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Enantioselective Synthesis of the C(1)–C(11) Fragment of Tedanolide C

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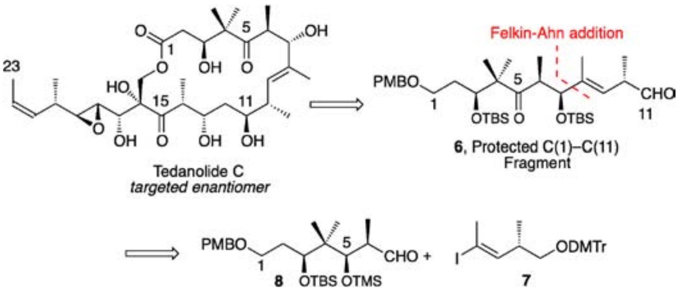
ABSTRACT



A convergent synthesis of the protected C(1)–C(11) fragment 6 of the targeted enantiomer of tedanolide C is described. The key step of the synthesis is the Felkin–Ahn addition of vinyl iodide 7 to aldehyde 8 that proceeds in 80% yield with 4:1 diastereoselectivity.

The isolation and structure determination of tedanolide C (**1**), a marine natural product isolated from a Papua New Guinea sponge of the *Ircinia* species, was reported by Ireland and co-workers in 2006.[1] Other members of the tedanolide family include tedanolide (**2**),[2] 13-deoxytedanolide (**3**),[3] and the candidaspongiolides (**4**, Figure 1).[4] The structure and relative stereochemistry of tedanolide C (**1**) was assigned by using NMR methods and DFT calculations, but the absolute stereochemistry remains unconfirmed.[1] Tedanolide C exhibits excellent potency against HCT-116 cells (colorectal cell line), with an IC_{50} value of 0.057 μg/mL (90 nM), and stops the growth of HCT-116 cells in the S-phase after 24 h of exposure at 0.2 μg/mL.[1] It has been postulated that tedanolide C is a protein synthesis inhibitor, like its closely related congener, 13-deoxytedanolide. Surprisingly, however, the structure reported for **1** depicts the C(11)–C(23) fragment with an enantiomeric configuration (except for the epoxide) relative to other members of the tedanolide family. The C(10)–C(23) fragment has been identified as the key pharmacophoric unit of 13-deoxytedanolide.[5] Therefore, in planning a synthesis of tedanolide

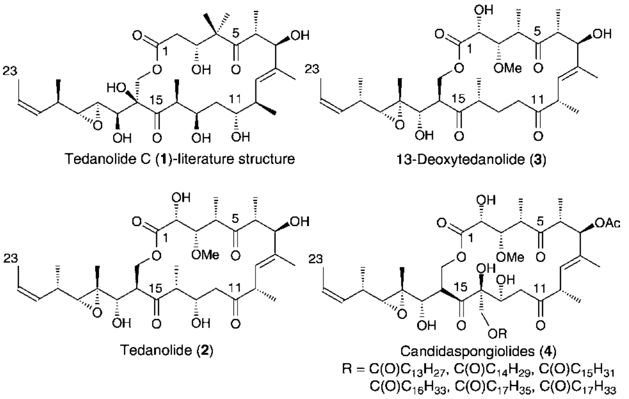


Figure 1. Tedanolide natural product family.

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[1] Chevallier, C.; Bugni, T. S.; Feng, X.; Orendt, A. M.; Ireland, C. M. *J. Org. Chem.* **2006**, *71*, 2510.

[2] Schmitz, F. J.; Gunasekera, S. P.; Yalamanchili, G.; Bilayet Hossain, M.; Van Der Helm, D. *J. Am. Chem. Soc.* **1984**, *106*, 7251.

[3] Fusetani, N.; Sugawara, T.; Matsunaga, S.; Hirota, H. *J. Org. Chem.* **1991**, *56*, 4971.

[4] (a) Meragelman, T. L.; Willis, R. H.; Woldemichael, G. M.; Heaton, A.; Murphy, P. T.; Snader, K. M.; Newman, D. J.; Van Soest, R.; Boyd, M. R.; Cardellina, J. H.; McKee, T. C. *J. Nat. Prod.* **2007**, *70*, 1133. (b) Whitson, E. L.; Pluchino, K. M.; Hall, M. D.; McMahon, J. B.; McKee, T. C. *Org. Lett.* **2011**, *13*, 3518.

