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Efficient and General Synthetic Method for Preparing Oligoenynes with Either *trans*- or *cis*-Olefinic Configuration

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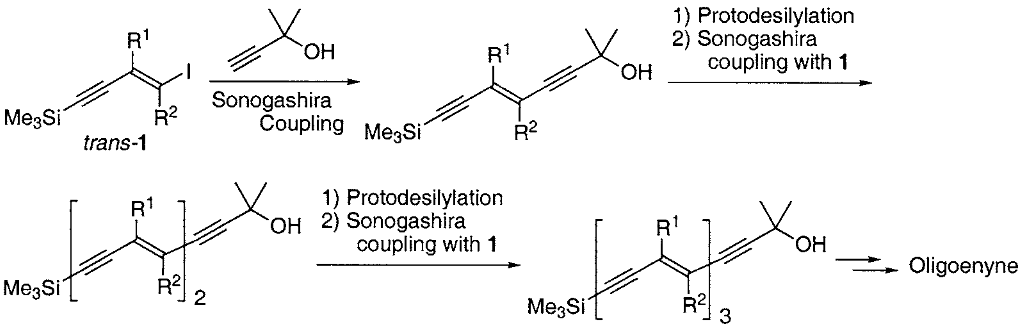
ABSTRACT



Efficient and practical synthesis of a variety of 1-iodo-4-trimethylsilylbut-1-en-3-yne derivatives with *trans*- and *cis*-olefinic configuration, and their repeated use as building blocks for the synthesis of *trans*- and *cis*-oligoenynes, respectively, are described.

Linear polymers and oligomers containing an iteratively π-conjugated carbon scaffold such as the ene-, enyne-, endiyne-, and yne-scaffold exhibit a variety of interesting electronic and optical properties.[1] Because variations in their molecular structure such as the chain length, olefin-geometry, olefinic substituent, and end-capping group can result in significant modifications of their properties, the development of synthetic methodology which allows access to a wide range of each of these π-conjugated compounds has attracted continuing interest.[2] Herein, we report a highly efficient and general synthetic method for preparing oligoenynes with either *trans*- or *cis*-olefinic configuration. Polymers and oligomers having an enyne-scaffold can be prepared by topochemical solid-state polymerization of suitably prearranged and substituted buta-1,3-diynes,[3] a requirement, however, that severely limits their accessibility. Wudl and Biter reported a synthetic method for preparing a systematic series of *trans*-oligoenynes using the coupling reaction of an alkynylmetal compound with *trans*-1,2-dihalo ethylene as the key reaction.[4] However, extension of this coupling method for synthesizing oligoenynes having olefinic substituent(s) failed.[5] An iterative approach to *cis*-oligoenynes with the Sonogashira coupling as the key reaction was reported by Hirsch and co-workers that allowed preparation of some kinds of oligoenyne with up to four triple and three double bonds, albeit the overall yield was rather low.[6]

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The characteristic features of our synthetic method for preparing oligoenynes include (1) efficient and practical synthesis of a variety of 1-iodo-4-trimethylsilylbut-1-en-3-yne derivative with *trans*- and *cis*-olefinic configuration, i.e., **1** and **2** shown in Figure 1, (2) repeated use of **1** and **2** as building blocks, for the synthesis of *trans*- and *cis*-oligoenynes, respectively, and (3) use of the Sonogashira coupling reaction as the key carbon-elongation reaction.[7]

