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CHINESE CHEMICAL LETTERS

Chinese Chemical Letters 22 (2011) 785-788

www.elsevier.com/locate/cclet

Synthesis of polynorbornene with pendant moiety bearing azide and terminal alkyne groups

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> Received 11 October 2010 Available online 19 April 2011

Abstract

A powerful approach to the synthesis of an unprecedented polynorbornene with pendant moiety bearing azide and terminal alkyne groups is developed. Two key intermediates, namely, 3-azido-5-(2-(trimethylsilyl)ethynyl) benzyl alcohol and 4-(4-aza-tricyclo [5.2.1.0^{2.6}]dec-8-en-4-yl) benzoic acid, were optimally synthesized for convergent synthesis of the corresponding monomer.

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Keywords: Polynorbornene; Azide; Alkyne; Esterification; Metathesis

Terminal alkynes and azides have broad applications in organic synthesis. Especially, the 1,3-dipolar cycloaddition between these functional groups exhibits great efficiency for the formation of triazole and has been well known as the most representative reaction in click chemistry, which has been attracting a great deal of interest since it can provide a powerful and broadly applicable method for researches in materials chemistry, medicinal chemistry, bioconjugation, *etc.* [1]. Molecules bearing both terminal alkyne and azide groups can be transformed into photoelectric polytriazole *via* self-cycloaddition. Thus the construction of this kind of multifunctional groups-containing structures is of great importance for development of advanced materials [2]. On the other hand, norbornenes have been employing as important monomers in ring-opening metathesis polymerizations (ROMP) for the synthesis of various polynorbornenes with high glass transition temperatures, high light harvesting and liquid crystal properties, high optical clarity, *etc.* [3]. These points prompted us to explore an efficient synthesis of the entitled polymer as preliminary work for single-stranded polynorbornene-templated synthesis of photoelectric polytriazoles.

1. Results and discussion

We first investigated on the synthesis of intermediate **6** as shown in Scheme 1. By following reported procedure [4], 3-iodo-5-nitrobenzyl alcohol (**1**) was easily obtained in 63% overall yield starting from 3,5-dinitrobenzoic acid *via* three steps: (1) reduction of carboxyl group into hydroxymethyl by borane; (2) selective reduction of nitro group into

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Scheme 1. Synthesis of intermediate 6.

amine with freshly prepared $(NH_4)_2S$; (3) diazotization and thus iodination of amino group. With compound **1** in hand, we explored three different potential ways towards **6**. Although pathway **1–2–3–6** can afford the desired compound **6** [5], the final transformation of **3–6** was achieved in very poor yield due to cycloaddition of **3** with trimethylsilylacetylene under the Sonogashira coupling condition. We have also turned to pathway **1–4–5–6**. But after the reduction of **4** using SnCl₂, the desired amine **5** was contaminated with the corresponding TMS-leaving byproduct, which is hard to be completely avoided during the afterward basification process, leading to tedious purification. To circumvent these problems, we finally employed the **1–2–5–6** route towards this target molecule in 66% overall yield.

As to the synthesis of the other key intermediate **10**, it was previously prepared by Cannizzaro reaction from the corresponding aldehyde, which was obtained by oxidation of the corresponding benzyl alcohol with 2,3-dichloro-5,6-dicyanobenzoquinone (DDQ) [3d]. It is obvious that this method involves more reaction steps, harsh condition, low yield and relatively expensive reagents. Herein, we developed a more straightforward and efficient method as shown in Scheme 2, in which a classical bromobenzene-benzoic acid transformation was employed. In addition, it should be noted that the reduction of maleimide **8** with LiAlH₄ involves cosolvent (CH_2Cl_2) and very long reaction time. We



Scheme 2. Synthesis of intermediate 10.



Scheme 3. Synthesis of target polymer 13.

have tentatively elevated the temperature to shorten the reaction time, but this condition led to significant removal of bromine. The present protocol gave an overall yield of 59% *via* only three steps from compound 7 [6] to norbornene benzoic acid **10**.

