ELSEVIER

Journal of Molecular Catalysis A: Chemical 129 (1998) 199–206

JOURNAL OF MOLECULAR CATALYSIS A: CHEMICAL

# Cationic palladium complex-catalyzed cyclocarbonylation of 3-butyn-1-ols

K. Tezuka, Y. Ishizaki, Y. Inoue *

*Department of Materials Chemistry, Graduate School of Engineering, Tohoku University, Sendai 980-77, Japan*

Received 14 July 1997; revised 4 August 1997; accepted 5 August 1997

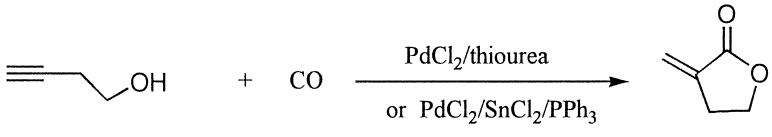
**Abstract**

Cyclocarbonylation of 3-butyn-1-ols catalyzed by cationic palladium complexes has been studied. Six-membered ring lactones were produced preferentially in acetonitrile using cationic complexes coordinated by certain chelating diphosphines as catalyst. A triphenylphosphine-coordinated cationic palladium complex, on the other hand, effected the formation of five-membered $\alpha$-alkylidene lactones exclusively in *N,N*-dimethylformamide. A mechanism involving a palladium hydride as active species has been presumed for the formation of six-membered ring lactones. © 1998 Elsevier Science B.V.

*Keywords:* Cyclocarbonylation; 3-Butyn-1-ol; Palladium; Lactone

## 1. Introduction

The palladium catalyzed hydroesterification of alkynes using carbon monoxide and alcohols has been the subject of many investigations [1,2]. This reaction normally gives $\alpha,\beta$-unsaturated carboxylic esters. The cyclocarbonylation of 3-butyn-1-ols is the intramolecular version of this chemistry. The system composed of $PdCl_2$-thiourea [3] or $PdCl_2$–$SnCl_2$–$PPh_3$ [4] was demonstrated to catalyze the cyclocarbonylation of 3-butyn-1-ol (**1a**) to afford a five-membered ring lactone, 2-methylenebutan-4-olide (**2a**) selectively.



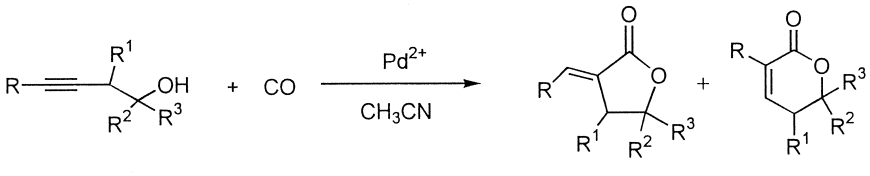

**1a** **2a**

* Corresponding author.


*PII* S1381-1169(97)00189-1

This type of reaction was shown to be also catalyzed by a platinum hydride complex [5]. Oxidative dicarbonylation of **1a** catalyzed by palladium(II) complexes was reported as well [6,7]. An $\alpha$-silylmethylene lactone was obtained selectively with the aid of $Rh_4(CO)_{12}$ in the carbonylation of a mixture of **1a**, triorganosilane, and triethylamine [8]. In these cases, the products obtained were generally five-membered alkylidene lactones.

During the studies directed toward the cyclocarbonylation of acetylenic alcohols [9], we found that certain palladium complexes promote the cyclocarbonylation of 3-butyn-1-ols 1 in acetonitrile to afford six-membered ring lactones 3 in preference to five-membered ring ones 2. Straightforward synthesis of 3 is of considerable interest since the compound 3 represents an intermediate for the synthesis of verrucarinic acid or $\alpha$-pyrone [10].