[5] (a) Nishimura, S.; Matsunaga, S.; Yoshida, M.; Hirota, H.; Yokoyama, S.; Fusetani, N. *Bioorg. Med. Chem.* **2005**, *13*, 449. (b) Nishimura, S.; Matsunaga, S.; Yoshida, S.; Nakao, Y.; Hirota, H.; Fusetani, N. *Bioorg. Med. Chem.* **2005**, *13*, 455.

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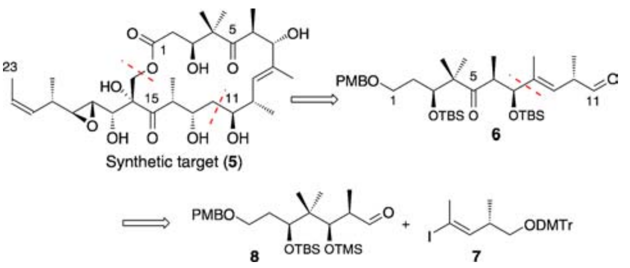
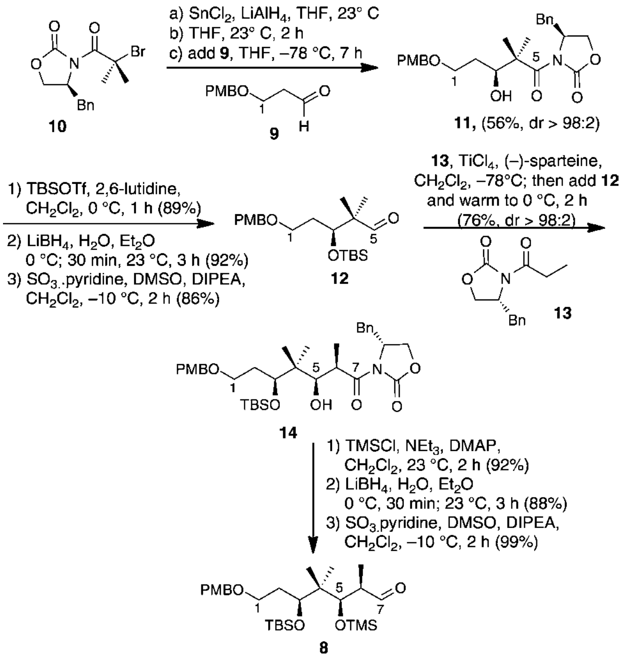
C (**1**) we decided to pursue the enantiomeric structure **5** as the synthetic target (Scheme 1) in anticipation that the configuration of the C(11)–C(23) unit of tedanolide C should be the same as that for the key C(10)–C(23) pharmacophore of 13-deoxytedanolide.

In 2010 our laboratory reported the synthesis of the C(15)–C(21) fragment of **5**.[6] Kalesse et al. subsequently published their synthesis of the C(14)–C(23) fragment of a diastereomeric analog of tedanolide C using a Kiyooka aldol reaction.[7,8] More recently still, a synthesis of the C(1)–C(12) fragment has been reported by Smith et al. by a route involving an asymmetric hydroformylation of a 1,3-diene.[9] We report herein our synthesis of **6**, a protected version of the C(1)–C(11) fragment of the targeted enantiomer of tedanolide C.

Scheme 1. Strategy for the Synthesis of the Protected C(1)–C(11) Fragment of the Targeted Enantiomer of Tedanolide C



Scheme 2. Synthesis of Aldehyde **8**



Our strategy for the synthesis of fragment **6** (Scheme 1) involves the formation of the secondary C(7) hydroxyl group by addition of vinyl iodide **7** to aldehyde **8**. We anticipated that the C(7) alcohol stereochemistry would be controlled by accessing a Felkin–Ahn transition state for the carbonyl addition.[10] Aldehyde **8** was synthesized starting from the known aldehyde **9**[11] (Scheme 2). Subjection of **9** to an enantioselective Reformatsky-type reaction[12] with oxazolidinone **10**[13] in the presence of $SnCl_2$ afforded **11** in 56% yield with >98:2 dr. The absolute configuration of the hydroxyl group at C(3) of **11** was confirmed by using the advanced Mosher ester method.[14] Protection of alcohol **11** as a TBS ether using TBSOTf and 2,6-lutidine, followed by reduction of the acyl oxazolidinone with $LiBH_4$ and subsequent Parish–Doering oxidation[15] of the primary alcohol, afforded aldehyde **12**.[16] The *syn* aldol reaction between **12** and propionyl oxazolidinone **13**[17] was performed in the presence of $TiCl_4$ and (–)-sparteine[18] and gratifyingly afforded aldol **14** in 76% yield as a single diastereomer. The use of (–)-sparteine in this reaction was essential to obtain synthetically useful diastereoselectivity; the aldol reaction of the titanium enolate generated with diisopropylethyl amine (DIPEA) as the base afforded a 1:1 mixture of diastereomers. Protection of the newly formed hydroxyl group of **14** as a TMS ether, followed by reduction of the acyl oxazolidinone with $LiBH_4$ and oxidation of the primary alcohol with $SO_3 \cdot$pyridine,[15] completed this synthesis of aldehyde **8**.

