Tetrahedron Letters 50 (2009) 5238–5240

Contents lists available at ScienceDirect

Tetrahedron Letters

journal homepage: www.elsevier.com/locate/tetlet

Diallylation of 2,2-dialkylbenzodioxoles from $TiCl_4$-mediated allylsilane reaction

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ARTICLE INFO

Article history:
Received 19 June 2009
Accepted 1 July 2009
Available online 10 July 2009

Keywords:
Allylsilane
Benzodioxoles
Diallylation
Titanium tetrachloride
Nitromethane
Metathesis

ABSTRACT

Reaction of aliphatic ketones with catechol afforded 2,2-dialkylbenzodioxoles. Treatment of these benzodioxoles with allyltrimethylsilane in the presence of titanium tetrachloride led to 4,4-dialkylhepta-1,6-dienes resulting from a diallylation process. Ring-closing metathesis gave rise to 4,4-dialkylcyclopentenes.

1. Introduction

The allylation of electrophilic reagents has gained in importance since the development from the seventies of the allylsilane chemistry.[1] In particular, allylation of acetals is well documented and homoallyl alkyl ethers can be obtained in this case (Hosomi–Sakurai reaction).[2] Ethylene ketals afforded homoallyl ether of glycol **2** (Scheme 1). These results suggested that the titanium glycolate ether is not a sufficient leaving group to allow the substitution reaction with a second allylsilane **1** reagent. Moreover, compound **2** does not lead to further manipulation due to the inactivity of the aliphatic ether linkage.

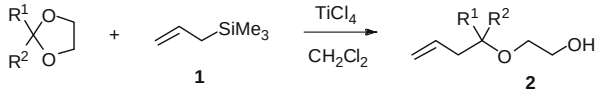
Diallylation occurred only with aryl aldehydes,[3] cyclopropylketones[4] or bis-dioxanes.[5]

The use of more reactive catechol ketals (2,2-dialkylbenzodioxoles) **3** could increase the leaving group ability of the titanium species and therefore enhance its reactivity.

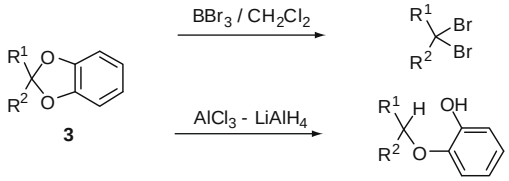
Although the chemistry of 2,2-dialkylbenzodioxoles **3** will be weakly developed, some results confirm the easy substitution of the ether linkage. In particular, treatment of **3** with boron tribromide exclusively led to *gem*-dibromo derivatives in excellent yields,[6] and the dichloroalane afforded reductive opening to give phenolic ether (Scheme 2).[7]

2. Results

We have prepared various benzodioxoles[8] to confirm this hypothesis. With 2,2-dialkyl-1,3-benzodioxoles **3**, a clean diallylation occurred when allyltrimethylsilane (3 equiv) was added to the complex benzodioxole–$TiCl_4$.[9] First, we studied the reaction of benzodioxole **4** derived from the methylisopropylketone (Scheme 3). Diallylation occurred in good yield (70%) and the structure of **5** was confirmed by a ring-closing metathesis reaction affording cyclopentene **6**.[10,11]



Scheme 1. Allylation of ethylene ketals with allylsilane **1**.



Scheme 2. Reactivity of 2,2-dialkylbenzodioxoles **3**.