**1** **2** **3**

| | R | $R^1$ | $R^2$ | $R^3$ |
|---|---|---|---|---|
| a: | H | H | H | H |
| b: | H | H | H | $CH_3$ |
| c: | H | H | H | Ph |
| d: | H | H | $CH_3$ | $CH_3$ |
| e: | H | $-(CH_2)_3-$ | | H (trans) |
| f: | H | $-(CH_2)_4-$ | | H (trans) |
| g: | $CH_3$ | H | H | H |
| h: | $(CH_3)_3Si$ | H | H | H |

## 2. Results and discussion

The effects of various reaction conditions on the cyclocarbonylation of 3-butyn-1-ol (**1a**) catalyzed by several cationic palladium complexes are given in Table 1. Treatment of **1a** with carbon monoxide in acetonitrile in the presence of a cationic complex, $[Pd(dppb)(PhCN)_2](BF_4)_2$ [dppb = 1,4-

Table 1
Cyclocarbonylation of 3-butyn-1-ol (**1a**)[a]

| Entry | Catalyst | Solvent (ml) | Yield (%) | **2a**:**3a** |
|---|---|---|---|---|
| 1 | $[Pd(dppb)(PhCN)_2](BF_4)_2$ | $CH_3CN(2)$ | 36 | 17:83 |
| 2[b] | $[Pd(dppb)(PhCN)_2](BF_4)_2$ | $CH_3CN(8)$ | 77 | 26:74 |
| 3 | $[Pd(dppb)(PhCN)_2](BF_4)_2$ | DMF(2) | 40 | 88:12 |
| 4 | $PdCl_2(dppb)$ | $CH_3CN(2)$ | 0 | — |
| 5 | $[Pd(dppf)(PhCN)_2](BF_4)_2$ | $CH_3CN(2)$ | 35 | 16:84 |
| 6 | $[Pd(dppp)(PhCN)_2](BF_4)_2$ | $CH_3CN(2)$ | 24 | 29:71 |
| 7 | $[Pd(dppe)(PhCN)_2](BF_4)_2$ | $CH_3CN(2)$ | 3 | — |
| 8 | $[Pd(PPh_3)_2(PhCN)_2](BF_4)_2$ | $CH_3CN(2)$ | 44 | 73:27 |
| 9 | $[Pd(PPh_3)_2(PhCN)_2](BF_4)_2$ | DMF(2) | 48 | 100:0 |
| 10 | $PdCl_2(PPh_3)_2$ | $CH_3CN(2)$ | 60 | 96:4 |

[a] 2 mmol **1a**; 10 atm CO; 0.04 mmol catalyst; 80°C; 3 h.
[b] 100°C; 20 atm CO.

bis(diphenylphosphino)butane], for 3 h at 10 atm pressure and 80°C, afforded **2a** and 2-penten-5-olide (**3a**) with a ratio of 17:83 in a combined yield of 36% (entry 1). The yield increased to 77% with 74% selectivity to **3a** when the reaction was effected at an elevated temperature of 100°C under 20 atm pressure (entry 2). The reaction in *N,N*-dimethylformamide (DMF) gave the five-membered methylene lactone **2a** as the main product (entry 3). A neutral complex $PdCl_2$(dppb) did not exhibit the catalytic activity in acetonitrile leaving the starting material **1a** intact (entry 4). Cationic palladium complexes coordinated by bidentate diphosphines such as 1,1′-bis(diphenylphosphino)ferrocene (dppf) and 1,3-bis(diphenylphosphino)propane (dppp) were also effective for six-membered ring lactone formation (entry 5, 6). The cationic complex coordinated by 1,2-bis(diphenylphosphino)ethane, $[Pd(dppe)(PhCN)_2](BF_4)_2$, was almost ineffective for this carbonylation process (entry 7). On the other hand, the reaction using a triphenylphosphine-coordinated complex, $[Pd(PPh_3)_2(PhCN)_2](BF_4)_2$, afforded **2a** as the main product in acetonitrile (entry 8). The complete selectivity to **2a** was observed with this complex, when the reaction was performed in DMF (entry 9). A neutral complex $PdCl_2(PPh_3)_2$ was active enough in acetonitrile to afford **2a** and **3a** with a ratio of 96:4 in a combined yield of 60%.

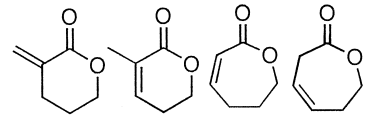
These preliminary findings indicate that the selectivity between the five- (**2a**) and six-membered ring lactone (**3a**) depends on phosphine ligand, solvent, and the electronic nature of the palladium catalyst. The suitable conditions for the formation of **3a** appear to be the combined employment of a bulky chelating diphosphine such as dppb or dppf as ligand, acetonitrile as solvent, and a cationic complex as catalyst precursor.

