ABSTRACT: Literature data are reviewed regarding the scientific advisability of allowing a waiver of in vivo bioequivalence (BE) testing for the approval of immediate release (IR) solid oral dosage forms containing either diclofenac potassium and diclofenac sodium. Within the biopharmaceutics classification system (BCS), diclofenac potassium and diclofenac sodium are each BCS class II active pharmaceutical ingredients (APIs). However, a biowaiver can be recommended for IR drug products of each salt form, due to their therapeutic use, therapeutic index, pharmacokinetic properties, potential for excipient interactions, and performance in reported BE/bioavailability (BA) studies, provided: (a) test and comparator contain the same diclofenac salt; (b) the dosage form of the test and comparator is identical; (c) the test product contains only excipients present in diclofenac drug products approved in ICH or associated countries in the same dosage form, for instance as presented in this paper; (d) test drug product and comparator dissolve 85% in 30 min or less in 900 mL buffer pH 6.8, using the paddle apparatus at 75 rpm or the basket apparatus at 100 rpm; and (e) test product and comparator show dissolution profile similarity in pH 1.2, 4.5, and 6.8. © 2008 Wiley-Liss, Inc. and the American Pharmacists Association


A project of the International Pharmaceutical Federation (FIP), Groupe BCS, www.fip.org/bcs. This article reflects the scientific opinion of the authors and not the policies of regulating agencies, the International Pharmaceutical Federation (FIP) and the World Health Organization (WHO).

Correspondence to: D.M. Barends (Telephone: 31-30-2744209; Fax: 31-30-2744462; E-mail: dirk.barends@rivm.nl) Journal of Pharmaceutical Sciences, Vol. 98, 1206–1219 (2009) © 2008 Wiley-Liss, Inc. and the American Pharmacists Association
**INTRODUCTION**

A biowaiver monograph of diclofenac is presented based on literature data and new experimental data. Risks are evaluated in basing a BE assessment on *in vitro* study results (i.e., “biowaiving”), rather than *in vivo* study results, for the approval of new IR solid oral dosage forms containing diclofenac sodium and diclofenac potassium, for example, plain IR tablets, dispersible tablets and powders for oral solutions. This risk evaluation considers diclofenac sodium and diclofenac potassium biopharmaceutical and clinical properties, as they pertain to reformulated products and new multisource products. This evaluation concerns drug products containing diclofenac as the only API and does not concern combination drug products. This evaluation does not concern delayed release products or any other modified release formulations of diclofenac.

The purpose and scope of this series of monographs have been previously discussed. Briefly, the aim is to evaluate all pertinent data available from literature sources for a given API to assess the risks associated with a biowaiver. For these purposes, risk is defined as the probability of making an incorrect biowaiver decision, as well as the resulting consequences of such a decision in terms of public health and individual patient risks. On the basis of these considerations, a recommendation can be made as to whether a biowaiver is advisable or not. This systematic approach to recommend for or to advise against a biowaiver is described in the recently published World Health Organization (WHO) Guideline.

These monographs do not intend to simply apply the WHO, FDA and/or EMEA Guidance, but aim to apply these guidances and further serve as a critical validation of these regulatory documents. Biowaiver monographs have already been published for acetaminophen (INN: paracetamol), acetazolamide, aciclovir, amitriptyline, atenolol, chloroquine, cimetidine, ethambutol, ibuprofen, isoniazid, metoclopramide, prednisolone, prednisone, pyrazinamide, propranolol, ranitidine, and verapamil. They are also available on-line at www.fip.org/bcs. Although diclofenac is not on the present WHO List of Essential Medicines, it was considered appropriate to include this widely used and important API in this series.

**Literature Review**

Published information was obtained from PubMed up to November 2007. Key words used were: diclofenac potassium, diclofenac sodium, NSAID, indication, therapeutic index, solubility, polymorphism, partition coefficient, pK<sub>a</sub>, absorption, permeability, distribution, metabolism, excretion, excipients, bioequivalence and dissolution.

**GENERAL CHARACTERISTICS**

**Name and Structure**

The chemical name of diclofenac is 2-[(2,6-dichlorophenyl)amino]benzeneacetic acid. Its structure is shown in Figure 1.

