiBr_2$: 10%; solvent: DMF/AN (15/15, mL/mL); EtOH: 1–4 equiv; supporting electrolytes: Bu_4NBr, Bu_4NI; temperature: 70 °C; cathode and anode: stainless steel; current intensity: 0.20 A.



85% from **16**
42.5% from **12**

70% from **18**
33.5% from **12**

70% from **20**
43.5% from **12**

76% from **25**
36.5% from **14**

Figure 3.

pyrimethamine.[2] The preparation of dinitrile **20** required four steps in the chemical route[2] (22% overall yield) whereas it can be prepared in a one step procedure by the electrochemical reaction (62% isolated yield). Compound **27**, which is obtained in six steps (16.5% overall yield) is prepared by our method in two steps from **12** (33.5% overall yield). It is worth noting that in the reaction of 2-bromophenylacetonitrile **12** with ethyl acrylate **7**, the bicyclic compound obtained by the two methods (chemical cyclization and electrochemical cyclization) are interestingly different (Table 2, product **17** and Fig. 3, compound **27**). Compound **17** is obtained in the one step method by the direct trapping of the enolate species. In the second method, the synthesis of **27** involves the formation of the more stabilized enolates from **18**.

3. Conclusion

We have shown that the electrochemical conjugate addition reaction mediated by nickel catalysis is an efficient tool to get functionalized carbocycles or carbocycle precursors. Indeed, this study has revealed that the cascade process could occur. Its synthetic scope is, however, somewhat limited since under these conditions the trapping of the enolate species is not fully achieved and a mixture of the carbocycle and of its precursor is obtained. We can alternatively prevent the cascade reaction by in situ protonating the enolate intermediate. The obtained product can later be converted more advantageously into the bicyclic derivative by a chemical route.

4. Experimental section

4.1. General

Unless indicated, all solvents and reagents were purchased from commercial sources and used as-received. DMF was stored under argon. The electrochemical cell has been previously described.[18] (*E*)-Ethyl 3-(2-bromophenyl)prop-2-enoate **1** and (*E*)-3-(2-bromophenyl)prop-2-en-1-nitrile **5** were prepared according to the known procedures.[19] ^{1}H and ^{13}C spectra were recorded on a Bruker Avance 300 (300 and 75 MHz, respectively). Chemical shifts are quoted in parts per million (ppm). The NOESY experiments[15] were run on a Bruker Avance 600 MHz with a mixing time of 800 ms. Mass spectra were obtained with a GCQ Thermoquest Spectrometer coupled to a chromatograph fitted with a 25-m CPSIL5 CB capillary column. The infrared spectra were recorded on a Perkin Elmer FT-IR Spectrometer 1720X. Melting points were measured on Electrothermal IA 9100 digital point apparatus in an open capillary tubes and were uncorrected. Elemental analyses and high resolution mass spectral analyses were made by the Service Central d'Analyse (CNRS, Lyon).

4.2. General procedure for the preparation of indane by the electrochemical way

In an undivided cell equipped with stainless steel grid as the cathode (area 30 cm^{-2}) and an iron rod as the anode, under argon, Bu_4NBr (0.15 g, 0.46 mmol) and Bu_4NI (0.11 g, 0.29 mmol) were dissolved as supporting electrolytes in a mixture of DMF (15 mL) and MeCN (15 mL). 1,2-Dibromoethane (80 μL, 0.93 mmol,) was introduced. A short pre-electrolysis was run at 0.15 A for 20 min, at room temperature, to generate small amount of iron ions. Then the current was turned off. $NiBr_2 \cdot 3H_2O$ (164 mg, 0.75 mmol) and activated olefin (2.5–4 equiv) were added. The mixture was stirred for 5 min at room temperature before the addition of *ortho*-substituted aryl bromide (7.5 mmol). Then the mixture was heated at 70 °C and the electrolysis was run at constant current intensity (0.5 A dm^{-2}). The reaction mixture was monitored by GC to establish the completion. The reaction mixture was cooled, hydrolyzed with HCl (1 N, 20 mL) and diluted with diethyl ether (40 mL). The aqueous layer was extracted twice with diethyl ether (40 mL). The organic layer was washed with H_2O and saturated NaCl solution, dried over $MgSO_4$ and the solvent was evaporated.