The lactonization process in acetonitrile employing $[Pd(dppb)(PhCN)_2](BF_4)_2$ is applicable to a variety of 3-butyn-1-ols 1 containing alkyl and aryl groups attached to the hydroxy-bearing carbon, yielding the corresponding six-membered ring lactones 3 preferentially as shown in Table 2 (entry 1–4). *Trans*-3-butyn-1-ols having five- (**1e**) and six- (**1f**) membered ring structure gave fused-ring lactones of the corresponding stereochemistry (entry 5, 6). The declined yield of 10% in entry 5 was ascribed to the occurrence of intermolecular reactions giving rise to higher boiling products.

The course of cyclocarbonylation of **1** with the internal C–C triple bond depended on the substituent R on the triple bond decidedly. Nearly equal amounts of five- and six-membered ring lactones were formed in a modest yield of 30% when the substituent R is methyl group (entry 7). The

Table 2
Cyclocarbonylation of 3-butyn-1-ols **1** in $CH_3CN$[a]

| Entry | **1** | Time (h) | Yield (%) | **2**:**3** |
|---|---|---|---|---|
| 1 | **1a** | 3 | 77 | **2a3a** 26:74 |
| 2 | **1b** | 3 | 65 | **2b3b** 34:66 |
| 3 | **1c** | 10 | 73 | **2c3c** 25:75 |
| 4 | **1d** | 10 | 61 | **2d3d** 36:64 |
| 5 | **1e** | 10 | 10 | **2e3e** 14:86 |
| 6 | **1f** | 10 | 63 | **2f3f** 22:78 |
| 7 | **1g** | 10 | 30 | **2g3g** 53:47 |
| 8 | **1h** | 30 | 62 | **2h3h** 100:0 |
| 9 | 4-pentyn-1-ol | 10 | 11 | |



36 10 39 15

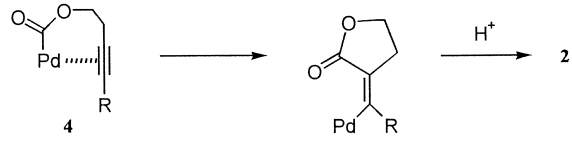
[a] 2 mmol substrate; 20 atm CO; 0.04 mmol $[Pd(dppb)(PhCN)_2](BF_4)_2$; 8 ml $CH_3CN$; 100°C.

E stereochemistry in **2g** was determined by comparison of the $^1$H-NMR data with the reported one [11]. Specifically, five-membered alkylidene lactone **2h** was generated exclusively from **1h** bearing a trimethylsilyl (TMS) substituent (entry 8). Cyclocarbonylation of a longer carbon chain substrate, 4-pentyn-1-ol, gave a mixture of six- and seven-membered ring lactones in a modest yield (entry 9).

In order to obtain further scope, cyclocarbonylation of **1** catalyzed by $[Pd(PPh_3)_2(CH_3CN)_2](BF_4)_2$ was studied in DMF. The results are given in Table 3. The reactions of **1a--f** with carbon monoxide took place with good selectivity to give five-membered methylene lactones **2a**–**f** in moderate yields (entry 1–6). Although the yield of 38% for significantly strained fused lactone **2e** is unsatisfactory (entry 5), it is still an improved value compared to the reported one [4], indicating the usefulness of the present procedure.

It is reported that cyclocarbonylation of methyl-substituted 3-butyn-1-ol **1g** with the internal triple bond is unsuccessful [4]. Our reaction with **1g** proceeded sluggishly to give the ethylidene lactone **2g** in a reduced yield of 11% (entry 7). On the other hand, trimethylsilyl-substituted butynol **1h** exhibited fair reactivity giving rise to five-membered ring lactone **2h** selectively in 61% yield (entry 8). 4-Pentyn-1-ol was converted selectively to six-membered 2-methylenepentan-5-olide although the yield was declined (entry 9).

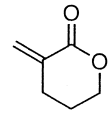
The mechanism for the synthesis of methylene lactone **2** catalyzed by $PdCl_2$/monodentate phosphine was studied carefully [12,13]. It involves the initial formation of a carboalkoxy species **4** from $PdCl_2$, carbon monoxide, and the substrate alcohol **1**, followed by intramolecular *cis* addition to the triple bond. Cleavage of the resulting vinyl–palladium bond by the proton generated initially eliminates the product **2** and regenerates the initial palladium(II) species.