Esterification of 3-azido-5-(2-(trimethylsilyl)ethynyl) benzyl alcohol **6** with 4-(4-aza-tricyclo[5.2.1.0^{2.6}]dec-8-en-4-yl)benzoic acid **10** afforded monomer **11** in 71% yield. ROMP of **11** with $(Cy_3P)_2Cl_2Ru = CHPh$ (Grubbs I catalyst) in CH₂Cl₂ under nitrogen atmosphere gave the corresponding single-stranded polynorbornnene **12**, which was easily converted into the final polynorbornene **13** with pendant moiety bearing azide and terminal alkyne groups by removal TMS with potassium carbonate (Scheme 3). The completion of this transformation is highly identified by ¹H NMR and IR analysis. In detail, the signal at 0.23 ppm (TMS) in the ¹H NMR of polymer **12** can not be observed in that of polymer **13**, while the signal at 3.2–3.3 ppm in the ¹H NMR of polymer **13** is enhanced comparing with that of polymer **12**, which can be ascribed to hydrogen in terminal alkyne (C=CH). This point can also be confirmed by the fact that absorption peak at 2162 cm⁻¹ in the IR of polymer **12** shifted to 2130 cm⁻¹ in that of polymer **13**. That is, middle carbon–carbon triple bond changes to the terminal one. GPC analysis demonstrates that the obtained polymers contain around 37 repeated units [8].

In summary, we have successfully developed an efficient synthesis of an unprecedented polynorbornene with pendant moiety bearing azide and terminal alkyne groups. Based on the present investigation, further extension of this unique polymer system into intramolecular click reaction between the azide and terminal groups in the pendant group is in progress in our laboratory. It is reasonablely anticipated as a potential precursor for complementary synthesis of polytriazoles difficult to be directly obtained from the corresponding azide and terminal alkyne groups-containing monomers.

Acknowledgment

We are grateful to financial support from National Science Foundation of China (No. 20902002) and Anhui Provincial Natural Science Foundation (No. 10040606Q04).

