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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.

<table>
<thead>
<tr>
<th>Solubility pH 7.4 (µg/mL)</th>
<th>pKₐ (25°C)</th>
<th>Chemical Hydrolysis pH 7.4 (µg/mL)</th>
<th>Solubility SF pH 7.4 (µg/mL)</th>
<th>Stability SF (min)</th>
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<tr>
<td>DP-1</td>
<td>2.57</td>
<td>4.07</td>
<td>4.67</td>
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* Determined by potentiometric titration

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

Release studies

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.

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 the physicochemical properties.

References

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

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 pH-dependent solubility, i.e. a desired low solubility at physiological pH 7.4 in combination with a significantly higher solubility in slightly acidic solution.

It has been demonstrated that after injection of a concentrated slightly acidic prodrug solution (the preformulation) into SF, pH 7.4, in situ precipitation of the neutral prodrug species in this biological matrix occurs (2). Only the small amount of dissolved prodrug, in equilibrium with the precipitate, is subject to SF enzyme-mediated cleavage (Fig. 2).

pH-rate profile

The degradation rate of the prodrugs was studied over the pH range 1-10 in aqueous solution at 37°C (I = 0.3 M) and in buffer free solution (pH 2-10 (n = 3-4)) as well as 80 % (v/v) human synovial fluid (SF) and 80 % (v/v) plasma at 37°C. Based on the experimental data (Fig. 3) an expression for the overall apparent first-order rate constant kₑ for the degradation of the individual diclofenac ester prodrug in the pH range 1-10 was proposed:

\[ kₑ = kₐ \times \frac{\gammaₐ}{\gammaₐ + \gammaₐ'} \]

where \( kₐ \) refers to the pseudo-first-order rate constant for prodrug degradation in buffer free solution (pH 2-10 (n = 3-4)) and in dilute HCl, pH 1.5-3 (n = 10). The full lines in Fig. 3 where obtained by fitting the data to Eq. 1 using 2 parameter logistic \( kₐ \times \frac{\gammaₐ}{\gammaₐ + \gammaₐ'} \) for the full lines in Fig. 3 where obtained by fitting the data to Eq. 1 using 2 parameter logistic and \( \gammaₐ \) for the full lines in Fig. 3 where obtained by fitting the data to Eq. 1 using 2 parameter logistic. As apparent from Fig. 3, good agreement between the solid curves and the experimental determined rate constants was achieved (R² = 0.997).

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

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Calculated using Eq. 1

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