Anti-Hepatitis B Virus Activity of New Pyrimidine and Adenine Peptide Nucleic Acid Analogues

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A number of \textit{N}-substituted thymine and adenine derivatives, 2\textsubscript{a,b} and 3\textsubscript{a,b}, were synthesized by the coupling reaction of 1-bromo-2,2-diethoxyethane with the corresponding base. The corresponding peptide nucleic acid (PNA) analogues, \textit{N}-substituted ethylamino-3-hydroxypropanoate derivatives 5\textsubscript{a,b} and ethylamino-3-hydroxybutanoate derivatives 6\textsubscript{a,b}, were synthesized from the corresponding 2-[3,4-dihydro-5-methyl-2,4-dioxopyrimidin-1(2\textit{H})-yl]-acetaldehyde (3\textsubscript{a}) and 2-[6-amino-4\textit{H}-purin-9(5\textit{H})-yl]-acetaldehyde (3\textsubscript{b}), respectively. The synthesized compounds were tested for their antiviral activity against hepatitis B virus (HBV). The plaque reduction infectivity assay was used to determine the virus count reduction as a result of the treatment with the tested compounds.

Key words: Peptide Nucleic Acid Analogues, Adenine and Thymine Nucleobases, Anti-Hepatitis B Virus

Introduction

Synthetic compounds that specifically recognize and bind to a specific DNA or RNA sequence of interest are of great significance (DeMesmaeker et al., 1995; Milligan et al., 1993; Uhlmann and Peymann 1990). A particular successful DNA-binding agent is a recently developed class of DNA analogues, the peptide nucleic acids (PNAs) (Fig. 1) (Nielsen et al., 1991; Egholm et al., 1992; Hyrup and Nielsen, 1996; Nielsen, 1998; Uhlmann et al., 1998; Ganesh and Nielsen, 2000). PNAs are oligonucleotide analogues, in which the entire phosphodiester pentose backbone of DNA or RNA is replaced by a polyamide or peptide backbone (Egholm et al., 1993). The complete replacement of the ribose phosphate backbone with an artificial pseudopeptide backbone results in a remarkably improved binding to complementary nucleic acid sequences occurring with both high affinity and high selectivity. These characteristics make them potentially useful as antisense and antigenic drugs or molecular probes, which have numerous applications in the field of molecular and experimental medicine (Egholm et al., 1995; Ray and Norden, 2000; Zhou et al., 2006; Hyun et al., 2006). Furthermore \textit{N}1/\textit{N}9-alkylation of nucleobases affords the important building blocks for PNAs, which have been widely described in the literature (Duehohm et al., 1994; Thomson et al., 1995; Will et al., 1995; Alahiane et al., 2003). The hybridization properties of PNAs have attracted widespread interest to this class of compounds (Zhou et al., 2003; Nielsen, 1999; Seitz, 2000). Their biological stability has made PNAs attractive as therapeutic and biomolecular tools. In PNAs, the phosphoribose backbone of

![Chemical structure of peptide nucleic acids](https://example.com/figure1.png)
Antiviral activity

The synthesized compounds were tested for their antiviral activity against hepatitis B virus (HBV) using the HepG2.2.2.15 cell line (Sells et al., 1987), a human hepatoplastoma cell line producing HBV viral particles (Korba and Gerin, 1992).

The cell line was maintained in RPMI-1640 (Glutamax) (Gibco BRL Life Technologies, Paisley, Scotland) culture medium containing 100 IU/ml nystatin (Gibco BRL Life Technologies), 380 μg/ml G418 (genetecin) (Gibco BRL Life Technologies) and 10 % fetal calf serum (FCS) (Gibco BRL Life Technologies). The transferred HEPG2.2.2.15 cells were kept in a tissue culture flask at 37 °C and 5 % CO₂. Subcultures were set up after a week by trypsination (10 % versin/trypsin; Biochrome KG, Berlin, Germany) and transferred to a 96-well tissue culture plate. Serial dilutions of the test compounds were added to the cell suspension and incubated for 6 d at 37 °C and 5 % CO₂. The antiviral activity and cytotoxic effect of the test compounds was estimated by comparing the DNA content in the culture supernatant and the viability of the cells with the test compounds to those of HepG2.2.2.15 cells without any compound added (blank cells). The drug lamivudine which is a potent selective inhibitor of HBV replication has been used as a standard positive control (Doong et al., 1991). Each compound was tested in triplicate.

DNA extraction

DNA extraction was done by incubating 10 μl of diluted supernatant with 10 μl of 0.2 m NaOH at 37 °C for 1 h; then 9.6 μl of 0.2 m HCl were carefully added followed by addition of 90 μl of Tris-EDTA (TE) buffer (Gibco BRL Life Technologies).

PCR-ELISA detection of HBV DNA

The DNA content in the cell culture supernatant was determined by PCR amplification of the HBV DNA using 1 μmol/l of each of the following primers: HCID-1 (5'-GGAAAGAGTCAGAGGGCA-3') and HCID-2 (5'-TTGAGGGGAGGAGAT-TAGGTT-3'), in a reaction mixture containing 14 μl extracted supernatant, 4 mmol/l MgCl₂, 10 μmol/l DIG-11-dUTP (Roche, Munich, Germany), 190 μmol/l dTTP, 200 μmol/l dATP, dGTP, dCTP (Roche), 1.5 U Taq polymerase (Roche) in a total volume of 50 μl. PCR reaction conditions were: 32 cycles of 10 min at 94 °C, 30 s at 58 °C and 30 s at 72 °C with a 3-s increment for each cycle in a Perkin Elmer 480 thermal cycler (Perkin Elmer, Waltham, MA, USA). The PCR product was detected by the DIG-ELISA assay (Roche). The optical density (OD) of the DNA of the test compound was compared to that of the blank culture.