4.2.1. Ethyl 2-(2-cyanoethyl)cinnamate ***3*** and ethyl 2-(2-cyano-2,3-dihydro-1H-inden-1-yl)acetate ***4***

The products were isolated by chromatography on silica gel (eluent: diethyl ether content increasing from 3 to 50% in pentane) to give 0.72 g (42%) of **3** and 0.74 g (43%) of **4**.

*4.2.1.1. Ethyl 2-(2-cyanoethyl)cinnamate **3**.* Oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.93 (d, 1H, J=15.73 Hz), 7.63–7.30 (m, 4H), 6.43 (d, 1H, J=15.73 Hz), 4.32 (q, 2H, J=7.13 Hz), 3.15 (t, 2H, J=7.40 Hz), 2.63 (t, 2H, J=7.40 Hz), 1.38 (t, 3H, J=7.13 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 166.6, 140.6, 137.2, 133.2, 130.4, 130.0, 128.0, 127.2, 121.2, 118.6, 60.7, 28.8, 18.9, 14.3. MS: *m*/*z* (%) 229, 200, 183, 175 (100%), 156, 147, 143, 129, 115, 103, 89, 77, 63. IR (neat), cm^{-1}: 2960, 2926, 2254, 1713, 1480, 1460, 908, 732. Anal. Calcd for $C_{14}H_{15}NO_2$: C, 73.34; H, 6.59. Found: C, 73.07; H, 6.85.

*4.2.1.2. Ethyl 2-(2-cyano-2,3-dihydro-1H-inden-1-yl)acetate **4**.* Characterization of *cis*-**4** was achieved as a pure fraction of the isolated compound: ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.26 (m, 4H), 4.26 (q, 2H, J=7.11 Hz), 3.91 (q, 1H, J=7.47 Hz), 3.71 (dt, 1H, J=7.46 and 6.60 Hz), 3.33 (d, 2H, J=6.60 Hz), 2.94 (d, 2H, J=7.47 Hz), 1.33 (t, 3H, J=7.11 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 171.6, 142.0, 139.5, 128.0, 127.5, 124.8, 123.8, 120.4, 61.0, 42.7, 36.3, 36.1, 34.3, 14.2. MS: *m*/*z* (%) 229, 203, 184, 174, 156, 154, 142, 130, 128 (100%), 115, 102, 89, 77, 63. Anal. Calcd for $C_{14}H_{15}NO_2$: C, 73.34; H, 6.59. Found: C, 73.07; H, 6.85.

Characterization of *trans*-**4** was achieved as a pure fraction of the isolated compound: ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.28 (m, 4H), 4.26 (q, 2H, J=7.14 Hz), 3.96 (m, 1H), 3.44 (dd, 1H, J=15.40 and 8.48 Hz), 3.33 (m, 1H), 3.20 (m, 1H), 2.89 (dd, 1H, J=15.66 and 5.86 Hz), 2.73 (dd, 1H, J=15.66 and 7.53 Hz), 1.33 (t, 3H, J=7.14 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 171.0, 141.8, 139.4, 128.0, 127.6, 124.6, 123.5, 121.5, 61.0, 46.4, 38.1, 36.2, 33.8, 14.1. MS: *m*/*z* (%) 229, 203, 184, 174, 156, 154, 142, 130, 128, 115, 102, 89, 77, 63. IR (neat), cm^{-1}: 2254, 1713, 908, 732. Anal. Calcd for $C_{14}H_{15}NO_2$: C, 73.34; H, 6.59; N, 6.11. Found: C, 73.38; H, 6.70; N, 5.71.

4.2.2. (E)-Ethyl 3-[2-(3-oxobutyl)phenyl]prop-2-enoate ***8*** and ethyl 2-(2-acetyl-2,3-dihydro-1H-inden-1-yl)acetate ***10***

The products were isolated by chromatography on silica gel (eluent: diethyl ether, content increasing from 3 to 25% in pentane) to give 1.05 g (56%) of **8**, 0.102 g (5.5%) and 0.153 g (8%) of the two diastereoisomers of **10**.