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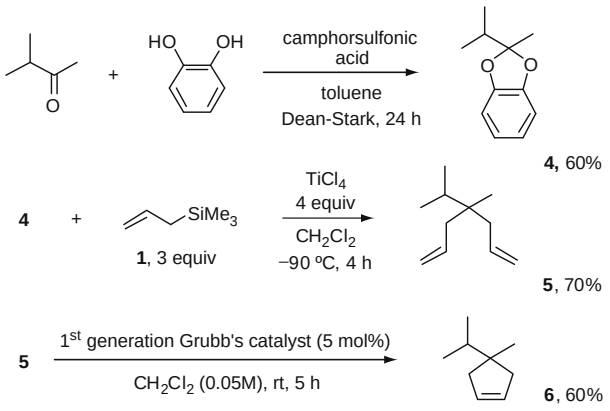
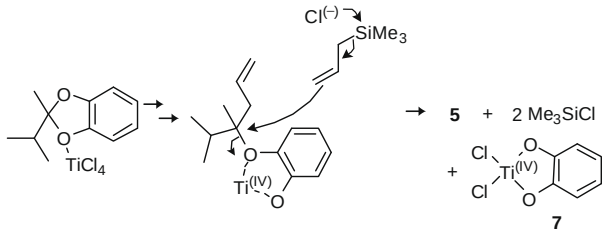
doi:10.1016/j.tetlet.2009.07.033



Scheme 3. Synthesis of the methylisopropyl ketone-derived benzodioxole **4**, its diallylation followed by a ring-closing metathesis.

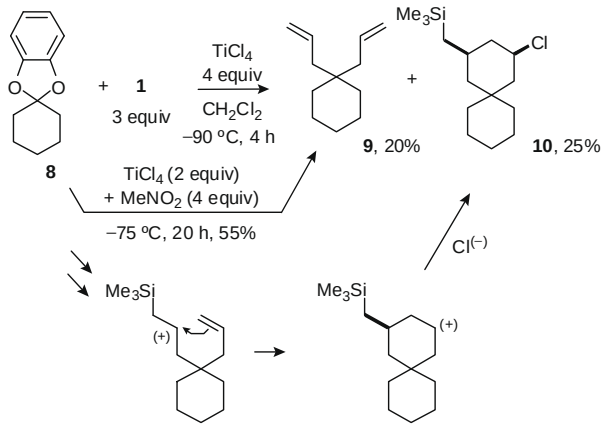


Scheme 4. Allylsilane substitution of the titanium catecholate.

The diallylation of **4** involved the formation of the titanium complex which underwent an allylsilane substitution. The resulting complex titanium dichloride catecholate **7** could be more stable than the glycolate counterpart. Complex **7** is a stable well-known compound (CAS number, 13523-46-1) (Scheme 4).[12]

Under the same experimental conditions, the diallylation of the cyclohexanone-derived benzodioxole **8** gave the 1,1-diallylcyclohexane **9** in a low yield (20%),[13] and the formation of a by-product **10** (25% yield) resulting from a participation reaction (Scheme 5).[14,15]

However, the yield of diallylcyclohexane **9** was increasing to 55% by the addition of nitromethane (4 M equiv), a higher temperature (−75 °C) and with only 2 equiv of $TiCl_4$ (allylcyclohexanol, 7% yield, was also isolated). The presence of nitromethane reduced or prevented the formation of by-products which result from a participation reaction.[16,17]



Scheme 5. Diallylation of the cyclohexanone-derived benzodioxole **8**.

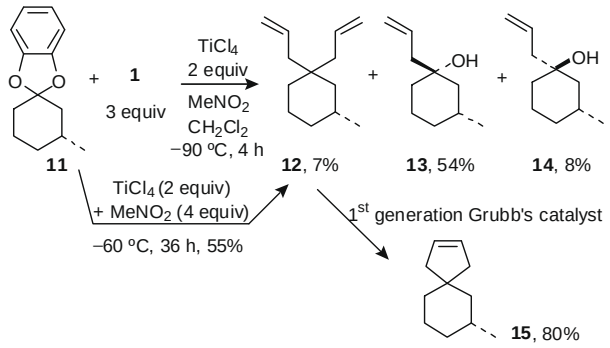
Similar results are observed with benzodioxole **11** derived from (*R*)-(+)-3-methylcyclohexanone.[18] At low temperatures (−90 °C, 4 h) and in the presence of nitromethane, (1*R*,3*R*)-1-allyl-3-methylcyclohexanol **13**[19] and (1*S*,3*R*)-1-allyl-3-methylcyclohexanol **14** are the major products.[20,21] In contrast, at −60 °C, the diallyl derivative **12**[22] was obtained in 55% yield (Scheme 6). The ring-closing metathesis afforded the spiro alkene **15**.[23]

Cyclopentanone-derived benzodioxole **16**[24] afforded diallylcyclopentane **17**[25] in a fair yield (Scheme 7).