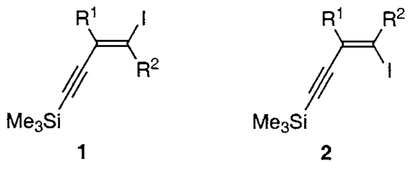
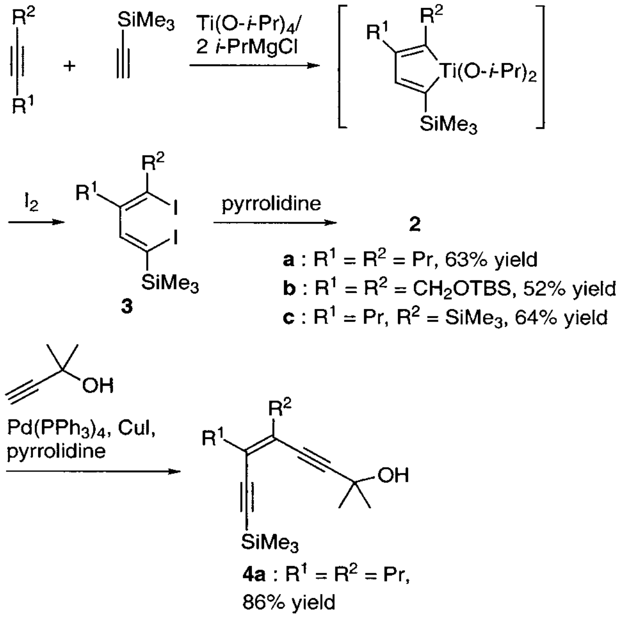


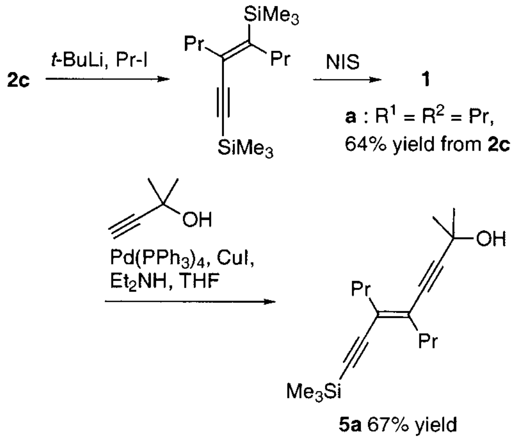
Figure 1.

Recently, we have developed a one-pot method for synthesizing 1-trimethylsilyl-1,4-diiodo-1,3-alkadienes **3** via regioselective coupling of internal acetylenes and ethynyltrimethylsilane mediated by a divalent titanium reagent Ti(O-*i*-Pr)$_4$/2 *i*-PrMgCl, and the following reaction of the resulting titanacyclopentadienes with I$_2$.[8,9] We have now found that treatment of crude **3** with pyrrolidine afforded **2** in high overall yield as shown in Scheme 1. Meanwhile, enynes **1** can be synthesized from **2** obtained by using 1-trimethylsilyl-1-alkynes as the internal acetylene by the conventional reaction sequence, as exemplified by the production of **1a** from **2c** as shown in Scheme 2. As also shown in Schemes 1 and 2, the Sonogashira coupling of **2** or **1** thus obtained with 3-methyl-1-butyn-3-ol provided endiynes **4** and **5**, respectively, which can be utilized as the terminal unit for synthesizing polyenyne oligomers (vide infra).

