Uterine Relaxant Effect of Zolpidem: A Comparison with Other Smooth Muscle Relaxants

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Zolpidem, Benzodiazepines, Rat Uterus, Calcium Channels

Zolpidem is an imidazopyridine sedative-hypnotic which interacts with central benzodiazepine-receptors. To examine its effects on uterine smooth muscle we have compared with those obtained by diltiazem, papaverine and diazepam on different experimental models.

The IC₅₀ values obtained indicate similar behaviour of zolpidem and diazepam. They showed more active against the spontaneous contractions and those induced by KCl (60 mM) or by CaCl₂ (0.01–10 mM) in Ca²⁺-free depolarizing medium than against acetylcholine (0.1 mM)-induced contractions. Both of them also showed more effectiveness against the tonic component of the acetylcholine-evoked contraction than against the phasic one. All the drugs tested were less powerful against contractions induced by oxytocin than against those induced by other agonists.

This observation let us speculate that the mechanism of action of zolpidem may be related to an action on Ca²⁺ influx through voltage-dependent Ca²⁺ channels due to an interaction with low affinity receptor located at the plasmalemma as has been suggested for diazepam.

Introduction

Zolpidem is a new, short-acting, imidazopyridine sedative-hypnotic. Like the benzodiazepine (BZD) agents, zolpidem interacts with central benzodiazepine-receptors to potentiate GABAergic transmission. However, unlike the traditional hypnotics, it does so selectively, demonstrating a much greater affinity for the θ₁ receptor subtype (Langer et al., 1988).

It has been demonstrated that benzodiazepine-receptor ligands interact with Ca²⁺ channels in peripheral tissues, while having another primary site of action (Godfraind et al., 1986).

In an attempt to clarify the mechanism of action of zolpidem in the peripheral tissues, we have compared its inhibitory potency with diltiazem, papaverine and diazepam, a non-specific smooth muscle relaxant and diazepam, a benzodiazepine which has affinity for both peripheral and central benzodiazepine-receptor. We have assayed the uterine relaxants effect of zolpidem in comparison with these drugs on the spontaneous contractions and on those induced by KCl, acetylcholine, oxytocin or CaCl₂ in Ca²⁺-free medium.

Material and Methods

Preparation of uterine horns

Uterine horns were obtained from virgin female Wistar rats (180–200 g) kept in room with controlled temperature (22 °C). The animals were treated with β-estradiol benzoate (0.5 mg/kg) 24 h before the experiments and killed by a blow on the head. One segment of each uterine horn was removed and mounted in a 10 ml organ bath filled with physiological solution bubbled with a mixture of 95% O₂, 5% CO₂ and maintained at 31 °C.

Drugs and solutions

Zolpidem (N,N,6- trimethyl-2-(p-toly)-imidazo [1,2-9] pyridine-3-acetamide) hemitartrate (Synthelabo, Paris), diltiazem (cis-(-)-3-(acetyloxy)-5-[2-(dimethyl-amino)ethyl]-2,3-dihydro-2-(4-methoxy-phenyl)-1,1-benzothiazepin-4 (5H) one) hydrochloride, papaverine (6,7 dimethoxy-1- veratrylsquinoline) hydrochloride, diazepam (7-chloro-1,3-dihydro-1-methyl-5[phenyl- ds] -2H-1,4- benzodiazepin-2-one), acetylcholine chloride, oxytocin (α-hypophamine) and β-estradiol 3-ben-

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zoate were purchased from Sigma Chemical Co. (St. Louis, MO, USA). All other reagents were of analytical grade.

All drugs reagents were dissolved in distilled water, except zolpidem and diazepam which were dissolved previously in dimethyl sulfoxide (DMSO) and further diluted in distilled water. Controls received the corresponding solvent.

The following physiological solutions were used: Jalon-Ringer solution (mm): NaCl 154, KCl 5.63, CaCl₂ 0.65, NaHCO₃ 5.95, glucose 2.77 (this solution has a low calcium concentration to reduce the interference of spontaneous contractile activity of the uterus preparation). Ca²⁺-free Jalon-Ringer solution was prepared as for Jalon-Ringer except for the omission of CaCl₂. Locke-Ringer solution (mm): NaCl 154, KCl 5.63, CaCl₂ 2.16, NaHCO₃ 5.95, MgCl₂ 2.10, glucose 5.55.

