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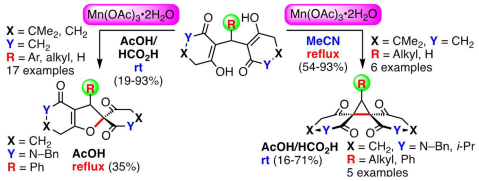

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ABSTRACT

The Mn(III)-based oxidation of methylenebis(cyclohexanedione)s and methylenebis(piperidinedione)s as a tetracarbonyl compound was investigated under various conditions, selectively producing spiro dihydrofurans and dispiro cyclopropanes depending on the solvent. The mechanism for the formation of the spiro dihydrofurans and dispiro cyclopropanes was discussed. In addition, a simple synthesis of a new type of alkaloid, 3,4,6,7,8,10-hexahydro-1*H*-pyrano[3,2-*c*:5,6-*c'*]dipyridine-1,9(2*H*)-diones, was demonstrated.

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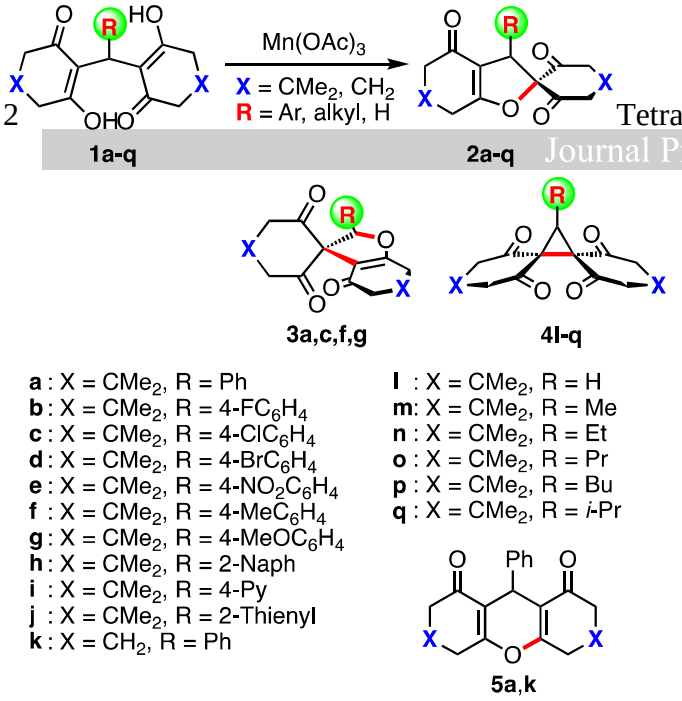


Scheme 1. Oxidation of **1a-q** with $Mn(OAc)_3$

1. Introduction

Polycarbonyl compounds are important and convenient building blocks in organic synthesis, especially for the Mn(III)-based reaction, to induce the oxidative tandem cyclization that produces heterocyclic compounds.[1] We recently reported that the reaction of tricarbonyl compounds, such as 3-acetylpentane-1,4-diones, 2-acetyl-4-oxobutanoates, and 2-(2-oxoethyl)malonates, with 1,1-disubstituted olefins exactly produced tetrahydrofuro[2,3-*b*]furans and dihydropyrans during the oxidative process.[2] Cyclic 1,3-diketones having a 2-oxoalkyl group, such as 3-(2-oxoethyl)piperidine-2,4-diones, 2-(oxoalkyl)cycloalkane-1,3-diones, and 3-(oxoalkyl)-1*H*-quinolin-2-ones, also effectively underwent the tandem cyclization to give dioxapropellanes[3] and endoperoxypropellanes.[4] To further demonstrate the usefulness of polycarbonyl building blocks, we applied the Mn(III)-based oxidation to tetraketones, such as 3,4-diacetylheptane-2,6-dione, in order to obtain more complex tandem cyclization products in one-pot. However, it was very difficult to control the reaction under various conditions and no desired products were isolated. The reaction probably developed into various directions because of the flexible aliphatic tetracarbonyls. To restrict the reaction directions, we envisioned the use of tetracarbonyl compounds to limit the flexibility, such as a cyclic carbonyl system. We then embarked on the reaction of 2,2'-methylenebis(cyclohexane-1,3-dione) derivatives as the cyclic polyketone. 2,2'-(Phenylmethylene)bis(5,5-dimethylcyclohexane-1,3-dione) (**1a**) was first selected as the substrate and underwent the Mn(III)-based oxidation to afford 4',4',6,6-tetramethyl-3-phenyl-3,5,6,7-tetrahydro-4*H*-spiro[benzofuran-2,1'-cyclohexane]-2',4,6'-trione (**2a**)[5,6] in moderate yield (Scheme 1). Recently, the spiro compounds including the dimedone framework were synthesized by various methods. For example, the reaction of dimedone with alkanals in the presence of iodine was carried out under mechanical ball milling conditions at room temperature to give the spiro compounds.[6] Electrolysis of dimedone in the presence of aromatic aldehydes afforded the corresponding spiro products.[7] Although the reaction using dimedone bismuthonium ylide also proceeded in dry benzene via a Wittig-type condensation, two-types of spiro compounds were also produced as a mixture in poor yields.[8] The reaction using iodonium ylide under microwave irradiation led to better results.[9] However, these methods were limited because of the use of a special apparatus or limited aldehydes. In general, spiro compounds bearing two rings linked together by one common atom are structurally very interesting because the spiro-atom is a quaternary carbon and the two rings are often perpendicular so that some spiro compounds display an axial chirality.[10] Furthermore, the heterocyclic spiro compounds including the spiro-dihydrofuranyl scaffold are found in various natural products as a significant unit.[11] Therefore, it must be very useful in organic chemistry to more simply and efficiently synthesize the spiro compounds, thus we commenced to develop the synthesis using our new technique in order to evaluate its possibility and usefulness as an oxidative radical promoter of manganese(III) acetate dihydrate, $Mn(OAc)_3•2H_2O$. The $Mn(OAc)_3•2H_2O$ as a single-electron transfer oxidant is stable in air and easy to prepare on a large scale from an inexpensive material,[12] so that it is a very useful and convenient oxidant. Furthermore, we recently found the activation effect of the Mn(III)-based reaction by adding formic acid.[13,10l] We now describe the results in detail.