Scheme 1

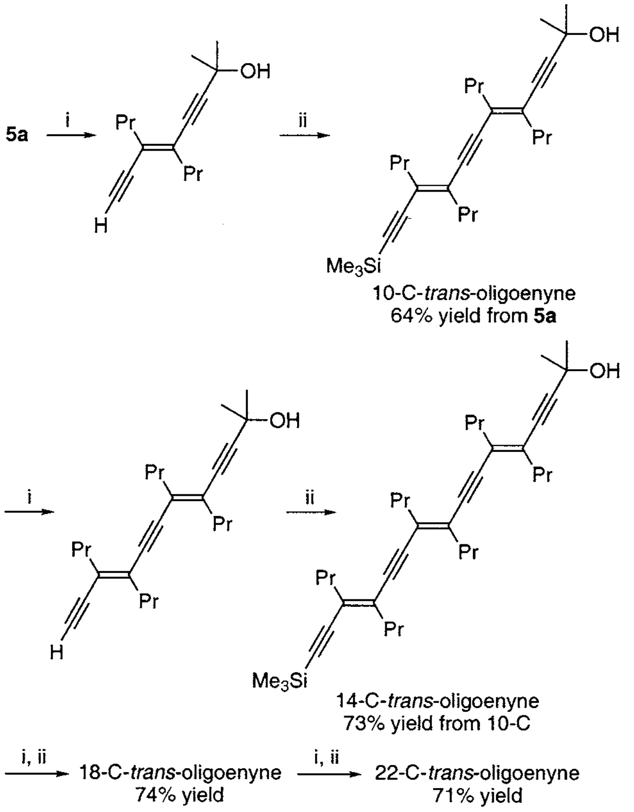


Scheme 2



Using **1a** and **5a** thus obtained, we carried out the synthesis of the corresponding *trans*-oligoenynes by sequential reactions which involve the Sonogashira coupling of **1a** with a terminal alkyne and removal of the trimethylsilyl group of the resulting product affording a new terminal alkyne, which

Scheme 3. Synthesis of *trans*-Oligoenynes[a]



[a] Reagents: (i) K$_2$CO$_3$, THF, MeOH, H$_2$O; (ii) **1a**, Pd(PPh$_3$)$_4$, CuI, Et$_2$NH, THF.

can be used for the next coupling with **1a**. Thus, oligoenyne with a 10-carbon atom backbone was prepared in 64% yield from **1a** and **5a** which, in turn, was converted into oligoenyne having a 14-carbon backbone in 73% yield by coupling, after desilylation, with **1a**. Applying these sequential reactions, oligoenynes with an 18- and a 22-carbon atom backbone were also prepared in good yield, respectively, as shown in Scheme 3. In the step of the Sonogashira coupling of **1a** with the terminal acetylenes, we used 2 equiv of **1a** to suppress production of the homo-coupling product of the terminal acetylenes. Even under these reaction conditions, 10−20% of the homo-coupling product was always coproduced; however, the homo-coupling product, which is a diol derivative, and the cross-coupling product, that is a monool derivative, and the starting nonpolar **1a** could be readily separated by column chromatography, and **1a** used in excess amount was recovered in excellent yield.

Using a similar reaction strategy, *cis*-oligoenynes having up to a 22-carbon atom backbone were prepared starting from **2a** and **4a** in the yields shown in Scheme 4. It should be noted that the Sonogashira coupling of **2a** with **4a** with the reagent shown in Scheme 3 afforded almost equal amounts of the cross- and homo-coupling products; however, use of $Pd_2(dba)_3$-dppb-CuI as the reagent improved the ratio of the cross- and homo-coupling products to 65:35. Thus, we used the latter reagent for the Sonogashira coupling for the synthesis of *cis*-oligoenynes. In these reactions the resulting cross- and homo-coupling product also can be readily separated by column chromatography.

Scheme 4. Synthesis of *cis*-Oligoenynes[a]

4a $\xrightarrow{\text{i, ii}}$ 10-C-*cis*-oligoenyne $\xrightarrow{\text{i, ii}}$ 14-C-*cis*-oligoenyne
57% yield from **4a** 42% yield from 10-C

$\xrightarrow{\text{i, ii}}$ 18-C-*cis*-oligoenyne $\xrightarrow{\text{i, ii}}$ 22-C-*cis*-oligoenyne
50 % yield from 14-C 48% yield from 18-C

[a] Reagents: (i) K_2CO_3, THF, MeOH, H_2O; (ii) **2a**, $Pd_2(dba)_3$, dppb, CuI, pyrrolidine.

