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Asymmetric synthesis of multi-substituted spiro[5,5]undecane-1,5,9-triones via organocatalytic three-component reaction

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ABSTRACT

The asymmetric domino three-component Knoevanagel-Diels–Alder addition (ATCDA) reaction, as an important methodology, has been utilized to construct complex product from ordinary starting materials. In this report, many typical organoamine catalysts were investigated to achieve highly efficient asymmetric three-component reaction of enones 2, aldehydes 3 and Meldrum's acid 4. Various pharmacological multi-substituted spiro[5,5]undecane-1,5,9-triones promoted by 9-amino-9-deoxy-*epi*-quinine 1 g in one-pot, were obtained in moderate to good yields (up to 81%) with excellent diastereo-(>99:1 dr) and enantioselectivities (up to 97% ee). Meanwhile, based on the controlled experiments and analytical data, a reasonable mechanism of dual-activity for this reaction has been proposed.

1. Introduction

Highly substituted spirocyclic ketones are a widespread library in natural products with pharmaceutical activities property, as well as the starting materials for the synthesis of exotic amino acids.[1] For example, the novel spiromentins, which feature with phenyls substituted spirocyclic ketone have endowed with interesting anti-proliferative activity (Fig. 1).[1f,g,7] Many interests have been concentrated on the synthetic procedure and biological evaluation of the spirocyclic ketones collections. However, it is difficult to successfully reach the objective configuration in a simple way for its particular and complex structure. Originated from the pioneer work of Barbas and co-workers, this kind of asymmetric three-component domino reaction provides an efficient way to obtain such special chiral molecules with excellent results, utilizing a simple 5,5-dimethyl thiazolidinium-4-carboxylate.[1c,e,2,3] Nevertheless, searching other efficient system, which rises both diastero- and enantioselectivity for a wide variety of substrates combining different functional groups is still useful.

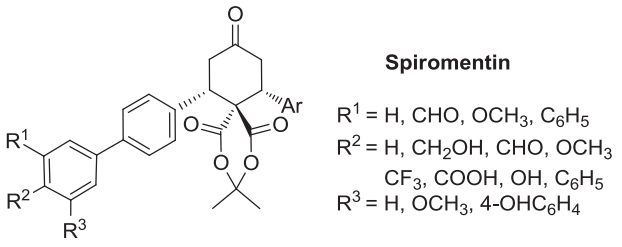

Fig. 1. Examples of bioactive substituted spirocyclic ketones derivatives.

2. Results and discussion

Secondary amines, usually originated from proline, are one of the most commonly used organocatalysts. Combination of iminium-enamine activation modes for activation of the carbonyl group is distinguished in asymmetric organocascade reactions, which allows for rapid conversion of simple achiral starting materials into optically active complex.[3,4] This type of aminocatalysis has broadly employed with a wide range of transformations, such as asymmetric cycloaddtion reaction, which is among the most powerful tools for generating functionalized cyclohexane frameworks. One protocol involves formation of an iminium ion from α,β-unsaturated aldehyde, which is sufficiently activated to engage a diene reaction partner. Another one is the inverse-electron-demand hetero-Diels–Alder reaction between enamine from aldehyde and α,β-unsaturated carbonyl compounds or 1-azabuta-1,3-dienes, while application of 2-amino-1,3-butadiene (Barbas dienamine) that should also been highlighted.[5] Enantiodivergent organocascade reactions, such as aldol–aldol, Michael-aldol, Mannich-cyanation, amination-aldol and Knoevanagel–Michael reactions have been realized by this activation strategy.[6] The first asymmetric three-component Knoevanagel-Diels–Alder reaction (ATCDA reaction) was reported by Barbas and co-workers.[5a–f] The 5,5-Dimethylthiazolidinium-4-carboxylate was used to create chiral dienamine diene for the synthesis of highly

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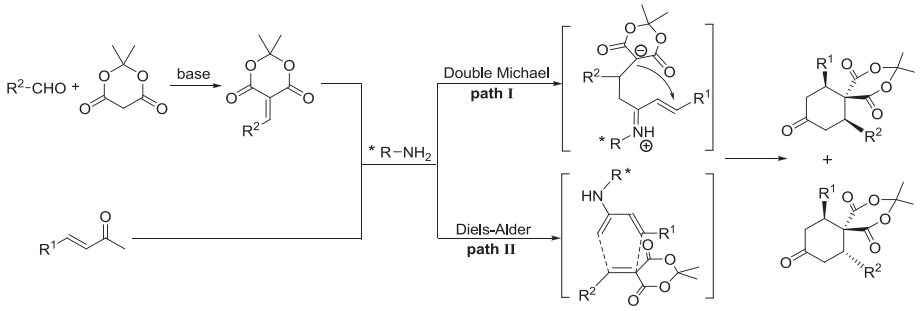
substituted spiro[5,5]-undecane-1,5,9-triones, which are a widespread library in natural products with pharmaceutical activities property, as well as the starting materials for the synthesis of exotic amino acids.[7] For example, the novel spiromentins, which feature with phenyls substituted spirocyclic ketone have endowed with interesting antiproliferative activity (Fig. 1). However, it is difficult to successfully construct the objective configuration in a simple way for its particular and complex structure. The importance of the spirocyclic ketones framework encouraged us to find other efficient system with raised diastereo- and enantioselectivity for a wide variety of substrates. Herein, we reported a useful catalysis system using 9-amino-9-deoxy-*epi*-quinine and good results were obtained.