The stereochemistry of aldol **14** was verified by the studies summarized in Scheme 3. Alcohol **15**, obtained in two steps from **14**, was elaborated into diol **16** in 62% yield by benzylation of the primary alcohol[19] and deprotection of the two silyl ethers. Analysis of the ^{13}C NMR spectrum of the derived acetonide **17** using Rychnovsky's method[20] confirmed the *syn* relationship between C(3)–OH and C(5)–OH. Independently, acetonide **18** was also generated in two steps from alcohol **15**. The small H_a–H_b and H_a–H_c coupling constants ($J < 2$ Hz) observed in the ^1H NMR spectrum of **18** suggested that this compound

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[6] Barth, R.; Roush, W. R. *Org. Lett.* **2010**, *12*, 2342.

[7] Bülow, L.; Naini, A.; Fohrer, J.; Kalesse, M. *Org. Lett.* **2011**, *13*, 6038.

[8] Kalesse's synthetic target has the C(10)–C(23) stereochemistry, the same as that for our target **5**, but has C(1)–C(7) stereochemistry, the same as that in the originally proposed structure for tedanolide C (**1**).

[9] Smith, T. E.; Fink, S. J.; Levine, Z. G.; McClelland, K. A.; Zackheim, A. A.; Daub, M. E. *Org. Lett.* **2012**, *14*, 1452.

[10] (a) Cherest, M.; Felkin, H.; Prudent, N. *Tetrahedron Lett.* **1968**, 2199. (b) Anh, N. T.; Eisenstein, O. *Nouv. J. Chim.* **1977**, *1*, 61.

[11] Oka, T.; Murai, A. *Tetrahedron* **1998**, *54*, 1.

[12] (a) Kögl, M.; Brecker, L.; Warrass, R.; Mulzer, J. *Angew. Chem., Int. Ed.* **2007**, *46*, 9320. (b) Kögl, M.; Brecker, L.; Warrass, R.; Mulzer, J. *Eur. J. Org. Chem.* **2008**, 2714.

[13] Kende, A. S.; Kawamura, K.; Orwat, M. J. *Tetrahedron Lett.* **1989**, *30*, 5821.

[14] (a) Dale, J. A.; Mosher, H. S. *J. Am. Chem. Soc.* **1973**, *95*, 512. (b) Hoye, T. R.; Jeffrey, C. S.; Shao, F. *Nat. Protoc.* **2007**, *2*, 2451.

[15] Parikh, J. R.; von Doering, E. W. *J. Am. Chem. Soc.* **1967**, *89*, 5505.

[16] Hartung, I. V.; Niess, B.; Haustedt, L. O.; Hoffmann, H. M. R. *Org. Lett.* **2002**, *4*, 3239.

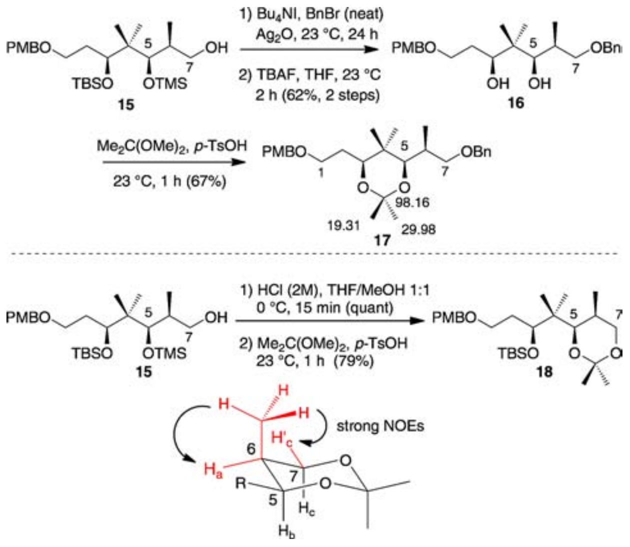
[17] Evans, D. A.; Bartroli, J.; Shih, T. L. *J. Am. Chem. Soc.* **1981**, *103*, 2127.

