Regular Article

Highlighted Paper selected by Editor-in-Chief

Stable and Selective Antiparallel Type Triplex DNA Formation by Targeting a GC Base Pair with the TFO Containing One \(N^2\)-Phenyl-2'-deoxyguanosine

Yosuke Taniguchi,* Mei Miyazaki, Nozomu Matsueda, Lei Wang, Hidenori Okamura, and Shigeki Sasaki*

Graduate School of Pharmaceutical Sciences, Kyushu University; 3–1–1 Maidashi, Higashi-ku, Fukuoka 812–8582, Japan.

Received January 21, 2018; accepted March 7, 2018

The antiparallel triplex DNA is formed by the interaction between purine-rich triplex forming oligonucleotides (TFOs) and the homo-purine region within a duplex DNA. The formation of such a structure with the genome DNA promises to control the gene expression in a living cell. In this study, in an attempt to enhance the stability of the triplex DNAs, we have designed the \(N^2\)-arylated deoxyguanosine derivatives. Among these analogues, we found that the TFOs containing \(N^2\)-phenyl-2'-deoxyguanosine (PhdG) showed a stable and selective triplex DNA formation with the GC base pair as compared to the natural dG/GC triplet. However, the multiple incorporation of PhdG into the TFOs hampered the stable triplex DNA, instead, showed a tendency to form a higher order structure. Therefore, we concluded that the stable and selective triplex DNA formation is expected by the replacement of dG by PhdG in the purine-rich TFO sequence.

Key words \(N^2\)-arylated deoxyguanosine; triplex forming oligonucleotide; triplex DNA

By forming the triplex DNA versus the duplex DNA, it is possible to control the gene expression, gene recombination, gene repair, etc. Therefore, the site specific and stable triplex DNA formation for the target duplex DNA is anticipated to become an important method for the gene targeting technologies and therapies as an antigenic method.\(^1\)\(^–\)\(^5\) The triplex DNA is formed by the interaction between the triplex forming oligonucleotides (TFOs) and the homopurine region within the duplex DNA.\(^6\) Triplex DNAs are classified into two types according to the orientation of the phosphate backbone of the TFOs. The antiparallel type triplex DNA is formed under neutral conditions, in which the TFOs composed of deoxyguanosine (dG) and deoxyadenosine (dA) form two hydrogen bonds in the guanine base of the GC base pair and the adenine base of the AT base pair of the duplex DNA, respectively, in an antiparallel orientation regarding the homopurine strand of the duplex DNA (Fig. 1A). On the other hand, the TFOs composed of deoxycytosine (dC) and thymidine (T) forms two hydrogen bond in the guanine base and adenine base of the homopurine strand in a parallel orientation, respectively. As the protonated cytidine is included in the parallel type triplex, its formation requires acidic conditions (Fig. 1B). To date, we have developed the artificial nucleoside analogues to form the nonnatural and antiparallel type triplex DNA for the duplex DNA containing the CG and TA base pair to expand the triplex recognition code.\(^7\)\(^–\)\(^12\) However, improvement of the stability of the antiparallel type triplex DNA by an artificial nucleic acid is a still challenging issue.

The stacking interaction has been shown to be more effective with the triplex DNA than with the duplex DNA. For example, adriamycin and actinomycin, having a high aromaticity, are known to interact with the duplex DNA, but have a rather high binding ability to the triplex DNA.\(^13\) Moreover, the duplex DNA containing \(N^2\)-phenyldideoxyguanosine (PhdG) showed a slightly higher thermal melting temperature \((T_m)\) value than the corresponding normal duplex DNA.\(^14\) Therefore, we anticipated that a stable triplex formation could be achieved by the molecular design of the \(N^2\) modified dG derivative aimed at enhancing the stacking interaction and/or hydrophobic interaction because it is located in the space of the

![Fig. 1. The Structure of the Base Triplet of the Antiparallel Type (A) and Parallel Type (B) Triplex DNA](image-url)
major groove side in the antiparallel type triplex DNA (Fig. 2A). In this study, we synthesized N^2-phenyl dG (PhdG), N^2-pyridinyl dG (PyrdG), N^2-pyrimidinyl dG (PymdG) and N^2-methyl pyrimidinonyl dG (MPdG) and evaluated the ability of the antiparallel type triplex DNA formation (Fig. 2B).

