THE STUDY OF REGULARITIES OF THE STRUCTURE – ANALGESIC ACTIVITY RELATIONSHIP IN A SERIES OF 4-HYDROXY-N-(PYRIDIN-2-YL)-2,2-DIOXO-1H-2λ,1-BENZOTHIAZINE-3-CARBOXAMIDES

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Key words: amidation; 2-aminopyridines; 4-hydroxy-2,2-dioxo-1H-2λ,1-benzothiazine-3-carboxamides; synthesis; analgesic activity

Continuing the search for new analgesics and with the purpose of revealing the structural-biological regularities, which are important for further studies, the synthesis of a series of 4-hydroxy-N-(pyridin-2-yl)-2,2-dioxo-1H-2λ,1-benzothiazine-3-carboxamides unsubstituted in position 1 has been carried out. The structure of all compounds synthesized has been confirmed by elemental analysis, 1H NMR spectra and mass spectra. Based on a detailed analysis of the mass spectra it has been concluded that 4-hydroxy-N-(pyridin-2-yl)-2,2-dioxo-1H-2λ,1-benzothiazine-3-carboxamides in crystals are inner salts – 3-[[pyridinium-2-yl]amino]carbonyl]-2,2-dioxo-1H-2λ,1-benzothiazin-4-olates. It has been noted that spectroscopy of 1H NMR does not allow either to confirm or disprove that in DMSO solution the substances studied exist in the form of inner salts since the signals of the active protons of OH and NH-groups that are important do not appear. According to the results of the pharmacological screening the substances – for example, 3-[[6-(methylpyridinium-2-yl)amino]carbonyl]-2,2-dioxo-1H-2λ,1-benzothiazin-4-olate – exceeding Piroxicam by the analgesic activity have been found. It has been unequivocally determined that removal of the 1-N-methyl group from the structure of 4-hydroxy-1-methyl-N-(pyridin-2-yl)-2,2-dioxo-1H-2λ,1-benzothiazine-3-carboxamides in general leads to a marked decrease in analgesic properties and may be considered inappropriate.

VIVЧЕННЯ ЗАКОНОМІРНОСТІ ЗВ‘ЯЗКУ СТРУКТУРА – АНАЛГЕТИЧНА АКТИВНІСТЬ У СЕРІЇ 4-ГІДРОКСИ-Н-(ПІРИДИН-2-ЇЛ)-2,2-ДІОКСО-1H-2λ,1-БЕНЗОТАХІЗІН-3-КАРБОКСАМІДІВ

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Ключові слова: амідування; 2-амінопіридини; 4-гідроксаміди; синтез; анальгетична активність


ИЗУЧЕНИЕ ЗАКОНОМЕРНОСТЕЙ СВЯЗИ СТРУКТУРА – АНАЛЕГЕТИЧЕСКАЯ АКТИВНОСТЬ В СЕРИИ 4-ГИДРОКСИ-N-(ПИРИДИН-2-ИЛ)-2,2-ДИОКСО-1H-2λ,1-БЕНЗОТАЗИНИН-3-КАРБОКСАМИДОВ

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Ключевые слова: амидирование; 2-аминопиридин; 4-гидроксамид, 2,2-диксо-1H-2λ,1-бензотиазин-3-карбоксамиды; синтез; аналгетическая активность