*4.2.2.1. (E)-Ethyl 3-[2-(3-oxobutyl)phenyl]prop-2-enoate **8**.* Oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ: 8.00 (d, 1H, J=15.8 Hz), 7.71–7.24 (m, 4H), 6.45 (d, 1H, J=15.8 Hz), 4.23 (q, 2H, J=7.0 Hz), 3.03–2.98 (m, 2H), 2.80–2.74 (m, 2H), 2.12 (s, 3H), 1.30 (t, 3H, J=7.0 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 206.8, 66.1, 141.4, 141.0, 132.9, 130.1, 129.8, 126.7, 126.6, 119.8, 59.9, 44.1, 28.9, 26.6, 13.7. MS: m/z (%) 246 (3), 201 (17), 200 (18), 172 (30), 158 (16), 157 (100), 131 (11), 130 (17), 129 (60),

128 (15), 115 (17). IR, cm^{-1}: 3068, 2985, 2940, 2905, 2876, 1704, 1634, 1601, 1368. HRMS *m*/*z* calcd for $C_{15}H_{18}O_3$: (M+H) 247.1334; found: 247.1335.

4.2.2.2. Ethyl 2-(2-acetyl-2,3-dihydro-1H-inden-1-yl)acetate ***10***. First diastereoisomer: oil; ^1H NMR (300 MHz, $CDCl_3$) δ: 7.27–7.16 (m, 4H), 4.16 (q, 1H, *J*=7.17 Hz), 4.16 (q, 1H, *J*=7.11 Hz), 3.99 (m, 1H), 3.67 (m, 1H), 3.32 (dd, 1H, *J*=15.91 and 9.26 Hz), 2.95 (dd, 1H, *J*=15.91 and 7.77 Hz), 2.59 (dd, 1H, *J*=16.28 and 7.11 Hz), 2.43 (dd, 1H, *J*=16.28 and 7.80 Hz), 2.28 (s, 3H), 1.27 (t, 3H, *J*=7.12 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 209.2, 172.3, 144.3, 141.2, 127.4, 126.8, 124.8, 124.0, 60.6, 55.4, 43.0, 35.8, 33.0, 30.5, 14.2. MS: *m*/*z* (%) 246 (M), 233, 228, 217, 201, 185, 172, 159, 143, 129 (100%), 115, 102, 91, 77. IR (neat), cm^{-1}: 3070, 2980, 2930, 2853, 1728, 1709, 1477, 1366, 1162, 1028, 750. HRMS (M+Na) *m*/*z* calcd for $C_{15}H_{18}O_3Na$: 269.1154; found: 269.1155.

Second diastereoisomer: ^1H NMR (300 MHz, $CDCl_3$) δ: 7.24–7.19 (m, 4H), 4.17 (q, 2H, *J*=7.14 Hz), 4.00 (m, 1H), 3.36–3.27 (m, 2H), 3.10 (dd, 1H, *J*=18.67 and 11.12 Hz), 2.84 (dd, 1H, *J*=15.38 and 5.23 Hz), 2.57 (dd, 1H, *J*=15.38 and 8.82 Hz), 2.32 (s, 3H), 1.30 (t, 3H, *J*=7.14 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 208.9, 172.2, 143.8, 140.7, 127.4, 127.3, 124.5, 123.7, 60.7, 57.9, 43.2, 39.6, 34.9, 28.7, 14.2. MS: *m*/*z* (%) 246 (M), 233, 228, 217, 201, 185, 172, 159, 143, 129 (100%), 115, 102, 91, 77. IR (neat), cm^{-1}: 3070, 2980, 2930, 2853, 1728, 1710, 1479, 1367, 1158, 1025, 748.

4.2.3. (E)-Ethyl 3-[2-(2-cyanovinyl)phenyl]propanoate ***9*** *and ethyl 1-(cyanomethyl)-2,3-dihydro-1H-indene-2-carboxylate* ***11***

The products were isolated by chromatography on silica gel (eluent: diethyl ether content increasing from 5 to 25% in pentane) to give 198 mg (11.5%) of only one diastereoisomer of **11** and 704 mg (41%) of **9**.

