Account

Carbon–carbon bond formation by means of organotellurium compounds

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This article is dedicated to the memory of Henrique Bellotti Formiga.

Abstract

Z vinylic tellurides are prepared by hydrotelluration of alkynes under nonreducing conditions using *n*-BuLi–Te–H_2O as the hydrotellurating system. The same system promotes the hydrotelluration of alkenes containing electron withdrawing groups. Lithium and magnesium organotellurolates effect vinylic substitutions on vinylic halides, phosphates, sulphonates and acetates leading to the *Z* vinylic telluride exclusively. Tellurides are transmetallated with easily available organometallic reagents to give valuable synthetic building blocks (e.g. organolithiums and organocuprates). Reaction of vinylic tellurides with alkynes under Pd catalysis or with organocuprates gives the coupling products with retention of the double bond geometry. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Organotellurium compounds; Transmetallation; Coupling reactions

1. Introduction

Organometallic compounds are used widely for carbon–carbon bond formation [1]. Transmetallation reactions involving organoelemental compounds have been a field of growing interest to generate such species. For example, the tin/metal exchange has been used in a number of processes to introduce fragments containing *E* double bonds into carbon skeletons [2]. In the last years, we and others have shown that vinylic tellurides behave very similarly to vinyl tin compounds toward transmetallation [3,4], with the remarkable difference that the tellurium/metal exchange gives rise to fragments containing *Z* double bonds, in view of the unique and highly stereoselective methods of synthesis of *Z* vinylic tellurides. In addition, stereoselective coupling processes of *Z* vinylic tellurides were developed, allowing the substitution of the tellurium atom for alkyl or alkynyl fragments. In this account, the more synthetically useful methods of synthesis of *Z* vinylic tellurides and the uses of these intermediates as well as allylic and ferrocenyl tellurides for carbon–carbon bond formation will be discussed.

Scheme 1.

2. Hydrotelluration of alkynes

The hydrotelluration of alkynes is the method of choice to prepare vinylic tellurides [3,4]. Up to now, the reaction has been performed by reduction of a dialkyl- or diarylditelluride with sodium borohydride in ethanol followed by addition of the appropriate alkyne (Scheme 1).

The limitation of this methodology is the commercial unavailability of dialkylditellurides and the notorious
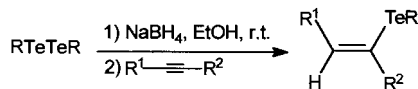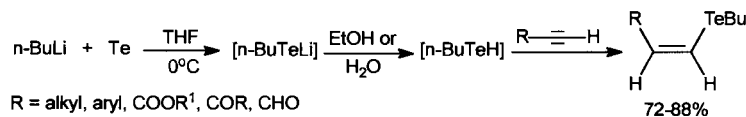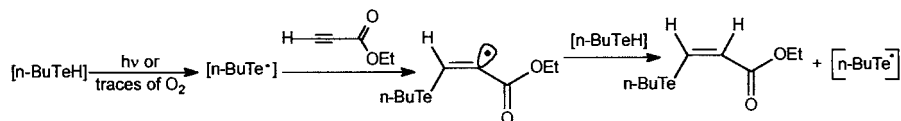
* Corresponding author. Tel./fax: +55-11-38182176.
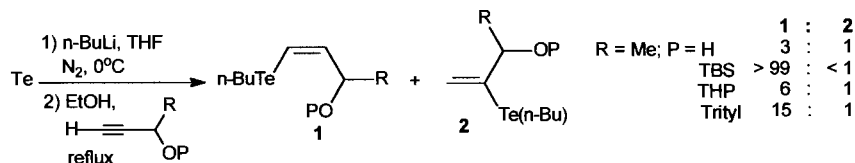*E-mail address:* jvcomass@iq.usp.br (J.V. Comasseto).
[1] In memorian.

Scheme 2.

Scheme 3.

Scheme 4.

bad smell of such compounds [4]. Recently we developed a convenient and practical alternative for this reaction, that circumvents these drawbacks. The new method consists of the reaction of commercial alkyllithiums with elemental tellurium in THF, followed by addition of equimolar amounts of ethanol or water to the organotellurolate solution. A tellurol is presumed to be formed. To the resulting clear solution is added the appropriate alkyne. After some time of stirring and heating, the alkyne is consumed and the vinylic telluride of *Z* configuration is formed in yields similar to those obtained by the sodium borohydride method (Scheme 2) [5].