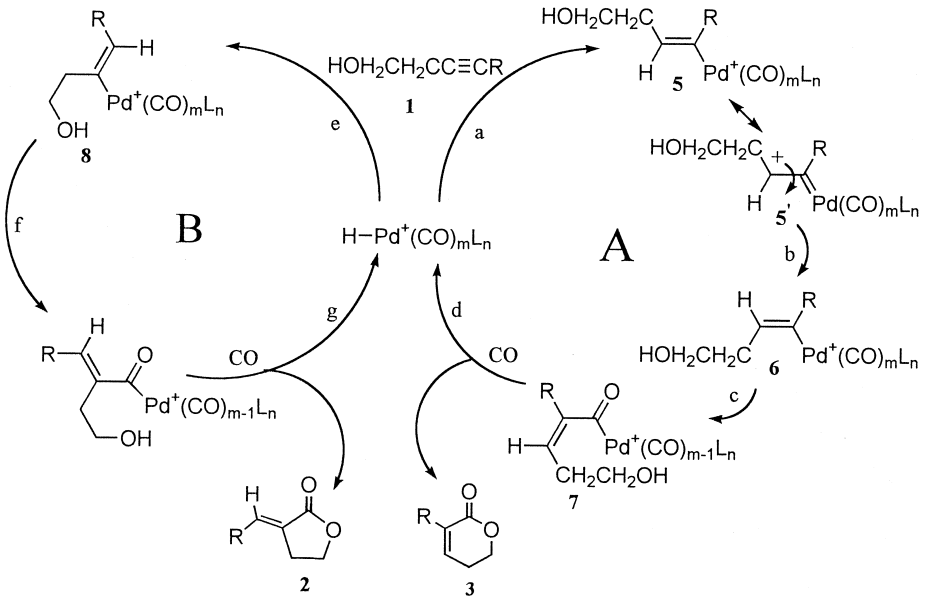

In our cationic palladium(II)-catalyzed reaction, the reaction in DMF is **2**-selective while the reaction in acetonitrile is controlled by both the phosphine ligand employed and the substituent on the

Table 3
Cyclocarbonylation of 3-butyn-1-ols **1** in DMF[a]

| Entry | **1** | Time (h) | Yield (%) | | **2**:**3** |
|---|---|---|---|---|---|
| 1 | **1a** | 3 | 49 | **2a3a** | 100:0 |
| 2 | **1b** | 10 | 66 | **2b3b** | 96:4 |
| 3 | **1c** | 20 | 50 | **2c3c** | 100:0 |
| 4 | **1d** | 20 | 45 | **2d3d** | 99:1 |
| 5 | **1e** | 10 | 38 | **2e3e** | 100:0 |
| 6 | **1f** | 10 | 53 | **2f3f** | 81:19 |
| 7 | **1g** | 10 | 11 | **2g3g** | 100:0 |
| 8 | **1h** | 30 | 61 | **2h3h** | 100:0 |
| 9 | 4-pentyn-1-ol | 10 | 28 | | |




[a] 2 mmol substrate; 20 atm CO; 0.04 mmol $[Pd(PPh_3)_2(CH_3CN)_2](BF_4)_2$; 2 ml DMF; 80°C.




Scheme 1.

triple bond in **1**. The results obtained in DMF could be explained in terms of the carboalkoxy mechanism mentioned above. However this mechanism cannot explain the formation of six-membered ring lactone **3** in acetonitrile. Because the formation of **3** requires opposite direction of addition to the triple bond which proceeds in a *cis* fashion and would result in the formation of a highly strained lactone containing a *trans* double bond [12]. Consequently the mechanism must be different. An alternative mechanism involving a metal hydride may be proposed to explain the results obtained in acetonitrile as illustrated in Scheme 1.