4.2.3.1. (E)-Ethyl 3-[2-(2-cyanovinyl)phenyl]propanoate ***9***. White crystals, mp: 65 °C; ^1H NMR (300 MHz, $CDCl_3$) δ: 7.77 (d, 1H, *J*=16.46 Hz), 7.51–7.26 (m, 4H), 5.86 (d, 1H, *J*=16.46 Hz), 4.16 (q, 2H, *J*=7.12 Hz), 3.06 (t, 2H, *J*=7.76 Hz,), 2.59 (t, 2H, *J*=7.76 Hz), 1.27 (t, 3H, *J*=7.12 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 172.2, 147.9, 139.7, 132.3, 131.2, 130.1, 127.3, 126.0, 118.2, 98.1, 60.7, 35.6, 28.0, 14.2. MS: *m*/*z* (%) 229, 215, 201, 183, 156 (100%), 140, 129, 115, 89, 77, 63. IR (in solution in $CDCl_3$), cm^{-1}: 3060, 3025, 2984, 2941, 2907, 2254, 2220, 1728, 1616, 1600, 1484, 1465, 1453, 1375, 964, 911, 733. Anal. Calcd for $C_{14}H_{15}NO_2$: C, 73.34; H, 6.59; N, 6.11. Found: C, 72.94; H, 6.58; N, 5.84.

4.2.3.2. Ethyl 1-(cyanomethyl)-2,3-dihydro-1H-indene-2-carboxylate ***11***. ^1H NMR (300 MHz, $CDCl_3$) δ: 7.40–7.28 (m, 4H), 4.28 (q, 2H, *J*=7.13 Hz), 3.84 (m, 1H), 3.36 (dd, 1H, *J*=15.86 and 9.36 Hz), 3.27 (m, 1H), 3.18 (m, 1H), 2.98 (dd, 1H, *J*=17.02 and 5.43 Hz), 2.91 (dd, 1H, *J*=17.02 and 6.01 Hz), 1.30 (t, 3H, *J*=7.13 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 173.6, 141.1 (2C), 128.2, 127.3, 124.8, 123.2, 118.0, 61.3, 49.5, 44.1, 34.9, 21.9, 14.4. MS: *m*/*z* (%) 229, 209, 200, 183, 174, 156 (100%), 140, 129, 115, 102, 89, 77, 63. IR (neat), cm^{-1}: 2980, 2858, 2927, 2855, 2246, 1726, 1449, 1372, 1244, 1215, 1174, 1037, 1015, 752. HRMS *m*/*z* calcd for $C_{14}H_{15}NO_2Na$: 252.1000; found: 252.1014.

4.3. General procedure for the preparation of dihydro and tetrahydronaphthalene

In an undivided cell equipped with stainless steel grid as the cathode (area 30 cm^{-2}) and an iron rod (entries 1–3, Table 2) or stainless steel rod (entries 4 and 5, Table 2) as the anode, under argon, Bu_4NBr (0.15 g, 0.46 mmol) and Bu_4NI (0.11 g, 0.29 mmol) were dissolved as supporting electrolyte in a mixture of DMF (15 mL) and MeCN (15 mL). 1,2-Dibromoethane (80 μL, 0.93 mmol) was introduced. A short pre-electrolysis was run at 0.15 A for 20 min, at room temperature, to generate small amount of iron ions. Then the current was turned off. $NiBr_2$ (164 mg, 0.75 mmol) and activated olefin (2.5–4 equiv) were added. The mixture was stirred for 5 min at room temperature before the addition of *ortho*-substituted arylbromide (7.5 mmol). Then the mixture was heated at 70 °C and the electrolysis was run at constant current intensity (0.5 A dm^{-2}). The reaction mixture was monitored by GC to establish the completion. For compounds **15**, **21** and **22**, the reaction mixture was cooled, hydrolyzed with HCl (1 N, 50 mL) and diluted with diethyl ether (50 mL). The aqueous layer was extracted twice with diethyl ether (50 mL). The organic layer was washed twice with 1 N HCl (50 mL) and saturated NaCl solution, dried over $MgSO_4$, filtered and the solvent was evaporated. For compounds **17** and **19**, the work up has been carried out as follows. After removal of the solvent by vacuo, the residue was solubilized in CH_2Cl_2 (100 mL) and washed with H_2O (50 mL). The aqueous layer was extracted with CH_2Cl_2 (50 mL). The organic layers are collected, dried over Na_2SO_4 and evaporated.

4.3.1. 2-Methyl-3,4-dihydronaphthalene-1-carbonitrile ***15***

The product was purified by column chromatography on silica gel (eluent: pentane/diethyl ether 8/2) to give 165 mg (13%) of viscous the desired compound **15**.