This procedure allows to perform the hydrotelluration starting from commercial reagents and avoids the use of malodorous dialkylditellurides, as well as reducing agents, which sometimes are not compatible with functional groups present in the alkyne substrate.

The mechanism of the hydrotelluration reaction has been subject of speculation [6], however, no experimental evidence for an ionic mechanism has been presented. Recently we obtained experimental evidence for a radicalar mechanism for this reaction. Reaction of the presumed organotellurol, obtained as indicated in Scheme 2, with ethylpropiolate in an EPR apparatus, in the presence of radical trapps (e.g. *N*-t-butyl-α-phenyl-nitrone and 3,5-dibromo-4-nitrosobenzeno-sulfonic acid), gave a strong characteristic signal of a free radical [7]. According to these results a plausible mechanism for the hydrotelluration of alkynes is the one shown in Scheme 3.

In connection with this methodology, other limitation of the hydrotelluration of alkynes was addressed. It is well known that alkynes conjugated to unsaturated systems are hydrotellurated with high regioselectivity
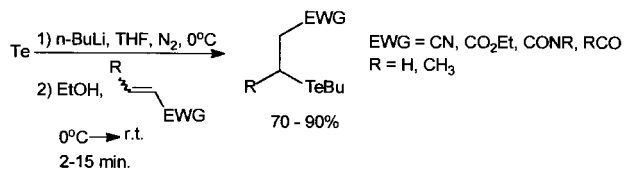
[3,4,6]. However alkynes presenting saturated alkyl chains exhibit lower regioselectivity.

We found that the hydrotelluration reaction is highly sensitive to steric factors. Protection of the OH group with different protecting groups gave the 1,2-disubstituted vinylic tellurides with different regioselectivity, depending on the steric demand of the protecting group (Scheme 4) [8].
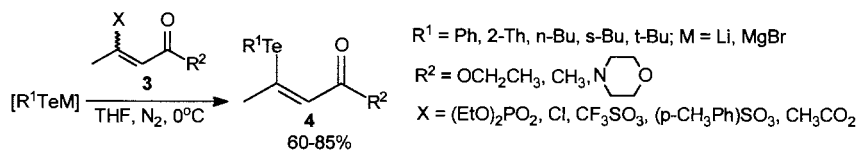
The above described hydrotelluration methodology was applied to alkenes containing electron withdrawing groups. The hydrotelluration of alkenes occurred in few minutes at room temperature in good yields (Scheme 5) [9].

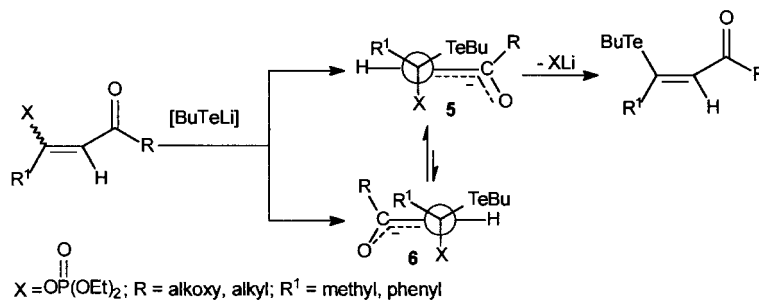## 3. Vinylic substitution by organotellurolate anions

The vinylic substitution using organotellurolate anions has been little studied. Several years ago it was reported the vinylic substitution in *trans*-β-bromostyrene by tellurolate anions, leading to *E* vinylic tellurides [10,11]. More recently, the vinylic substitution in β-chloroenones and enals by organotellurolate anions was reported [12]. The reaction is highly stereoselective giving the *Z* vinylic telluride exclusively.
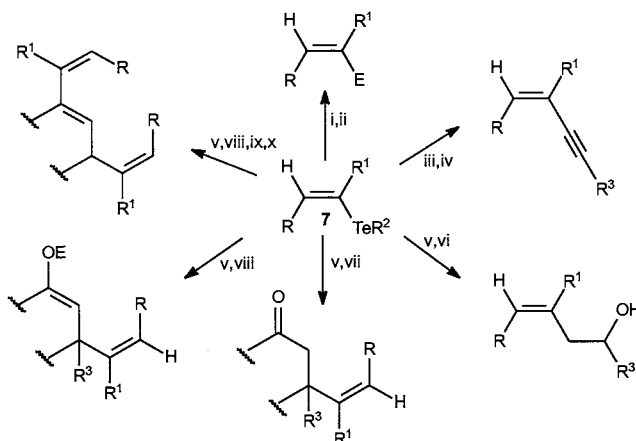
Scheme 5.

