Supporting Information

for

Synthesis of Symmetrical and Unsymmetrical 1,4-Dithiins by

Rhodium-Catalyzed Sulfur Addition Reaction to Alkynes

Mieko Arisawa*, Takuya Ichikawa, Saori Tanii, and Masahiko Yamaguchi*

Department of Organic Chemistry, Graduate School of Pharmaceutical Sciences,

Tohoku University, Aoba, Sendai, 980-8578, Japan

CONTENTS

Page

Supplementary materials 2

Typical Procedures 2

The Spectral and Analytical Data 2

NMR Spectra 5
Supplementary Materials

$^1$H- and $^{13}$C-NMR spectra were recorded on a Varian Mercury (400 MHz) and JEOLECA (600 MHz) and tetramethylsilane, triphenylphosphine were used as standard. IR spectra were measured on a JASCO FT/IR-410 spectrophotometer. Melting points were determined with a Yanagimoto micro melting point apparatus without correction. High- and low-resolution mass spectra were measured on a JEOL JMS-DX-303, a JEOL JMS-700, or a JMS-T100GC spectrometer. Merck silica gel 60 (63-200 mm) was employed for flash column chromatography. X-ray diffraction data were recorded on Rigaku R-AXISIP and Bruker APEX- II CCD.

Typical experimental procedures for the synthesis of 1,8-dimethoxy-2,3,4,5,6,9,10,11,12,13-decahydrodicycloocta[1,4]dithiin (3g) and 1,13-dimethoxy-2,3,4,5,6,8,9,10,11,12-decahydrodicycloocta[1,4]dithiin (3g’). In a two-necked flask equipped with a reflux condenser were placed RhH(PPh$_3$)$_4$ (5 mol%, 7.2 mg), dppe (10 mol%, 5.0 mg), sulfur (0.15 mmol, 5.0 mg), and 3-methoxycyclooctyne (1g) (0.375 mmol, 51.8 mg) in 2-butanone (0.5 mL) under an argon atmosphere, and the solution was heated at reflux for 3 h. The solvent was removed under reduced pressure, and the residue was purified by flash column chromatography on silica gel giving 1,8-dimethoxy-2,3,4,5,6,9,10,11,12,13-decahydrodicycloocta[1,4]dithiin (3g) (31%, 6.4 mg) and 1,13-dimethoxy-2,3,4,5,6,8,9,10,11,12-decahydrodicycloocta[1,4]dithiin (3g’) (29%, 6.1 mg). 3g: Colorless oil. $^1$H-NMR (400 MHz, CDCl$_3$) $\delta$ 1.27-1.39 (4H, m), 1.43-1.51 (2H, m), 1.59-1.67 (2H, m), 1.72-1.81 (6H, m), 1.80-1.89 (2H, m), 2.32 (2H, bd, J = 12.0 Hz), 2.51 (2H, t, J = 12.0 Hz), 3.37 (6H, s) 4.33 (2H, dd, J = 10.8, 4.8 Hz). $^{13}$C-NMR (100 MHz, CDCl$_3$) $\delta$ 24.4, 27.1, 30.6, 34.3, 35.3, 57.7, 81.5, 132.1, 132.8. IR (neat) 2924, 2847, 1449, 1260, 1097 cm$^{-1}$. MS (EI) m/z 340 ($M^+$, 100%). HRMS Calcd for C$_{18}$H$_{28}$O$_2$S$_2$: 340.1531. Found: 340.1532. 3g’: Colorless oil. $^1$H-NMR (400 MHz, CDCl$_3$) $\delta$ 1.25-1.41 (4H, m), 1.49-1.55 (2H, m), 1.58-1.65 (2H, m), 1.70-1.86 (8H, m), 2.43 (2H, ddd, J = 14.0, 9.2, 2.8 Hz), 2.66-2.72 (2H,m), 3.13 (6H, s), 4.20 (2H, dd, J = 9.2, 2.8 Hz). $^{13}$C-NMR (100 MHz, CDCl$_3$) $\delta$ 23.1, 26.6, 29.9, 32.7, 35.8, 56.9, 81.4, 131.1, 134.5. IR (neat) 2925, 2853, 1449, 1260, 1097 cm$^{-1}$. MS (EI) m/z 340 ($M^+$, 100%). HRMS Calced for C$_{18}$H$_{28}$O$_2$S$_2$: 340.1531. Found: 340.1557. $^1$H-NMR and $^{13}$C-NMR of 3g and 3g’ showed these products to be single stereoisomers. With regard
to the position of the methoxy group, the structures were determined by desulfurization reaction (Scheme 1). The desulfurization reaction of 3g in refluxing o-dichlorobenzene for 3 h gave the unsymmetric thiophene 4g in 41% yield. $^{1}$H-NMR analysis of 4g showed two singlet methyl protons at $\delta$ 3.28 and $\delta$ 3.42, which indicated the structure not to be the C$_2$-symmetric. Then, 3g was determined to be 1,8-dimethoxy isomer. The desulfurization reaction of 3g$'$ in refluxing o-dichlorobenzene for 3 h gave a C$_2$-symmetric thiophene in 32% yield with a single methyl proton at $\delta$ 3.33, the structure of which can be either 4g$'$ or 4g$''$. Thus, the C$_2$-symmetric structure of 3g$'$ possessing the 1,13-dimethoxy groups was determined.