Experimental procedure

Spontaneous contractions. The uterine horn was immersed in Locke-Ringer solution with a resting tension of 0.5 g until stabilization of spontaneous contractions was reached. This solution contains Ca²⁺-physiological concentrations so that the uterus shows spontaneous activity (Ivorra et al., 1993).

K⁺-depolarized uterus. The organ was immersed in Jalon-Ringer solution and equilibrated for 20 min with basal tension of 1 g, then KCl (60 mm) was added. This addition caused a rapid contraction, followed by a slight relaxation and a prolonged contraction. In these experimental conditions, cumulative doses of drugs were administered and dose-related relaxations could be observed.

CaCl₂ induced contractions in a depolarizing Ca²⁺-free medium. To assess the effects of these drugs on the influx of Ca²⁺ through voltage-sensitive channels, Ca²⁺ dose-response curves were established according to Godfraind et al. (1968) and Weiss (1981). The uterine horns were incubated for 20 min in Jalon-Ringer solution, then for 1 h in Ca²⁺-free solution. The preparations were washed at intervals of 15 min. Before adding CaCl₂, tissues were exposure to a single dose of KCl (60 mm), in these conditions, this addition did not cause contraction. Two cumulative concentration-response curves to CaCl₂ (0.01 to 10 mm) were obtained at 60 min intervals in each preparation (Van Rossum, 1963). After obtaining the first curves, washing until complete relaxation, different concentration of diltiazem (0.01, 0.1 and 1 μm), papaverine (1, 10 and 100 μm), diazepam (1, 10 and 100 μm) and zolpidem (1, 10 and 100 μm) were added to the bath and left in contact with the tissue for 20 min. Then, a second cumulative concentration-response curve to CaCl₂ in presence of the tested drugs was obtained.

Each antagonist was tested in separate horns and control experiments were performed using only CaCl₂ in the absence of antagonists. The maximal contraction obtained with the first dose-response curve to CaCl₂ was taken as 100% and all contractions calculated as a function of this value. Each preparation was exposed to only one concentration of the antagonist.

Acetylcholine-induced contractions. A uterine horn was incubated in Jalon-Ringer solution with a resting tension of 1 g for 20 min. Acetylcholine (0.1 mm) was added, which induced an initial phasic contraction followed by a plateau with small rhythmic contractions. After obtaining two successive responses which were almost identical, two experimental procedures were performed as above:

a) Cumulative amounts of diltiazem (0.003-10 μm), papaverine (0.01-3 μm), diazepam (1-300 μm) and zolpidem (0.1-100 μm) were added when the contractile response to acetylcholine was reached. After washing, another addition of acetylcholine induced a contractile response.

b) A control contraction was obtained by addition of acetylcholine 0.1 mm; after washing, the drugs tested were added 15 min before the second addition of acetylcholine. The doses used were: diltiazem (0.01, 0.1 and 1 μm), papaverine (10, 30 and 100 μm), diazepam (30, 100 and 300 μm) and zolpidem (30, 100 and 300 μm).

Oxytocin-induced rhythmic contractions. The uterine horn was incubated in Locke-Ringer solution with a resting tension of 0.5 g for 20 min. Oxytocin (0.01 units ml⁻¹) was added and rhythmic contractions were induced by this agonist. Cumulative amounts of the drugs tested were added to the organ bath. The doses used were: diltiazem (0.1-100 μm), papaverine (0.1-50 μm), diazepam (0.1-300 μm) and zolpidem (0.1-1000 μm).
**Statistical analysis**

The results were expressed as a percentage of the maximum effect (E\text{max}) obtained by agonist addition. A regression of responses against -\log C of test compound was performed by the least squares method for each preparation. The concentration needed to produce 50% inhibition (IC\text{50}) was obtained from the regression plot and a mean IC\text{50} ± 95% confidence interval was calculated for each dose assessed. Results are expressed as the mean value and S. E. M. of 6–8 preparations. The significance of differences between values was determined with an one-way analysis of variance (ANOVA) followed by LSD (least significant difference) test. P values smaller than 0.05 were regarded as significant.