As a meaningful hypothesis of mechanism firstly, when the reaction starts with the Knoevenagel condensation between aldehyde and 2,2-dimethyl-1,3-dioxane-4,6-dione (Meldrum's acid), there are two possible pathways to reach the desired spirocyclic ketone products. One is that the α-methyl of (*E*)-enone attacks alkylidene derivative of Meldrum's acid following intermediately another intramolecular Michael addition (Scheme 1, path I); the other is that the dienamine acted as an activated 1,3-diene and a concerted [4+2] cycloaddition would take place with alkylidene as dienophiles (Scheme 1, path II). It was notable the formation of enamination will play the key role whatever pathways occurred actually. Primary amine organocatalysts were equally useful for the formation of iminium-based Knoevenagel condensation firstly as well as for the formation of the 2-amino-1,3-butadiene from (*E*)-enone subsequently.

amount of amine in $CHCl_3$ at 20 °C among 2-enone (**2a**), 4-nitrobenzaldehyde (**3a**) and Meldrum's acid (**4a**). Some natural primary amino acids could catalyze the reaction to afford spirocyclic ketone **5a** with low yields and enantioselectivities (Table 1, entries 1 and 2). When amino acid **1b** combined with equivalent NaOH was used, the yield dropped dramatically and only trace amount of product was obtained (Table 1, entry 3), which implied that the H^+ played as necessary co-catalyst during the catalytic process. Then we changed our attention to other primary diamine catalysts in the presence of $PhCO_2H$ (Table 1, entries 4–9). In the beginning, a bicyclic bispidine catalyst derived from L-phenylglycine (**1c**) was investigated, and the corresponding product was obtained with 53% yield and 45% ee (Table 1, entry 4). It was obvious that catalysts containing dual activation center could efficiently promote the reaction. There was an obvious enhancement, especially when a substituted diamine derived from (1*S*,2*S*)-1,2-diphenylethane-1,2-diamine was used with 65% yield and 50% ee (Table 1, entry 6). Encouraged by these results, more widely used organoamines were then investigated. To our delight, the 9-amino-9-deoxy-*epi*-quinidine **1f** exhibited high catalytic activity, and the reaction gave adduct **5a** in 60% yield with 85% ee (Table 1, entry 7). Although a bit lower enantioselectivity with reversed configuration was obtained by the 9-amino-9-deoxy-*epi*-quinine **1g**, a higher yield was afforded (Table 1, entry 8). No product was obtained if the primary amine moiety of **1g** was protected with Boc-group (Table 1, entry 9). This result was an important evidence that primary amine group



Scheme 1. Two possible pathways to reach the spirocyclic ketone.

Initially, we evaluated the relationships of the reactivity and the structure of several kinds of organoamines (Fig. 2). The model asymmetric three-component reaction was carried out with

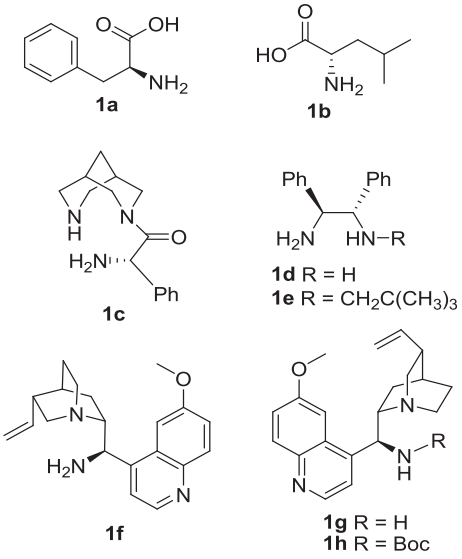
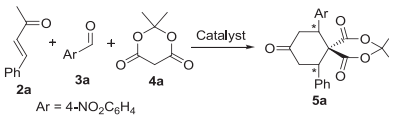


Fig. 2. Typical organoamine catalysts evaluated.

Table 1
Screening the organoamine catalyst[a]



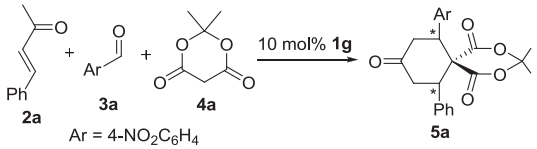
Entry	Catalyst	Yield [%][b]	ee [%][c]
1	**1a**	38	−17
2	**1b**	29	−20
3[d]	**1b**	Trace	
4[e]	**1c**	53	45
5[e]	**1d**	49	−39
6[e]	**1e**	65	50
7[e]	**1f**	60	−85
8[e]	**1g**	76	83
9[e]	**1h**	N.R	
10	**1g**	62	11

[a] Unless otherwise noted, all reactions were carried out with 10 mol % catalyst, 0.1 mmol 4-nitrobenzaldehyde, and 0.1 mmol Meldrum's acid were stirred in $CHCl_3$ for 1 h at 30 °C. Then, 0.11 mmol (*E*)-4-phenylbut-3-en-2-one was added and the mixture was stirred for 4 days under 20 °C.
[b] Isolated yield.
[c] Determined by chiral HPLC analysis.
[d] Added 10 mol % NaOH as co-catalyst.
[e] Added 10 mol % $PhCO_2H$ as co-catalyst.

played a key role for the formation of 2-amino-1,3-butadiene. To further confirm the assistant of acid, a comparative reaction without addition of $PhCO_2H$ was tested, only a moderate yield and low ee was obtained according to expectation (Table 1, entry 10).

Then, we investigated a series of acids, which are crucial for the stereoinduction in the process of the ATCD reaction. In general, the enantioselectivities were higher in combination of phenols than carboxylic acids (Table 2, entries 8–10 vs entries 1–7). It was noteworthy that adduct **5a** was obtained in high yield with the same configuration when D- or L-mandelic acid was employed with amine **1g**, respectively. While the disparity in the enantioselectivity indicated that the structure of anion moiety could also affect the chiral environment of the catalyst greatly (Table 2, entry 6 vs entry 7). When bromophenol was tested as additive, an excellent result was supplied (77% yield, 95% ee, Table 2, entry 10). Other conditions were also optimized, but no better results were gained. Extensive screening showed that the optimal condition was 10 mol % **1g** and 4-bromophenol complex (molar ratio: 1/1) in chloroform at 20 °C.

Table 2
Screening the acidic additives[a]

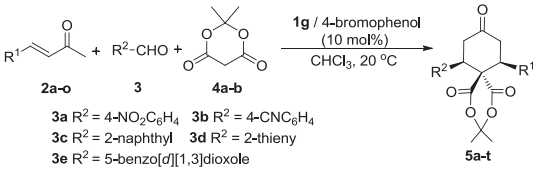


Entry	Additive	Yield (%)[b]	ee (%)[c]
1	3,5-Dimethoxybenzoic acid	77	82
2	4-Nitrobenzoic acid	80	71
3	AcOH	62	90
4	TFA	84	83
5	Ts–OH	85	91
6	L-Mandelic acid	88	43
7	D-Mandelic acid	91	16
8	4-Nitrophenol	52	95
9	Biphenyl-2,2′-diol	64	92
10	4-Bromophenol	77	95

[a] Unless otherwise noted, all reactions were carried out with 1 g (0.01 mmol), additive (0.01 mmol), 4-nitrobenzaldehyde (0.10 mmol), and Meldrum's acid (14.4 mg, 0.10 mmol) stirring in 0.5 mL $CHCl_3$ for 1 h at 30 °C. Then, (*E*)-4-phenylbut-3-en-2-one (0.11 mmol) was added and the reaction mixture was stirred for 4 days at 20 °C.
[b] Isolated yield.
[c] Determined by chiral HPLC analysis.