**Scheme 1**

1,8-Dimethoxy-2,3,4,5,6,9,10,11,12,13-decahydrodicycloocta[b,d]thiophene (4g):

Colorless oil. $^{1}$H-NMR (400 MHz, CDCl$_3$) $\delta$ 0.85-0.92 (3H, m), 1.17-1.41, (8H, m), 1.73-1.80 (3H, m), 1.95-2.01 (1H, m), 2.02-2.05 (1H, m), 2.38-2.44 (1H, m), 2.67-2.74 (1H, m), 3.00-3.05 (1H, m), 3.10-3.16 (1H, m), 3.28 (3H, s), 3.42 (3H, s), 4.53 (1H, dd, $J$ = 8.4, 4.0 Hz), 4.56 (1H, dd, $J$ = 10.4, 4.0 Hz). $^{13}$C-NMR (100 MHz, CDCl$_3$) $\delta$ 23.9, 25.1, 26.1, 26.3, 26.8, 29.7, 31.6, 32.5, 36.9, 38.7, 56.4, 57.4, 78.2, 78.9, 135.1, 137.5, 137.6, 138.7. IR (neat) 2924, 2853, 1451, 1260, 1099 cm$^{-1}$. MS (EI) $m/z$ 308 (M$^+$, 100%). HRMS Calcd for C$_{18}$H$_{28}$O$_2$S: 308.1810. Found: 308.1815.

6,8-Dimethoxy-2,3,4,5,6,7,8,9,10,11-decahydrodicycloocta[b,d]thiophene (4g$'$) or 1,13-Dimethoxy-2,3,4,5,6,7,8,9,10,11-decahydrodicycloocta[b,d]thiophene (4g$''$):