The syntheses of TFO1–11 incorporating N^2-arylated dG derivatives (1–4) are summarized in Chart 1. The key intermediate 5 was prepared according to a reported method. The chlorobenzene, 2-chloropyridine, 2-chloropyrimidine and 4-chloro-1-methylcytosine^6) as arylating agents were coupled with 5 to obtain the corresponding N^2-arylated dG derivatives (6a–d) in moderate yields. We tried various reagents and conditions to improve the yield, but the conditions of Pd(OAc)_2, Xanthos and toluene at 85°C were the best conditions for this step. They were then treated with triethylamine trihydrofluoride to afford the diol derivatives (7a–d), which were converted into the phosphoroamidite compounds (8a–d). After
The synthesis of the TFOs having the corresponding N2-arylated dG derivatives by the DNA synthesizer, the resin conjugated dimethoxytrityl-on (DMTr-on) TFOs \(1\)–\(11\) were treated with a 1 M 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) solution in acetonitrile for 30 min for removing the \(p\)-nitrophenylethyl group of the artificial nucleoside derivative, then they were cleaved from the resin and the protecting group of natural nucleoside removed using a 28% ammonia solution at 55°C for 12 h. The crude products were purified by HPLC, and deprotection of the DMTr group was done in 5% AcOH for 15 min. The obtained TFOs \(1\)–\(11\) were washed with Et2O, and their structures were identified by matrix-assisted laser desorption/ionization-time of flight (MALDI-TOF)/MS measurement.

The triplex forming abilities of TFOs \(1\)–\(11\) were evaluated by the gel shift assay using 100 nM FAM-labeled target duplexes in 20 mM Tris–HCl, 5 mM MgCl2, 2.5 mM spermidine, and 10% sucrose at pH 7.5. We initially evaluated the natural TFO (n-TFO) containing dG as a control oligonucleotide and TFOs \(1\)–\(4\) having one artificial nucleoside analogue. The gel results of n-TFO and TFOs \(1\)–\(4\) are shown in Fig. 3, and the triplex formations were identified by the lower mobility bands in the non-denatured polyacrylamide gel in comparison to the faster mobility bands of the FAM-labeled duplexes. The fluorescent intensities of all the triplex and duplex DNA bands were quantified, and the equilibrium association constants \(K_s\) were calculated from these bands and summarized in Table 1.

The natural TFO (n-TFO) showed the stable triplex formation with the GC base pair in the target duplex DNA. However, the triplex DNA was also observed for the AT base pair at a high concentration of n-TFO (Fig. 3). Interestingly, TFO1 having PhdG clearly formed the triplex DNA only with the GC base pair from a low concentration of TFO1. According to the \(K_s\) values of n-TFO and TFO1, the PhdG in the TFO enhanced the stability and selectivity for formation of the triplex DNA with the GC base pair in this sequence (Table 1, entries 1 and 2). Although TFO2, 3 and 4 having PydG, PymdG and MPdG, respectively, showed some stabilizing effect for the triplex formation with the CG, AT and TA base pair, it was observed that the \(K_s\) values slightly decreased for the GC base pairs as compared to the dG/GC triplet (Table 1, entries 3–5). Consequently, the selectivity and stability of the triplex DNA using TFO containing PydG, PymdG and MPdG were significantly decreased. In addition, TFO11, including six MPdGs, did not form the triplex DNA for any sequences with a high concentration condition (data not shown). These results may be due to the preferable formation of a closed-type conformation as shown in Fig. 4, in which the attachment of heterocyclic ring with the hydrogen acceptor atom at the N2 position of the guanine may disturb the suitable Hoogsteen hy-