R^1 = Ph, 2-Th, n-Bu, s-Bu, t-Bu; M = Li, MgBr

R^2 = OCH$_2$CH$_3$, CH$_3$, N$\bigcirc$O

X = (EtO)$_2$PO$_2$, Cl, CF$_3$SO$_3$, (p-CH$_3$Ph)SO$_3$, CH$_3$CO$_2$

Scheme 6.

X = OP(OEt)$_2$; R = alkoxy, alkyl; R^1 = methyl, phenyl

Scheme 7.

i, RM (M = Li [17-19], MgX [20], CaI [20], Na [20], Zn [21]); ii, E = RCHO, R$_2$CO, RX, etc.

iii, Me$_2$Cu(CN)Li$_2$, THF, N$_2$, r.t. then ZnCl$_2$, Et$_2$O, - 20°C, 2h; iv, R^3——≡——Br, - 20°C, 1h [22].

v, LL^{1}Cu(CN)Li$_2$ (L = L^1 = Me, L = n-Bu, L^1 = 2-Th), THF, N$_2$, 1h, r.t.; vi, R^3——, - 78°C, BF$_3$ · Et$_2$O, 2h [23,24]

v, vii, R^{3}CH=CHCOR^4, THF, - 78°C → r.t. [24-27].

v, viii, E = Me$_3$SiCl, (EtO)$_2$P(O)Cl or PhN(SO$_2$CF$_3$)$_2$, - 75°C → r.t. [28,29].

v, viii, E = PhN(SO$_2$CF$_3$)$_2$), - 75°C → r.t.; ix, 7 (R^1 = H) + n-BuLi, THF, - 78°C, then ZnCl$_2$, THF;

x, Pd[P(Ph$_3$)$_3$]$_4$ 10 mol%, THF, r.t., 12-24h [28,29].
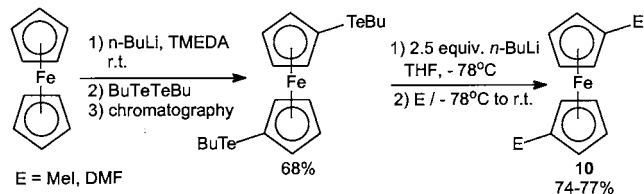
Scheme 8.

We found that the easily prepared enolphosphates of β-dicarbonyl compounds react in a similar way at 0°C. Starting from *E* or *Z* enolphosphates, only *Z* vinylic tellurides were formed [13]. In order to determine the scope of this reaction we performed it using different tellurolate anions. We observed that the aromatic tellurolates react much slower than the aliphatic ones, even when R^1 was the *t*-butyl group (Scheme 6). In the following, several types of enols **3** were prepared from the corresponding 1,3-dicarbonyl compounds and reacted with lithium *n*-butyltellurolate. The reaction times were not dependent on the leaving group and the yields were quite similar in all cases [14].

The reaction was stereoselective, and only the *Z* isomer of **4** was formed, even starting from diastereomeric *E/Z* mixtures of **3**. This fact is probably due to the interaction between the tellurium atom and

E = MeI, DMF, Ph$_2$CO

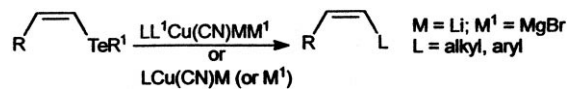Scheme 9.

E = MeI, DMF
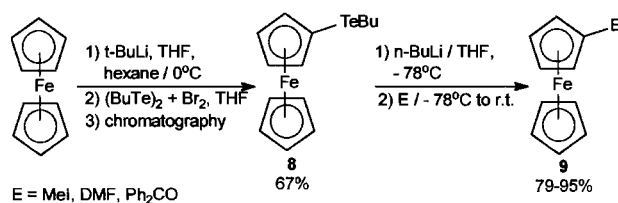
Scheme 10.

the carbonyl oxygen in the transition state [13]. X-ray diffraction studies [15] showed that this interaction exists in the products of the substitution reaction. This fact supports the proposed mechanism responsible for the high stereoselectivity of this vinylic substitution reaction (Scheme 7) [13].