Colorless oil. $^{1}$H-NMR (400 MHz, CDCl$_3$) $\delta$ 0.87-0.90 (2H, m), 1.27-1.36, (6H, m),
1.68-1.81 (8H, m), 2.51 (2H, ddd, J = 13.6, 10.0, 2.2 Hz), 2.56-2.61 (2H, m), 3.33 (6H, s), 4.32 (2H, dd, J = 9.2, 4.8 Hz). $^{13}$C-NMR (100 MHz, CDCl$_3$) δ 23.5, 26.6, 29.7, 30.0, 33.0, 36.0, 81.1, 132.3, 133.4. IR (neat) 2928, 2849, 1736, 1689, 1541, 1455 cm$^{-1}$. MS (EI) m/z 308 (M$^+$, 59%), 244 (M$^+$-64, 100%). HRMS Calcd for C$_{18}$H$_{28}$O$_2$S: 308.1810. Found: 308.1812.
1,2,3,4,5,6,8,9,10,11,12,13- Dodecahydrodicycloocta[1,4]dithiin (3a)
1,2,3,4,5,6,8,9,10,11,12,13-Dodecahydrodicycloocta[b,d]thiophene (4a)
exo-3b \[\text{syn-3b:anti-3b} = 1:1\]
exo-4b \[\text{meso-4b} : (\pm )-4b = 1:1\]
exo-3c [syn-3c:anti-3c = 1:1]
exo-4e \[\text{meso-4e:}(\pm)-4e = 1:1\]
exo-3d [syn-3d:anti-3d = 1:1]
exo-4d \[\text{meso-4d:}(\pm)-4d = 1:1\]
exo-3e [{syn-3e:anti-3e = 1:1}]
exo-4e \textit{meso-4e}(\pm)-4e = 1:1
rel-(2aS,3aR,8aR,9aS)-3,9-Bis(t-butoxymethyl)-1,2,2a,3,3a,4,5,7,8,8a,9,9a,10,11-tetradecahydrocyclopropa[5,6:5',6']cycloocta[1,2-b:1',2'-e][1,4]dithien (syn-3b)
endo-3d [syn-3d or anti-3d]
Tetetrabenzo[\(a,e,j,n\)]-5,6,16,17-tetrahydrodicycloocta[1,4]dithiin (3f)
Tettrabenzo[a,e,j,n]-5,6,16,17-tetrahydrodicyclooctab[b,d]thiophene (4f)
1,8-Dimethoxy-2,3,4,5,6,9,10,11,12,13-decahydrocycloocta[1,4]dithin (3g)
1,13-Dimethoxy-2,3,4,5,6,8,9,10,11,12-decahydrodicycloocta[1,4]dithiin (3g’)
1,8-Dimethoxy-2,3,4,5,6,9,10,11,12,13-decahydropycoctab\textit{d}thiophene (4g)
6,8-Dimethoxy-2,3,4,5,6,7,8,9,10,11-decahydrodicycloocta[b,d]thiophene (4g') or
1,13-Dimethoxy-2,3,4,5,6,7,8,9,10,11-decahydrodicycloocta[b,d]thiophene (4g'')
1,2,3,4,5,6,7,9,10,11,12,13,14,15-tetradecahydrodicyclonona[1,4]dithin (3h)
$1,2,3,4,5,6,7,8,10,11,12,13,14,15,16,17$-hexadecahydrodicyclodeca[1,4]dithiin (3i)
2,3,5,6-Tetrakis(ethoxycarbonyl)-1,4-dithiin (3j)
Tetraethyl 2,3,4,5-thiophenetetracarboxylate (4j)
2,3,5,6-Tetrakis(methoxycarbonyl)-1,4-dithin (3k)
Tetramethyl 2,3,4,5-thiophenetetracarboxylate (4k)
1,2-Bis(ethoxycarbonyl)-4,5,6,7,8,9-hexahydroocta[1,4]dithiin (3aj)
1,2-Bis(methoxycarbonyl)-4,5,6,7,8,9-hexahydroocta[1,4]dithiiin (3ak)
rel-(5aR,6S,6aS)-6-t-Butoxymethyl-1,2-bis(ethoxycarbonyl)-4,5,7,8-tetrahydrocyclopropa[5,6]cycloocta[1,2-b][1,4]dithiën (3b)
1,2-Bis(ethoxycarbonyl)-4,5,6,7,8,9-heptahydronona[1,4]dithin (3hj)
2,3-Bis(ethoxycarbonyl)-5-butoxy-5,6-dihydro-1,4-dithiin (6aj)
2,3-Bis(ethoxycarbonyl)-5-ethoxy-5,6-dihydro-1,4-dithiin (6bj)
5,6,7,8,9-Pentahydro-4H-cycloocta-1,3-dithiole-2-thione (9a)
4,5-Bis(ethoxycarbonyl)-1,3-dithiole-2-thione (9j)
rel-(2aR,3S,3aS)-3-\textit{t}-butoxymethyl-1,2,4,5-tetrahydrocyclopropa[5,6]cycloocta-7,8, 9,10,11,12-hexahydrocycloocta[1,2-\textit{b};1',2'-\textit{d}]thiophene (endo-4ab)
rel-(2aR,3S,3aS)-3-t-Butoxymethyl-1,2,4,5-tetrahydrocyclopropa[5,6]cycloocta-7,8,9,10,11,12-hexahydrocycloocta[1,2-b;1',2'-d]thiophene (exo-4ab)