This mechanism begins with *cis* addition of a palladium hydride to the acetylenic bond in **1** [1]. Obviously, the regiochemistry of addition reaction should be influenced by the steric and electronic nature of the substrate **1** and the complex. In the present reaction, however, this process appears to be controlled decidedly by steric factors. Thus, in the case where the ligand is a bulky chelating diphosphine and the substituent R in **1** is H, palladium would preferentially combine with the less hindered terminal position remote from the methylene group to give **5** (cycle A; step a). The existence of intermediate **5** was confirmed by trapping it with CO and methanol. Thus, the reaction of **1a** with carbon monoxide in methanol at 100°C in the presence of $[Pd(dppb)(PhCN)_2](BF_4)_2$ afforded methyl *trans*-5-hydroxy-2-pentenoate regio- and stereoselectively as the major product in addition to **2a** and **3a**. Then, *trans–cis* isomerization of the double bond in the alkenylpalladium species **5** would take place via a route involving a possible carbocation species **5′** (step b). Carbonylation (step c) followed by intramolecular alcoholysis (step d) affords the six-membered ring lactone **3** and regenerates the metal hydride. A metal hydride is known to be a double-bond isomerization catalyst. The occurrence of the double bond-isomerized products in the reaction of 4-pentyn-1-ol also suggests the presence of such a species (Table 2, entry 9). When the substituent R is a bulky trimethylsilyl group, on the other hand, palladium would combine exclusively with the internal carbon of the triple bond to minimize

[1] Several trans addition reactions were also reported [14].

steric interaction affording **8** (cycle B; step e). Carbonylation (step f) followed by intramolecular alcoholysis (step g) affords the five-membered alkylidene lactone **2** of E stereochemistry. In the case where the substituent R is methyl group, which is not so bulky, both the cycles A and B may be operative to give **2** and **3** in a comparable yield. In the case where the ligand L is monodentate triphenylphosphine, the steric repulsion may be relieved to some extent because the triple bond may displace a phosphine ligand prior to insertion. Consequently, the selectivity to **3** will be declined in the reaction using monodentate phosphine as ligand compared to that using a bulky chelating diphosphine as ligand.

The observation that cationic $[Pd(dppb)(PhCN)_2](BF_4)_2$ is active for the cyclocarbonylation of **1a** while neutral $PdCl_2(dppb)$ is inactive, suggests that the ready availability of two coordination sites [15] is crucial to this reaction. Another key to the formation of **3** may be the ability of dppb to coordinate to palladium through one or both phosphine atoms depending on the circumstances [16,17] inferring the result that $[Pd(dppb)(PhCN)_2](BF_4)_2$ is effective whereas $[Pd(dppe)(PhCN)_2](BF_4)_2$ is almost ineffective for this cyclocarbonylation process.

## 3. Experimental

### *3.1. Materials*

Diphosphines, i.e., dppe, dppp, dppb, and dppf, were obtained commercially. The cationic palladium complexes were prepared according to the reported procedure [18]. Acetylenic alcohols were purchased (**1a**, **1b**, **1g**, 4-pentyn-1-ol) or prepared (**1c**, **1d**, **1e**, **1f**, **1h**) according to the literature method [19,20].

### *3.2. General methods*

$^1$H- and $^{13}$C-NMR spectra were recorded in $CDCl_3$ solution at 400 and 100 M Hz, respectively, with $Me_4Si$ as internal standard. IR spectra were run on a FT/IR 350 spectrometer. GLC analyses were performed with 3 mm $\times$ 3 m columns packed with PEG-20M, 5%. Preparative GLCs were done with 6 mm $\times$ 3 m columns packed with PEG-20M, 5%. Column chromatography was carried out on silica gel using hexane/ethyl acetate as eluent.

### *3.3. General procedure for the cyclocarbonylation of 3-butyn-1-ols **1***

#### *3.3.1. Procedure for reactions of Table 2*

Into a 50 ml stainless-steel autoclave were added 0.04 mmol of $[Pd(dppb)(PhCN)_2](BF_4)_2$, 8 ml of $CH_3CN$, and 2 mmol of **1** under nitrogen atmosphere. The reaction vessel was then pressurized with 20 atm of carbon monoxide. The reaction was allowed to proceed at 100°C. After the reaction, the resulting solution was taken up in diethyl ether and passed through a short florisil® column to remove palladium complexes. The products were isolated by either column chromatography (**2a**, **3a**, **2b**, **3b**, **2c**, **3c**, **2d**, **3d**, **2e**, **3e**, **2g**, **3g**, the products from 4-pentyn-1-ol) or Kugelrohr distillation (**2f**, **3f**, **3h**). Analytical samples were obtained by preparative GLC. Quantitative analyses by GLC were performed if necessary (**2a**, **3a**, **2b**, **3b**, **2f**, **3f**, **2g**, **3g**, products from 4-pentyn-1-ol).