Solid, mp: <40 °C; ^1H NMR (300 MHz, $CDCl_3$) δ: 7.47 (d, 1H, *J*=7.15 Hz), 7.27 (m, 2H), 7.16 (d, 1H, *J*=6.96 Hz), 2.85 (t, 2H, *J*=7.76 Hz), 2.46 (t, 2H, *J*=7.76 Hz), 2.30 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 155.3, 133.1, 129.7, 128.1, 127.6, 127.1, 124.3, 116.6, 109.2, 30.1, 26.5, 23.4. MS: *m*/*z* (%) 169, 154 (100%), 141, 127, 115, 84, 75, 63. IR (neat), cm^{-1}: 3065, 3023, 2937, 2836, 2220, 1622, 1492, 1454, 1435. Anal. Calcd for $C_{12}H_{11}N$: C, 85.17; H, 6.55; N, 8.28. Found: C, 85.08; H, 6.69; N, 8.26.

4.3.2. Ethyl 3-amino-1,4-dihydronaphthalene-2-carboxylate ***17***

The product was purified by column chromatography on neutral aluminium oxide (eluent: pentane/ethyl acetate 7/3) to afford 325 mg (20%) of compound **17** as yellow solid.

Yellow solid, mp: 86–86.5 °C; ^1H NMR (300 MHz, $CDCl_3$) δ: 7.32–7.15 (m, 4H), 4.29 (q, 2H, *J*=7.11 Hz), 3.70 (t, 2H, *J*=2.90 Hz), 3.54 (t, 2H, *J*=2.90 Hz), 1.41 (t, 3H, *J*=7.10 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 169.6, 155.5, 136.1, 132.2, 127.9, 127.2, 126.4, 125.9, 90.3, 59.3, 35.8, 29.1, 14.8. MS: *m*/*z* (%) 217 (M), 188, 170, 144 (100%), 127, 115. IR (in solution in $CDCl_3$), cm^{-1}: 3499, 3338, 3029, 2982, 2904, 2826, 2252, 1664, 1619, 1542, 1458, 1277, 1223, 908, 732. Anal. Calcd for $C_{13}H_{15}NO_2$: C, 71.87; H, 6.96; N, 6.45; O 14.73. Found: C, 71.71; H, 6.96; N, 6.45.

4.3.3. 2-Amino-3,4-dihydronaphthalene-1-carbonitrile ***19***

The black viscous residue was purified by column chromatography on aluminium oxide (eluent: diethyl ether/pentane 8/2) to afford 115 mg (9%) of compound **19**, which darkens rapidly in the light.

White powder, mp: 83 °C (lit.[2] 83–84 °C); ^1H NMR (300 MHz, $CDCl_3$) δ: 7.30–7.22 (m, 2H), 7.14–7.04 (m, 2H), 5.20 (s br d, 2H), 2.88 (t, 2H, *J*=7.75 Hz), 2.53 (t, 2H, *J*=7.75 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 159.5, 131.5, 129.7, 127.3, 127.2, 124.5, 122.2, 118.4, 28.7, 26.9. MS: *m*/*z* (%) 170 (100%), 155, 142, 127, 115, 102, 89. IR (in solution in $CDCl_3$), cm^{-1}: 3512, 3403, 3069, 2947, 2900, 2252, 2195, 1628, 1592, 1566, 1493, 909, 735.

4.3.4. Ethyl 3-hydroxy-3-methyl-1,2,3,4-tetrahydro-naphthalene-2-carboxylate ***22***

The two diastereoisomers were purified by column chromatography on silica gel (eluent: pentane/diethyl ether 8/2) to give 378 mg (21.5%) of the first diastereoisomer as a white solid and 149 mg (8.5%) of the second one as a liquid.

First diastereoisomer: white powder; ^1H NMR (300 MHz, $CDCl_3$) δ: 7.21–7.11 (m, 4H), 4.30 (m, 2H), 3.50 (br s, 1H, OH), 3.34 (dd, 1H,

J=16.36 and 11.67 Hz), 3.04–2.97 (m, 2H), 2.86 (d, 1H, J=17.03 Hz), 2.81 (dd, 1H, J=11.66 and 5.43 Hz), 1.45 (s, 3H), 1.38 (t, 3H, J=7.14 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 175.9, 133.9, 133.6, 129.3, 128.3, 126.3, 126.0, 68.9, 61.0, 48.6, 42.2, 30.0, 28.3, 14.3. MS: m/z (%) 235, 216, 202, 191, 173, 155, 143 (100%), 128, 117, 104, 91, 78. IR (neat), cm^{-1}: 3530, 3062, 3020, 2978, 2935, 1715, 1585, 1498, 1456, 1379. Anal. Calcd for $C_{14}H_{18}O_3$: C, 71.77; H, 7.74. Found: C, 71.69; H, 7.99.