2. Results and discussion

2.1. Reaction of methylenebis(cyclohexanedione)s 1a-q

The reaction of phenyl-substituted methylenebis(cyclohexanedione) **1a** with $Mn(OAc)_3•2H_2O$ was carried out in AcOH at room temperature until the oxidant was completely consumed (Scheme 1). The reaction took 8 h and phenyltetrahydrospiro[benzofuran-2,1'-cyclohexane] **2a** was obtained in 54% yield (Table 1, Entry 1). Since the long reaction time caused the retro-Michael addition of **1a** and might lead to the moderate yield of the spiro dihydrofuran **2a**, we explored the reaction temperature in order to quickly consume the Mn(III) oxidant. As a result, the reaction at reflux temperature resulted in the best yield of **2a** along with a small amount of isomeric spiro dihydrofuran **3a** (Entry 3). With the optimized conditions in hand, other methylenebis(cyclohexanedione)s **1b-q** underwent the Mn(III)-based oxidation to give the corresponding spiro dihydrofurans **2b-q** in decent yields (Entries 4-21) except for **2j**, **2k**, and **2q** (Entries 12, 13, and 21). The thienyl group of **1j** strongly coordinated with $Mn(OAc)_3$ so that the reaction should be complicated.[14] Although (2-furanylmethylene)bis(cyclohexanedione) also underwent the reaction, an intractable mixture was obtained and no product was isolated. The reaction of **1k** at 70 °C led to a slight increase in the yield of **2k** (Entry 14). Alkyl-substituted methylenebis(cyclohexanedione)s **1m-q** also produced dispiro cyclopropanes **4m-q** together with the desired spiro dihydrofurans **2m-q** (Entries 16, 18-21). When the reaction of **1m** was continued to heat for 10 min after consumption of the oxidant, the methyldispiro cyclopropane **4m** disappeared and the yield of **2m** slightly increased (Entry 16 compared to Entry 17). Especially, the isopropyl-substituted methylenebis(cyclohexanedione) **1q** mainly afforded the dispiro cyclopropane **4q** rather than the spiro dihydrofuran **2q** (Entry 21), probably due to steric hindrance (vide infra).[15]

With the efficiency of the $Mn(OAc)_3•2H_2O$ as the oxidative radical promoter in the reaction of tetracarbonyl compounds, we aimed to increase the product yield by the activation of the Mn(III) initiator. Since we recently found that the addition of formic acid, HCO_2H, caused an increase in the oxidative ability, which resulted in shortening the reaction times and increased the product yield,[13] the reaction in the presence of HCO_2H was also explored.

Surprisingly, when the reaction of **1a** was conducted in the presence of HCO_2H at the reflux temperature, intramolecular

dehydration preferentially occurred and 3,3,6,6-tetramethyl-9-phenyl-3,4,5,6,7,9-hexahydro-1*H*-xanthene-1,8(2*H*)-dione (**5a**) was quantitatively produced (Entry 22).[16] On the other hand, a similar reaction of **1a** was carried out at room temperature, and to our delight, the reaction times considerably shortened, giving the desired phenylspiro dihydrofuran **2a** in high yield (Entry 23 compared to Entry 1). The tendency was also observed in the reaction of **1n** (Entries 37 compared to Entry 36). With the activation of $Mn(OAc)_3$•$2H_2O$ in hand, we applied the conditions to other methylenebis(cyclohexanedione)s **1b-q** (Entries 24-41) and obtained the corresponding spiro dihydrofurans **2b-q** with much better yields except for **2g-j** (Entries 29-32).[17] In addition, for the reaction of the non-substituted **1l** and alkyl-substituted methylenebis(cyclohexanedione)s **1m-q**, only using HCO_2H led to rather better results, giving **2l-q** (Entries 34, 35, 38-41). Although the yield of isopropylspiro dihydrofuran **2q** also increased under the stated conditions, the isopropyldispiro cyclopropane **4q** was preferentially produced (Entry 41).

2.2. Predominant production of dispiro cyclopropanes in various solvents

We were very interested in the production of the isopropyldispiro cyclopropane **4q** from the standpoint of the D_{3h} symmetric highly-strained structure of cyclopropane[18] and the formation mechanism.[19] The H-13 methine proton of the cyclopropane ring and the isopropylmethine proton were extremely shifted upfield (δ 2.37 and *ca.* 2.10) compared to those of the starting material's **1q** methine protons (δ 3.46 and *ca*. 2.93) by the magnetic anisotropy of two pairs of the carbonyl group in the rigid structure (See supporting information). In addition, it must be theoretically formed by the oxidative radical coupling during the reaction. We then scrutinized the reaction using ethyl-substituted methylenebis(cyclohexanedione) **1n** in protic and aprotic solvents (Table 2). Although the reaction afforded both the ethylspiro dihydrofuran **2n** and ethyldispiro cyclopropane **4n** in EtOH, benzene, toluene, *N*,*N*-dimethylformamide (DMF), and dimethylsulfoxide (DMSO) (Entries 1-5), the dispiro cyclopropane **4n** was selectively produced in acetonitrile (MeCN) (Entry 6). After optimization of the reaction, the best yield of **4n** was accomplished in MeCN (1 mL) at the reflux temperature for 5 min (Entry 8). The reactions of other methylenebis(cyclohexanedione)s **1l-q** were carried out under similar conditions to mainly give the dispiro cyclopropanes **4l-q** (Entries 9-14), especially, **4q** was exclusively produced (Entry 14). We also applied the conditions to the aryl-substituted methylenebis(cyclohexanedione) **1a-k** in order to obtain the corresponding dispiro cyclopropane, however, the attempt failed probably due to the insolubility in MeCN.

2.3. Reaction of methylenebis(piperidinedione)s 6a-e.

Table 1
Oxidation of methylenebis(cyclohexanedione)s **1a-q** with $Mn(OAc)_3 \cdot 2H_2O$ [a]