*3.3.2. Procedure for reactions of Table 3*

In the same manner as above, 0.04 mmol of $[Pd(PPh_3)_2(CH_3CN)_2](BF_4)_2$, 2 ml of DMF, and 2 mmol of 1 were agitated under the pressure of 20 atm of carbon monoxide at 80°C. The products were isolated by column chromatography (**2a**, **2b**, **2c**, **2e**, **2f**, **3f**, **2g**, **2h**, 2-methylenepentan-5-olide) or by Kugelrohr distillation (**2d**). Quantitative analyses by GLC were performed if necessary (**2f**, **3f**, products from 4-pentyn-1-ol).

*3.3.3. Lactones*

The following lactones are known compounds and have spectral data in accord with the reported ones: **2a**, **2b**, **2c**, **2d**, **2e** [4], **2f** [21], **2g** [11], **2h** [22], **3a**, **3b**, **3d**, **3e** [23], **3g**, 2-methylenepentan-5-olide, 2-hexen-6-olide [24].

5-Phenyl-2-penten-5-olide (**3c**): Mp 47–48°C. IR(neat), 1723, 1246, 1022 $cm^{-1}$. $^1$H-NMR ($CDCl_3$), $\delta$ 7.42–7.34 (5H, m), 6.97 (1H, ddd, $J = 9.7$, 3.1, 5.4 Hz), 6.13 (1H, ddd, $J = 9.7$, 1.1, 2.4 Hz), 5.44 (1H, dd, $J = 10.7$, 5.3 Hz), 2.70–2.57 (2H, m). $^{13}$C-NMR ($CDCl_3$), $\delta$ 164.1, 145.0, 138.4, 128.7, 128.6, 126.0, 121.6, 79.2, 31.6. MS (70 eV), $m/z$ 68, 174 ($M^+$). Calcd. for $C_{11}H_{10}O_2$: C: 75.83, H: 5.70. Found: C: 75.66, H: 5.85.

2-Oxabicyclo[4.4.0]-4-decen-3-one (**3f**): Mp 41–44°C. IR(neat), 1730, 1700, 1250, 1040 $cm^{-1}$. $^1$H-NMR ($CDCl_3$), $\delta$ 6.67 (1H, d, $J = 9.4$ Hz), 5.96 (1H, d, $J = 9.4$ Hz), 3.98 (1H, dt, $J = 4.0$, 11.2 Hz), 2.33–1.20 (9H, m). $^{13}$C-NMR ($CDCl_3$), $\delta$ 164.6, 150.9, 120.9, 82.0, 39.6, 31.2, 28.9, 25.3, 23.9. MS (70 eV), $m/z$ 67, 81, 152 ($M^+$). Calcd. for $C_9H_{12}O_2$: C: 71.03, H: 7.95. Found: C: 70.86, H: 7.96.

(*E*)-2-(Trimethylsilylmethylene)butan-4-olide (**2h**): IR(neat), 1758, 1636, 1251, 1174, 1020, 841 $cm^{-1}$. $^1$H-NMR ($CDCl_3$), $\delta$ 6.94 (1H, t, $J = 2.8$ Hz), 4.38 (2H, t, $J = 7.3$ Hz), 2.97 (2H, dt, $J = 2.8$, 7.3 Hz), 0.19 (9H, s). $^{13}$C-NMR ($CDCl_3$). $\delta$ 170.5, 139.5, 138.9, 65.0, 27.3, −1.4. MS (70 eV), $m/z$ 83, 155, 170 ($M^+$). Calcd. for $C_8H_{14}O_2Si$: C: 56.41, H: 8.30. Found: C: 56.23, H: 8.14.

3-Hexen-6-olide: IR(neat), 1730, 1660, 1150, 1060 $cm^{-1}$. $^1$H-NMR ($CDCl_3$), $\delta$ 5.74 (1H, dtt, $J = 11.3$, 3.5, 1.7 Hz), 5.56 (1H, dtt, $J = 11.3$, 1.8, 5.5 Hz), 4.44 (2H, t, $J = 5.4$), 3.40 (2H, ddt, $J = 1.5$, 5.5, 1.7 Hz), 2.58–2.46 (2H, m). MS (70 eV), $m/z$ 39, 54, 67, 112 ($M^+$).