Second diastereoisomer: oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.20–7.10 (m, 4H), 4.30 (q, 2H, J=7.14 Hz), 3.28 (dd, 1H, J=16.66 and 5.58 Hz), 3.10–2.90 (m, 4H), 1.38 (t, 3H, J=7.14 Hz), 1.34 (s, 3H), 1.30 (s, OH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 173.9, 134.5, 133.4, 129.3, 128.5, 126.2, 126.2, 70.4, 61.0, 49.4, 44.6, 30.6, 22.6, 14.3. MS: m/z (%) 235, 225, 216 (100%), 170, 155, 142 (100%), 133, 117, 104, 91, 77. HRMS (M+Na) m/z calcd for $C_{15}H_{18}O_3Na$: 269.1154; found: 269.1163.

4.4. General procedure for nickel-catalyzed conjugate addition reaction in the presence of ethanol

In an undivided cell equipped with stainless steel grid as the cathode (area 30 cm^{-2}) and stainless steel rod as the anode, under argon, Bu_4NBr (0.11, 0.34 mmol), Bu_4NI (77 mg, 0.21 mmol) and 1,2-dibromoethane (80 μL, 0.93 mmol) were added in a mixture of DMF (15 mL) and MeCN (15 mL). A short pre-electrolysis was conducted at controlled intensity (0.15 A) for 20 min, at room temperature. Then the current was turned off. $NiBr_2\cdot 3H_2O$ (164 mg, 0.75 mmol), the activated olefin (2.5 equiv), aryl bromide (7.50 mmol) and ethanol (1–4 equiv) were successively added. The mixture was warmed at 70 °C and the electrolysis was run at constant intensity (0.2 A). The reaction mixture was monitored by GC to establish the completion. The reaction mixture was cooled, hydrolyzed with HCl (1 N, 50 mL) and diluted with diethylether (50 mL). The aqueous layer was extracted twice with ether (50 mL); the organic layers were collected, washed with 2×50 mL portion of 1 N HCl and then brine, dried over $MgSO_4$ and filtered. After evaporation of the solvent, the product was subjected to chromatography on silica gel column.

4.4.1. 2-[(3-Oxo-butyl)phenyl]acetonitrile ***16***

The reaction mixture was purified by column chromatography using pentane/diethyl ether (7/3) as eluent to afford 0.70 g (50%) of the desired compound.

^{1}H NMR (300 MHz, $CDCl_3$) δ 7.38–7.19 (4H, m), 3.80 (2H, s), 2.85 (4H, m), 2.16 (3H, s). ^{13}C NMR (75 MHz, $CDCl_3$) δ 207.3, 139.1, 129.4, 129.2, 128.6, 128.4, 127.1, 118.2, 43.8, 30.1, 25.9, 21.5. MS: m/z (%) 187, 169, 154, 144 (100%), 129, 117, 115, 103, 91, 77, 63. IR (neat), cm^{-1}: 3020, 2240, 1720, 1600, 1490, 1400, 1360, 1160, 750. HRMS (M+Na) m/z calcd for $C_{12}H_{13}NONa$: 210.0895; found: 210.0905.

4.4.2. Ethyl 3-(2-cyanomethylphenyl)propionate ***18***

The reaction mixture was purified by column chromatography using 5–40% ethyl acetate gradient in pentane as eluent to afford 0.78 g (48%) of the desired compound.

^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.41–7.22 (m, 4H), 4.13 (q, 2H, J=7.14 Hz), 3.80 (s, 2H), 2.96 (t, 2H, J=7.60 Hz), 2.65 (t, 2H, J=7.61 Hz), 1.23 (t, 3H, J=7.15 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 172.5, 138.5, 129.3, 129.1, 128.6, 128.4, 127.2, 117.9, 60.4, 34.6, 27.2, 21.4, 14.2. MS: m/z (%) 217 (M), 189, 171, 144 (100%), 129, 116, 103, 91, 77. IR (neat), cm^{-1}: 3060, 2983, 2938, 2248, 1729, 1600, 1494, 1455, 1420, 1375, 1189, 1040, 757. Anal. Calcd for $C_{13}H_{15}O_2N$: C, 71.86; H, 6.96; N, 6.45. Found: C, 71.97; H, 7.10; N, 6.24.