[18] Crimmins, M. T.; King, B. W.; Tabet, E. A.; Chaudhary, K. *J. Org. Chem.* **2001**, *66*, 894.

[19] Brummond, K. M.; Hong, S.-P. *J. Org. Chem.* **2005**, *70*, 907.

[20] Rychnovsky, S. D.; Rogers, B.; Yang, G. *J. Org. Chem.* **1993**, *58*, 3511.

Scheme 3. Stereochemical Assignments

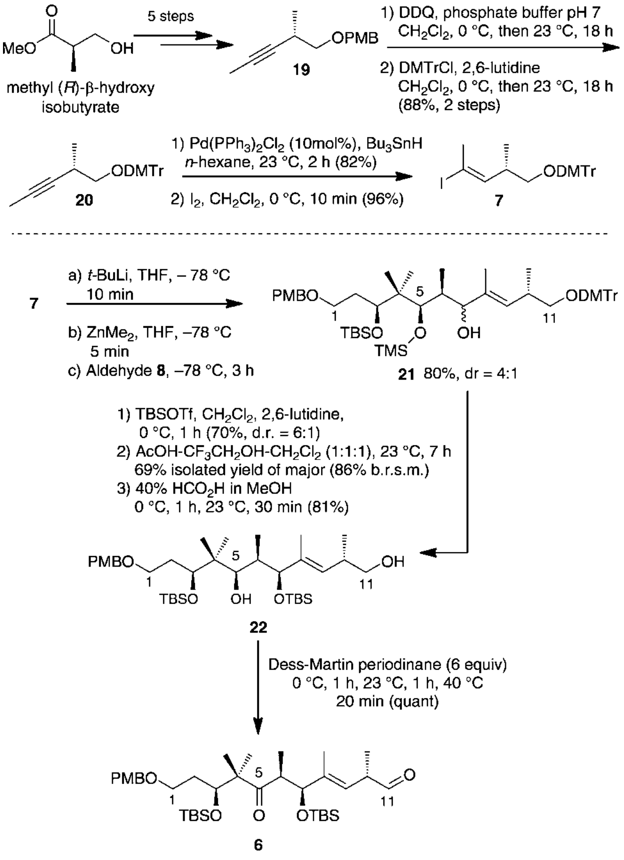


adopts a chairlike conformation in which H_a is in an equatorial position. Furthermore, the ^1H NOE data obtained for **18** highlighted in Scheme 3 supported the assignment of *syn* stereochemistry between C(5)−OH and C(6)−CH_3 in aldol **14**.

Vinyl iodide **7** was synthesized from alkyne **19**,[21] which is available in five steps from commercial methyl (*R*)-*β*-hydroxyisobutyrate (Scheme 4). We considered **19** to be a useful intermediate as the protecting group for the primary hydroxyl group can be easily removed and modified. Deprotection of the *p*-methoxybenzyl (PMB) ether was accomplished by treatment of **19** with DDQ at 0 °C in a 1:1 mixture of pH 7 phosphate buffer and CH_2Cl_2. The volatile propargyl alcohol was quickly treated with dimethoxytrityl chloride (DMTrCl) to give **20** in 88% yield over these two steps. Hydrostannylation of **20** using freshly distilled Bu_3SnH proceeded in 82% yield and with 93:7 regioselectivity. Treatment of the vinylstannane with I_2 afforded vinyl iodide **7** almost quantitatively.[22]

In a first attempt toward the coupling of **7** and **8**, treatment of **7** with *t*BuLi (2.2 equiv) at −78 °C, followed by addition of **8** at −78 °C, provided **21** as a 1:1 ratio of diastereomers. It has been reported that vinyl zincates provide higher diastereoselectivity upon addition to chiral aldehydes than the corresponding vinyl lithium reagents.[23] Thus, as shown in Scheme 4, treatment of vinyl iodide **7** with 2.2 equiv of *t*BuLi at −78 °C for 10 min, followed by addition of 1.1 equiv of $ZnMe_2$ at −78 °C for 5 min, afforded a solution of the vinyl zincate reagent. To this solution was added a solution of aldehyde **8**, and the mixture was stirred for 3 h at −78 °C prior to workup.