Entry	Substrate	X	R	**1**:$Mn(OAc)_3$ [b]	Solvent/mL	Temp/°C	Time/min	Product yield/% [c]	
1	**1a**	$C(Me)_2$	Ph	1:2.5	AcOH/10	rt	8 h	**2a** (54)	
2	**1a**	$C(Me)_2$	Ph	1:2.5	AcOH/10	70	45	**2a** (48)	
3	**1a**	$C(Me)_2$	Ph	1:2.5	AcOH/10	reflux	3	**2a** (72)	**3a** (8)
4	**1b**	$C(Me)_2$	4-FC_6H_4	1:2.5	AcOH/10	reflux	1	**2b** (65)	
5	**1c**	$C(Me)_2$	4-ClC_6H_4	1:2.5	AcOH/10	reflux	2.5	**2c** (66)	**3c** (10)
6	**1d**	$C(Me)_2$	4-BrC_6H_4	1:2.5	AcOH/10	reflux	1	**2d** (68)	
7	**1e**	$C(Me)_2$	4-$NO_2C_6H_4$	1:2.5	AcOH/10	reflux	1	**2e** (58)	
8	**1f**	$C(Me)_2$	4-MeC_6H_4	1:2.5	AcOH/10	reflux	2	**2f** (71)	**3f** (8)
9	**1g**	$C(Me)_2$	4-$MeOC_6H_4$	1:3	AcOH/10	reflux	2	**2g** (63)	**3g** (9)
10	**1h**	$C(Me)_2$	2-Naph	1:2.5	AcOH/10	reflux	0.5	**2h** (79)	
11	**1i**	$C(Me)_2$	4-Py	1:2.5	AcOH/10	reflux	1	**2i** (54)	
12	**1j**	$C(Me)_2$	2-Thienyl	1:2.5	AcOH/10	reflux	1	**2j** (32)	
13	**1k**	CH_2	Ph	1:2.5	AcOH/10	reflux	1	**2k** (32)	
14	**1k**	CH_2	Ph	1:2.5	AcOH/10	70	5	**2k** (38)	
15	**1l**	$C(Me)_2$	H	1:2.5	AcOH/10	reflux	2	**2l** (69)	
16	**1m**	$C(Me)_2$	Me	1:2.5	AcOH/10	reflux	1	**2m** (51)	**4m** (17)
17	**1m**	$C(Me)_2$	Me	1:2.5	AcOH/10	reflux	10	**2m** (60)	
18	**1n**	$C(Me)_2$	Et	1:2.5	AcOH/10	reflux	10	**2n** (53)	**4n** (5)
19	**1o**	$C(Me)_2$	Pr	1:2.5	AcOH/10	reflux	10	**2o** (49)	**4o** (7)
20	**1p**	$C(Me)_2$	Bu	1:2.5	AcOH/10	reflux	10	**2p** (43)	**4p** (9)
21	**1q**	$C(Me)_2$	*i*-Pr	1:2.5	AcOH/10	reflux	10	**2q** (8)	**4q** (36)
22	**1a**	$C(Me)_2$	Ph	1:2.5	AcOH/4, HCO_2H/6	reflux	7	**5a** (quant)	
23[d]	**1a**	$C(Me)_2$	Ph	1:2.5	AcOH/6, HCO_2H/4	rt	5	**2a** (93)	
24[d]	**1b**	$C(Me)_2$	4-FC_6H_4	1:2.5	AcOH/6, HCO_2H/4	rt	5	**2b** (80)	
25[d]	**1c**	$C(Me)_2$	4-ClC_6H_4	1:2.5	AcOH/6, HCO_2H/4	rt	5	**2c** (89)	
26[d]	**1d**	$C(Me)_2$	4-BrC_6H_4	1:2.5	AcOH/6, HCO_2H/4	rt	3	**2d** (86)	
27[d]	**1e**	$C(Me)_2$	4-$NO_2C_6H_4$	1:2.5	AcOH/6, HCO_2H/4	rt	2	**2e** (88)	
28[d]	**1f**	$C(Me)_2$	4-MeC_6H_4	1:2.5	AcOH/6, HCO_2H/4	rt	5	**2f** (89)	
29[d]	**1g**	$C(Me)_2$	4-$MeOC_6H_4$	1:2.5	AcOH/6, HCO_2H/4	rt	5	**2g**(48)	
30[d]	**1h**	$C(Me)_2$	2-Naph	1:2.5	AcOH/6, HCO_2H/4	rt	5	**2h** (48)	
31[d]	**1i**	$C(Me)_2$	4-Py	1:2.5	AcOH/6, HCO_2H/4	rt	5	**2i** (48)	
32[d]	**1j**	$C(Me)_2$	2-Thienyl	1:2.5	AcOH/6, HCO_2H/4	rt	8	**2j** (13)	
33[d]	**1k**	CH_2	Ph	1:2.5	AcOH/6, HCO_2H/4	rt	1	**2k** (85)	**5k** (3)
34[d]	**1l**	$C(Me)_2$	H	1:2.5	HCO_2H/10	rt	5	**2l** (90)	**4l** (8)
35[d]	**1m**	$C(Me)_2$	Me	1:2.5	HCO_2H/10	rt	1	**2m** (71)	**4m** (8)
36[d]	**1n**	$C(Me)_2$	Et	1:2.5	AcOH/10	rt	6 h	**2n** (40)	**4n** (22)
37[d]	**1n**	$C(Me)_2$	Et	1:2.5	AcOH/6, HCO_2H/4	rt	1	**2n** (73)	**4n** (11)
38[d]	**1n**	$C(Me)_2$	Et	1:2.5	HCO_2H/10	rt	1	**2n** (74)	**4n** (14)
39[d]	**1o**	$C(Me)_2$	Pr	1:2.5	HCO_2H/10	rt	1	**2o** (59)	**4o** (13)
40[d]	**1p**	$C(Me)_2$	Bu	1:2.5	HCO_2H/10	rt	1	**2p** (61)	**4p** (14)
41[d]	**1q**	$C(Me)_2$	*i*-Pr	1:2.5	HCO_2H/10	rt	1	**2q** (19)	**4q** (72)

[a] The reaction of methylenebis(cyclohexanedione) **1** (0.5 mmol) was carried out in a solvent (10 mL).
[b] Molar ratio.
[c] Isolated yield based on **1**.
[d] The reaction was conducted under argon.

With the desirable results for the synthesis of the spiro compounds using tetreaketones in hand, we attempted the reaction using methylenebis(piperidinedione)s **6** instead of the methylenebis(cyclohexanedione)s **1** in order to synthesize new intriguing azaspiro compounds (Scheme 2). In addition, to

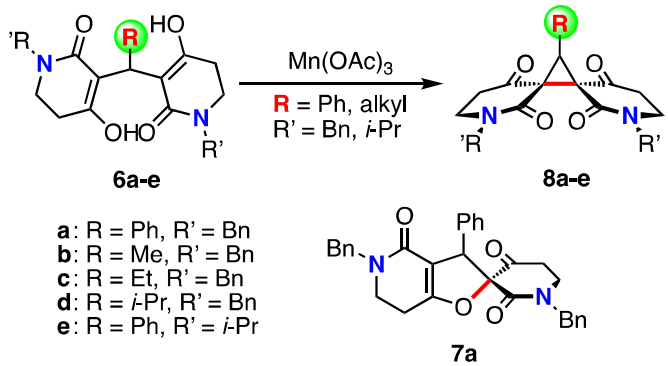
anticipate the production of the hexahydropyrano[3,2-*c*:5,6-*c*′]dipyridinediones, a similar dehydration was also investigated (Scheme 3) because the hexahydroxanthenediones **5** were easily synthesized by the acid-catalyzed dehydration of the tetraketones **1** (see Scheme 1 and Table 1, Entry 22).

Table 2
Oxidation of methylenebis(cyclohexanedione)s **1l-q** with $Mn(OAc)_3$•$2H_2O$ in various solvents[a]

Entry	Substrate	X	R	**1**:$Mn(OAc)_3$[b]	Solvent/mL	Temp/°C	Time/min	Product yield/%[c]	
1	**1n**	$C(Me)_2$	Et	1:5	EtOH/10	reflux	60	**2n** (11)	**4n** (23)
2	**1n**	$C(Me)_2$	Et	1:5	benzene/10	reflux	60	**2n** (26)	**4n** (36)
3	**1n**	$C(Me)_2$	Et	1:5	toluene/10	reflux	10	**2n** (39)	**4n** (22)
4	**1n**	$C(Me)_2$	Et	1:5	DMF/10	80	5	**2n** (11)	**4n** (64)
5	**1n**	$C(Me)_2$	Et	1:5	DMSO/10	80	5	**2n** (24)	**4n** (46)
6	**1n**	$C(Me)_2$	Et	1:5	MeCN/10	reflux	60	**2n** (9)	**4n** (68)
7	**1n**	$C(Me)_2$	Et	1:5	MeCN/10	50	120	**2n** (3)	**4n** (73)
8	**1n**	$C(Me)_2$	Et	1:3	MeCN/1	reflux	5	**2n** (11)	**4n** (77)
9	**1l**	$C(Me)_2$	H	1:3	MeCN/1	reflux	5	**2l** (41)	**4l** (55)
10	**1m**	$C(Me)_2$	Me	1:3	MeCN/1	reflux	5	**2m** (20)	**4m** (54)
11	**1n**	$C(Me)_2$	Et	1:3	MeCN/1	reflux	5	**2n** (11)	**4n** (77)
12	**1o**	$C(Me)_2$	Pr	1:3	MeCN/1	reflux	5	**2o** (11)	**4o** (80)
13	**1p**	$C(Me)_2$	Bu	1:3	MeCN/1	reflux	5	**2p** (10)	**4p** (76)
14	**1q**	$C(Me)_2$	*i*-Pr	1:3	MeCN/1	reflux	5	**2q** (trace)	**4q** (93)

[a] The reaction of methylenebis(cyclohexanedione) **1** (0.5 mmol) was conducted in solvent.
[b] Molar ratio.
[c] Isolated yield based on **1**.