Under the optimized conditions, the scope of the asymmetric three-component reaction with various enones, aldehydes, and 1,3-dicarbonyl compounds were further explored. The corresponding spirotriones **5a**–**t** were obtained as single diastereomers with moderate to good yields and excellent ee values. Generally, enones with the phenyl group bearing electron-donating substituents could provide higher enantioselectivities, while higher yields could be obtained when enones with electron-withdrawing substituent on the phenyl group (Table 3, entries 2–6 vs entries 7–11). Other aromatic and heterocyclic enones were also investigated, and the related products were furnished with moderate yields and excellent ee values (Table 3, entries 12–14). It was notable that an aliphatic enone was successfully utilized leading the objective product with 55% yield and 81% ee (Table 3, entry 15). Next, different aldehydes were also tested in the same manner. The electronic nature of aldehyde has obvious effect on the reaction capability, which might be due to the diversity of the key alkylidene intermediate generated from the Knoevenagel condensation of aldehyde and Meldrum's acid (Table 3, entries 16–19). Finally, when the 1*H*-indene-1,3(2*H*)-dione was employed instead of Meldrum's acid, the system showed moderate reactivity and enantioselectivity (Table 3, entry 20).

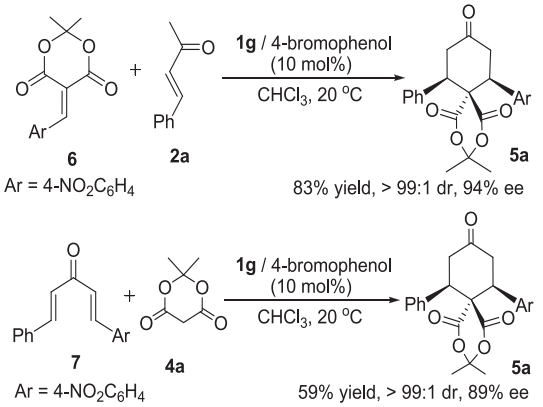
Table 3
Substrate scope of the asymmetric three-component reactions[a]



Entry	R^1	Aldehyde	Yield (%)[b]	ee (%)[c]
1[d]	C_6H_5 (**2a**)	**3a**	77 (**5a**)	95
2	4-FC_6H_4 (**2b**)	**3a**	72 (**5b**)	86
3	2-ClC_6H_4 (**2c**)	**3a**	71 (**5c**)	80
4	4-ClC_6H_4 (**2d**)	**3a**	81 (**5d**)	83
5	4-BrC_6H_4 (**2e**)	**3a**	67 (**5e**)	85
6	4-CNC_6H_4(**2f**)	**3a**	82 (**5f**)	84
7	3-$MeOC_6H_4$ (**2g**)	**3a**	64 (**5g**)	91
8	4-$MeOC_6H_4$ (**2h**)	**3a**	68 (**5h**)	97
9	3-MeC_6H_4 (**2i**)	**3a**	79 (**5i**)	90
10	3-HOC_6H_4 (**2j**)	**3a**	64 (**5j**)	88
11	4-HOC_6H_4 (**2k**)	**3a**	54 (**5k**)	95
12	2-Furyl (**2l**)	**3a**	57 (**5l**)	90
13	2-Thienyl (**2m**)	**3a**	61 (**5m**)	90
14	1-Naphthyl (**2n**)	**3a**	62 (**5n**)	93
15	*n*-Propanyl (**2o**)	**3a**	55 (**5o**)	81
16	C_6H_5 (**2a**)	**3b**	73 (**5p**)	80
17	C_6H_5 (**2a**)	**3c**	57 (**5q**)	96
18	C_6H_5 (**2a**)	**3d**	65 (**5r**)	81
19	C_6H_5 (**2a**)	**3e**	74 (**5s**)	80
20[e]	C_6H_5 (**2a**)	**3a**	53 (**5t**)	83

[a] Unless otherwise noted, all reactions were carried out with 4-bromophenol (1.7 mg, 0.01 mmol), 9-amino-9-deoxy-*epi*-quinine **1g** (3.2 mg, 0.01 mmol), aldehyde (0.10 mmol), and Meldrum's acid (14.4 mg, 0.10 mmol) were stirred in 0.5 mL $CHCl_3$ for 1 h at 30 °C. Then, (*E*)-enone (0.11 mmol) was added at 20 °C, and the reaction mixture was stirred for 4 days at 20 °C.
[b] Isolated yield.
[c] Determined by chiral HPLC analysis.
[d] Ratio of cis/trans was determined by ^1H NMR spectroscopy.
[e] Utilized **4b** 1*H*-indene-1,3(2*H*)-dione (0.10 mmol) instead of Meldrum's acid **4a** under the same condition.

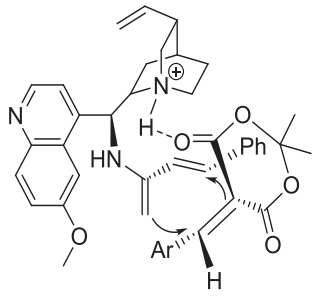
To further understand the mechanism of the asymmetric three-component reaction, more experiments were carried out in late (Scheme 2). As shown in Scheme 2, when a prepared 2,2-dimethyl-5-(4-nitrobenzylidene)-1,3-dioxane-4,6-dione **6** reacted with enone **2a** under the same condition, the same result was obtained and no single Michael intermediate was observed compared with one-pot method. Although slightly decreased enantioselectivity was afforded under the same reaction condition through a double-Michael reaction of Meldrum's acid **4a** and 1-(4-nitrophenyl)-5-phenylpenta-1,4-diene-3-one **7** as Michael acceptor, remarkably lower yield was observed (Scheme 2). Condensation product **7** was neither detected from cinnamone **2a** and aldehyde **3a** in one-pot in the presence of amine **1g**.[8] Therefore, the double-Michael process would be excluded. It was also demonstrated that alkylidene derivative **6** was



Scheme 2. The further experiments under the same condition.

more likely to be the dienephile and 2-amino-1,3-butadiene (Barbas dienamine) generated from enone and primary amine of **1g** could act as active diene partner.