Scheme 4. Synthesis of the C(1)−C(11) Fragment **6** of Tedanolide C



This procedure provided alcohol **21** in 80% yield as a 4:1 mixture of diastereomers that were not separated at this stage. The absolute configuration of the C(7) hydroxyl group of the major diastereomer was assigned by using the advanced Mosher ester method.[14] Protection of the C(7) hydroxyl group of **21** as a TBS ether proceeded in 70% yield. In the next step, the DMTr protecting group was removed selectively by treatment of the fully protected intermediate with a 1:1:1 mixture of AcOH, trifluoroethanol, and CH_2Cl_2 without removal of the TMS ether.[24] Gratifyingly, this step enabled the separation of the two C(7)-diastereomers by standard column chromatography; the major diastereomer was isolated in 62% yield from this sequence (86% b.r.s.m.). The hindered C(5)−OTMS ether protecting group was removed in a subsequent step by using a solution of 40% HCO_2H in methanol, which afforded diol **22** in 81% yield.

For the final step of the synthesis of **6**, we expected the oxidation of the very hindered C(5)-hydroxyl group to be slower than the oxidation of the primary alcohol and were concerned that problems could arise with the *β*,*γ*-unsaturated aldehyde which in related systems is known to be sensitive toward epimerization at C(10). We selected the Dess-Martin periodinane reagent[25] for this step, since

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[21] Organ, M. G.; Wang, J. *J. Org. Chem.* **2003**, *68*, 5568.

[22] Sun, X. -Y.; Tian, X. -Y.; Li, Z. -W.; Peng, X. -S.; Wong, H. N. C. *Chem.—Eur. J.* **2011**, *17*, 5874.

[23] (a) Hayashi, Y.; Shoji, M.; Ishikawa, H.; Yamaguchi, J.; Tamura, T.; Imai, H.; Nishigaya, Y.; Takabe, K.; Kakeya, H.; Osada, H. *Angew. Chem., Int. Ed.* **2008**, *47*, 6657. (b) Marshall, J. A.; Eidam, P. *Org. Lett.* **2004**, *6*, 445.

[24] Matysiak, S.; Böldicke, T.; Tegge, W.; Frank, R. *Tetrahedron Lett.* **1998**, *39*, 1733.

this reagent is known to be useful for oxidations that give aldehyde products that are highly prone to epimerization when other oxidation conditions are used.[26] However complete oxidation of **22** could not be achieved by using 5 equiv of the Dess–Martin periodinane even when the reaction was performed for 1 h at ambient temperature. The reaction had to be gently heated to 40 °C for 20 min to drive the oxidation of the C(5) alcohol to completion. In this way, the fully protected C(1)–C(11) fragment **6** of tedanolide C was obtained as a single isomer in almost quantitative yield, with no evidence of epimerization at C(10).

In summary, we developed a diastereoselective synthesis of the protected C(1)–C(11) fragment **6** of the targeted enantiomer of tedanolide C in 13 steps starting from the known aldehyde **9**. The synthesis involves a $SnCl_2$ mediated enantioselective Reformatsky-type reaction to set the C(3) stereocenter and an Evans–Crimmins aldol reaction to set the *syn* relationship between C(5) and C(6). The C(7) stereocenter was set by the Felkin–Ahn controlled addition of the vinylzincate derived from vinyl iodide **7** to aldehyde **8**. The synthesis of **6** was completed by the Dess-Martin periodinane oxidation of the C(5)–C(11) diol unit. Further progress toward completion of a synthesis of tedanolide C will be reported in due course.

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Supporting Information Available. Experimental procedures and copies of ^1H and ^{13}C NMR spectra of new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

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(25) Dess, D. B.; Martin, J. C. *J. Am. Chem. Soc.* **1991**, *113*, 7277.

(26) Myers, A. G.; Zhong, B.; Movassaghi, M.; Kung, D. W.; Lanman, B. A.; Kwon, S. *Tetrahedron Lett.* **2000**, *41*, 1359.

The authors declare no competing financial interest.