Продолжая поиск новых аналгетиков и с целью выявления важных для последующих исследований структурно-биологических закономерностей, мы осуществили синтез серий незамещенных в положении 1 4-гидроксамидов N-(пирдин-2-ил)-2,2-диксо-1H-2λ,1-бензотиазин-3-карбоксамидов. Будову всех синтезированных соединений подтверждено данными элементного анализа, спектрами NЯМР и масс-спектрами. На основании детального анализа масс-спектров сделан вывод, что в кристаллах 4-гидроксамидов N-(пирдин-2-ил)-2,2-диксо-1H-2λ,1-бензотиазин-3-карбоксамиды представляют собой внутренние соли – 3-[[пирдинум-2-ил]аминокарбонил]-2,2-диксо-1H-2λ,1-бензотиазин-4-олаты. Отмечено, что спектроскопия НЯМР не позволяет ни подтверждать, ни опровергнуть то, что в растворе DМСО исследуемые соединения существуют в виде внутренних солей, поскольку важные для подобных отнесений сигналы активных протонов ОН и NH-групп в спектрах не проявляются. По результатам фармакологического скрининга выявлены вещества, например, 3-[[6-метилпирдинум-2-ил]аминокарбонил]-2,2-диксо-1H-2λ,1-бензотиазин-4-олаты, которые превосходят по аналгетической активности Пироксикам. Однозначно установлено, что удаление 1-Н-метильной группы из структуры 4-гидроксамид-1-метил-N-(пирдин-2-ил)-2,2-диксо-1H-2λ,1-бензотиазин-3-карбоксамидов в целом приводит к заметному снижению аналогетических свойств и может быть признано нецелесообразным.
By now a chemical modification (both reversible and irreversible) has become such a powerful tool for identification of promising compounds and optimization of lead compounds obtained earlier, and it is impossible to imagine practical work of medicinal chemists engaged in the search for new biologically active substances without it. Using these methodologies a variety of problems – pharmacological, pharmaceutical, technological, etc., – faced by researchers on the long and arduous road from substance to medication are being successfully solved [1-6]. Essentially, guided by these principles we have recently begun to study derivatives of 4-hydroxy-2,2-dioxo-1H-2λ6,1-benzothiazine-3-carboxylic acids. As one of the first objects of our research N-R-amides with the general formula I have been chosen. Being isomers of highly effective pain killers of oxicam series II (e.g., Piroxicam R = pyridin-2-yl or Meltoxicam R = 5-methyl-1,3-thiazol-2-yl) [7], these compounds are of interest as potential new analgesics. Their main and, at first glance, a very simple structural difference – atoms of nitrogen and sulphur in the benzothiazine cycle changed places, thanks to it this methodology actually got the name of "flip-flop drugs" [8] – appeared to be quite difficult task for practical implementation. However, a solution was found among ketahyramides [9-10] and anilides [11-12] of 4-hydroxy-1-methyl-2,2-dioxo-1H-2λ6,1-benzothiazine-3-carboxylic acid I, highly active analgesics were really found.

The next stage of our research was an obvious, easily done removal of the N-methyl substituent from the base molecule carried out on the example of the series of 4-hydroxy-N-(pyridin-2-yl)-2,2-dioxo-1H-2λ6,1-benzothiazine-3-carboxamides 3a-g. The present work aims to clarify the impact of this transformation on the structure, physico-chemical and, most importantly, the biological properties of the compounds of the series studied. It is clear that obtaining the target products only looks like N-demethylation. In reality, from the synthetic scheme the stage of alkylation of the initial methyl anthranilate 1 is simply excluded. Based on it, ethyl 4-hydroxy-2,2-dioxo-1H-2λ6,1-benzothiazine-3-carboxylate (2) unsubstituted in position 1 was synthesized according the method previously described [13]. The target amides 3a-g were obtained with good yields by interaction of this ester with equimolar amounts of the corresponding 2-aminopyridines in boiling xylene.

After recrystallization from DMF amides 3a-g synthesized are colourless or white with a yellowish tint crystalline substances with narrow intervals of melting points, when heating they are soluble in DMF and DMSO and insoluble in ethanol and water. To confirm their structure the elemental analysis, spectroscopy 1H NMR, mass spectrometry were used, and in the case of 6-methylpyridine-2-ylamides 3d the X-ray analysis was also applied. Unfortunately, the low solubility of all amides 3a-g in DMSO-d6, at room temperature did not allow to record 13C NMR spectra.

A distinctive feature of 1-N-methylsubstituted pyridine-2-ylamides with the general formula I is their existence in the form of inner salts (at least in the crystal phase) [10]. However, the question whether such a structure preserves in solution is still open. One fails to solve it in the case of 4-hydroxy-N-(pyridin-2-yl)-2,2-dioxo-1H-2λ6,1-benzothiazine-3-carboxamides 3a-g as well. The 1H NMR spectra give important and useful information about their structure. However, they do not allow either confirm or disprove that in DMSO solution the substances studied exist in the form of inner salts since the signals of the active protons OH and NH-groups that are important do not appear (obviously, due to rapid deuterium exchange).