The absolute configuration of product **5a** was established to be (7*S*, 11*R*) in comparison with the previous reports and NOE data.[9] It was reasoned that cinchona alkaloid-based primary amine **1g** might promote the asymmetric Diels–Alder reaction by simultaneously activating enones and alkylidene with its primary amine and protonated quinuclidine moiety, respectively. Such a dual activation was expected to bring the two reactants into vicinal chiral environment, thus facilitating the addition reaction (Scheme 3).



Scheme 3. A possible mechanism for the asymmetric three-component reaction.

The spiro[5,5]undecane-1,5,9-trione, as a useful starting material with distinct biological activity, has been investigated for a long time. It has been identified that chiral spiroundecanes could act as effective block recombiant HIV integrase.[7f] The desired spirocyclic ketones with bromophenyl group could be used for the construction of the natural product-like cores by Suzuki coupling as the derivating step (Fig. 3).[7f]

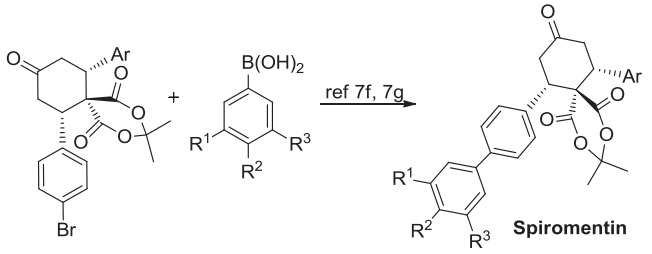


Fig. 3. The Suzuki reaction for the synthesis of spiromentin.

3. Conclusions

In summary, we have developed an efficient asymmetric one-pot three-component reaction catalyzed by the 9-amino-9-deoxy-*epi*-quinine **1g** under mild conditions. A wide variety of highly substituted spiro[5,5]undecane-1,5,9-triones were obtained in moderate to good yields (up to 81%) with excellent diastereo- (up to >99:1 dr) and enantioselectivities (up to 97% ee). This methodology provides useful procedure for the synthesis of chiral spirocyclic ketone scaffolds owing to that both the direct products and some derivatives through simple transformation are important candidates with dramatic biological value.

4. Experimental section

4.1. General information

Solvents were purified by standard procedures and distilled before use. Reagents and starting materials obtained from commercial suppliers were used without further purification unless otherwise stated. All the aldehydes were distilled freshly prior to use. NMR spectra were recorded on a 400/600 MHz spectrometer. ^{1}H NMR chemical shifts were reported in parts per million with tetramethylsilane (TMS) as the internal standard. Data for ^{1}H are reported as follows: chemical shift (in ppm) and multiplicity (s=singlet, d=doublet, t=triplet, q=quartet, m=multiplet, br=broad). Splitting patterns that could not be clearly distinguished are designated as multiplets (m). Data for ^{13}C NMR are reported in ppm. High-resolution mass spectral analyses (HRMS) were measured using ESI ionization. High performance liquid chromatography (HPLC) analysis was performed on chiral columns. Optical rotations were measured in the solvent indicated. Flash chromatography was performed on>400 mesh silica gel.

4.2. General procedure for the synthesis of compounds (2a–o)

The aldehyde (10 mmol) was added gradually to a solution of NaOH (0.5 g) in H_2O (10.0 mL) and ketone (10 mmol) in ethanol (15 mL) at 0 °C. The mixture was then allowed to warm to room temperature and stirred for overnight. At the end of this period, $KHSO_4$ (1 N) solution was added to the flask until *p*H≈6, followed by extraction with ether. The combined organic layers were dried over Na_2SO_4 and concentrated to give a solid, which was purified by flash column chromatography using EtOAc/petroleum ether at last.

4.3. General procedure for the asymmetric three-component reaction

The 4-bromophenol (1.7 mg, 0.01 mmol), 9-amino-9-deoxy-*epi*-quinine **1g** (3.2 mg, 0.01 mmol), aldehyde (0.10 mmol), and Meldrum's acid (14.4 mg, 0.10 mmol) were stirred in 0.5 mL $CHCl_3$ for 1 h at 30 °C. Subsequently, (*E*)-enone (0.11 mmol) was added at 20 °C, and the reaction mixture was stirred for 4 days at 20 °C. The residue was purified by flash chromatography on silica gel to afford the desired product.

*4.3.1. (7S,11R)-3,3-Dimethyl-7-(4-nitrophenyl)-11-phenyl-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5a**).* ($C_{23}H_{21}NO_7$) a white solid; 32.6 mg, 77% yield, 95% ee $[\alpha]_D^{20}$ −2.43 (*c*=3.7 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=80/20, flow rate=1.0 mL/min, *λ*=254 nm, retention time: 15.373 min (minor), 16.235 min (major). ^{1}H NMR (400 MHz, $CDCl_3$) *δ*=8.208 (d, 2H), 7.245–7.458 (m, 7H), 4.138 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 4.035 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 3.725 (dt, J_1=5.2 Hz, J_2=14.8 Hz, 2H), 2.676 (dt, J_1=4.4 Hz, J_2=15.2 Hz, 2H), 0.661 (s, 3H), 0.514 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) *δ*=206.2, 167.8, 164.9, 147.9, 144.2, 136.7, 129.7, 129.4, 129.1, 128.5, 124.3, 106.7, 60.1, 50.1, 49.8, 42.8, 42.5, 28.9, 28.1 ppm; HRMS (ESI-TOF) calcd for $C_{23}H_{21}NO_7$ ([M−H$^+$])=422.1240, Found 422.1233.