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- [8] 3-Amino-5-iodobenzyl alcohol (2) mp 66–68 °C; ¹H NMR (300 MHz, CDCl₃); δ 2.07 (br, 1H), 3.92 (br, 2H), 4.81 (s, 2H), 6.45 (s, 1H), 6.86 (s, 1H), 7.02 (s, 1H); IR (film): 3370, 2974, 2872, 749 cm⁻¹. 3-Azido-5-iodobenzyl alcohol (**3**) mp 89–91 °C; ¹H NMR (300 MHz, CDCl₃): δ 1.91 (br, 1H), 4.71 (s, 2H), 7.09 (s, 1H), 7.47 (s, 1H), 7.67 (s, 1H); IR (film): 3330, 2980, 2878, 2113, 789 cm⁻¹. 3-Nitro-5-(2-(trimethylsily-1)ethynyl)benzyl alcohol (4) mp 82–84 °C; ¹H NMR (300 MHz, CDCl₃): δ 0.26 (s, 9H), 1.95 (br, 1H), 4.79 (s, 2H), 7.76 (s, 1H), 8.17 (s, 1H), 8.20 (s, 1H); IR (film): 3305, 2968, 2165, 1535, 1347 cm⁻¹. 3-Amino-5-(2-(trimethylsilyl)ethynyl)benzyl alcohol (5) mp 78-80 °C; ¹H NMR (300 MHz, CDCl₃); & 0.23 (s, 9H), 2.70–3.25 (br, 3H), 4.56 (s, 2H), 6.67 (s, 1H), 6.72 (s, 1H), 6.87 (s, 1H); IR (film): 3365, 2975, 2873, 2161 cm⁻¹. 3-Azido-5-(2-(trimethylsilyl)ethynyl)benzyl alcohol (6) mp 88–90 °C; ¹H NMR (300 MHz, CDCl₃): δ 0.25 (s, 9H), 2.11 (br, 1H), 4.62 (s, 2H), 6.96 (s, 1H), 7.02 (s, 1H), 7.20 (s, 1H); IR (film): 3308, 2974, 2872, 2163, 2118 cm⁻¹; HR-MS (ESI) calcd. for C₁₂H₁₅N₃OSi (M⁺): 245.0984, found: 245.0982. 4-(3,5-Dioxo-4-aza-tricyclo[5.2.1.0^{2,6}]dec-8-en-4-yl)-bromide (8) mp 153–155 °C (Lit. [7] 156 °C); ¹H NMR (400 MHz, CDCl₃): δ 1.59 (d, 1H, J = 8.8 Hz), 1.77 (d, 1H, J = 8.8 Hz), 3.41–3.42 (m, 2H), 3.48–3.50 (m, 2H), 6.23 (t, 2H, J = 1.8 Hz), 7.02 (d, 1H, J = 8.8 Hz), 7.02 (d, 1Hz), 7.02 (d, 1Hz), 7.02 (d, 1Hz), 7.02 (d, 1Hz), 2H, J = 8.6 Hz), 7.53 (d, 2H, J = 8.6 Hz). 4-(4-Azatricyclo[5.2.1.0^{2.6}]dec-8-en-4-yl)-phenyl bromide (9) mp 156–158 °C; ¹H NMR (400 MHz, CDCl₃): δ 1.50 (d, 1H, J = 8.2 Hz), 1.60 (d, 1H, J = 8.2 Hz), 2.82–2.85 (m, 2H), 2.95–2.96 (m, 2H), 3.04–3.07 (m, 2H), 3.15–3.20 (m, 2H), 6.14 (t, 2H, J = 1.9 Hz), 6.28 (d, 2H, J = 8.8 Hz), 7.23 (d, 2H, J = 8.8 Hz); ¹³C NMR (100 MHz, CDCl₃): 845.5, 46.5, 50.6, 52.1, 107.2, 113.4, 131.6, $135.8, 146.4; IR (film): 3056, 2970, 2955, 2887, 1592, 1503, 1475, 1374, 793, 722 \ cm^{-1}. HR-MS (FAB) calcd. for C_{15}H_{16}BrN (M^+): 289.0466, 1400,$ Found: 289.0467. 4-(4-Azatricyclo[5.2.1.0^{2.6}]dec-8-en-4-yl)-benzoic acid (10) mp 306–308 °C (Lit. [3d]. 310 °C, dec.); ¹H NMR (400 MHz, DMSO-d₆): δ 1.48 (s, 2H), 2.88–2.91 (m, 2H), 2.94–2.95 (m, 2H), 3.05–3.07 (m, 2H), 3.21–3.23 (m, 2H), 6.15 (t, 2H, J = 1.9 Hz), 6.40 (d, 2H, J = J = 8.9 Hz), 7.69 (d, 2H, J = 8.9 Hz); ¹³C NMR (100 MHz, DMSO-d₆): 844.8, 46.1, 50.1, 51.6, 110.9, 116.3, 130.9, 135.8, 150.0, 167.6; HR-MS (FAB) calcd. for C₁₆H₁₇NO₂ (M⁺): 255.1259, found: 255.1264. Monomer 11 mp 172–174 °C; ¹H NMR (300 MHz, CDCl₃): δ 0.25 (s, 9H), 1.52 (d, 1H, J = 8.6 Hz), 1.62 (d, 1H, J = 8.6 Hz), 2.94–3.33 (m, 8H), 5.23 (s, 2H), 6.16 (s, 2H), 6.39 (d, 2H, J = 8.7 Hz), 7.01 (s, 1H), 7.07 (s, 1H), 7.28 (s, 1H), 7.89 (d, 2H, J = 8.7 Hz); ¹³C NMR (75 MHz, CDCl₃): δ -0.2, 45.4, 46.6, 50.5, 52.1, 64.1, 95.5, 103.6, 110.8, 116.6, 117.4, 121.1, 124.7, 126.6, 131.2, 135.8, 140.4, 142.9, 150.3, 168.3; IR (film): 2967, 2939, 2856, 2160, 2116, 1693, 1608, 1525, 1479 1384, 1364, 1278 cm⁻¹; HR-MS (FAB) calcd. for C₂₈H₃₀N₄O₂Si (M⁺): 482.2138, found: 482.2134. Polymer **12** ¹H NMR (300 MHz, CDCl₃): δ 0.23 (brs, 9 H), 1.32 (brs, 1 H), 1.83 (brs, 1 H), 2.73 (brs, 2 H), 2.89 (brs, 2 H), 3.24 (brs, 4 H), 5.20 (brs, 2 H), 5.36 (brs, 2 H), 6.48 (brs, 2 H), 6.99 (brs, 1 H), 7.04 (brs, 1 H), 7.25 (brs, 1 H), 7.89 (brs, 2 H); IR (KBr): 2965, 2930, 2162, 2114, 1720, 1606, 1527, 1350, 1271, 720 cm⁻¹; GPC (THF): $M_n = 17800$; PDI = 1.36. Polymer 13 ¹H NMR (300 MHz, CDCl₃): δ 1.31 (brs, 1H), 1.87 (brs, 1H), 2.73–2.92 (brs, 4H), 3.31 (brs, 5H), 5.22 (brs, 2H), 5.34 (brs, 2H), 6.56 (brs, 2H), 6.99–7.05 (brs, 2H), 7.25 (brs, 1H), 7.92 (brs, 2H); IR (KBr): 3323, 2963, 2932, 2130, 2110, 1721, 1604, 1528, 1353, 1270, 721 cm⁻¹; GPC (THF): $M_n = 15100$; PDI = 1.36.