Methylenebis(piperidinedione) **6a** was initially selected and the reaction was evaluated in boiling AcOH (Scheme 2 and Table 3, Entry 1). Although the reaction was complicated, the corresponding tetrahydrospiro[furo[3,2-*c*]pyridine-2,3'-piperidine]trione **7a** was somehow isolated as a diastereomeric mixture from the intractable mixture. All attempts to improve the product yield of **7a** failed (Entries 2-5). However, increasing the addition of HCO_2H to the reaction culminated in the formation of another crystalline product **8a** (Entries 6-10). The NMR spectrum of **8a** showed a symmetrical structure pattern, and especially, characteristic peaks (δ 52.7 and 39.7) assigned to the dispiro cyclopropane ring appeared in the ^{13}C MNR spectrum (see supporting information). In addition, the COSY, HMQC, and HMBC spectra also supported the dispiro cyclopropane structure containing bis(piperidinedione), and finally, the structure of **8a** was determined by an X-ray single crystal analysis as (*6R*,*7S*,13*r*)-2,9-dibenzyl-13-phenyl-2,9-diazadispiro[5.0.5^7.1^6]tridecane-1,5,8,12-tetraone (See supporting information). Other methylenebis(piperidinedione)s **6b-e** were then allowed to react under the optimized conditions, giving the corresponding diazadispiro cyclopropanes **8b-e** (Entries 11-14) though the yield was modest compared to that of the dispiro cyclopropanes **4l-q** except for **8d** bearing an isopropyl substituent (Entry 13).

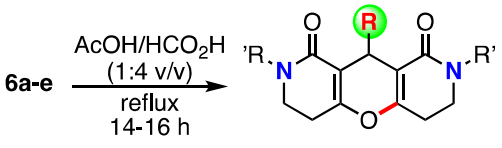


Scheme 2. Oxidation of **6a-e** with $Mn(OAc)_3$

Recently, Bayat et al. reported the synthesis of the 3,4,5,6,7,9-hexahydro-1*H*-xanthene-1,8(2*H*)-diones, such as **5a**, in the presence of *p*-toluene sulfonic acid (*p*-TsOH).[20] We also found a similar synthesis using $AcOH/HCO_2H$ (see Scheme 1 and Table 1, Entry 22). The application to the reaction using methylenebis(piperidinedione)s **6** then intrigued us from the synthetic viewpoint of the 3,4,6,7,8,10-hexahydro-1*H*-pyrano[3,2-*c*:5,6-*c*′]dipyridine-1,9(2*H*)-diones as an important class of alkalids.[21] Although the reaction of **6a** with *p*-TsOH was conducted according to the literature,[20] unfortunately, no reaction occurred. On the other hand, methylenebis(piperidinedione) **6a** underwent the reaction based on our conditions to give the desired pyranodipyridinedione **9a**. The best yield of **9a** was achieved in $AcOH/HCO_2H$ (1:4 v/v) at reflux temperature (Scheme 3). Other methylenebis(piperidinedione)s **6b-e** under the same conditions also produced the corresponding pyranodipyridinediones **9b-e** in synthetically acceptable yields.

2.4. Mechanism for the formation of spiro and dispiro compounds

The mechanism of the Mn(III)-based oxidation using 1,3-dicarbonyl compounds was well-documented by Snider[22] and us.[2,3,23] The reaction of tetracarbonyl compounds **1** could also be understandable similar to that of the 1,3-dicarbonyl compounds. In a protic solvent, such as AcOH, the enol of tetraketone **1** underwent a ligand-exchange reaction with $Mn(OAc)_3$ to preferentially produce the enolate complex **A** (Scheme 4, path a), of which two hydroxycyclohexenone moieties should be orthogonal through the methylene group and independently



Scheme 3. Condensation of **6a-e** in $AcOH/HCO_2H$

oxidized with Mn(III), followed by cyclization between the methine carbon and the nearest carbonyl oxygen of the other hydroxycyclohexenone part (solid half arrow in step **B**), corresponding dispiro cyclopropanes **4l-q** were also produced in poor yields except for the isopropyl **4q** (Table 1, Entries 16, 18-21 and 34-41). In the case of the reaction of **1q** in a protic solvent, the orthogonal enolate complex, such as **A**, might be difficult to generate because of steric hindrance of the isopropyl group, and therefore, the bridged parallel enolate complex, such as **C**, should be exclusively formed, culminating in the dispiro cyclopropane **4q** (Table 1, Entry 41).

Table 3
Oxidation of methylenebis(piperidinedione)s **6a-e** with $Mn(OAc)_3$[a]

Entry	Substrate	R	R'	**6**:$Mn(OAc)_3$[b]	Solvent/mL	Temp/°C	Time/min	Product yield/%[c]
1	**6a**	Ph	Bn	1:2	AcOH/6	reflux	1	**7a** (35)
2	**6a**	Ph	Bn	1:3	AcOH/6	reflux	1	**7a** (20)
3	**6a**	Ph	Bn	1:2	EtOH/6	reflux	30	nr[d]
4	**6a**	Ph	Bn	1:2	MeCN/6	reflux	21 h	nr[d]
5	**6a**	Ph	Bn	1:2	AcOH/4, HCO_2H/1	rt	30	c.m.[e]
6	**6a**	Ph	Bn	1:2	AcOH/2, HCO_2H/3	rt	4	**8a** (33)
7	**6a**	Ph	Bn	1:2	AcOH/1, HCO_2H/4	rt	4	**8a** (40)
8	**6a**	Ph	Bn	1:2	HCO_2H/5	rt	4	**8a** (23)
9	**6a**	Ph	Bn	1:3	AcOH/1, HCO_2H/4	rt	5	**8a** (36)
10	**6a**	Ph	Bn	1:2.5	AcOH/1, HCO_2H/4	50	2	**8a** (33)
11	**6b**	Me	Bn	1:2	AcOH/1, HCO_2H/4	rt	5	**8b** (16)
12	**6c**	Et	Bn	1:2	AcOH/1, HCO_2H/4	rt	4	**8c** (25)
13	**6d**	*i*-Pr	Bn	1:2	AcOH/1, HCO_2H/4	rt	7	**8d** (71)
14	**6e**	Ph	*i*-Pr	1:2	AcOH/1, HCO_2H/4	rt	5	**8e** (48)

