Synthesis and antiviral properties of spirocyclic [1,2,3]-triazolooxazine nucleosides


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**Abstract:** An efficient synthesis of spirocyclic triazolooxazine nucleosides is described. This was achieved by the conversion of β-ribo-
psicofuranose to the corresponding azido-derivative, followed by alkylation of the primary alcohol with a range of propargyl bromides - obtained via Sonogashira chemistry. The products of these reactions underwent 1,3-dipolar addition smoothly to generate the protected spirocyclic adducts. These were easily deprotected to give the corresponding ribose nucleosides. The library of compounds obtained was investigated for its antiviral activity, using MHV (Mouse Hepatitis Virus) as a model wherein derivative 3F showed the most promising activity and tolerability.

The design and synthesis of nucleoside analogues has been a subject of great interest in the discovery of novel anticancer and antiviral agents owing to the fact that they can be involved in the disruption of nucleic acid biosynthesis and thus inhibit cellular division and viral replication.[1] Additionally, they have been utilised for various gene silencing techniques as constituents of antisense oligonucleotides, small interfering RNAs (siRNAs) and microRNA-targeting oligonucleotides (anti-miRNAs).[2]

In particular, conformationally restricted nucleosides such as “locked nucleic acids” (LNAs), whereby the sugar moiety of the nucleoside is locked in the bioactive C3'-endo (North) or C2'-endo (South) conformations, represent an interesting class of nucleoside inhibitor as they can show a dramatic improvement in enzymatic recognition, as well as enhancing base stacking and backbone pre-organization.[3] Most of these systems are locked by virtue of bridging groups on the furanose unit alone, but there are also examples whereby the nucleobase is directly involved in the conformational restriction of the nucleoside (so-called ‘cyclonucleosides’).[4] In this respect, we have an interest in the synthesis and use of anomic spironucleosides, whereby the anomic carbon belongs to both the sugar moiety and the nucleobase (Figure 1). This fixes the nucleobase in a specific orientation around the N-glycosidic bond, imposing an altered flexibility on the sugar moiety. Spiro-functionalised nucleosides have gained considerable interest with the discovery of (+)-hydantocidin 1, a natural spironucleoside with potent herbicidal and plant growth regulatory activity.[5] However, to the best of our knowledge, synthetic work in this field is limited, with the majority of anomic spirocycles being hydantoines or diketopiperazines analogues, or simple pseudonucleosides with anchored purinic and pyrimidinic bases.[6]

As part of an on-going programme within our laboratories on the synthesis of non-natural nucleic acids,[7] we aimed to prepare a library of spiro-fuctionalised nucleosides, containing a [1,2,3]-triazolyl moiety using a straightforward and highly stereoselective route. It was felt that this class of spironucleoside would make an interesting alternative to the [1,2,4]-triazolyl class of nucleoside whose biological activity is well known, owing to their resemblance to ribavirin 2.[8] We therefore evaluated our resulting [1,2,3]-triazolospironucleosides for their anti-HMV activity in vitro.

**Results and Discussion**

As depicted in the retrosynthetic path (Scheme 1), the versatility of the synthetic strategy towards novel anomic spironucleosides lies in the strategic installation of azide and alkyne moieties on the β-ribo-
psicofuranose derivative 4, followed by an intramolecular Huisgen 1,3-dipolar cycloaddition to generate the spirocyclic [1,2,3]-triazolooxazine ring.[9]
to its furanose form remaining alcohol was then converted to the benzoate ester the general procedure described by Fuentes and co-workers. This involved isomerisation of 1,2,4,5-di-O-isopropylidene-psicopyranose 7 (easily prepared in a multigram scale using a straightforward three-step procedure from β-D-fructopyranose) to its furanose form 6a using amberlyst acid resin in acetone. The crude propargyl ether intermediate s then then 9 as the sole anomer. The silyl group was then removed smoothly with a mixture of acetone, TMSN₃, TMSOTf, 0°C for 5 min to provide the β-azido-1-trimethylsilyl ether 8 as the sole anomer. The silyl group was then removed smoothly with a mixture of acetone, acetic acid and methanol, giving alcohol 5a in 98% yield.

The alkylation of alcohol 5a with a range of propargyl bromides was then undertaken using BEMP (2-tert-Butylimino-2-diethylamino-1,3-dimethylperhydro-1,3,2-diazaphosphorine) as base to give the crude propargyl ether intermediates. The 3-arylpreg-2-ynyl partners for the O-alkylation were prepared from commercially available aryl iodides and propargyl alcohol using a two-step process involving Sonogashira coupling followed by conversion of the resulting 3-arylpreg-2-ynyl alcohols to their corresponding bromides under Appel conditions (see supporting information). The crude propargyl ether intermediates 9 then underwent efficient intramolecular 1,3-dipolar cycloaddition upon heating in toluene for 24h to give the novel protected anomeric spironucleoside library 10 (Table 1). Finally, deacylation of the spiroderivative 10, using a 7 N solution of ammonia in methanol, followed by hydrolysis of the isopropylidene group with acidic resin (Dowex® 50W) gave straightforward access to anomeric spironucleosides 3 in good yield (Scheme 3).