*4.3.2. 7-(4-Fluorophenyl)-3,3-dimethyl-11-(4-nitrophenyl)-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5b**).* ($C_{23}H_{20}FNO_7$) a white solid; 31.8 mg, 72% yield, 86% ee $[\alpha]_D^{20}$ −5.84 (*c*=3.08 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=90/10, flow rate=1.0 mL/min, *λ*=254 nm, retention time: 29.599 min (minor), 30.371 min (major). ^{1}H NMR (400 MHz, $CDCl_3$) *δ*=8.212 (d, 2H), 7.028–7.443 (m, 6H), 4.110 (dd, J_1=4.0 Hz, J_2=14.0 Hz, 1H), 4.023 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 3.677 (dt, J_1=10.4 Hz, J_2=14.8 Hz, 2H), 2.655 (dt, J_1=4.4 Hz, J_2=8.8 Hz, 2H), 0.653 (s, 3H), 0.623 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) *δ*=205.6, 167.7, 164.8, 148.0, 143.9, 135.1, 129.9, 129.7, 129.6, 124.3, 106.7, 59.9, 49.7, 49.6, 42.7, 42.4, 28.9, 28.4 ppm; HRMS (ESI-TOF) calcd for $C_{23}H_{20}FNO_7$ ([M−H$^+$])=440.1146, Found 440.1141.

*4.3.3. 7-(2-Chlorophenyl)-3,3-dimethyl-11-(4-nitrophenyl)-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5c**).* ($C_{23}H_{20}ClNO_7$) a white solid; 32.5 mg, 71% yield, 80% ee $[\alpha]_D^{20}$ −5.283 (*c*=1.06 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IB, *n*-hexane/2-propanol=80/20, flow rate=1.0 mL/min, *λ*=254 nm, retention time: 16.125 min (major), 17.439 min (minor). ^{1}H NMR (400 MHz, $CDCl_3$) *δ*=8.225 (d, 2H),

7.122–7.453 (m, 6H), 4.118 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 4.001 (dd, J_1=4.0 Hz, J_2=14.4 Hz, 1H), 3.687 (dt, J_1=4.4 Hz, J_2=14.8 Hz, 2H), 2.673 (dt, J_1=4.4 Hz, J_2=7.2 Hz, 2H), 0.675 (s, 3H), 0.645 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=205.5, 167.6, 164.8, 148.0, 143.9, 138.7, 135.4, 130.7, 129.7, 129.3, 128.68, 126.8, 124.3, 106.8, 59.8, 49.9, 49.78, 42.2, 42.4, 28.95, 28.4 ppm; HRMS (ESI-TOF) calcd for $C_{23}H_{20}ClNO_7$ ([M−H$^+$])=456.0850, Found 456.0847.

*4.3.4. 7-(4-Chlorophenyl)-3,3-dimethyl-11-(4-nitrophenyl)-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5d**).* ($C_{23}H_{20}ClNO_7$) a white solid; 37.1 mg, 81% yield, 83% ee $[\alpha]_D^{20}$ −0.94 (c=3.18 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=80/20, flow rate=1.0 mL/min, λ=254 nm, retention time: 19.210 min (minor), 21.630 min (major). ^{1}H NMR (400 MHz, $CDCl_3$) δ=8.225 (d, 2H), 7.172–7.452 (m, 6H), 4.123 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 4.016 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 3.684 (dd, J_1=14.4 Hz, J_2=27.6 Hz, 2H), 2.673 (dt, J_1=2.0 Hz, J_2=4.4 Hz, 2H), 0.659 (s, 3H), 0.650 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=205.6, 167.7, 164.8, 148.0, 143.9, 135.1, 129.9, 129.7, 129.6, 124.3, 106.7, 59.9, 49.7, 49.67, 42.7, 42.4, 28.97, 28.4 ppm; HRMS (ESI-TOF) calcd for $C_{23}H_{20}ClNO_7$ ([M−H$^+$])= 456.0850, Found 456.0854.

*4.3.5. 7-(4-Bromophenyl)-3,3-dimethyl-11-(4-nitrophenyl)-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5e**).* ($C_{23}H_{20}BrNO_7$) a white solid; 33.7 mg, 67% yield, 85% ee $[\alpha]_D^{20}$ −3.93 (c=1.78 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=80/20, flow rate=1.0 mL/min, λ=254 nm, retention time: 20.920 min (minor), 24.832 min (major). ^{1}H NMR (400 MHz, $CDCl_3$) δ=8.221 (d, 2H), 7.108–7.511 (m, 6H), 4.119 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 3.999 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 3.681 (dd, J_1=2.4 Hz, J_2=28.8 Hz, 2H), 2.646 (dt, J_1=2.4 Hz, J_2=4.4 Hz, 2H), 0.655 (s, 6H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=205.6, 167.6, 164.8, 147.9, 143.9, 135.6, 132.5, 130.2, 129.7, 124.3, 123.2, 106.8, 59.8, 49.7, 49.6, 42.6, 42.4, 28.9, 28.4 ppm; HRMS (ESI-TOF) calcd for $C_{23}H_{20}BrNO_7$ ([M−H$^+$])=500.0345, Found 500.0350.

*4.3.6. 4-(3,3-Dimethyl-11-(4-nitrophenyl)-1,5,9-trioxo-2,4-dioxaspiro[5.5]undecan-7-yl)benzonitrile (**5f**).* ($C_{24}H_{20}N_2O_7$) a white solid; 36.7 mg, 82% yield, 84% ee $[\alpha]_D^{20}$ −2.84 (c=2.82 in CH_2Cl_2). HPLC DAICEL CHIRALCEL ADH, *n*-hexane/2-propanol=80/20, flow rate=1.0 mL/min, λ=254 nm, retention time: 41.879 min (major), 49.206 min (minor). ^{1}H NMR (400 MHz, $CDCl_3$) δ=8.232 (d, 2H), 7.369–7.690 (m, 6H), 4.137 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 4.089 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 3.701 (dt, J_1=5.6 Hz, J_2=14.4 Hz, 2H), 2.685 (dt, J_1=2.0 Hz, J_2=4.0 Hz, 2H), 0.635 (s, 3H), 0.627 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=204.8, 167.4, 164.6, 148.1, 143.6, 141.7, 133.1, 129.7, 129.5, 124.4, 113.2, 106.8, 59.6, 50.1, 49.8, 42.4, 42.2, 28.8, 28.6 ppm; HRMS (ESI-TOF) calcd for $C_{24}H_{20}N_2O_7$ ([M−H$^+$])=447.1192, Found 447.1200.