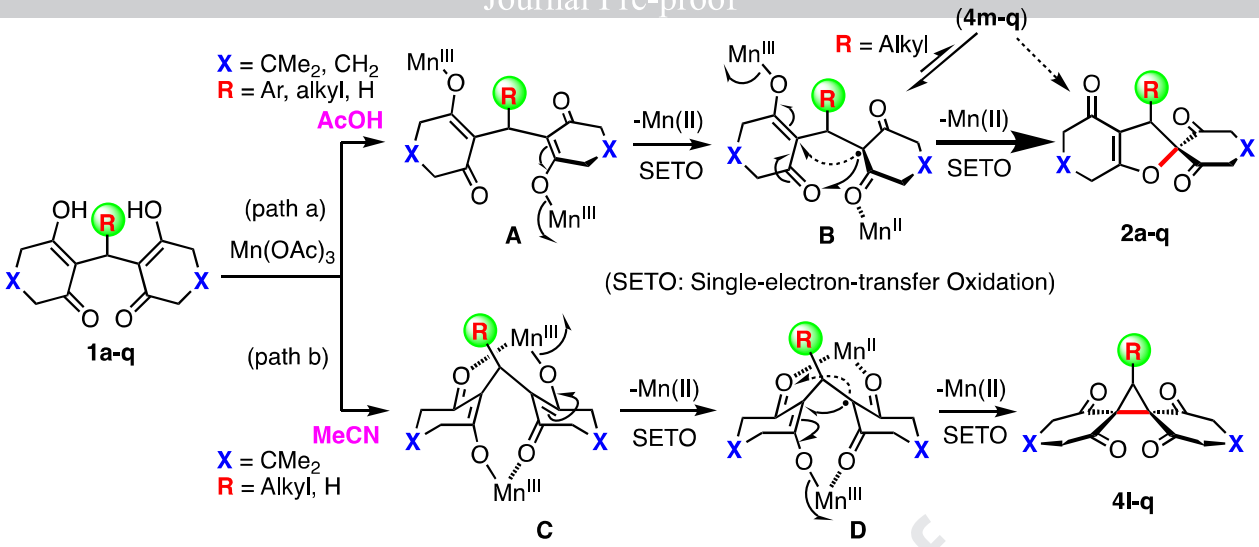
[a] The reaction of methylenebis(piperidinedione) **6** (0.3 mmol) was carried out in a solvent (6 mL) under argon.
[b] Molar ratio.
[c] Isolated yield based on **6**.
[d] No reaction.
[e] Complex mixture.

Although the reaction of the methylenebis(piperidinedione)s **6a-e** were also understood according to the above mechanism, the planar 4-hydroxy-5,6-dihydropyridin-2-one rings probably tend to be arranged parallel by coordination of the oxygen-centered Mn(III) complex through the enolate carbonyls in a protic solvent at room temperature similar to **C** in Scheme 4, so that the head-to-head coupling should be preferred and the corresponding diazadispiro cyclopropanes **8a-e** must be formed in spite of the complexity of the reaction.

selectively producing the spiro dihydrofurans **2** (path a). The reaction of the alkyl-substituted **1m-p** also afforded a small amount of the dispiro cyclopropanes **4m-p** under the acidic conditions (Table 1, Entries 16, 18-20, 35-40). Probably, the head-to-head coupling (C–C bond forming) somewhat involved in the step **B** (dashed half arrow shown in **B**) to produce the dispiro cyclopropanes **4m-p**. However, the head-to-head coupling must be reversible under the conditions, and the head-to-tail coupling (C–O bond coupling) predominantly proceeded (solid half arrow shown in **B**) to form thermodynamically stable spiro dihydrofuranes **2m-p** except for the case of isopropyl-substituted **1q** (vide infra). Treatment of **4n** in AcOH at reflux temperature for 5 min afforded **2n** only in 3% yield together with **4n** unchanged (70% recovered). Therefore, the process from **B** to **2m-q** via **4m-q** might not contribute under the acidic conditions. On the other hand, in a polar aprotic solvent, such as MeCN, the oxidant $Mn(OAc)_3 \cdot 2H_2O$ and the methylenebis(cyclohexanedione)s **1a-k** did not dissolve in MeCN, but bridged the enolate complex **C** (R = alkyl and H), of which two hydroxycyclohexenone moieties, which should be arranged parallel by coordination of the Mn(III), gradually formed (Scheme 4, path b). Once the enolate complex **C** was formed, it must undergo a single-electron-transfer oxidation (SETO) followed by predominant cyclization (head-to-head coupling) between the nearest methine carbons (solid half arrow in step **D**), resulting in the dispiro cyclopropanes **4** (path b). Since the spiro dihydrofurans **2l-p** also produced in low yields, the head-to-tail coupling (C–O bond forming) might somewhat occur under the polar aprotic conditions (dashed half arrow in step **D**). In addition, the bridged enolate complex **C** might somewhat generate under the acidic conditions because the

3. Conclusion

The efficient and convenient syntheses of the spiro dihydrofurans **2a-p** and dispiro cyclopropanes **4l-q** were realized by the Mn(III)-based oxidation of tetracarbonyl compounds such as the 2,2'-methylenebis(cyclohexane-1,3-dione) derivatives **1a-q**. The reaction in a protic solvent at room temperature mainly produced the spiro dihydrofurans **2a-p**, while the dispiro cyclopropanes **4l-q** were selectively produced in an aprotic polar solvent at reflux temperature. A similar reaction of the methylenebis(piperidinedione)s **6a-e** in a protic solvent at room temperature preferentially generated the corresponding diazadispiro cyclopropanes **8a-e**. The interpretation for the selective production of the spiro **2** and dispiro compounds **4** and **8** was also given based on the intermediate Mn(III)-enolate complex formation (Scheme 4). In addition, we demonstrated the synthesis of the hexahydropyrano[3,2-*c*:5,6-*c'*]dipyridinediones **9a-e**, which would contribute to the synthesis of a new type of alkaloid.[24]



Scheme 4. Mechanism for the formation of spiro dihydrofurnans **2a-q** and dispiro cyclopropanes **4l-q**

4. Experimental section

4.1. Measurements

Melting points were taken using a MP-J3 Yanagimoto micromelting point apparatus and are uncorrected. The IR spectra were measured in $CHCl_3$ or KBr using a Shimadzu 8400 and in neat or $CHCl_3$ using an IRAffinity-1S FT IR spectrometer with MIRacle 10 ATR accessary. All the IR data were expressed in cm^{-1}. The NMR spectra were recorded using a JNM ECX 500 FT-NMR spectrometer at 500 MHz for the ^1H and at 125 MHz for ^{13}C, with tetramethylsilane as the internal standard. The chemical shifts are reported as δ values (ppm) and the coupling constants in Hz. The following abbreviations are used for the multiplicities: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; and brs, broad singlet for the ^1H NMR spectra. The EI MS spectra were obtained by a Shimadzu QP-5050A gas chromatograph-mass spectrometer at the ionizing voltage of 70 eV. The high-resolution mass spectra using a JEOL JMS-700 MStation and the elemental analyses using a J-SCIENCE LAB JM10 for the products were performed at the Instrumental Analysis Center, Kumamoto University, Kumamoto, Japan. The X-ray analysis was performed by a Rigaku RAXIS-RAPID Imaging Plate diffractometer with graphite monochromated Mo-Kα radiation, and the structure was solved by direct methods and expanded using Fourier techniques.