---

**Fig. 3.** Gel Results of the Evaluation of Triplex Forming Ability of n-TFO and TFO1–4

Conditions: FAM-labeled duplex DNA (24 bp; 100 nM) was incubated with increasing concentrations of n-TFO and TFO1–4 (18 mer; 0–1000 nM) in the buffer containing 20 mM Tris–HCl and 5 mM MgCl2, 2.5 mM spermidine, and 10% sucrose at pH 7.5 and 37°C. Electrophoresis was performed with 10% non-denatured polyacrylamide gel.

**Table 1.** Association Constants \(K_s\) of the n-TFO and TFO1–4 for the Formation of the Triplex DNA \((10^6 \text{M}^{-1}\text{M}^0)\)

| Entry | TFOs (Z=) | \(5\'\text{AGGGAGGAGGZGGAAGG}\) | \(3\'\text{CAAGGAGGAGGACGGAGAGGAAGG}\) | \(5\'\text{FAM-GCTTCCCTCCTCCYCCCTTCCCTC}\) |
|-------|-----------|---------------------------------|---------------------------------|---------------------------------|
| 1     | n-TFO (dG)| 11.6 <0.1 7.5 0.7              |                                 |                                 |
| 2     | TFO1 (PhdG)| 19.2 <0.1 0.8 <0.1            |                                 |                                 |
| 3     | TFO2 (PydG)| 7.2 3.3 2.6 6.1               |                                 |                                 |
| 4     | TFO3 (PymdG)| 2.7 <0.1 0.1 0.6             |                                 |                                 |
| 5     | TFO4 (MPdG)| 3.3 1.4 1.4 1.4              |                                 |                                 |

*Values are means of three or more independent experimental values with errors within 10%.*
drogen bond formation with the target base. The calculated energy barriers of the conformational change of Nφ-arylated 9-methyl-dG derivatives are shown in Fig. 4. The low energy barrier (1.91 kcal/mol) of the benzene ring at the Nφ position of guanine was obtained from DFT calculations (Fig. 4A). On the other hand, PyrG, PymG and MPG showed higher values than PhG (Fig. 4B, C and D, respectively). Therefore, it is considered that the open-type conformation of PhdG is stabilized and it is easier to form two Hoogsteen hydrogen bonds to dG of the GC base pair during the triplex formation.

We next tested the triplex forming ability of PhdG incorporated in the different or multiple positions within the TFO sequences (TFO5–10). Their Ks values are summarized in Table 2. In TFO5 and TFO6 containing only one PhdG, the stable triplex DNA was observed for the DNA duplex containing the GC base pair (Table 2, entries 1–3). When there were mismatch sites beside PhdG, they did not form stable triplex DNAs, thereby the PhdG/GC triplet was stabilized with a high selectivity. In the case of TFO7–9 having two or three PhdGs, the corresponding Ks values were dramatically decreased for all four target duplex DNAs (Table 2, entries 4–6). The TFO with the six consecutive PhdGs no longer formed the triplex DNA (Table 2, entry 7). Multiple phenyl groups at the Nφ-position of dG might cause unfavorable interactions, such as steric repulsions, regarding the formation of the triplex DNA. These results indicated that the stable and selective triplex DNA formation is expected by rationally designing the TFO sequence containing PhdG.