But in the gas phase the salt forms of amides 3a-g are obviously preserved as evidenced by their mass spectrometric behaviour. Unlike existing conventional and therefore quite stable 4-0H forms of 4-hydroxy-1-methyl-N-(1,3-thiazol-2-yl)-2,2-dioxo-1H-2λ6,1-benzothiazine-3-carboxamides [9], here by electron impact ionization the molecular ion peak was managed to be fixed in one case only and in extremely low intensity (see Scheme 2). And if the main pathway of
The primary decomposition of molecular radical cations of thiazolyl-2-amides was breaking of the bond of the benzothiazine-carbamide fragment (pathway A), but with transition to inner salts the probability of such direction is considerably lost. As a result, the intensity of peaks of the corresponding fragment ions of isocyanate, benzothiazine and hydroxyindole does not exceed 2-7%. The primary destruction of the CO-NHet bond (pathway B) comes to the fore, as a rule, it leads to appearance of high-intensity fragment ion peaks of the corresponding 2-aminopyridines, as well as ketene and oxindole that are common to all samples under research. However, the main distinctive feature of the mass spectra of amides conditioned by their existence in the form of inner salts is an easy elimination of SO$_2$ from molecular ions (pathway C). It is of interest that in this case two types of products are formed: 3-hydroxyindole-2-carboxamide (main) and its 3-oxo analogue (minor). Apparently, their sources are different zwitterionic forms of amide.

The analgesic activity of the compounds synthesized was studied compared to Piroxicam being similar by its structure on the model of the thermal tail-flick procedure in white male rats weighing 180-200 g (Tail Immersion Test) [14]. For this purpose the rat's tail tip was immersed in a water bath heated to 54°C, and the latent period of the tail withdrawal (immersion) expressed in seconds was determined. The analgesic effect (in %) was assessed by the change of the latent period in 1 h after introduction of the test substances and the reference drug. Seven experimental animals were involved to obtain statistically reliable results (the significance level of the confidence interval accepted in this work was $p \leq 0.05$) in testing each of amides, the reference drug and control. All substances under research and Piroxicam were introduced orally in the form of fine aqueous suspensions stabilized with Tween-80 in a screening dose of 20 mg/kg. The animals of the control group received an equivalent amount of water with Tween-80.

All biological experiments were carried out in full accordance with the European Convention on the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes and the Ukrainian Law No. 3447-IV "On protection of animals from severe treatment" (2006).

The results of our pharmacological experiments presented in Table show that removal of the 1-N-methyl group reflects ambiguously on the analgesic properties of 4-hydroxy-N-(pyridin-2-yl)-2,2-dioxo-1H-2λ$^6$,1-benzothiazine-3-carboxamides. In some cases -

Scheme 2. The mass spectrometric fragmentation of amide molecular ion.
Alkaline activities of 4-hydroxy-N-(pyridin-2-yl)-2,2-dioxo-1H-2λ6,1-benzothiazine-3-carboxamides (3a-g) and Piroxicam

<table>
<thead>
<tr>
<th>Compound</th>
<th>R</th>
<th>The latent period in 1 h after introduction of the compounds, s</th>
<th>Change of the latent period compared to control, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>3a</td>
<td>H</td>
<td>3.52±0.11</td>
<td>+12.0 (+5.8)</td>
</tr>
<tr>
<td>3b</td>
<td>4-Me</td>
<td>3.46±0.10</td>
<td>+10.1 (+42.3)</td>
</tr>
<tr>
<td>3c</td>
<td>5-Me</td>
<td>4.08±0.12</td>
<td>+29.9 (+3.6)</td>
</tr>
<tr>
<td>3d</td>
<td>6-Me</td>
<td>4.63±0.14</td>
<td>+47.6 (+76.2)</td>
</tr>
<tr>
<td>3e</td>
<td>5-Cl</td>
<td>3.61±0.10</td>
<td>+15.0 (+96.7)</td>
</tr>
<tr>
<td>3f</td>
<td>3,5-Cl₂</td>
<td>3.92±0.11</td>
<td>+24.7 (+25.1)</td>
</tr>
<tr>
<td>3g</td>
<td>5-Br</td>
<td>4.25±0.16</td>
<td>+35.3 (+7.0)</td>
</tr>
<tr>
<td>Piroxicam</td>
<td></td>
<td>3.96±0.15</td>
<td>+26.1</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>3.14±0.14</td>
<td>-</td>
</tr>
</tbody>
</table>