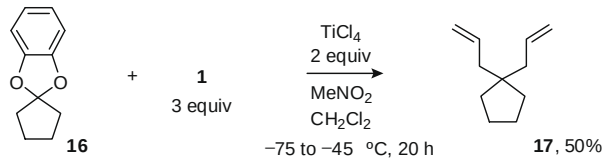
The diallylation to give **19**[26] can be performed in the good yield of 65% even with the strained norcamphor-derived benzodioxole **18**.[27] The corresponding spiro tricyclic hydrocarbon **20**[28] is easily obtained by ring-closing metathesis (Scheme 8).

3. Conclusion

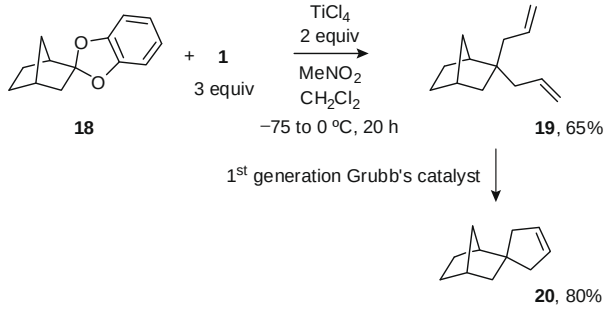
To the best of our knowledge, the titanium tetrachloride-mediated diallylation with allylsilane of ketone-derived benzodioxole constitutes the only one-step method. Gratefully, metathesis easily gave rise to 4,4-dialkylcyclopentenes.



Scheme 6. Diallylation of the 3-methylcyclohexanone-derived benzodioxole **11** followed by a ring-closing metathesis.



Scheme 7. Diallylation of the cyclopentanone-derived benzodioxole **16**.



Scheme 8. Diallylation of the norcamphor-derived benzodioxole **18** followed by a ring-closing metathesis.

Acknowledgements

D.M. is grateful to the MEN for a grant and N.G. is grateful to the *CNRS* and the *Région Provence-Alpes-Côte d'Azur* for a grant. This work has been financially supported by the *CNRS* and the *Ministère de l'Education Nationale*.