The higher-ordered structure of TFO could also interfere with the triplex formation. To check the effect of Nφ-phenyl-dG on the conformation of the single TFO, the Tm analysis, circular dichroism (CD) spectra and gel shift analysis were evaluated. Based on the Tm value measurement, no clear sigmoid curve was observed for all the single-stranded TFOs under the same conditions for the CD measurement (data not shown). The results of the CD spectra and gel analysis are shown in Figs. 5 and 6, respectively. The CD spectrum of n-TFO showed a positive peak around 260 nm and a negative peak around 240 nm (Fig. 5(A)), resembling the CD spectra for the parallel-stranded G-quadruplex. However, n-TFO showed multiple bands in the gel analysis (Fig. 6, Lane 1). These results indicated that n-TFO exists as the mixture of the higher-ordered structures. As the Tm of TFO1 is similar to that of n-TFO, TFO1 may be in a similar mixture of the higher-ordered structures (Figs. 5(B) and 6, Lane 2). The CD spectrum of TFO10 showed a positive peak around 310 nm and a negative peak around 270 nm in Fig. 5(C), suggesting the formation of the anti-parallel type quadruplex. In the gel analysis, TFO10 showed a relatively clear band (Fig. 6, Lane 3, position d), supporting the formation of the higher-ordered structure such as the quadruplex. In contrast, although there are a postive band around 260 nm and a negative band around 240 nm in the CD spectrum of TFO11 (Fig. 5(D)), the gel analysis showed a smear pattern (Fig. 6, Lane 4, position b), indicating that TFO11 forms different structures compared to n-TFO and also TFO10. These results may imply that the triplex formation with the purine-rich TFO modified by the Nφ-arylated dG derivative at multiple sites is competitive with the unexpected higher-ordered structure.

**Conclusion**

In this study, we successfully synthesized purine-rich TFOs containing Nφ-arylated dG derivatives and evaluated the ability of the antiparallel type triplex DNA formation. Among these derivatives, PhdG showed the more stable and selective triplex DNA formation with the GC base pair than the corresponding dG/GC base triplet. Interestingly, one PhdG with dG on both sides in the purine-rich TFO enhanced the recog-
nition ability for the GC base pair in the target duplex DNA. One drawback is that the multiple or continuously PhdG incorporated TFOs showed the formation of the higher-ordered structure to prevent the triplex DNA formations. These results seem to be very important findings when designing a novel sequence of TFO in the antiparallel triplex formation for the gene targeting strategy in the future.

Experimental

General

The \(^1\)H-NMR (400 MHz, 500 MHz), \(^{13}\)C-NMR (125 MHz) and \(^{31}\)P-NMR (202 MHz) spectra were recorded by Varian UNITY-400 and Bruker Ascend-500 spectrometers. The high-resolution (HR) mass spectra were recorded by an Applied Biosystems Mariner System 5299 spectrometer using bradykinin, angiotensin and neurotensin as the internal standards. The MALDI-TOF/MS spectra were recorded by a Bruker Daltonics Microflex. The UV-Vis spectra were measured by a Beckman Coulter DU-800.

General Procedure of Buchwald–Hartwig Cross-Coupling Reaction

Under an argon atmosphere, the mixture of compound 5 (1.0 g, 1.55 mmol), aryl halide (3.88 mmol), Xantphos (450 mg, 0.78 mmol) and palladium acetate (174 mg, 0.76 mmol) in dry toluene (22 mL) was degassed, then sodium t-butoxide (268 mg, 2.79 mmol) was added to this mixture. After stirring and heating at 80°C for 20 min, they were filtered off and washed with Et2O and water. The organic layer was washed with a sat. NaCl solution and dried over Na2SO4, then evaporated under reduced pressure. The residue was purified by silica gel column chromatography to obtain the corresponding coupling products.

3,5'-Bis-O-(tert-butylidemethysilyl)-6-O-(p-nitrophenyl-ethyloxy)-N2-phenyl-2'-deoxyguanosine (6a)