**Results and Discussion**

**Effects on spontaneous uterine contractions**

The addition of cumulative concentrations of diltiazem (0.0001–1 \mu M), papaverine (0.1–1 \mu M), diazepam (0.1–100 \mu M) and zolpidem (0.1–100 \mu M), diminished both the frequency and the amplitude (represented as % contraction in Fig. 1) of the spontaneous contractions of rat uteri immersed in Locke-Ringer solution. Papaverine, diazepam and zolpidem at 100 \mu M, abolished the uterine spontaneous activity. Diltiazem 1 \mu M also produced a 100% relaxation of the spontaneous contractions.

The IC\text{50} values are summarized in Table I. The rank order of potencies of these agents was: diltiazem > papaverine > diazepam > zolpidem. After washing, the contractile response was restored except for the experiments with diltiazem (data not shown).

**Relaxant effects of drugs tested on K+ -depolarized rat uterus**

All drugs produced dose-dependent relaxations in KCl-depolarized uterus. Fig. 2 shows these dose-response curves and Table I summarizes IC\text{50} for each drug tested and the rank of order of potencies of these was: diltiazem > papaverine > diazepam > zolpidem. All the agents tested produced a 100% relaxation of the contraction caused by KCl.

<table>
<thead>
<tr>
<th>Drugs</th>
<th>n</th>
<th>Spont.</th>
<th>KCl</th>
<th>ACh</th>
<th>Ox</th>
</tr>
</thead>
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<tr>
<td>Diltiazem</td>
<td>7</td>
<td>2.12±0.81\times10^{-8}</td>
<td>2.02±0.68\times10^{-8}</td>
<td>2.12±0.63\times10^{-7}</td>
<td>3.15±0.91\times10^{-6}</td>
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<tr>
<td>Papaverine</td>
<td>8</td>
<td>7.13±0.67\times10^{-7}</td>
<td>2.42±0.49\times10^{-7}</td>
<td>7.28±2.24\times10^{-7}</td>
<td>2.21±0.14\times10^{-5}</td>
</tr>
<tr>
<td>Diazepam</td>
<td>6</td>
<td>7.33±1.50\times10^{-6}</td>
<td>2.50±1.27\times10^{-6}</td>
<td>3.48±0.77\times10^{-5}</td>
<td>4.24±1.47\times10^{-5}</td>
</tr>
<tr>
<td>Zolpidem</td>
<td>8</td>
<td>6.23±0.22\times10^{-6}</td>
<td>2.67±0.39\times10^{-5}</td>
<td>4.29±1.36\times10^{-6}</td>
<td>1.47±0.35\times10^{-4}</td>
</tr>
</tbody>
</table>

Figs. 1+2. Concentration-response curves of inhibition of spontaneous contractions (1) or KCl 60 mM-evoked contractions (2) obtained after the addition of diltiazem (●), papaverine (○), diazepam (♦) and zolpidem (▼). Vehicle control (□).
Effect of preincubation with the drugs on CaCl$_2$-induced contractions in a depolarizing Ca$^{2+}$-free medium

Cumulative concentration-response curves in response to CaCl$_2$ (0.01 to 10 mM) on rat uteri immersed in K$^+$-depolarizing Ca$^{2+}$-free solution were reproducible at 60 min intervals. Fig. 3 shows the mean cumulative concentration-response curves for CaCl$_2$ alone and in the presence of different concentrations of diltiazem (0.01, 0.1 and 1 μM), papaverine (1, 10 and 100 μM), diazepam (1, 10 and 100 μM) and zolpidem (1, 10 and 100 μM). The ED$_{50}$ and $E_{max}$ values are summarized in Table II. Papaverine and diltiazem produced a parallel and concentration-dependent rightward displacement of the dose-response curve to CaCl$_2$ with significantly reducing the maximal response with all doses tested. These data indicate that these drugs block CaCl$_2$-induced contraction non-competitively. Diazepam and zolpidem only at 100 μM produced displacement of the dose-response curve with significantly reducing the maximal response.