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9. A three-necked flask equipped with a thermometer, a septum cap, a magnetic stirring bar and argon outlet was charged with anhydrous CH_2Cl_2 (30 mL) and anhydrous nitromethane (2.1 mL, 40 mmol). The solution was cooled to −75 °C, and $TiCl_4$ was added (2.2 mL, 20 mmol) followed by the dioxole (10 mmol) in CH_2Cl_2 (10 mL) and then allylsilane (3.42 g, 30 mmol) in CH_2Cl_2 (20 mL). The completion of the reaction was followed by TLC. Then, the solution was poured onto aqueous saturated NH_4Cl solution and extracted with CH_2Cl_2. The extract was washed until neutrality and possibly filtrated on Celite®. The solution was dried over $MgSO_4$, and concentrated under vacuum. The residue was purified by chromatography on silica gel, eluting with a gradient of pentane–diethyl ether.
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11. *4-Methyl-4-isopropylcyclopentene* (**6**): ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.00–4.96 (m, 2H), 1.32–1.25 (m, 4H), 0.87 (t, J = 6.9 Hz, 6H), 0.87 (s, 3H) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ = 130.0 (d), 128.1 (d), 34.3 (t), 29.2 (d), 22.5 (t), 14.2 (q) (2C).
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13. *1,1-Diallylcyclohexane* (**9**): ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.80 (ddt, J = 15.9, 11.3, 7.4 Hz, 2H), 5.05–4.94 (m, 4H), 2.01 (d, J = 7.4 Hz, 4H), 1.6–1.2 (m, 10H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 135.2 (d), 117.0 (t), 41.9 (t), 35.9 (s), 35.4 (t), 26.5 (t), 21.8 (t).
14. *2-Chloro-4-(trimethylsilylmethyl)spiro[5.5]undecane* (**8**): ^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.00 (tt, J = 12.15, 4.16 Hz, 1H), 2.2–2.08 (m, 2H), 1.7–1.6 (m, 2H), 1.42–1.30 (m, 6H), 1.25–1.08 (m, 4H), 0.65 (t, J = 13.4 H, 1H), 0.49 (t, J = 6.2 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 57.2 (d), 48.1 (t), 47.4 (t), 45.8 (t), 41.7 (t), 36.3 (s), 33.2 (t), 29.6 (d), 26.8 (t), 25.3 (t), 21.8 (t), 21.7 (t), −0.40 (q) (3C).
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18. *Compound* **11**: mp 76 °C (CH_2Cl_2–pentane), $[\alpha]_D^{20}$ −31.4 (c 5.1, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 6.81 (br s, 4H), 2.18 (m, 2H), 1.85–1.65 (m, 6H), 1.42 (t, J = 12.8 Hz, 1H), 1.2 (d, J = 6.6 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 147.5 (s), 147.4 (s), 121.0 (d) (2C), 118.6 (s), 108.6 (d), 108.5 (d), 43.4 (t), 34.7 (t), 33.4 (t), 30.0 (d), 22.6 (t), 22.1 (q).
19. *(1R,3R)-1-Allyl-3-methylcyclohexanol* (**13**): $[\alpha]_D^{20}$ 3.5 (c 3.85, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.95 (ddt, J = 16.8, 10.4, 7.1 Hz, 1H), 5.16–5.03 (m, 2H), 2.49 (dt, J = 7.1, 1.0 Hz, 2H), 1.95–1.85 (m, 3H), 1.75–1.30 (m, 5H), 1.08 (½AB, J = 12.4 Hz, 1H), 1.02 (½AB, J = 12.4 Hz, 1H), 0.87 (d, J = 6.2 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 133.5 (d), 118.6 (t), 75.1 (s), 50.9 (t), 47.8 (t), 39.0 (t), 34.5 (t), 28.1 (d), 22.2 (q), 22.1 (t).
20. *(1S,3R)-1-Allyl-3-methylcyclohexanol* (**14**): $[\alpha]_D^{20}$ 3.7 (c 3.4, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.85 (ddt, J = 16.9, 10.3, 7.5 Hz, 1H), 5.12–5.02 (m, 2H), 2.14 (d, J = 7.5 Hz, 2H), 1.70–1.50 (m, 5H), 1.25–1.10 (m, 2H), 1.0–0.72 (m, 2H), 0.84 (d, J = 6.45 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 133.8 (d), 118.7 (t), 71.5 (s), 49.0 (t), 45.8 (t), 36.7 (t), 34.8 (t), 27.9 (d), 22.7 (q), 21.6 (t).