As proof of final structure and to gain an understanding of the conformation of these systems, an X-ray crystal structure of 3g was obtained from a thin (0.02 x 0.03 x 0.31 mm) single crystal. The structure in space group P2₁ has two independent molecules in the asymmetric unit, each having a disordered benzene ring occupying two distinct conformations (A and B) at ca. 60° different rotations about the aryl bond. In the upper

Table 1. Alkylation and 1,3-dipolar cycloaddition to access the spirocyclic nucleoside.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Product</th>
<th>R</th>
<th>Overall yield, %[^a]</th>
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<tr>
<td>1</td>
<td>10a</td>
<td>H</td>
<td>51</td>
</tr>
<tr>
<td>2</td>
<td>10b</td>
<td>Me</td>
<td>53</td>
</tr>
<tr>
<td>3</td>
<td>10c</td>
<td>Et</td>
<td>43</td>
</tr>
<tr>
<td>4</td>
<td>10d</td>
<td>2-Naph</td>
<td>59</td>
</tr>
<tr>
<td>5</td>
<td>10e</td>
<td>Ph</td>
<td>44</td>
</tr>
<tr>
<td>6</td>
<td>10f</td>
<td>4-Cl-C₆H₄</td>
<td>45</td>
</tr>
<tr>
<td>7</td>
<td>10g</td>
<td>4-MeO-C₆H₄</td>
<td>43</td>
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<tr>
<td>8</td>
<td>10h</td>
<td>4-F-C₆H₄</td>
<td>43</td>
</tr>
<tr>
<td>9</td>
<td>10i</td>
<td>3-F-C₆H₄</td>
<td>39</td>
</tr>
<tr>
<td>10</td>
<td>10j</td>
<td>2-F-C₆H₄</td>
<td>45</td>
</tr>
<tr>
<td>11</td>
<td>10k</td>
<td>n-Pentyl</td>
<td>36</td>
</tr>
</tbody>
</table>

[^a] Overall isolated yield for alkylation and cycloaddition.

Scheme 1. Retrosynthetic access to [1,2,3]-spirotriazolooxazines

Scheme 2. Synthesis of the azido-ribose system.

Scheme 3. Final deprotection steps to obtain novel anomeric spirocyclic system.

The benzoate ester was then treated with azidotrimethylsilane in the presence of trimethylsilyl triflate in acetonitrile under stringently anhydrous conditions at 0°C for 5 min to provide the β-azido-1-trimethylsilyl ether 8 as the sole anomer. The silyl group was then removed smoothly with a mixture of acetone, acetic acid and methanol, giving alcohol 5a in 98% yield.

The alkylation of alcohol 5a with a range of propargyl bromides was then undertaken using BEMP (2-tert-Butylimino-2-diethylamino-1,3-dimethylperhydro-1,3,2-diazaphosphorine) as base to give the crude propargyl ether intermediates. The 3-arylpreg-2-ynyl partners for the O-alkylation were prepared from commercially available aryl iodides and propargyl alcohol using a two-step process involving Sonogashira coupling followed by conversion of the resulting 3-arylpreg-2-ynyl alcohols to their corresponding bromides under Appel conditions (see supporting information). The crude propargyl ether intermediates 9 then underwent efficient intramolecular 1,3-dipolar cycloaddition upon heating in toluene for 24h to give the novel protected anomeric spironucleoside library 10 (Table 1).

Finally, deacylation of the spiroderivative 10, using a 7 N solution of ammonia in methanol, followed by hydrolysis of the isopropylidene group with acidic resin (Dowex® 50W) gave straightforward access to anomeric spironucleosides 3 in good yield (Scheme 3).
In order to test for antiviral effects, MHV was grown on cells that had been pre-treated with the experimental compounds at a concentration of 1 mM. The amount of MHV released from infected cells usually peaks at about 14 hours after infection. Two of the treatments, 3b and 3f reduced the amount of MHV that was released by about ten-fold (Fig. 4A).

Figure 4. Antiviral effects of novel nucleosides. (A) Cells were pre-treated with 1 mM compounds, DMSO-containing vehicle or mock treated 3 hours before infection. Virus growth is shown relative to untreated controls. Compounds that reduced virus growth significantly (P<0.5 after unpaired t-test with Bonferroni correction) are indicated with stars. (B) Reduction of cytopathic effects by 3f. Infected cells were fixed, stained with crystal violet and adherent cells were imaged by light microscopy. The number of nuclei in single cell bodies and in virus-induced multinucleate syncytia was normalized to the number of nuclei present in uninfected, untreated controls (Uninfected). (C) Experimental compounds were applied 3 hours before addition of the virus, and were maintained throughout the experiment. Data points show the average virus titer ± standard deviation based on 5-8 replicates. Virus growth was measured by plaque assay 14 hours after inoculation.