Relaxant effects on acetylcholine-induced contraction of rat uterus

Addition of diltiazem (0.003–10 μM), papaverine (0.01–30 μM), diazepam (1–300 μM) and zolpidem (0.1–100 μM), during the plateau of contraction by acetylcholine (0.1 mM), produced dose-dependent relaxation; hence, dose-response curves were constructed by addition of cumulative doses of these drugs. These dose-response curves are represented in Fig. 4. The IC$_{50}$ values are summarized in Table I. The rank of order of potencies: diltiazem > papaverine > zolpidem > diazepam. After washing, a new addition of acetylcholine (0.1 mM) produced a contraction that was similar to the first except for the experiences using diltiazem in this case, the second contraction was significantly different in magnitude and morphology from the first.

When the uterus was preincubated with different doses of the agents tested: diltiazem (0.01, 0.1 and 1 μM), papaverine (10, 30 and 100 μM), diazepam (30, 100 and 300 μM) and zolpidem (30, 100 and 300 μM), 15 min before the addition of acetylcholine (0.1 mM), inhibition of the phasic

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![Fig. 3. CaCl$_2$-induced contraction in Ca$^{2+}$-free medium. Control (●) or in presence of diltiazem (A) 0.01 μM (○), 0.1 μM (●) and 1 μM (▲), papaverine (B) 1 μM (○), 10 μM (●) and 100 μM (▲), diazepam (C) 1 μM (○), 10 μM (●) and 100 μM (▲) and zolpidem (D) 1 μM (○), 10 μM (●) and 100 μM (▲).]
Figs. 4+6. Dose response relaxation curves in uterus previously contracted with acetylcholine 0.1 mM (4) or oxytocin 0.01 units ml⁻¹ (6) obtained after the addition of different agents, diltiazem (●), papaverine (○), diazepam (♦) and zolpidem (◇). Vehicle control (□).

Table II. Parameters of dose-response curves of contraction induced by cumulative doses of CaCl₂ (0.01–10 mM) in Ca²⁺-free depolarizing medium, in the absence (control) or in the presence of diltiazem 0.01 μM, 0.1 μM and 1 μM; papaverine 1 μM, 10 μM and 100 μM; diazepam 1 μM, 10 μM and 100 μM and zolpidem 1 μM, 10 μM and 100 μM. Values of ED₅₀ were obtained from the regression plot. Maximal effect (E_max) values obtained as a percentage with respect to control curve. Values expressed as the mean value and S. E. M. of n experiences.

Table:<br><br>Drugs | n | E_max(%) | ED₅₀ [M]<br><br>CaCl₂ | – | – | 3.09±0.15×10⁻⁴<br>CaCl₂+Diltiazem<br>0.01 μM | 6 | 93.67±7.85 | 1.21±0.61×10⁻³★<br>0.1 μM | 6 | 69.36±4.13 | 4.71±1.79×10⁻³***<br>1 μM | 6 | 41.38±3.39 | 2.83±0.71×10⁻²**<br>CaCl₂+Papaverine<br>1 μM | 7 | 110.36±7.85 | 1.65±0.36×10⁻⁴★<br>10 μM | 6 | 70.06±3.91 | 4.18±0.44×10⁻³**<br>100 μM | 8 | 7.14±3.79 | 4.00±1.31×10⁻⁴★<br>CaCl₂+Diazepam<br>1 μM | 7 | 107.89±2.04 | 4.00±1.31×10⁻⁴★<br>10 μM | 6 | 100.29±3.88 | 3.76±0.35×10⁻⁴★<br>100 μM | 6 | 45.39±4.88 | 2.63±0.89×10⁻²***<br>CaCl₂+Zolpidem<br>1 μM | 8 | 102.44±3.75 | 3.31±1.91×10⁻⁴★<br>10 μM | 6 | 108.91±3.20 | 4.29±1.17×10⁻⁴★<br>100 μM | 6 | 85.09±7.17 | 1.76±0.31×10⁻³★