Yellow foam (342 mg, 0.47 mmol, 31%). \(^1\)H-NMR (400 MHz, CDCl3) \(\delta\): 8.15 (2H, d, \(J=9\) Hz), 7.99 (1H, s), 7.63 (2H, d, \(J=7.5\) Hz), 7.47 (2H, d, \(J=9\) Hz), 7.32 (2H, m), 7.04 (1H, m), 6.41 (1H, m), 4.79 (2H, m), 4.58 (1H, m), 4.01 (1H, m), 3.80 (2H, m), 3.30 (2H, m), 2.54 (1H, m), 2.43 (1H, m), 0.94 (9H, s), 0.91 (9H, s), 0.12 (6H, s), 0.09 (6H, s); \(^{13}\)C-NMR (125 MHz, CDCl3) \(\delta\): 130.8, 130.4, 128.9, 123.9, 121.7, 119.1, 87.6, 83.4, 72.7, 66.5, 63.3, 40.4, 40.3, 40.1, 39.9, 39.2, 34.8, 26.2, 26.1, 22.1; HR-MS (electrospray ionization (ESI)-TOF) Calcd for C36H53N6O6Si2 [M+H]+: 721.3560. Found: 721.3595.

3,5'-Bis-O-(tert-butylidemethysilyl)-6-O-(p-nitrophenyl-ethyloxy)-N2-(2-pyridyl)-2'-deoxyguanosine (6b)

Yellow foam (447 mg, 0.62 mmol, 40%). \(^1\)H-NMR (400 MHz, CDCl3) \(\delta\): 8.27 (2H, m), 8.17 (2H, m), 8.06 (1H, s), 7.69 (1H, m), 7.51 (2H, m), 6.95 (2H, m), 6.46 (1H, m), 4.81 (2H, m), 4.58 (1H, m), 4.01 (1H, m), 3.81 (2H, m), 3.32 (2H, m), 2.48 (2H, m), 0.94 (18H, m), 0.12 (12H, s); \(^{13}\)C-NMR (125 MHz, CDCl3) \(\delta\): 138.8, 130.1, 123.9, 117.4, 88.0, 84.2, 72.3, 66.6, 63.1, 42.0, 35.3, 26.1, 25.8, 22.1, 18.6, 18.1; HR-MS (ESI-TOF) Calcd for C38H37N7O8Si2 [M+H]+: 723.3516. Found: 722.3515.
5.26 (1H, m), 4.83 (1H, m), 4.78 (2H, m), 4.49 (1H, m), 3.84 (1H, m), 3.20 (2H, m), 2.69 (1H, m), 2.46 (1H, m), 0.92 (9H, s), 0.90 (9H, s), 0.10 (6H, s); 13C-NMR (125 MHz, CDC13) δ: 160.6, 158.7, 158.3, 153.2, 153.1, 147.0, 146.7, 139.1, 133.7, 133.5, 132.3, 131.2, 130.1, 128.3, 128.1, 123.7, 117.9, 114.9, 88.1, 84.4, 72.3, 70.2, 66.7, 63.0, 41.2, 35.3, 25.5, 22.1, 16.6, 18.2; HR-MS (ESI-TOF) Calcd for C20H28N8O7Si2 [M+H]+: 873.3465. Found: 873.3442.

5.35 (1H, s), 7.40 (12H, m), 6.90 (2H, m), 6.75 (4H, m), 6.43 (1H, m), 3.84 (1H, m), 3.55 (2H, m), 2.82 (1H, m), 2.25 (1H, m); 13C-NMR (125 MHz, DMSO-d6) δ: 159.6, 159.1, 158.1, 153.3, 152.9, 146.6, 140.9, 130.3, 123.4, 116.9, 114.8, 87.9, 83.5, 70.8, 66.1, 61.7, 34.2, 30.7; HR-MS (ESI-TOF) Calcd for C22H22N6O8 [M+H]+: 549.1735. Found: 549.1707.