*4.3.7. 7-(3-Methoxyphenyl)-3,3-dimethyl-11-(4-nitrophenyl)-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5g**).* ($C_{24}H_{23}NO_8$) a white solid; 29.0 mg, 64% yield, 91% ee $[\alpha]_D^{20}$ −2.977 (c=2.36 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=80/20, flow rate=1.0 mL/min, λ=254 nm, retention time: 18.478 min (major), 20.159 min (minor). ^{1}H NMR (400 MHz, $CDCl_3$) δ=8.215 (d, 2H), 6.735–7.449 (m, 6H), 4.116 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 4.001 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 3.781 (s, 3H), 3.717 (dd, J_1=11.2 Hz, J_2=14.4 Hz, 2H), 2.670 (dt, J_1=4.4 Hz, J_2=15.2 Hz, 2H), 0.681 (s, 3H), 0.601 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=205.8, 167.8, 160.2, 144.1, 138.1, 130.5, 129.7, 124.3, 120.6, 114.5, 114.2, 106.7, 59.9, 55.4, 50.0, 42.8, 42.5, 29.7, 28.9, 28.3 ppm; HRMS (ESI-TOF) calcd for $C_{24}H_{23}NO_8$ ([M−H$^+$])=452.1345, Found 452.1346.

*4.3.8. 7-(4-Methoxyphenyl)-3,3-dimethyl-11-(4-nitrophenyl)-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5h**).* ($C_{24}H_{23}NO_8$) a white solid; 30.8 mg, 68% yield, 97% ee $[\alpha]_D^{20}$ +2.50 (c=1.20 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=80/20, flow rate=1.0 mL/min, λ=254 nm, retention time: 21.607 min (major), 26.160 min (minor). ^{1}H NMR (400 MHz, $CDCl_3$) δ=8.213 (d, 2H), 6.858–7.447 (m, 6H), 4.105 (dd, J_1=4.4 Hz, J_2=14.8 Hz, 1H), 3.988 (dd, J_1=4.4 Hz, J_2=14.0 Hz, 1H), 3.770 (s, 3H), 3.687 (dt, J_1=5.6 Hz, J_2=14.4 Hz, 2H), 2.648 (dt, J_1=4.4 Hz, J_2=10.8 Hz, 2H), 0.674 (s, 3H), 0.605 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=206.2, 167.5, 165.2, 159.8, 147.8, 144.2, 129.6, 128.6, 124.1, 114.5, 106.7, 102.9, 60.3, 55.3, 49.9, 43.4, 41.9, 29.7, 28.9, 28.4 ppm; HRMS (ESI-TOF) calcd for $C_{24}H_{23}NO_8$ ([M−H$^+$])=452.1345, Found 452.1345.

*4.3.9. 3,3-Dimethyl-7-(4-nitrophenyl)-11-m-tolyl-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5i**).* ($C_{24}H_{23}NO_7$) a white solid; 34.5 mg, 79% yield, 90% ee $[\alpha]_D^{20}$ −1.70 (c=2.94 in CH_2Cl_2). HPLC DAICEL CHIRALCEL ADH, *n*-hexane/2-propanol=80/20, flow rate=1.0 mL/min, λ=254 nm, retention time: 15.373 min (minor), 16.235 min (major). ^{1}H NMR (400 MHz, $CDCl_3$) δ=8.217 (d, 2H), 7.023–7.455 (m, 6H), 4.127 (dd, J_1=4.0 Hz, J_2=14.4 Hz, 1H), 3.988 (dd, J_1=4.0 Hz, J_2=14.4 Hz, 1H), 3.687 (t, J=14.4 Hz, 2H), 2.663 (dt, J_1=4.4 Hz, J_2=11.2 Hz, 2H), 2.326 (s, 3H), 0.677 (s, 3H), 0.532 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=204.8, 167.4, 164.6, 148.1, 143.6, 141.7, 133.1, 129.7, 129.5, 124.4, 113.2, 106.8, 59.6, 50.1, 49.8, 42.4, 42.2, 28.8, 28.6 ppm; HRMS (ESI-TOF) calcd for $C_{24}H_{23}NO_7$ ([M−H$^+$])= 436.1396, Found 436.1395.

*4.3.10. 7-(3-Hydroxyphenyl)-3,3-dimethyl-11-(4-nitrophenyl)-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5j**).* ($C_{23}H_{21}NO_8$) a white solid; 28.1 mg, 64% yield, 88% ee $[\alpha]_D^{20}$ −1.27 (c=3.24 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=90/10, flow rate=1.0 mL/min, λ=254 nm, retention time: 49.972 min (major), 51.944 min (minor). ^{1}H NMR (400 MHz, $CDCl_3$) δ=8.221 (d, 2H), 6.696–7.451 (m, 6H), 5.016 (s, 1H), 4.135 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 3.995 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 3.695 (dt, J_1=7.6 Hz, J_2=14.8 Hz, 2H), 2.678 (dt, J_1=4.4 Hz, J_2=14.0 Hz, 2H), 0.687 (s, 3H), 0.630 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=206.5, 167.9, 164.96, 156.5, 147.9, 144.0, 138.3, 130.8, 129.7, 124.3, 120.5, 116.1, 115.4, 106.8, 59.9, 49.9, 49.7, 42.8, 42.5, 30.3, 29.7, 28.9, 28.3 ppm; HRMS (ESI-TOF) calcd for $C_{23}H_{21}NO_8$ ([M−H$^+$])=438.1189, Found 438.1188.

*4.3.11. 7-(4-Hydroxyphenyl)-3,3-dimethyl-11-(4-nitrophenyl)-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5k**).* ($C_{23}H_{21}NO_8$) a white solid; 23.7 mg, 54% yield, 95% ee $[\alpha]_D^{20}$ −3.13 (c=1.28 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=80/20, flow rate=1.0 mL/min, λ=254 nm, retention time: 16.640 min (major), 30.828 min (minor). ^{1}H NMR (400 MHz, $CDCl_3$) δ=8.215 (d, 2H), 6.797–7.446 (m, 6H), 5.140 (s, 1H), 4.102 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 3.976 (dd, J_1=4.0 Hz, J_2=14.4 Hz, 1H), 3.680 (dt, J_1=9.2 Hz, J_2=14.4 Hz, 2H), 2.649 (dt, J_1=4.8 Hz, J_2=10.0 Hz, 2H), 0.677 (s, 3H), 0.637 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=206.4, 167.9, 165.1, 156.1, 147.9, 144.2, 129.99, 129.6, 128.8, 124.3, 116.1, 106.7, 60.3, 49.7, 49.4, 43.1, 42.5, 29.7, 28.9, 28.4 ppm; HRMS (ESI-TOF) calcd for $C_{23}H_{21}NO_8$ ([M−H$^+$])=438.1189, Found 438.1179.