4.2. Materials.

Manganese(II) acetate tetrahydrate, $Mn(OAc)_2$•$4H_2O$, was purchased from Wako Pure Chemical Ind., Ltd. Dimedone and 1,3-cyclohexanedione were purchased from Tokyo Kasei Co., Ltd. Methylenebis(cyclohexanedione)s **1a-q** were prepared by condensation of 1,3-cyclohexanedione with the corresponding commercially available aldehyde in the presence of piperidine (See supporting information).[25] Methylenebis(piperidinedione)s **6a-e** were prepared by condensation of 1-benzyl- and 1-isopropyl-piperidine-2,4-diones with the corresponding commercially available aldehyde in the presence of piperidine (See supporting information).[26] Manganese(III) acetate dihydrate, $Mn(OAc)_3$•$2H_2O$, was synthesized according to our modified method.[12] Flash column chromatography was performed on silica gel 60N (40-50 mm), which was purchased from Kanto Chemical Co., Inc., and preparative thin layer chromatography (TLC) on Wakogel B-10 and B-5F from Wako Pure Chemical Ind., Ltd. The solvents were commercially-available first-grade and used as received.

4.3. Reaction of methylenebis(cyclohexanedione)s 1a-q in AcOH.

Methylenebis(cyclohexanedione) **1** (0.5 mmol) in AcOH (10 mL) was heated at 110 °C to dissolve **1**, and $Mn(OAc)_3$•$2H_2O$ (1.25 mmol) was added. The mixture was heated under reflux until the Mn(III) oxidant was completely consumed and the brown color of Mn(III) turned transparent. The existence of the Mn(III) was monitored by iodine-starch paper and each reaction time is listed in Table 1. After completion of the reaction, 2M HCl (10 mL) was added and the aqueous mixture was extracted with $CHCl_3$ (10 mL × 5). The combined extracts were washed with water (10 mL), a saturated aqueous solution of $NaHCO_3$ (10 mL), brine (10 mL), dried over anhydrous $MgSO_4$ (3 g), then concentrated to dryness. The residue was separated by column chromatography on silica gel eluting with 10% EtOAc/$CHCl_3$, mainly giving the corresponding spiro dihydrofuran **2** together with a small amount of isomeric spiro dihydrofuran **3** and dispiro cyclopropane **4** in some cases (see Table 1).

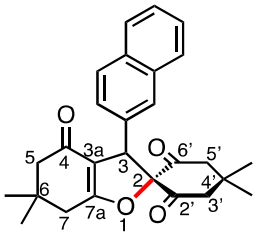
A mixture of 2,2'-(phenylmethylene)bis(3-hydroxy-5,5-dimethylcyclohex-2-en-1-one) (**1a**) (0.5 mmol, 0.184 g) and $Mn(OAc)_3$•$2H_2O$ (1.25 mmol, 0.284 g) was heated under reflux in AcOH/HCO_2H (10 mL, 3:2 v/v) for 7 min. After the work-up described above, 3,3,6,6-tetramethyl-9-phenyl-3,4,5,6,7,9-hexahydro-1*H*-xanthene-1,8(2*H*)-dione (**5a**) was obtained in quantitative yield (0.175 g) instead of **2a** (Table 1, Entry 22). The reaction in the absence of $Mn(OAc)_3$•$2H_2O$ gave the same result.

4.4. Reaction of methylenebis(cyclohexanedione)s 1a-q using HCO_2H.

AcOH (6 mL) and HCO_2H (4 mL) were added to a 50-mL round-bottomed flask and degassed under reduced pressure for 10 min using an ultrasonicator for exchange in an argon atmosphere. Methylenebis(cyclohexanedione) **1** (0.5 mmol) and $Mn(OAc)_3$•$2H_2O$ (1.25 mmol) were added to the degassed solution and the mixture was stirred at room temperature under an argon atmosphere until the brown color of Mn(III) turned transparent (normally 5 min, see Table 1, Entries 23-33). After finishing the reaction, the usual work-up described above was performed. The specific details of the new compound **2h** are

given below and the other new and known compounds are described in the Supporting Information.

*4.4.1. 4',4',6,6-Tetramethyl-3-(naphthalen-2-yl)-3,5,6,7-tetrahydro-4*H*-spiro[benzofuran-2,1'-cyclohexane]-2',4,6'-trione*



2h

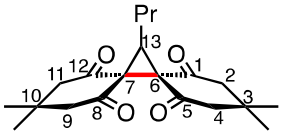
*(**2h**).*

Yield (79%); colorless microcrystals (from EtOH); mp 279-280 °C; R_f = 0.55 (EtOAc/$CHCl_3$ 1:9 v/v); IR (KBr) ν 1769 (C=O), 1697 (C=O); ^{1}H NMR ($CDCl_3$) δ7.81−7.78 (2H, m, naph-H), 7.78 (1H, d, J = 8.4 Hz, naph-H-4), 7.69 (1H, br, s, naph-H-1), 7.50-7.46 (2H, m, naph-H), 7.20 (1H, dd, *J* = 8.4, 1.5 Hz, naph-H-3), 4.62 (1H, s, H-3), 3.16 (1H, d, *J* = 14.8 Hz, H-5'-a), 2.71 (2H, s, H-7), 2.56 (1H, dd, *J* = 14.8, 2.6 Hz, H-5'-b), 2.23 (1H, d, *J* = 16.2 Hz, H-5-a), 2.15 (1H, d, *J* = 16.2 Hz, H-5-b), 2.07 (1H, dd, *J* = 14.3, 2.9 Hz, H-3'-a), 1.99 (1H, d, *J* = 14.3 Hz, H-3'-b), 1.17 (6H, s, Me-6), 1.09 (3H, s, 4'-Me), 0.82 (3H, s, 4'-Me); ^{13}C NMR ($CDCl_3$) δ199.4, 198.9 (C-2', C-6'), 193.3 (C-4), 176.8 (C-7a), 133.7, 133.3, 133.2 (arom C), 129.2, 128.2, 128.0, 127.8, 126.6 (2C), 125.8 (arom CH), 113.9 (C-3a), 104.1 (C-2), 55.2 (C-3), 53.9 (C-5'), 51.2 (C-5), 50.1 (C-3'), 37.4 (C-7), 34.4 (C-6), 30.7 (C-4'), 30.6 (Me), 29.0 (Me), 28.5 (Me), 26.4 (Me). FAB HRMS (acetone-NBA): calcd for $C_{27}H_{29}O_4$ 417.2066 (M+H). Found 417.2072.