Cytotoxicity assay

3-(3,5-Dimethylthiazole-2-yl)-2,5-diphenyltetrazolium bromide (MTT) (Sigma, St. Louis, MO, USA) is a colourless substrate that is transferred to a coloured product by any living cell but not by dead cells. The assay utilizes this compound to test for the viability of cells in the presence of test compound compared to the viability of the blank cells (Fouad et al., 1998).

Calculation of IC₅₀, CC₅₀, and SI values

The 50 % inhibitory concentration of antiviral drugs (IC₅₀) was determined by plotting the DNA content of the serial dilutions of the test compound versus the concentration of this compound. The 50 % cytotoxic effect (CC₅₀) was calculated.
from the average viability of the cells with 0.1 μm concentration of drugs. The selectivity index (SI) was calculated as CC\textsubscript{50}/IC\textsubscript{50} (Fouad et al., 1998).

**Results and Discussion**

**Chemistry**

The coupling reaction at one of the nitrogen atoms in the heterocyclic base is the most effective method for introducing certain substituents with desired functionalities into the heterocyclic base. Thus, the reaction of thymine and adenine with 1-bromo-2,2-diethoxyethane was carried out in the presence of anhydrous potassium carbonate to give 1-(2,2-diethoxyethyl)-5-methylpyrimidine-2,4(1\textsubscript{H},3\textsubscript{H})-dione (2a) and 9-(2,2-diethoxyethyl)-9\textsubscript{H}-purin-6-amine (2b), respectively. The structures of these compounds were proved by IR, \textsuperscript{1}H NMR and mass spectra which were in agreement with the assigned structure. The \textsuperscript{1}H NMR spectra of compounds 2a and 2b showed the signals of ethyl protons as triplets and quartets at δ 1.19, 3.55 ppm and δ 1.17, 3.51 ppm, respectively. Hydrolysis of 2a and 2b was carried out by means of 4 m hydrochloric acid to give the corresponding 2-[3,4-dihydro-5-methyl-2,4-dioxopyrimidin-1(2H)-yl]-acetaldehyde (3a) and 2-[6-amino-4\textsubscript{H}-purin-9(5\textsubscript{H})-yl]-acetaldehyde (3b) in good yields. The \textsuperscript{1}H NMR spectrum of 3a showed the protons of N–CH\textsubscript{2} as a doublet at δ 3.62 ppm, the proton in the pyrimidine ring as a singlet at δ 7.25 ppm in addition to the NH as a singlet at δ 8.85 ppm. When 3a and 3b were allowed to react with l-serine and l-threonine methylester in the presence of potassium hydroxide at room temperature, they afforded the corresponding ethylamino-3-hydroxypropanoate derivatives 5a and 5b and ethylamino-3-hydroxybutanoate derivatives 6a and 6b, respectively, in moderate yields. The IR spectra of these compounds showed the characteristic absorption band at 1740–1755 cm\textsuperscript{-1}. The \textsuperscript{1}H NMR spectra of these compounds are in agreement with the assigned structures. For compound 5b the spectrum showed a peak at δ 3.62 ppm corresponding to O–CH\textsubscript{3} in addition to the peak of the hydroxy group at δ 3.95 ppm and the triplet at δ 4.05 ppm corresponding to the CH–CH\textsubscript{2} group which is in agreement with the assigned structure. The \textsuperscript{1}H NMR spectrum of compound 6a showed the two methyl groups as a doublet at δ 1.22 ppm and a singlet at δ 1.68 ppm in addition to the peak corresponding to the O–CH\textsubscript{3} group at δ 2.43 ppm and the hydroxy group as a doublet at δ 3.75 ppm (Fig. 2).

**Antiviral testing**

The results of the antiviral activity measurements against HBV are shown in Tables I and II. Preliminary screening indicated that 5b and 6b showed

<table>
<thead>
<tr>
<th>Compound</th>
<th>HBV DNA IC\textsubscript{50} [μm]</th>
<th>SI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamivudine</td>
<td>0.1</td>
<td>1000</td>
</tr>
<tr>
<td>2a</td>
<td>0.6</td>
<td>166.6</td>
</tr>
<tr>
<td>2b</td>
<td>0.5</td>
<td>200.0</td>
</tr>
<tr>
<td>3a</td>
<td>0.7</td>
<td>142.8</td>
</tr>
<tr>
<td>3b</td>
<td>0.6</td>
<td>166.6</td>
</tr>
<tr>
<td>5a</td>
<td>0.5</td>
<td>200.0</td>
</tr>
<tr>
<td>5b</td>
<td>0.2</td>
<td>500.0</td>
</tr>
<tr>
<td>6a</td>
<td>0.3</td>
<td>333.3</td>
</tr>
<tr>
<td>6b</td>
<td>0.2</td>
<td>500.0</td>
</tr>
</tbody>
</table>

* HepG2.2.15 CC\textsubscript{50} for all tested compounds was 100 μm.

Fig. 2. Pyrimidine and adenine peptide nucleic acid analogues.
the highest activity against HBV with an effective concentration of 0.2 μM and the selectivity index 500, followed by 6a whereas 2a, 3a and 3b showed the lowest activity (Table I).


Sells M.A., Chem M.L., and Acs G. (1987), Production of hepatitis B virus particles in HepG2 cells trans-