*4.3.12. 7-(Furan-2-yl)-3,3-dimethyl-11-(4-nitrophenyl)-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5l**).* ($C_{21}H_{19}NO_8$) a white solid; 23.6 mg, 57% yield, 90% ee $[\alpha]_D^{20}$ −1.59 (c=2.52 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=80/20, flow rate=1.0 mL/min, λ=254 nm, retention time: 18.685 min (minor), 22.337 min (major). ^{1}H NMR (400 MHz, $CDCl_3$) δ=8.223 (d, 2H), 6.250–7.445 (m, 5H), 4.187 (dd, J_1=4.4 Hz, J_2=14.0 Hz, 1H), 4.052 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 3.642 (dt, J_1=1.6 Hz, J_2=14.8 Hz, 2H), 2.649 (ddd, J_1=4.4 Hz, J_2=15.6 Hz, 2H), 0.967 (s, 3H), 0.736 (s, 3H) ppm; ^{13}C NMR (100 MHz, CDCl3) δ=205.2, 167.8, 164.5, 150.4, 148.0, 143.9, 142.9, 129.7, 124.3, 111.0, 109.3, 106.6, 58.3, 49.3, 43.9,

42.3, 41.3, 28.7, 28.5 ppm; HRMS (ESI-TOF) calcd for $C_{21}H_{19}NO_8$ ([M−H$^+$])=412.1032, Found 412.1034.

*4.3.13. 3,3-Dimethyl-7-(4-nitrophenyl)-11-(thiophen-2-yl)-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5m**).* ($C_{21}H_{19}NSO_7$) a white solid; 26.2 mg, 61% yield, 90% ee. $[\alpha]_D^{20}$ +1.905 (c=4.02 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=80/20, flow rate=1.0 mL/min, λ=254 nm, retention time: 20.323 min (minor), 21.299 min (major). ^{1}H NMR (400 MHz, $CDCl_3$) δ=8.226 (d, 2H), 6.967–7.435 (m, 5H), 4.384 (dd, J_1=4.8 Hz, J_2=14.4 Hz, 1H), 4.060 (dd, J_1=4.0 Hz, J_2=14.0 Hz, 1H), 3.651 (dt, J_1=12.8 Hz, J_2=14.8 Hz, 2H), 2.843 (dt, J_1=1.2 Hz, J_2=4.8 Hz, 1H), 2.644 (dq, J_1=1.2 Hz, J_2=4.4 Hz, 1H), 0.736 (s, 6H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=204.9, 167.9, 164.9, 148.0, 143.8, 139.7, 129.5, 127.5, 125.9, 124.3, 106.6, 60.7, 49.8, 45.1, 44.37, 42.2, 28.7, 28.6 ppm; HRMS (ESI-TOF) calcd for $C_{21}H_{19}NSO_7$ ([M−H$^+$])=428.0804, Found 428.0795.

*4.3.14. 3,3-Dimethyl-7-(naphthalen-1-yl)-11-(4-nitrophenyl)-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5n**).* ($C_{27}H_{23}NO_7$) a white solid; 29.4 mg, 62% yield, 93% ee $[\alpha]_D^{20}$ −1.38 (c=2.62 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=80/20, flow rate=1.0 mL/min, λ=254 nm, retention time: 14.744 min (major), 17.840 min (minor). ^{1}H NMR (400 MHz, $CDCl_3$) δ=8.177 (t, 3H), 7.475–7.850 (m, 8H), 4.996 (dd, J_1=4.0 Hz, J_2=14.0 Hz, 1H), 4.307 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 3.829 (dt, J_1=14.8 Hz, J_2=22.8 Hz, 2H), 2.734 (dd, J_1=4.4 Hz, J_2=15.2 Hz, 2H), 0.596 (s, 3H), 0.437 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=206.3, 167.4, 165.5, 147.9, 144.3, 134.07, 133.4, 130.7, 130.3, 129.9, 129.6, 128.9, 127.1, 126.5, 125.5, 125.2, 124.2, 123.9, 122.8, 104.2, 63.8, 59.3, 50.1, 43.4, 42.8, 29.2, 27.9 ppm; HRMS (ESI-TOF) calcd for $C_{27}H_{23}NO_7$ ([M+H$^+$])= 474.1553, Found 474.1561.

*4.3.15. 3,3-Dimethyl-7-(4-nitrophenyl)-11-propyl-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5o**).* ($C_{20}H_{23}NO_7$) a white solid; 21.4 mg, 55% yield, 81% ee $[\alpha]_D^{20}$ −2.33 (c=1.76 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=90/10, flow rate=1.0 mL/min, λ=254 nm, retention time: 14.650 min (minor), 15.772 min (major). ^{1}H NMR (400 MHz, $CDCl_3$) δ=8.214 (d, 2H), 7.432 (d, 2H), 4.003 (dd, J_1=4.8 Hz, J_2=14.4 Hz, 1H), 3.598 (t, J=14.4 Hz, 1H), 2.538–2.796 (m, 4H), 1.630 (s, 3H), 0.862–0.970 (m, 7H), 0.677 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=206.5, 168.5, 165.2, 147.9, 144.7, 129.9, 124.3, 106.7, 58.8, 48.5, 45.9, 42.5, 41.3, 34.6, 30.3, 29.7, 29.5, 29.3, 19.7, 13.6 ppm; HRMS (ESI-TOF) calcd for $C_{20}H_{23}NO_7$ ([M+H$^+$])= 390.1553, Found 390.1553.