4.4.3. 3-(2-Cyanomethylphenyl)propionitrile ***20***

The reaction mixture was purified by column chromatography using 25–75% diethyl ether gradient in pentane as eluent to yield 0.79 g (62%) of the desired compound.

White crystals, mp: 57 °C (lit.[2] 57 °C); ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.46–7.31 (m, 4H), 3.80 (s, 2H), 3.05 (t, 2H, J=7.33 Hz), 2.72 (t, 2H, J=7.35 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 136.1, 129.8, 129.7, 129.2, 128.4, 128.3, 118.9, 117.7, 28.1, 21.6, 18.3. MS: m/z (%) 170 (M), 143, 130 (100%), 116, 103, 89, 77. IR (neat), cm^{-1}: 3030, 2920, 2220, 1410, 1350, 715. Anal. Calcd for $C_{11}H_{10}N_2$: C, 77.62; H, 5.92; N, 16.45. Found: C, 77.60; H, 6.10; N, 16.25.

4.4.4. 3-Hydroxy-3-methyl-1,2,3,4-tetrahydronaphthalene-2-carbonitrile ***21***

Characterization of the separated pure diastereoisomer: white solid, mp: 178.5 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.15–7.06 (4H, m), 3.36 (1H, dd, J=16.90 and 10.27 Hz), 3.15 (dd, J=16.90 and 5.75 Hz, $H_{3'}$), 3.05 (d, J=17.06 Hz, 1H, H_{10}), 2.93 (1H, dd, J=10.27 and 5.75 Hz), 2.93 (d, 1H, J=17.06 Hz), 2.61 (s br d, OH), 1.57 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 207.4, 132.9, 131.5, 129.5, 128.4, 126.8, 126.5, 120.5, 67.8, 42.0, 37.8, 30.0, 27.8. MS: m/z (%) 187, 169 (100%), 154, 145, 129, 115, 104, 91, 78. IR (in solution in $CDCl_3$), cm^{-1}: 3448, 2945, 2972, 2929, 2898, 2248, 1649, 1463, 1428, 1382, 1114, 907, 732. Anal. Calcd for $C_{12}H_{13}NO$: C, 76.98; H, 7.00; N, 7.48. Found: C, 76.64; H, 6.80; N, 7.39.

4.4.5. Ethyl [2-(3-oxo-butyl)phenyl]ethanoate ***25***

The reaction mixture was purified on silica gel column chromatography using pentane/diethyl ether (7/3) as eluent to afford 0.84 g (48%) of **25**.

Oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.34–7.15 (m, 4H), 4.16 (q, 2H, J=7.14 Hz), 3.69 (s, 2H), 2.93 (t, 2H, J=7.5 Hz), 2.77 (t, 2H, J=7.5 Hz), 2.16 (s, 3H), 1.27 (t, 3H, J=7.14 Hz,). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 207.6, 171.6, 139.7, 132.5, 130.6, 129.2, 127.5, 126.4, 60.8, 44.3, 38.6, 29.9, 26.5, 14.2. MS: m/z (%) 234 (M), 219, 216, 188, 170, 145 (100), 129, 117, 103, 91. IR (neat), cm^{-1}: 3064, 2982, 1718, 1734, 1492, 1457. HRMS m/z calcd for $C_{14}H_{18}O_3$: (M+H) 235.1334; found: 235.1329.

4.5. Intramolecular cyclization by chemical way

4.5.1. Ethyl 2-hydroxy-2-methyl-1,2,3,4-tetrahydronaphthalene-1-carboxylate ***26***

After consumption of sodium (63 mg, 2.74 mmol) in ethanol (4 mL), ethyl [2-(3-oxo-butyl)phenyl]ethanoate **25** (0.50 g, 2.13 mmol) in ethanol (1 mL) was slowly added. The temperature is allowed to rise to 38 °C. After 40 min at room temperature, the reaction mixture was diluted with CH_2Cl_2 (15 mL) and hydrolyzed with H_2O (10 mL). The aqueous layer was extracted with CH_2Cl_2 (25 mL). The organic layers are collected, rinsed with H_2O (20 mL) and dried over $MgSO_4$. After removal of the solvent, the mixture of the diastereoisomers found in proportion 50/50 was purified by column chromatography (eluent: pentane/ethyl acetate 7/3) to give 382 mg (76%) of diastereoisomers **26**.