*3.3.4. Carbonylation of **1a** in methanol*

A mixture of 2 mmol of **1a** and 0.04 mmol of $[Pd(dppb)(PhCN)_2](BF_4)_2$ was dissolved in 8 ml of methanol and placed in a 50 ml autoclave. The autoclave was pressurized with 20 atm of carbon monoxide and heated for 3 h at 100°C. The reaction mixture was then cooled to room temperature and filtered through a short florisil® column. Column chromatograpy on silica gel eluting with hexane/ethyl acetate gave methyl *trans*-5-hydroxy-2-pentenoate in 44% yield together with **2a** and **3a** as minor products.

Methyl *trans*-5-hydroxy-2-pentenoate: IR(neat), 3442, 1724, 1660, 1283, 1210, 1047, 977 $cm^{-1}$. $^1$H-NMR ($CDCl_3$), $\delta$ 6.98 (1H, dt, $J = 15.1$, 6.3), 5.93 (1H, dt, $J = 15.1$, 1.4 Hz), 3.77 (2H, t, $J = 6.3$ Hz), 3.73 (3H, s), 2.45–2.50 (2H, m), 2.22 (1H, br). $^{13}$C-NMR ($CDCl_3$), $\delta$ 166.9, 145.8, 123.0, 60.9, 51.6, 35.3. MS (70 eV), $m/z$ 41, 69, 100.

## References

[1] E. Drent, P. Arnoldy, P.H.M. Budzelaar, J. Organomet. Chem. 475 (1994) 57.
[2] B.E. Ali, H. Alper, J. Mol. Catal. 96 (1995) 197.
[3] J.R. Norton, K.E. Shenton, J. Schwartz, Tetrahedron Lett. (1975) 51.

[4] T.F. Murray, E.G. Samsel, V. Varma, J.R. Norton, J. Am. Chem. Soc. 103 (1981) 7520.
[5] Y. Tsuji, T. Kondo, Y. Watanabe, J. Mol. Catal. 40 (1987) 295.
[6] Y. Tamaru, M. Hojo, Z. Yoshida, J. Org. Chem. 56 (1991) 1099.
[7] H. Gabriele, G. Salerno, F. De Pascali, M. Costa, G.P. Chiusoli, J. Chem. Soc. Perkin Trans 1 (1997) 147.
[8] I. Matsuda, A. Ogiso, S. Sato, J. Am. Chem. Soc. 112 (1990) 6120.
[9] K. Matsushita, T. Komori, S. Oi, Y. Inoue, Tetrahedron Lett. 35 (1994) 5889.
[10] F. Bonadies, R. Di Fabio, J. Org. Chem. 49 (1984) 1647.
[11] C.P. Cassey, W.R. Brunsvold, J. Organomet. Chem. 102 (1975) 175.
[12] T.F. Murry, V. Varma, J.R. Norton, J. Am. Chem. Soc. 99 (1977) 8085.
[13] E.G. Samsel, J.R. Norton, J. Am. Chem. Soc. 106 (1984) 5505.
[14] S. Otsuka, A. Nakamura, Adv. Organomet. Chem. 14 (1976) 245.
[15] Y. Kayaki, I. Shimizu, A. Yamamoto, Chem. Lett. (1995) 1089.
[16] B.E. Ali, H. Alper, J. Org. Chem. 56 (1991) 5357.
[17] B.E. Ali, K. Okuro, G. Vasapollo, H. Alper, J. Am. Chem. Soc. 118 (1996) 4264.
[18] J.A. Davies, F.R. Hartley, S.G. Murray, J. Chem. Soc. Dalton Trans. (1980) 2246.
[19] R.G. Carlson, D.E. Henton, J. Chem. Soc. Chem. Commun. (1969) 674.
[20] R.G. Carlson, J.-A. Huber, D.E. Henton, J. Chem. Soc. Chem. Commun. (1973) 223.
[21] J.A. Marshall, N. Cohen, J. Org. Chem. 30 (1965) 3475.
[22] K. Nozaki, K. Oshima, K. Utimoto, Tetrahedron Lett. 29 (1988) 6127.
[23] H.L. Slates, Z.S. Zelawski, D. Taub, N.L. Wendler, Tetrahedron 30 (1974) 819.
[24] H.J. Reich, J.M. Renga, I.L. Reich, J. Am. Chem. Soc. 97 (1975) 5434.