* – The data on the alkaline activity of the corresponding 1-N-methyl-substituted 4-hydroxy-N-(pyridin-2-yl)-2,2-dioxo-1H-2λ6,1-benzothiazine-3-carboxamides (I) are given in parentheses [10]; ** – Significantly different from control, p<0.05

3a-f amides – such chemical modification has almost no effect on the biological properties, and in other cases – 3b,d,e amides – it causes a significant decline. At the same time there are positive examples of a substantial increase in activity – 3c,g amides significantly exceed not only their 1-N-methyl-substituted analogues, but Piroxicam as well by the level of the alkaline effect.

Experimental Part

1H NMR spectra (400 MHz) were received on a Varian Mercury-400 instrument (USA) in DMSO-d₆ solution with TMS as an internal standard. The electron impact mass spectra were recorded on a Varian 1200L mass spectrometer (USA) with complete scanning in the m/z range from 35 to 700 and direct sample inlet. The electron impact ionization was at 70 eV. Elemental analysis was performed on a Euro Smp10 digital melting point apparatus (Great Britain). The starting ethyl 4-hydroxy-2,2-dioxo-1H-2λ6,1-benzothiazine-3-carboxylate (2) was prepared by our previous procedure [13]. The commercially available o-xylene was dried over anhydrous granular CaCl₂ before use and distilled.

The general procedure for the synthesis of 4-hydroxy-N-(pyridin-2-yl)-2,2-dioxo-1H-2λ6,1-benzothiazine-3-carboxamides (3a-g). Keep the mixture of ethyl ester 2 (2.69 g, 0.01 Mol), the corresponding 2-aminopyridine (0.01 Mol), and dry o-xylene (5 mL) for 1 h at 150°C on a liquid metal bath using a suitable air-cooled distilling column that allows to distill off the ethanol formed without removing the o-xylene solvent. Cool the reaction mixture, add EtOH (15 mL), and leave the mixture for several hours at room temperature. Filter the crystalline amide 3 precipitated, wash with cold EtOH, dry, and recrystallize from DMF.

4-Hydroxy-N-(pyridin-2-yl)-2,2-dioxo-1H-2λ6,1-benzothiazine-3-carboxamide (3a).
Yield – 92%. M. p. – 271-272°C (decomp.); 1H NMR, δ: 8.23 (d, J = 4.7 Hz, 1H, H-6'); 7.96-7.90 (m, 2H, H-4', 5'); 7.70 (d, J = 7.2 Hz, 1H, H-3'); 7.49 (t, J = 7.7 Hz, 1H, H-7), 7.29 (t, J = 6.6 Hz, 1H, H-5'), 7.12 (t, J = 7.4 Hz, 1H, H-6'), 7.06 (d, J = 8.1 Hz, H-8); MS, m/z (I₉%): 253 [M – SO₂]⁺ (15), 252 (2), 223 (3), 197 (5), 133 (14), 132 (6), 120 (2), 106 (100), 104 (39), 77 (87); Anal. Calcd. for C₃₁H₂₁N₅O₅S: C, 52.99; H, 3.49; N, 13.24; S, 10.10. Found: C, 53.06; H, 3.55; N, 13.17; S, 10.03.

