Basic characteristics and kinetics of degradation in aqueous buffer of selected diclofenac prodrugs intended for joint injection
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Basic characteristics and kinetics of degradation in aqueous buffer of selected diclofenac prodrugs intended for joint injection
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Introduction
Recently, a novel ester prodrug approach for the accomplishment of local and sustained diclofenac action after injection into joints was reported (1). It is to be expected that both onset and duration of diclofenac action can be modified by variation of inherent ester prodrug properties including their pH dependent solubility and charge as well as their susceptibility to undergo esterase facilitated hydrolysis. In the present study, three diclofenac ester prodrugs differing with respect to the spacer carbon chain length (Fig. 1) were synthesized and evaluated in vitro. Thus, the objectives of the present study were:
(i) to determine the effect of the spacer chain length on the pKₐ value and aqueous pH-dependent solubility of the prodrugs.
(ii) to investigate the kinetics and mechanism of degradation of the three prodrugs in aqueous solution in the pH-range 1-10 as well as in 80 % (v/v) human synovial fluid (SF) and 80 % (v/v) plasma at 37°C.
(iii) to characterize in vitro release of diclofenac from prodrug suspensions using the rotating dialysis cell model.

Mechanism of degradation of the diclofenac ester prodrugs in aqueous solution pH 1-10
The experimental data suggested that below pH 5 formation of diclofenac and the indolinone 1:2, 6-dichlorophenyl)-1,3-dihydro-2H-indol-2-one (ILO) took place in a consecutive manner (Fig. 4A). In the pH range 6-10, HPLC analyses revealed that the prodrugs were subject to parallel degradation to yield diclofenac and ILO (Fig. 4B).

Stability in human plasma and synovial fluid
The stability of the diclofenac ester prodrugs after incubation in human 80 % (v/v) SF and 80 % (v/v) plasma was studied at 37°C. Compared to the stability in 67 mM phosphate buffer solution at pH 7.4, the prodrugs underwent much faster degradation in the biological media indicating the involvement of enzyme-mediated prodrug conversion (Table 1) to yield the active diclofenac.

Prodrug concept
The prodrug approach involves the employment of pro-moieties that besides having an OH group (for diclofenac ester bond formation) comprises a weak base functionality with a pKₐ value of about 6-8 (2). Hence, this prodrug type experiences a complex relationship between solubility, dissolution and prodrug cleavage rate.

Prodrug conversion
A total dose of approximately 25 µmol prodrug was added to the donor compartment. DP-3 in 80 % (v/v) human synovial fluid at 37°C in the rotating dialysis model (n=2-3).

Conclusion
The rate of degradation of the prodrugs was about 6-fold faster in 80 % (v/v) human plasma than in 80 % (v/v) human SF, which might reflect the higher protein content of human plasma relative to SF or the presence of different esterases in the biological media. In vitro release studies performed on pre-formed suspensions of the prodrugs revealed significantly different release behaviour among the prodrugs and indicate a complex relationship between solubility, dissolution and prodrug cleavage rate. Overall the results from the study indicated that design of prodrugs suited for local pain management through joint injection may be feasible by tuning of the physicochemical properties.

References:

Various experimental data including 

\[ pK_a = \text{Electromotive forces of cells without liquid junction. J Am Chem Soc. 1933;55(6):2203-4.} \]

Figure 1: Chemical structures of the diclofenac ester prodrug.

Figure 2: Schematic representation of the in situ formulation principle.

Figure 3: pH-rate profiles for the degradation of the diclofenac prodrugs in aqueous solution at 37°C (I = 0.3 M).

Figure 4: Reaction schemes for formation of diclofenac and ILO from degradation of the DP-2 prodrug at pH below 2 (A) and at 5.8 ± 0.1 (B) and 37°C.

Figure 5: Release profiles of diclofenac from prodrug suspensions of DP-1, DP-2, and DP-3 in 80 % (v/v) human synovial fluid at 37°C in the rotating dialysis model (n=2-3). A total dose of approximately 25 µmol prodrug was added to the donor compartment. Bars represent standard deviations.

Table 1: pKₐ, half-lives and solubility (mean ± S.D., n=3) of prodrugs in aqueous solution at pH 7.4, 80 % (v/v) SF and 80 % (v/v) plasma at 37°C.

<table>
<thead>
<tr>
<th>pKₐ (25°C)</th>
<th>pKₐ (37°C)</th>
<th>Chemical hydrolysis pH range</th>
<th>SF (min)</th>
<th>Plasma (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP-1</td>
<td>7.4 ± 0.3</td>
<td>6.6 ± 0.4</td>
<td>6.5 ± 0.9</td>
<td>6.1 ± 0.7</td>
</tr>
<tr>
<td>DP-2</td>
<td>4.3 ± 0.6</td>
<td>7.0 ± 0.1</td>
<td>11.5 ± 0.9</td>
<td>10.5 ± 0.7</td>
</tr>
<tr>
<td>DP-3</td>
<td>4.6 ± 1.7</td>
<td>7.4 ± 0.1</td>
<td>18.9 ± 2.2</td>
<td>3.0 ± 0.1</td>
</tr>
</tbody>
</table>

* Determined by potentiometric titration
* Calculated using Eq. 1

In vitro release studies performed on pre-formed suspensions of the prodrugs revealed significantly different release behaviour among the prodrugs and indicate a complex relationship between solubility, dissolution and prodrug cleavage rate.