MHV infection in 17Cl-1 cells normally results in formation of large multinucleate syncytia followed by detachment of cells from the culture flask.[18] The most effective experimental compound from the previous assay was screened for the ability to protect cells from MHV-induced cytopathology. 17Cl-1 cells were pre-treated with 3f 3 hours before infection, and surviving cells were photographed 24 hours after infection. Treatment with 3f resulted in a dose-dependent reduction in both syncytium formation and detachment (Fig. 4B). From these data it was concluded that 3f exerted a protective effect on treated cells at concentrations up to 2 mM. This also demonstrated that the apparent antiviral activity of 3f was not simply an artifact of cytotoxicity.

More detailed dose-response experiments were performed for four of the experimental compounds in order to better gauge their antiviral potential. Pretreatment with 2 mM of 3f produced the strongest antiviral effects, resulting in approximately one million-fold reduction of MHV growth (Fig. 4C). Together, these results demonstrate that 3f had antiviral activity against the model coronavirus MHV.

The 17Cl-1 mouse lung fibroblast line supports high-titre MHV growth, and was therefore chosen for both toxicity and antiviral testing. The effects of treatment on cell viability were assessed by
MTT assay.\cite{19} Cell viability was assessed after one day or three days. Of the compounds studied, the most promising were tested in this assay. 3d was the most cytotoxic, while 3b, 3f and 3k (included as a control) were better tolerated (Figure 5).

The concentration which produced a 50% reduction in cell viability in these assays was greater than 1 mM for each of the experimental compounds tested (Table 2), demonstrating that the compounds are relatively non-toxic.

A further experiment was performed in order to learn more about the mechanism of 3f antiviral activity by evolving drug resistance. MHV was serially passaged eight times on 17Cl-1 cells, which had been pre-treated with 1 mM 3f, a concentration that reproducibly reduced viral growth by about 90%. Previous work\cite{12} suggested that these conditions were appropriate for the selection of drug-resistant coronavirus within about five passages.\cite{20} However, MHV grown in the presence of 3f consistently produced about 10% of the virus produced in untreated control cells, and did not develop resistance (data not shown). These results suggest that the mechanism of action of 3f is unclear, and that effects of 3f on the cell cannot be ruled out as a potential explanation of the antiviral effects.

In conclusion, a novel triazolospirocyclic nucleoside array was assembled efficiently through intramolecular 1,3-dipolar cycloaddition methodology, and allowed the identification of agents that showed promising antiviral activity towards MHV - the most promising of these being the 4-chlorophenyl derivative 3f. Further work is underway to establish the mechanism of action of this inhibitor.

### Acknowledgements

The authors wish to acknowledge financial contributions from the University of Reading (to AD and HMNA-M) and Syngenta (to AD), as well as Fraser White of Agilent Technologies for X-ray data collection and structure determination of 3g.

### Keywords

alkynes • cycloaddition • nucleosides • spiro compounds • antiviral

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**Table 2. Relative activity of spirocyclic nucleosides 3b, 3d, 3f and 3k.**

<table>
<thead>
<tr>
<th>Entry</th>
<th>Nucleoside</th>
<th>EC50 (µM)</th>
<th>CC50 (µM)</th>
<th>Therapeutic Index</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>3b</td>
<td>410 ± 50</td>
<td>1510 ± 90</td>
<td>3.7</td>
</tr>
<tr>
<td>2</td>
<td>3d</td>
<td>&gt; 2000</td>
<td>1170 ± 180</td>
<td>&lt; 0.6</td>
</tr>
<tr>
<td>3</td>
<td>3f</td>
<td>36 ± 13</td>
<td>&gt; 2000</td>
<td>&gt; 56</td>
</tr>
<tr>
<td>4</td>
<td>3k</td>
<td>1290 ± 110</td>
<td>&gt; 2000</td>
<td>&gt; 1.6</td>
</tr>
</tbody>
</table>

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References:


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Layout 2:

Non-natural Nucleosides


Synthesis and Antiviral Properties of Spirocyclic [1,2,3]-Triazolooxazine Nucleosides

Taming the ring : Reported herein is the synthesis of a novel class of conformationally restricted nucleoside. The synthesis relies on an intramolecular 1,3-dipolar cycloaddition to generate a class of compound which have conformational similarities to Ribaviran.

Consequently, these systems were tested for their antiviral properties and several were shown to have promising activity against Mouse Hepatitis Virus.