6.0-N-(2-Pyrinyl)hypoxanthine)-N2-(4,4-dimethoxytrityl)-6-O-(4-nitrophenylethoxy)phosphino)-5'-O-(4,4-dimethoxytrityl)-2'-deoxyguanosine (8d) DMT-protected compound as a pale yellow foam (82.7 mg, 0.10 mmol, 52%). 1H-NMR (500 MHz, CDCl3) δ: 8.33 (2H, m), 8.10 (1H, m), 7.97 (1H, s), 7.40 (12H, m), 6.90 (2H, m), 6.75 (4H, m), 6.43 (1H, m), 4.75 (2H, m), 4.18 (1H, m), 3.72 (6H, s) 3.38 (3H, m), 2.92
(2H, m), 2.70 (2H, m); $^1$C-NMR (125 MHz, CDCl$_3$): $\delta$: 162.7, 160.4, 158.6, 154.4, 152.9, 148.1, 146.9, 145.8, 144.6, 138.8, 137.9, 136.6, 130.1, 129.9, 128.1, 127.9, 126.9, 123.8, 117.4, 116.7, 113.2, 112.2, 86.6, 86.2, 84.1, 77.2, 72.4, 66.5, 64.0, 55.2, 40.5, 36.6, 35.2, 31.5; HR-MS (ESI-TOF) Calcd for C$_{44}$H$_{42}$N$_{7}$O$_{8}$P $[M]$ +: 997.4142. Found: 997.4120. 1H-NMR (400 MHz, CDCl$_3$): $\delta$: 8.14 (2H, d, $J=7.6$ Hz), 7.73–7.24 (14H, m), 6.75 (4H, m), 6.14 (1H, m), 4.79 (2H, m), 4.15 (1H, m), 3.75 (6H, s), 3.49–3.29 (10H, m), 2.83–2.72 (6H, m), 1.25 (12H, m); $^3$P-NMR (162 MHz, CDCl$_3$): $\delta$: 148.9; HR-MS (ESI-TOF) Calcd for C$_{53}$H$_{59}$N$_{10}$O$_{9}$P $[M]$ +: 1027.4226. Found: 1027.4276.

**DNA Synthesis** The triplex forming oligonucleotides (TFO-11) were synthesized using standard DNA synthesis procedures with a NTS-H6 DNA/RNA synthesizer (Nihon Techno Science Co., Ltd., Japan). The synthesized TFOs were treated with 1.0 m DBU in CH$_3$CN for 30 min at room temperature (r.t.) to remove the protecting group at the 6 position of the nucleoside analogue, and the solvent was changed to a 28% ammonia solution to cleave from the resin and deprotect at the nucleobase at 55°C for 12 h. The DMTr-ODN was purified by HPLC (Nacalai Tesque (Kyoto, Japan) COSMOSIL C18-ARII) using a linear gradient (A: 0.1 m triethylamine acetic acid (TEAA) buffer, B: CH$_3$CN, B conc. 10 to 30%/20 min). The DMTr-group on the TFO-11 was removed with 5% aqueous acetic acid at r.t. for 15 min, then the resulting DMTr-off TFO-11 were washed with ether. The purities and structures were confirmed by MALDI-TOF mass measurements (Table 3).

**Determination of Triplex Forming Ability by Gel Shift Assay** The FAM labelled duplex DNA (24 bp, 100 nm) was incubated with increasing concentrations of the TFO (0–1000 nM) in the buffer containing 20 m M Tris–HCl, 5 m M MgCl$_2$, 2.5 mM spermidine and 10% sucrose at pH 7.5 and 25°C. Electrophoresis was performed at 4°C using 10% non-denatured polyacrylamide gel. The gel was visualized using a Luminoimage LAS-4000 analyzer (FUJIFILM, Tokyo, Japan), and the fluorescence intensity of each band was quantified for the calculation of the association constants. $K_a$ (10$^6$ M$^{-1}$) = [Triplex]/([TFO][Duplex)]. Each $K_a$ value was the mean of three or more independent experimental values. The errors were estimated to be within 10%.

**CD Measurements** The CD spectra were recorded using 2.5 μM solutions of each strand in the buffer containing 20 mM Tris–HCl, 5 mM MgCl$_2$, 2.5 mM spermidine and 10% sucrose at pH 7.5 and 25°C by a JASCO J-720W spectrometer in cylindrical quartz cell with a 0.1 cm path length.