The partial characterization of the first diastereoisomer has been achieved on a 95/5 ratio of enrichissed fraction.

Oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.26–7.14 (m, 4H), 4.33 (q, 2H, J=7.13 Hz), 3.82 (s, 1H), 3.41 (s, OH), 3.18 (dt, 1H, J=17.50 and 6.90 Hz), 2.83 (dt, 1H, J=17.50 and 6.48 Hz), 2.32 (dt, 1H, J=13.24 and 6.48 Hz), 1.78 (dt, 1H, J=13.24 and 6.90 Hz), 1.39 (t, 3H, J=7.13 Hz), 1.37 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 174.3, 135.7, 132.4, 129.2, 128.7, 127.2, 126.0, 69.6, 61.2, 55.3, 33.8, 27.9, 26.7, 14.3. MS: m/z (%) 235, 216, 201, 188, 170, 143 (100%), 128, 117, 91. IR (neat), cm^{-1}: 3463, 3062, 3020, 2977, 2932, 1719, 1582, 1497, 1450, 1371. Anal. Calcd for $C_{14}H_{18}O_3$: C, 71.77; H, 7.74. Found: C, 71.43; H, 7.97.

4.5.2. 2-Hydroxy-3,4-dihydronaphthalen-1-carbonitrile ***27***

After consumption of sodium (66 mg, 2.87 mmol) in ethanol (4 mL), ethyl 3-(2-cyanomethylphenyl)propionate **18** (0.50 g, 2.30 mmol) in ethanol (1 mL) was slowly added. After 15 min at 80 °C, the reaction mixture was cooled, diluted with diethyl ether

(10 mL) and hydrolyzed with H_2O (10 mL). The aqueous layer was extracted with diethyl ether (25 mL). The organic layers are collected, washed with brine and dried over $MgSO_4$. After removal of the solvent, the mixture was purified by column chromatography (pentane/ethyl acetate: 9/1) to yield 275 mg (70%) of **27**.

^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.70 (s br d, OH), 7.34–7.16 (m, 4H), 2.98 (t, 2H, J=7.98 Hz), 2.67 (t, 2H, J=7.98 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ 171.8, 130.5, 129.8, 127.5, 127.3, 126.2, 123.2, 116.4, 85.1, 28.3, 27.1. MS: m/z (%) 171 (100%), 154, 143, 129, 115. IR (in solution in $CDCl_3$), cm^{-1}: 3220, 2254, 2219, 1640, 1611, 1572, 1494, 1390, 908, 734. ^{1}H NMR spectrum is in good agreement with the literature data.[2]

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17. *2-(2-Bromophenyl)pentan-1,5-dinitrile* (***24***). ^{1}H NMR (300 MHz, $CDCl_3$) δ: 7.65 (dd, 1H, J=7.97 and 1.16 Hz), 7.59 (dd, 1H, J=7.63 and 1.66 Hz), 7.44 (m, 1H), 7.29 (m, 1H), 4.49 (dd, 1H, J=9.10 and 5.43 Hz), 2.71–2.54 (m, 2H), 2.40–2.17 (m, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 133.8, 133.2, 130.6, 129.0, 128.7, 123.0, 118.7, 117.8, 36.3, 29.9, 15.2. IR (neat), cm^{-1}: 2254, 1670, 1473, 1442, 909, 732. MS: m/z (%) 250, 248, 210, 208, 196, 194, 183, 181, 169 (100%), 142, 128, 115, 102, 88, 75, 63. Anal. Calcd for $C_{11}H_9N_2Br$: C, 53.04; H, 3.64; N, 11.25; Br, 32.08. Found: C, 53.50; H, 3.73; N, 11.12; Br, 31.90. (**23**): MS: m/z (%) 223, 209, 195, 183, 169, 155, 142, 129, 115, 102, 89, 78, 63.
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