Modification of uterine response to oxytocin

Addition of oxytocin 0.01 units ml⁻¹ to uterine horn incubated in Locke-Ringer solution induced rhythmic contractile response with stable frequency and amplitude. The addition of cumulative amounts of diltiazem (0.1–100 μM), papaverine (0.1–50 μM), diazepam (0.1–300 μM) and zolpidem (0.1–100 μM), diminished both the frequency and amplitude of the contractions. Fig. 6 shows the decrease of the amplitude of contraction (% contraction). The parameters of these curves are summarized in Table I. All the agents at the higher dose tested completely abolished the contractile response to oxytocine 0.01 units ml⁻¹. After washing, complete recovery of rhythmic contractions induced by oxytocin was observed except for the experiments carried out with diltiazem.

The IC₅₀ values obtained indicate less effectiveness of all tested drugs against acetylcholine on spontaneous contractions and on those evoked by KCl, although they are smaller than those obtained against oxytocin. Diltiazem, diazepam and zolpidem were more active against the tonic component than against the phasic phase of the acetylcholine-induced contraction; this results suggest a major influence on the Ca²⁺ influx from extracellular medium through VOCs. On the other hand, papaverine was less specific inhibiting the acetylcholine-induced contraction, this result is in accordance with its mechanism of action (Cumiskey and Feigenson, 1983).
Diltiazem is a calcium antagonist with selectivity for the entry of calcium through the VOCs ( Caulin et al., 1983; Hurwitz, 1986; Nayler and Horowitz, 1983). Besides, the most of the calcium entry blockers have an additional intracellular site of action, related to an increase of Ca$^{2+}$ efflux or to stimulation of Ca$^{2+}$ uptake (Spedding, 1983; Saida and Van Breemen, 1983; Cohen et al., 1984), this justify the inhibitory potency of diltiazem on acetylcholine and oxytocin-induced contractions. Diltiazem appeared like the most powerful drug tested with a great difference in these experiences independent of the agonist used to contract the uterus, and was the only able to inhibit irreversibly the uterine contractions.

Papaverine is a non-specific smooth muscle relaxant (Cumiskey and Feigenson, 1983) that increase the efflux and uptake of Ca$^{2+}$ by intracellular organelles (Imai and Kitagwa, 1981; Koike and Takayanagi, 1981; Huddart et al., 1984). This action could be related to an increase in cAMP that leads to the accumulation of calcium in endoplasmic reticulum and induces phosphorilation of myosin light chain kinase, which causes smooth muscle relaxation (Cumiskey and Feigenson, 1983; Calixto and Loch, 1985).

Benzodiazepines have been reported to have relaxant effects on different preparations of smooth muscle as the guinea-pig trachea (Raeburn et al., 1988; Herrera et al., 1996), the rat aorta (French et al., 1988; Pérez-Guerrero et al., 1996a), the skinned rat urinary bladder (Martí-Cabrera et al., 1994) and the rat uterus (Kazanietz and Elghyhen, 1990; Pérez-Guerrero et al., 1996b). It has been demonstrated that benzodiazepines interact with Ca$^{2+}$ channels while having another primary site of action (Godfraind et al., 1986). Diazepam is an agonist with affinity for both peripheral and central sites (Schoemaker et al., 1983).

Diazepam showed more activity against the spontaneous contractions and those induced by KCl (60 mM) or CaCl$_2$ in Ca$^{2+}$-free medium and this behaviour was likely to zolpidem. This data support that the mechanism underlying by micromolar concentrations inhibition of different benzodiazepines is an action on Ca$^{2+}$ influx through Ca$^{2+}$ channels due to an interaction with low affinity receptor located at the plasmalemma of
different isolated preparations (Raeburn et al., 1988; De Lorenzo et al., 1981; Fares et al., 1987).

The present findings suggest that zolpidem shows a similar behaviour to diazepam on rat uterus and the the mechanism underlying the relaxant effect of zolpidem may be similar to diazepam and this hypothesis could explain our results and our current studies.