4.5. Predominant production of dispiro cyclopropanes in MeCN.

Methylenebis(cyclohexanedione) **1** (0.5 mmol) was dissolved in MeCN (1 mL) at 70 °C and $Mn(OAc)_3$•$2H_2O$ (1.25 mmol) was added. The mixture was heated under reflux for 5 min. After cooling, 2M HCl (5 mL) was added to the reaction mixture and the aqueous solution was extracted with $CHCl_3$ (5 mL × 5). The combined extracts were washed with water (10 mL), a saturated aqueous solution of $NaHCO_3$ (10 mL), brine (10 mL), dried over anhydrous $MgSO_4$ (3 g), then concentrated to dryness. The residue was separated by column chromatography on silica gel eluting with 2% EtOAc/$CHCl_3$, mainly giving the corresponding dispiro cyclopropane **4** together with a small amount of the spiro dihydrofuran **2** (see Table 2). The specific details of the new compound **4o** are given below, and the other new and known compounds are described in the Supporting Information.

*4.5.1. 3,3,10,10-Tetramethyl-13-propyldispiro[5.0.5^7.1^6]tridecane-1,5,8,12-tetraone (**4o**).*



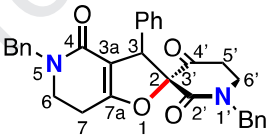
4o

Yield (80%); colorless microcrystals (from EtOH); mp 153 °C; R_f = 0.33 (EtOAc/$CHCl_3$ 1:50 v/v); IR (KBr) ν 1701 (C=O); ^{1}H NMR ($CDCl_3$) δ2.64 (2H, d, *J* = 14.0 Hz, CH_2), 2.59 (2H, d, *J* = 14.3 Hz, CH_2), 2.57 (1H, t, *J* = 6.9 Hz, H-13), 2.56 (2H, d, *J* = 14.3 Hz, CH_2), 2.51 (2H, d, *J* = 14.0 Hz, CH_2), 1.75 (2H, q, *J* = 7.0 Hz, >CH-C$\underline{H_2}$-CH_2CH_3), 1.45 (2H, sext, *J* = 7.5 Hz, CH_2-C$\underline{H_2}$-CH_3), 1.11 (6H, s, Me×2), 1.04 (6H, s, Me×2), 0.95 (3H, t, *J* = 7.5 Hz, CH_2-CH_2-C$\underline{H_3}$); ^{13}C NMR ($CDCl_3$) δ201.0 (C=O×2), 199.9 (C=O×2), 58.2 (2C) (C-6, C-7), 55.3 (CH_2×2), 54.2 (CH_2×2), 44.2 (C-13), 30.9 (2C) (C-3, C-10), 28.9 (Me×2), 27.8 (Me×2), 25.5 (CH_2), 22.7 (CH_2), 13.8 ($\underline{C}H_3$-CH_2-). Anal. Calcd for $C_{20}H_{28}O_4$: C, 72.26; H, 8.49. Found: C, 72.09; H, 8.70.

4.6. Reaction of methylenebis(piperidinedione)s 6a-e.

3,3'-(Phenylmethylene)bis(1-benzyl-4-hydroxy-5,6-dihydropyridin-2(1*H*)-one) (**6a**) (0.3 mmol, 0.148 g) was dissolved in AcOH (6 mL) at 110 °C and $Mn(OAc)_3$•$2H_2O$ (0.6 mmol, 0.161 g) was added. The mixture was heated under reflux for 1 min. The work-up procedure mentioned above was performed and the crude product was separated by column chromatography on silica gel eluting with 2% MeOH/CH_2Cl_2, affording 1',5-dibenzyl-3-phenyl-3,5,6,7-tetrahydro-4*H*-spiro[furo[3,2-*c*]pyridine-2,3'-piperidine]-2',4,4'-trione (**7a**) in 35% yield (0.052 g) as a diastereomeric mixture.

*4.6.1. 1',5-Dibenzyl-3-phenyl-3,5,6,7-tetrahydro-4H-spiro[furo[3,2-c]pyridine-2,3'-piperidine]-2',4,4'-trione (**7a**).*

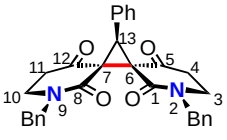


7a

Yield (35%); R_f = 0.21 (1:49 MeOH/CH_2Cl_2 v/v); Amorphous solid; IR (neat) ν 1740 (C=O), 1649 (O=C–C=C); ^{1}H NMR ($CDCl_3$) δ7.57-7.15 (13H, m, arom H), 6.68-6.66 (2H, m, arom H), 4.85-4.61 (4H, m, N-C$\underline{H_2}$-Ph), 4.51 (1H, s, Ph-C$\underline{H}$<), 3.77-3.18 (4H, m, -CH_2-), 2.93-2.85, 2.69-2.20, 1.82-1.73 (4H, m, -CH_2-); ^{13}C NMR ($CDCl_3$) δ197.6 (C-4'), 184.4 (C-2'), 168.7 (C-4), 163.6 (C-7a), 137.6, 135.5, 135.1 (arom C) 129.0 (2C), 128.7 (2C), 128.6 (2C), 128.5 (2C), 128.48 , 128.46 (2C), 128.2 (2C), 128.0, 127.7 (arom CH), 96.8 (>C=), 91.1 (C-2), 52.2 (N-C$\underline{H_2}$-Ph), 51.5 (C-3), 50.3 (N-C$\underline{H_2}$-Ph), 45.9, 39.4, 35.0, 33.9 (-$\underline{C}H_2$-). FAB HRMS (acetone/NBA): calcd for $C_{31}H_{29}N_2O_4$ 493.2127 (M+H). Found 493.2125.

The reaction in AcOH/HCO_2H was as follows. AcOH (1 mL) and HCO_2H (4 mL) were added to a 30-mL round-bottomed flask and degassed under reduced pressure for exchange with an argon atmosphere. Methylenebis(piperidinedione) **6** (0.3 mmol) was dissolved in the AcOH/HCO_2H and $Mn(OAc)_3$•$2H_2O$ (0.6 mmol) was added. The mixture was stirred at room temperature under an argon atmosphere until the Mn(III) was completely consumed (see Table 3, Entries 5-14). After the usual work-up, the crude product was separated by column chromatography on silica gel eluting with 4% EtOAc/$CHCl_3$, affording the diazadispiro cyclopropane **8a**.

*4.6.2. (6R,7S,13r)-2,9-Dibenzyl-13-phenyl-2,9-diazadispiro[5.0.5^7.1^6]tridecane-1,5,8,12-tetraone (**8a**).*