**Acknowledgments** This study was supported by a Grant-in-Aid for Scientific Research (B) (Grant Number 16H05100 for Y.T.) and a Grant-in-Aid for Scientific Research (B) (15H04633 for S.S.), a Challenging Exploratory Research (Grant Number 26670056 for Y.T.) from the Japan Society for the Promotion of Science (JSPS).

| TFO            | Calcd [M–H]$^-$ | Found  |
|----------------|-----------------|--------|
| TFO1           | 5856.05         | 5855.56|
| TFO2           | 5857.04         | 5860.89|
| TFO3           | 5858.04         | 5858.85|
| TFO4           | 5888.05         | 5888.45|
| TFO5           | 5853.19         |        |
| TFO6           | 5856.05         | 5859.39|
| TFO7           | 5932.08         | 5935.10|
| TFO8           | 5932.08         | 5938.84|
| TFO9           | 6008.11         | 6010.72|
| TFO10          | 6236.21         | 6236.36|
| TFO11          | 6428.21         | 6429.86|

Table 3. MALDI-TOF MS Results of Synthesized TFOs
Conflict of Interest  The authors declare no conflict of interest.

References
1) He X., Sha R., Zhuo R., Mi Y., Chaikin P. M., Seeman N. C., Nat. Mater., 16, 993–997 (2017).
2) Vasquez K. M., Glazer P. M., Q. Rev. Biophys., 35, 89–107 (2002).
3) Mukherjee A., Vasquez K. M., Biochimie, 93, 1197–1208 (2011).
4) Jain A., Magistri M., Napoli S., Carbone G. M., Catapano C. V., Biochimie, 92, 317–320 (2010).
5) Rogers F. A., Lloyd J. A., Glazer P. M., Curr. Med. Chem. Anticancer Agents, 5, 319–326 (2005).
6) Beal P. A., Dervan P. B., Nucleic Acids Res., 20, 2773–2776 (1992).
7) Taniguchi Y., Sasaki S., Angew. Chem. Int. Ed., 55, 12445–12449 (2016).
8) Taniguchi Y., Tomizaki A., Matsueda N., Okamura H., Sasaki S., Chem. Pharm. Bull., 63, 920–926 (2015).
9) Okamura H., Taniguchi Y., Sasaki S., ChemBioChem, 15, 2374–2378 (2014).
10) Okamura H., Taniguchi Y., Sasaki S., Org. Biomol. Chem., 11, 3918–3924 (2013).
11) Taniguchi Y., Sasaki S., Org. Biomol. Chem., 10, 8336–8341 (2012).
12) Sasaki S., Taniguchi Y., Takahashi R., Senko Y., Kodama K., Nagatsugi F., Maeda M., J. Am. Chem. Soc., 126, 516–528 (2004).
13) Lohani N., Rajeswari M. R., RSC Adv., 6, 39903–39917 (2016).
14) Nakatani K., Dohno C., Saito I., J. Am. Chem. Soc., 124, 6802–6803 (2002).
15) Focher F., Hildebrand C., Freese S., Ciarrocchi G., Noonan T., Sangalli S., Brown N., Spadari S., Wright G., J. Med. Chem., 31, 1496–1500 (1988).
16) Inoue T., Masaki Y., Maruyama A., Ito Y., Makio N., Miyatake Y., Tomori T., Sekine M., Seio K., Org. Biomol. Chem., 15, 8371–8383 (2017).
17) Potier P., Abdennaji A., Behr J.-P., Chem. Eur. J., 6, 4188–4194 (2000).
18) Ciszewski K., Cielewicz L., Golankiewicz K., Biochem. Biophys. Res. Commun., 187, 1545–1550 (1992).
19) Kypr J., Kajnovská I., Renčík D., Vorlíčková M., Nucleic Acids Res., 37, 1713–1725 (2009).