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22. *(3R)-(+)-1,1-Diallyl-3-methylcyclohexane* (**12**): $[\alpha]_D^{20}$ 6.0 (c 1.20, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.94–5.68 (m, 2H), 5.06–4.94 (m, 4H), 2.11 (d, J = 7.4 Hz, 2H), 1.92 (d, J = 7.5 Hz, 2H), 1.70–1.42 (m, 6H), 1.1–0.7 (m, 3H), 0.84 (d, J = 6.2 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 135.3 (d), 135.1 (d), 117.1 (t), 116.9 (t), 46.5 (t), 44.5 (t), 38.1 (t), 36.7 (s), 35.4 (t), 35.0 (t), 27.6 (d), 23.3 (q), 21.8 (t).
23. *(7R)-(−)-7-Methylspiro[4.5]dec-2-ene* (**15**): $[\alpha]_D^{20}$ −3.6 (c 1.0, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.60 (½AB, t, J = 5.86, 2.1 Hz, 1H), 5.55 (½AB, t, J = 5.86, 2.1 Hz, 1H), 2.15 (quint., J = 2.1 Hz, 2H), 2.10 (quint., J = 2.1 Hz, 2H), 1.57 (AB, m, J = 16.0 Hz, 2H), 1.50–1.35 (m, 6H), 0.84 (d, J = 6.5 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 129.2 (d), 129.1 (d), 49.4 (t), 48.0 (t), 42.7 (t), 42.5 (s), 38.4 (t), 35.1 (t), 29.7 (d), 23.6 (t), 23.1 (q).
24. *Compound* **16**: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 6.84–6.80 (m, 4H), 2.18–2.12 (m, 4H), 1.91–1.86 (m, 4H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 147.5 (s), 127.2 (s), 121.1 (d), 108.3 (d), 37.2 (t), 23.3 (t).
25. *1,1-Diallylcyclopentane* (**17**): ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.82 (ddt, J = 15.8, 11.2, 7.4 Hz, 2H), 5.04 (br s, 2H), 5.02–4.98 (m, 2H), 2.06 (d, J = 7.5 Hz, 4H), 1.65–1.55 (m, 4H), 1.45–1.37 (m, 4H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 136.2 (d), 116.8 (t), 45.2 (s), 43.6 (t) (2C), 36.9 (t) (2C), 24.9 (t) (2C).
26. *2,2-Diallylbicyclo[3.3.1]heptane* (**19**): ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.77 (ddt, J = 17.0, 10.4, 7.2 Hz, 2H), 5.06–4.96 (m, 4H), 2.2–2.06 (m, 4H), 2.0 (q, J = 7.1 Hz, 1H), 1.7–1.22 (m, 6H), 1.2–1.02 (m, 2H), 0.85 (dd, J = 12.0, 2.6 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 136.6 (d), 135.6 (d), 116.9 (t), 116.6 (t), 44.6 (d), 43.6 (t), 43.1 (s), 42.7 (t), 40.3 (t), 37.7 (t), 37.7 (d), 28.7 (t), 24.6 (t).
27. *Compound* **18**: mp 37 °C (subl.). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 6.75 (m, 4H), 2.44 (d, J = 3.2 Hz), 2H), 2.37 (t, J = 3.8 Hz, 2H), 2.12 (dd, J = 4.4, 3.9 Hz, 1H), 2.07 (dd, J = 4.4, 3.0 Hz, 1H), 1.88–1.80 (m, H), 1.78–1.75 (m, H), 1.72 (d, J = 3.4 Hz, 1H), 1.63–1.55 (m, H), 1.50 (t, J = 4.15 Hz, 1H), 1.46 (t, J = 4.03 Hz, 1H), 1.42 (br d, J = 2.5 Hz, 1H), 1.38 (quint., J = 1.6 Hz, 1H), 1.35 (quint., J = 1.7 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 147.7 (s), 147.3 (s), 125.3 (s), 121.1 (d), 121.0 (d), 108.3 (d), 108.2 (d), 45.6 (d), 44.9 (t), 37.6 (t), 36.1 (d), 28.1 (t), 21.3 (t).
28. *Compound* **20**: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.67–5.58 (m, 2H), 2.47 (d, quint. J = 16.1, 2.50 Hz, 1H), 2.32 (d, quint., J = 16.1, 2.25 Hz, 1H), 2.2–2.08 (m, 3H), 1.92 (br d, J = 3.6 Hz, 1H), 1.64–1.34 (m, 6H), 1.20–1.10 (m, 4H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 130.0 (d), 129.5 (d), 50.3 (t), 50.2 (t), 49.6 (s), 47.6 (d), 43.7 (t), 39.0 (t), 37.9 (t), 29.2 (t), 25.2 (t).