8a

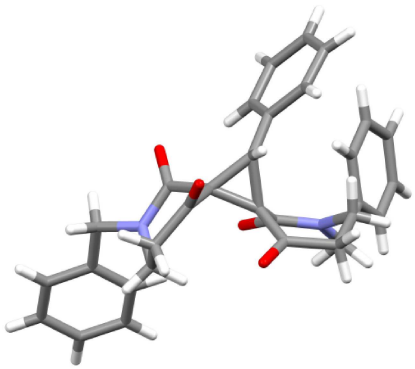


Figure 1. X-Ray Crystal Structure of **8a**

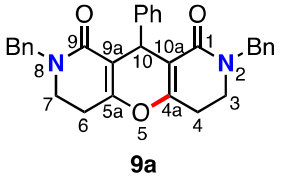
Yield (40%); R_f = 0.39 (1:49 EtOAc/$CHCl_3$ v/v); colorless microcrystals (from EtOH); mp 213.6-214.9 °C; IR (neat) ν 1734 (C=O), 1709 (C=O), 1655 (C=O); ^{1}H NMR ($CDCl_3$) δ 7.55-7.53 (2H, m, arom H), 7.32-7.22 (13H, m, arom H), 4.93 (2H, d, J = 14.0 Hz, N-C<u>H</u>$_2$-Ph), 4.52 (2H, d, J = 14.0 Hz, N-C<u>H</u>$_2$-Ph), 3.75 (1H, s, Ph-C<u>H</u><), 3.527 (1H, ddd, J = 13.7, 6.1, 5.9 Hz, H-3 or H-10), 3.526 (1H, ddd, J = 13.7, 6.1, 5.9 Hz, H-3 or H-10), 3.38 (2H, ddd, J = 13.7, 5.7, 5.4 Hz, H-3, H-10), 2.64 (2H, ddd, J = 18.8, 6.1, 5.7 Hz, H-4, H-11), 2.547 (1H, ddd, J = 18.8, 5.9, 5.4 Hz, H-4 or H-11), 2.546 (1H, ddd, J = 18.8, 5.9, 5.4 Hz, H-4 or H-11); ^{13}C NMR ($CDCl_3$) δ 201.4 (2C) (C-5, C-12), 163.8 (2C) (C-1, C-8), 136.3 (2C), 131.3 (arom C), 130.0 (3C), 128.7 (3C), 128.4 (5C), 128.03, 127.80, 127.76 (2C) (arom CH), 52.7 (2C) (C-6, C-7), 50.0 (2C) (N-<u>C</u>H$_2$-Ph), 40.9 (2C) (C-3, C-10), 39,7 (Ph-<u>C</u>H<), 38.4 (2C) (C-4, C-11). Anal. Calcd for $C_{31}H_{28}N_2O_4$: C, 75.59; H, 5.73; N, 5.69. Found: C, 75.52; H, 5.87; N, 5.73. X-ray crystallographic data of **8a**: empirical formula $C_{31}H_{28}N_2O_4$; formula weight 492.57; colorless platelet crystal; crystal dimensions 0.54 × 0.38 × 0.18 mm; monoclinic; space group $P2_1/c$ (# 14); a = 11.475(1), b = 22.139(3), c = 10.259(1) Å, β = 100.772(2)°, V = 2560.3(5) Å^3, Z = 4; D_{calcd} = 1.278 g/cm^3; F(000) = 1040.00; μ(MoKα) = 0.848 cm^{-1}; $2\theta_{max}$ = 54.9°; No. of reflections measured 24626; No. of observations 5830; No. of variables 334; Reflection/parameter ratio was 17.46; R = 0.1096; R_w = 0.1840; GOF = 1.086. X-ray coordinates were deposited with the Cambridge Crystallographic Data Centre: CCDC 1987107.

The specific details of other new compounds **8b-e** were mentioned in the Supporting Information.

4.7. Transformation of methylenebis(piperidinedione)s 6a-e into the pyranodipyridinediones 9a-e.

Methylenebis(piperidinedione) **6a** (0.1 mmol, 49.2 mg) was heated under reflux in AcOH/HCO_2H (3 mL, 1:4 v/v) for 14 h. After cooling, the reaction was quenched by adding a saturated aqueous solution of $NaHCO_3$ (6 mL). The aqueous solution was extracted with $CHCl_3$ (5 mL × 5) and the combined extracts were washed with a saturated aqueous solution of $NaHCO_3$ (10 mL), brine (10 mL), dried over anhydrous $MgSO_4$ (3 g), then concentrated to dryness. The crude product (45.7 mg) was separated by column chromatography on silica gel eluting with 40% EtOAc/hexane, giving the corresponding pyranodipyridinedione **9a** (39.5 mg, 83%). Other methylenebis(piperidinedione)s **6b-e** underwent the same reaction to produce the corresponding pyranodipyridinediones **9b-e**. The specific details of **9a** are given below and the other new compounds **9b-e** are described in the Supporting Information.

*4.7.1. 2,8-Dibenzyl-10-phenyl-3,4,6,7,8,10-hexahydro-1H-pyrano[3,2-c:5,6-c']dipyridine-1,9(2H)-dione (**9a**).*



9a

Yield (83%); R_f = 0.24 (4:6 EtOAc/hexane v/v); colorless microcrystals (from EtOH); mp 196.5-197.0 °C; IR (neat) ν 1705 (C=O), 1643 (C=O), 1630 (C=C); ^{1}H NMR ($CDCl_3$) δ 7.45 (2H, d, J = 7.5 Hz, arom H), 7.31-7.17 (9H, m, arom H), 7.13 (4H, d, J = 7.5 Hz, arom H), 5.12 (1H, s, Ph-C<u>H</u><), 4.81 (2H, d, J = 15.5 Hz, N-C<u>H</u>$_2$-Ph), 4.22 (2H, d, J = 15.5 Hz, N-C<u>H</u>$_2$-Ph), 3.36 (2H, ddd, J = 12.5, 12.2, 5.2 Hz, H-3, H-7), 3.21 (2H, ddd, J = 12.5, 6.5, 4.1 Hz, H-3, H-7), 2.63 (1H, ddd, J = 17.7, 12.2, 6.5 Hz, H-4 or H-6), 2.62 (1H, ddd, J = 17.7, 12.2, 6.5 Hz, H-4 or H-6), 2.46 (1H, ddd, J = 17.7, 5.2, 4.1 Hz, H-4 or H-6), 2.45 (1H, ddd, J = 17.7, 5.2, 4.1 Hz, H-4 or H-6); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.1 (2C) (C-1, C-9), 154.1 (2C) (C-4a, C-5a), 144.9, 137.4 (2C) (arom C), 128.6 (2C), 128.5 (4C), 128.1 (2C), 127.8 (4C), 127.2 (2C), 126.3 (arom CH), 109.9 (2C) (C-9a, C-10a), 49.6 (2C) (N-<u>C</u>H$_2$-Ph), 42.7 (2C) (C-3, C-7), 34.1 (Ph-<u>C</u>H<), 25.7 (2C) (C-4, C-6). Anal. Calcd for $C_{31}H_{28}N_2O_3$: C, 78.13; H, 5.92; N, 5.88. Found: C, 77.94; H, 5.99; N, 5.88.

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15. The methine proton of the *i*-propyl group in the spiro dihydrofuran **2q** extremely shifted upfield due to the magnetic anisotropy of the 1,3-cyclohexanedionecarbonyl group, and one of the *i*-propyl groups close became to one of the C-6 methyl groups based on the 0.5% NOE observation (See supporting information).
16. The reaction of **1a** in the absence of $Mn(OAc)_3$ gave also the same result.
17. The retro-Michael addition of **1g-j** concurrently occurred under the same conditions, resulting in the decrease of **2g-j**.
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Supplementary Material

Experimental detail, spectroscopic data of the starting materials **1a-q**, **6a-e**, and the products **2a-q** (except for **2h**), **3a,c,f,g,** and **4l-q (**except for **4o**), **5a,k, 3a,c,f,g, 4l-q, 5a,k**, **7a, 8b-e, 9b-e**, and the copies of ^{1}H NMR, ^{13}C NMR, DEPT, COSY, HMQC, and HMBC spectra for the starting materials and the products.

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