The interaction between tellurium and oxygen is possible in conformer **5**, but it is not in conformer **6** what shifts the equilibrium to favor the first, which leads to the *Z* isomer.

4. Tellurium–metal exchange reaction

The rate of the Te–Li exchange is one of the fastest among the metalloid–Li exchange reactions [16]. This property of the organotellurium compounds was explored to generate reactive organometallic species [3,4]. Among these species we mention the *Z* vinylic organometallics, which on reaction with carbon electrophiles (*E*) allow the formation of carbon–carbon bonds with retention of the alkene geometry. In Scheme 8 [17–29], the most important transformations performed using *Z* vinylic tellurides are summarized. As it can be observed, vinylic tellurides 7 are transformed into vinyl lithium, sodium, magnesium, calcium, zinc and copper species, which react in the usual way with carbon electrophiles.

Mono- and 1,1′-di-lithioferrocenes are difficult to obtain in pure form. Recently we prepared them by means of a tellurium–lithium exchange reaction. Pure *n*-butyltelluroferrocene (**8**) was obtained as shown in

Scheme 12.

Scheme 9. Treatment of **8** with *n*-BuLi followed by capture of the monolithioferrocene with carbon electrophiles led to monosubstituted ferrocenes (**9**) [32].

1,1′-Disubstituted ferrocenes (**10**) were obtained in a similar way as shown in Scheme 10 [32].

A very convenient method to generate allylic higher order cyanocuprates starting from allylic tellurides was recently developed by us. Allylic tellurides are very sensitive to air oxidation [30]. In this way, these compounds were prepared in situ and immediately reacted with lithium dimethyl cyanocuprates to generate the corresponding allylic cyanocuprates, which react with vinyl triflates to give highly unsaturated systems, as shown in Scheme 11 [31].

5. Coupling reactions of vinylic tellurides

Some time ago we observed that the transmetallation reaction of vinylic tellurides with higher order cyanocuprates is dependent on the nature of the cuprate counter ion. Magnesium cyanocuprates or mixed lithium–magnesium cyanocuprates, instead of a transmetallation reaction, promote a coupling reaction of the *Z* vinylic telluride with the transferable ligand of the cuprate, with retention of the alkene configuration [33]. Lower order cyanocuprates behave similarly even when the counter ion is lithium (Scheme 12) [34].

Recently we found that the system PdCl$_2$–CuI in methanol promotes the coupling of *Z* vinylic tellurides with terminal alkynes leading to *Z* enynes and *Z* enediynes [35]. Other Pd compounds such as Pd(PPh$_3$)$_4$, and Pd(OAc)$_2$ in THF/DMF (1:1) are also effective as coupling agents (Scheme 13) [36].

Similar coupling reactions involving organozinc compounds were also described [37,38].
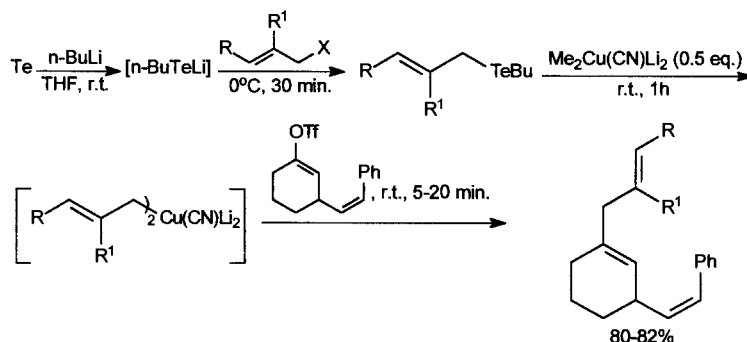
Scheme 11.
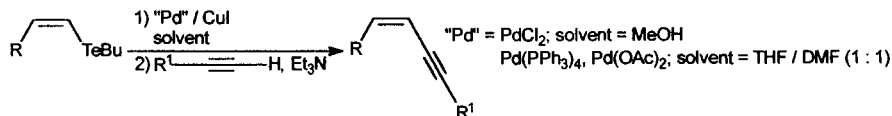
Scheme 13.

6. Conclusion

The results commented in this account show that organotellurium compounds constitute valuable reagents for stereoselective carbon–carbon bond formation and have a promising future in the synthesis of complex molecules.

Acknowledgements

References

[1] J.H. Bateson, M.B. Mitchell (Eds.), Organometallic Reagents in Organic Synthesis, Academic Press, London, 1994.