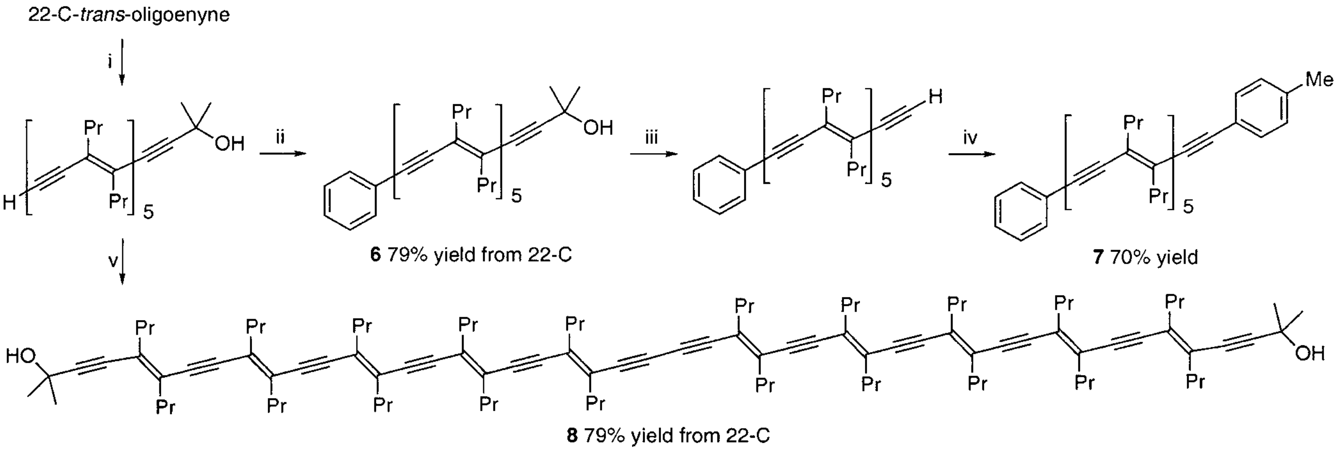
Oligoenynes thus obtained can be readily manipulated as exemplified by the transformation of 22-C-*trans*-oligoenyne shown in Scheme 5. Oligoenynes **7** having a different aryl end-cap can be readily synthesized by the successive deprotection of the trimethylsilyl group and 2-hydroxyisopropyl group and Sonogashira coupling, respectively, with an aryl iodide. The homo-coupling reaction of the oligoenyne under Hay condition[10] after desilylation afforded poly-π-conjugated oligomer **8** with 12 triple and 10 double bonds.

The electronic absorption spectra of the *trans*- and *cis*-oligoenynes thus prepared were measured in hexane at room temperature. The longest wavelength absorption maxima λ_{max} are summarized in Table 1. From Table 1, the following interesting trend can be seen, namely, that the longest energy electronic absorption in the series 10- to 14- to 18- to 22-C-oligoenynes goes from 346 to 385 to 386 to 400 nm for *trans*-oligoenynes, respectively, while for *cis*-oligoenynes, the conjugated lengths had already reached saturation and essentially the λ_{max} values for each of these *cis*-oligoenynes remained similar, around 345 nm.

Table 1. UV/Vis Data of *trans*- and *cis*-Oligoenynes

	λ_{max} [nm] (ϵ [M^{-1} cm^{-1}])	
	trans-oligoenyne	*cis*-oligoenyne
10-C	346 (24 700)	343 (16 500)
14-C	385 (35 200)	348 (24 700)
18-C	386 (65 900)	351 (31 000)
22-C	400 (67 700)	340 (17 600)
6	401 (25 500)	
7	402 (21 600)	
8	427 (68 200)	

Scheme 5. Manipulation of 22-C-*trans*-Oligoenyne[a]



[a] Reagents: (i) K_2CO_3, MeOH, THF, H_2O; (ii) PhI, $Pd(PPh_3)_4$, pyrrolidine; (iii) NaOH, toluene; (iv) 4-iodotoluene, $Pd(PPh_3)_4$, pyrrolidine; (v) CuCl, TMEDA, O_2.

Although we prepared oligoenynes using **1a** and **2a** as building blocks, a variety of **1** and **2** are accessible as shown in Schemes 1 and 2, and therefore, the present synthetic method might allow access to an oligoenyne with the designed structure.

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Supporting Information Available: Experimental procedures, spectroscopic date, and physical properties of **1a**, **2a**, **2c**, **4a**, **5a**, *trans*- and *cis*-oligoenynes, **6**, **7**, and **8**. This material is available free of charge via the Internet at http://pubs.acs.org.

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