*4.3.16. 4-(3,3-Dimethyl-1,5,9-trioxo-11-phenyl-2,4-dioxaspiro[5.5]undecan-7-yl)benzonitrile (**5p**).* ($C_{24}H_{21}NO_5$) a white solid; 29.5 mg, 73% yield, 80% ee $[\alpha]_D^{20}$ −1.89 (c=2.62 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=80/20, flow rate=1.0 mL/min, λ=254 nm, retention time: 14.018 min (minor), 16.125 min (major). ^{1}H NMR (400 MHz, $CDCl_3$) δ=7.218–7.668 (m, 9H), 4.072 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 4.018 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 3.714 (dt, J_1=3.6 Hz, J_2=14.4 Hz, 2H), 2.661 (dt, J_1=4.4 Hz, J_2=19.2 Hz, 2H), 0.656 (s, 3H), 0.518 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=205.9, 167.8, 164.9, 142.3, 136.7, 132.9, 129.4, 129.4, 129.0, 128.5, 117.9, 112.8, 106.6, 60.1, 50.1, 42.8, 42.4, 28.8, 28.2 ppm; HRMS (ESI-TOF) calcd for $C_{24}H_{21}NO_5$ ([M−H$^+$])= 402.1341, Found 402.1350.

*4.3.17. 3,3-Dimethyl-7-(naphthalen-2-yl)-11-phenyl-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5q**).* ($C_{27}H_{24}O_5$) a white solid; 24.4 mg, 57% yield, 96% ee $[\alpha]_D^{20}$ +3.45 (c=1.16 in CH_2Cl_2). HPLC DAICEL CHIRALCEL ASH, *n*-hexane/2-propanol=80/20, flow rate=1.0 mL/min, λ=254 nm, retention time: 8.208 min (minor), 8.763 min (major). ^{1}H NMR (400 MHz, $CDCl_3$) δ=7.255–7.807 (m, 11H), 4.189 (dd, J_1=4.8 Hz, J_2=14.0 Hz, 1H), 4.075 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 3.816 (dt, J_1=2.4 Hz, J_2=15.6 Hz, 2H), 2.709 (ddd, J_1=4.4 Hz, J_2=12.4 Hz, 2H), 0.506 (s, 3H), 0.337 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=207.6, 168.3, 165.4, 137.1, 134.4, 133.2, 133.0, 129.3, 129.0, 128.7, 128.5, 127.6, 126.7, 126.7, 125.6, 106.4, 60.5, 50.3, 50.0, 43.1, 42.9, 28.3, 28.3 ppm; HRMS (ESI-TOF) calcd for $C_{27}H_{24}O_5$ ([M+H$^+$])=429.1702, Found 429.1712.

*4.3.18. 3,3-Dimethyl-7-phenyl-11-(thiophen-2-yl)-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5r**).* ($C_{21}H_{20}SO_5$) a white solid; 25.0 mg, 65% yield, 81% ee $[\alpha]_D^{20}$ −4.91 (c=2.24 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=90/10, flow rate=1.0 mL/min, λ=254 nm, retention time: 15.563 min (major), 16.892 min (minor). ^{1}H NMR (400 MHz, $CDCl_3$) δ=6.947–7.361 (m, 8H), 4.364 (dd, J_1=5.2 Hz, J_2=14.4 Hz, 1H), 3.942 (dd, J_1=4.4 Hz, J_2=14.4 Hz, 1H), 3.656 (dt, J_1=4.4 Hz, J_2=14.8 Hz, 2H), 2.718 (ddd, J_1=4.4 Hz, J_2=14.8 Hz, 2H), 0.756 (s, 3H), 0.612 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=206.3, 168.4, 165.2, 140.2, 136.8, 129.2, 128.8, 129.3, 127.3, 127.1, 125.5, 106.6, 61.2, 50.0, 45.3, 44.5, 42.6, 28.9, 28.0 ppm; HRMS (ESI-TOF) calcd for $C_{21}H_{20}SO_5$ ([M−H$^+$])= 383.0953, Found 383.0955.

*4.3.19. 7-(benzo[d][1,3]dioxol-5-yl)-3,3-dimethyl-11-phenyl-2,4-dioxaspiro[5.5]undecane-1,5,9-trione (**5s**).* ($C_{24}H_{22}O_7$) a white solid; 31.3 mg, 74% yield, 80% ee. $[\alpha]_D^{20}$ −7.917 (c=2.44 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=90/10, flow rate=1.0 mL/min, λ=254 nm, retention time: 20.557 min (minor), 21.573 min (major). ^{1}H NMR (400 MHz, $CDCl_3$) δ=6.703–7.352 (m, 8H), 5.928 (s, 2H), 3.949 (m, 2H), 3.656 (dt, J_1=14.8 Hz, J_2=25.2 Hz, 2H), 2.619 (dt, J_1=4.8 Hz, J_2=12.0 Hz, 2H), 0.759 (s, 3H), 0.590 (s, 3H) ppm; ^{13}C NMR (100 MHz, $CDCl_3$) δ=205.9, 168.2, 165.3, 148.2, 147.7, 137.1, 129.2, 128.7, 128.5, 122.1, 108.8, 108.8, 106.4, 101.3, 60.7, 50.2, 49.8, 43.4, 42.8, 28.8, 28.3 ppm; HRMS (ESI-TOF) calcd for $C_{24}H_{22}O_7$ ([M−H$^+$])=421.1287, Found 421.1290.

*4.3.20. 2-(4-nitrophenyl)-6-phenylspiro[cyclohexane-1,2′-indene]-1′,3′,4-trione (**5t**).* ($C_{26}H_{19}NO_5$) a yellow solid; 22.5 mg, 53% yield, 83% ee $[\alpha]_D^{20}$ −0.870 (c=0.92 in CH_2Cl_2). HPLC DAICEL CHIRALCEL IA, *n*-hexane/2-propanol=90/10, flow rate=1.0 mL/min, λ=215 nm, retention time: 42.625 min (major), 46.276 min (minor). ^{1}H NMR (400 MHz, $CDCl_3$) δ=6.953–7.915 (m, 13H), 3.795–3.918 (m, 4H), 2.661 (t, J=8.8 Hz) ppm; HRMS (ESI-TOF) calcd for $C_{26}H_{19}NO_5$ ([M−H$^+$])=424.1185, Found 424.1161.

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Supplementary data

Supplementary data related to this article can be found online at doi:10.1016/j.tet.2011.01.037.

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