[2] R.J.K. Taylor (Ed.), Organocopper Reagents, Oxford University Press, Oxford, 1994.

[3] J.V. Comasseto, W.L. Lo, N. Petragnani, H.A. Stefani, Synthesis (1997) 373.

[4] J.V. Comasseto, R.E. Barrientos-Astigarraga, Aldrichim. Acta 33 (2000) 66.

[5] G. Zeni, H.B. Formiga, J.V. Comasseto, Tetrahedron Lett. 41 (2000) 1311.

[6] J.V. Comasseto, Rev. Heteroatom Chem. 9 (1993) 61.

[7] J.V. Comasseto, O. Augusto, unpublished results.

[8] J.V. Comasseto, unpublished results.

[9] J.V. Comasseto, unpublished results.

[10] M.J. Dabdoub, V.B. Dabdoub, J.V. Comasseto, N. Petragnani, J. Organomet. Chem. 308 (1986) 211.

[11] K. Ohe, H. Takahashi, S. Uemura, N. Sugita, Nippon Kagaku Kaishi (1987) 1469.

[12] R.M. Minyaev, V.I. Minkin, Can. J. Chem. 76 (1998) 776.

[13] R.E. Barrientos-Astigarraga, P. Castelani, C.Y. Sumida, J.V. Comasseto, Tetrahedron Lett. 40 (1999) 7717.

[14] J.V. Comasseto, unpublished results.

[15] J. Zukerman-Schpector, J.V. Comasseto, unpublished results.

[16] G. Boche, M. Schimeczek, J. Cioslowski, P. Piskorz, Eur. J. Org. Chem. (1998) 1851.

[17] T. Kauffmann, Angew. Chem. Int. Ed. Engl. 21 (1982) 410.

[18] T. Hiiro, N. Kambe, A. Ogawa, N. Miyoshi, S. Murai, N. Sonoda, Angew. Chem. Int. Ed. Engl. 26 (1987) 1187.

[19] S.M. Barros, J.V. Comasseto, J. Berriel, Tetrahedron Lett. 30 (1989) 7353.

[20] T. Kanda, T. Sugino, N. Kambe, N. Sonoda, Phosphorous Sulfur Silicon Relat. Elem. 67 (1992) 103.

[21] J. Terao, N. Kambe, N. Sonoda, Tetrahedron Lett. 37 (1996) 4741.

[22] M.A. de Araujo, J.V. Comasseto, Synlett (1995) 1145.

[23] J.P. Marino, F.C. Tucci, J.V. Comasseto, Synlett (1993) 761.

[24] F.C. Tucci, A. Chieffi, J.V. Comasseto, J.P. Marino, J. Org. Chem. 61 (1996) 4975.

[25] J.V. Comasseto, J. Berriel, Synthetic Commun. 20 (1990) 1681.

[26] F.C. Tucci, A. Chieffi, J.V. Comasseto, Tetrahedron Lett. 33 (1992) 5721.

[27] M.A. Araujo, R.E. Barrientos-Astigarraga, R.M. Ellensohn, J.V. Comasseto, Tetrahedron Lett. 40 (1999) 5115.

[28] R.E. Barrientos-Astigarraga, D.N. Moraes, J.V. Comasseto, Tetrahedron Lett. 40 (1999) 265.

[29] D.N. Moraes, R.E. Barrientos-Astigarraga, P. Castelani, J.V. Comasseto, Tetrahedron 56 (2000) 3327.

[30] J.V. Comasseto, J.T.B. Ferreira, J.A. Fontanilas-Val, J. Organomet. Chem. 277 (1984) 261.

[31] J.V. Comasseto, unpublished results.

[32] A. Chieffi, J.V. Comasseto, V. Snieckus, Synlett (2000) 269.

[33] A. Chieffi, J.V. Comasseto, Tetrahedron Lett. 35 (1994) 4063.

[34] A. Chieffi, J.V. Comasseto, Synlett (1995) 671.

[35] G. Zeni, J.V. Comasseto, Tetrahedron Lett. 40 (1999) 4619.

[36] J.V. Comasseto, unpublished results.

[37] M.J. Dabdoub, V.B. Dabdoub, J.P. Marino, Tetrahedron Lett. 41 (2000) 433.

[38] M.J. Dabdoub, V.B. Dabdoub, J.P. Marino, Tetrahedron Lett. 41 (2000) 437.