4-Hydroxy-N-(4-methylpyridin-2-yl)-2,2-dioxo-1H-2λ6,1-benzothiazine-3-carboxamide (3b).
Yield – 90%. M. p. – 297-299°C (decomp.); 1H NMR, δ: 8.12 (d, J = 5.7 Hz, 1H, H-6'); 7.99 (d, J = 7.8 Hz, 1H, H-5), 7.52-7.47 (m, 2H, H-7, 3'), 7.20-7.11 (m, 3H, H-6, 8, 5'), 2.35 (s, 3H, 4'-CH₃); MS, m/z (I₉%): 267 [M – SO₂]⁺ (17), 266 (3), 223 (30), 197 (12), 159 (5), 148 (13), 134 (29), 133 (12), 132 (14), 120 (33), 119 (95), 108 (100), 104 (62), 92 (81), 81 (36), 80 (57), 77 (53); Anal. Calcd. for C₃₁H₂₃N₅O₅S: C, 54.37; H, 3.95; N, 12.68; S, 9.68. Found: C, 54.43; H, 4.02; N, 12.62; S, 9.59.

4-Hydroxy-N-(5-methylpyridin-2-yl)-2,2-dioxo-1H-2λ6,1-benzothiazine-3-carboxamide (3c).
Yield – 91%. M. p. – 290-292°C (decomp.); 1H NMR, δ: 8.16 (s, 1H, H-6'); 7.98 (d, J = 7.6 Hz, 1H, H-5), 7.88-7.75 (m, 2H, H-4', 3'), 7.53 (t, J = 7.6 Hz, 1H, H-7), 7.21-7.08 (m, 2H, H-6, 8), 2.35 (s, 3H, 5'-CH₃); MS, m/z (I₉%): 267 [M – SO₂]⁺ (49), 266 (7), 223 (2), 197 (3), 159 (3), 148 (17), 134 (10), 133 (16), 132 (8), 120 (32), 108 (100), 104 (18), 92 (47), 81 (25), 80 (40), 77 (22); Anal. Calcd. for C₃₁H₂₃N₅O₅S: C, 54.37; H, 3.95; N, 12.68; S, 9.68. Found: C, 54.44; H, 4.01; N, 12.60; S, 9.62.

4-Hydroxy-N-(6-methylpyridin-2-yl)-2,2-dioxo-1H-2λ6,1-benzothiazine-3-carboxamide (3d).
Yield – 95%. M. p. – 266-268°C (decomp.); 1H NMR, δ: 8.02-7.85 (m, 3H, H-5, 4', 3'); 7.51 (t, J = 7.4 Hz, 1H, H-7), 7.27-7.04 (m, 3H, H-6, 8, 5'), 2.50 (s, 3H, 6'-CH₃) coincides with the signals of the residual protons in DMSO-d₆; MS, m/z (I₉%): 331 [M⁺ (2), 267 [M – SO₂]⁺ (34), 266 (3), 223 (22), 197 (2), 159 (2), 148 (39), 134 (7), 133 (10), 132 (6), 120 (100), 108 (67), 104 (4), 92 (84), 91 (62), 81 (88), 80 (58), 77 (17); Anal. Calcd. for C₃₁H₂₃N₅O₅S: C, 54.37; H, 3.95; N, 12.68; S, 9.68. Found: C, 54.40; H, 4.00; N, 12.59; S, 9.61.

N-(5-Chloropyridin-2-yl)-4-hydroxy-2,2-dioxo-1H-2λ6,1-benzothiazine-3-carboxamide (3e).
Yield – 93%. M. p. – 285-287°C (decomp.); 1H NMR, δ: 8.35
C₁₄H₉Cl₂N₃O₄ (24), 77 (38), 73 (63), 64 (100); Anal. Calcd. for C₁₄H₁₀BrN₃O₄: C, 42.44; H, 2.54; N, 10.61; S, 8.09. Found: C, 42.49; H, 2.61; N, 10.68; S, 8.01.

Conclusions

1. The article presents a new series of 4-hydroxy-N-(pyridin-2-yl)-2,2-dioxo-1H-2λ⁶,1-benzothiazine-3-carboxamides without substituents at the nitrogen atom of the benzothiazine cycle. The analgesic properties of all substances synthesized have been studied. It has been observed that position 1 readily subjected to modification can be used for purposeful improvement of pharmaceutical or pharmacological properties of N-substituted 4-hydroxy-2,2-dioxo-1H-2λ⁶, 1-benzothiazine-3-carboxamides.

References