**Therapeutic Indication, Side Effect and Therapeutic Index**

Diclofenac is a well-known nonsteroidal anti-inflammatory drug (NSAID) with anti-inflammatory, analgesic and antipyretic properties, comparable or superior to other NSAIDs. Diclofenac shows preferential inhibition of the cyclooxygenase-2

![Figure 1. Structure of diclofenac, where M=K⁺ or Na⁺ for potassium or sodium salt, respectively.](image-url)
(COX-2) enzyme. Diclofenac sodium is mainly indicated in the treatment of osteoarthritis, rheumatoid arthritis and ankylosing spondylitis. Diclofenac potassium is claimed to dissolve faster, and hence absorbed faster, than the sodium salt and is recommended for the treatments that need short onset of action, mainly for its analgesic properties. Diclofenac potassium is also indicated for the treatment of primary dysmenorrheal and mild to moderate pain. As with other NSAIDs, diclofenac is known to increase the risk of gastrointestinal bleeding and cardiovascular side effects. However, diclofenac has a relatively high therapeutic index in comparison to other NSAIDs.

PHYSICOCHEMICAL PROPERTIES

Salts, Esters, Polymorphs, Hydrates

Diclofenac is usually formulated as the sodium or potassium salt, but other salts are also used, such as hydroxyethylpyrrolidine salt for oral preparations, and diethylammonium and diethylamine for topical preparation. This monograph refers to drug products containing the sodium or potassium salt of diclofenac only. Most “plain” tablets contain the potassium salt, whereas most dispersable dosage forms contain diclofenac sodium, see Tables 1 and 2. In this monograph, the term diclofenac without indicating the salt form refers to the sodium and potassium salts. Trihydrates and tetrahydrates exist for both of diclofenac potassium and diclofenac sodium, but in pharmacopoeial drug products only the anhydrate is used.

Solubility

Solubility values for diclofenac sodium taken from the literature are shown in Table 3 and experimentally determined solubilities of diclofenac potassium are show in Table 4, respectively, together with the dose to solubility ratios (D/S) for several tablet strengths.

Polymorphism

Reports of diclofenac potassium or diclofenac sodium polymorphs were not found in the literature.

Partition Coefficient

Partition coefficient in n-octanol/aqueous buffer (log D) are reported to be 1.4 and 1.1 for pH 6.8 and 7.4, respectively. The experimental log P (n-octanol/water) and ClogP values of diclofenac are 4.40 and 4.71, respectively, which are larger than the corresponding values of 1.72 and 1.35 for the highly permeable marker drug metoprolol.

pKₐ

The pKₐ of diclofenac is about 3.80 at 25°C.

Strengths of Marketed Drug Products

Dosage form strength is expressed in mg of salt present, not equivalent of the free acid. In the United States (US) and in the EU, Marketing Authorizations (MAs), that is, registrations, exist for IR solid oral dosage forms for 12.5, 25, and 50 mg diclofenac salt, see Tables 1 and 2. Higher strengths of these drugs have been marketed, but only as delayed release solid forms or combination oral products; however, such products are outside the scope of this monograph.

PHARMACOKINETIC PROPERTIES

The majority of pharmacokinetic data concerns diclofenac sodium. Literature reports indicate that diclofenac sodium and diclofenac potassium are similar in terms of extent of oral absorption, pattern of distribution, metabolism, and elimination.

Absorption and Permeability

Diclofenac is 100% absorbed after oral administration, compared to intravenous administration, based on urine recovery studies. Only about 60% of drug reaches the systemic circulation due to first pass metabolism. In some fasting volunteers, measurable plasma levels are observed within 10 min of dosing with diclofenac potassium, although peak plasma levels are generally achieved after 0.33–2 h. For enteric-coated diclofenac sodium tablets, drug is released once the tablet reaches the duodenum, with subsequent rapid absorption. Absorption of diclofenac occurs throughout the intestinal tract. Diclofenac shows linear pharmacokinetics. The absolute BA of diclofenac potassium after oral administration did not differ significantly when 1 × 12.5- and 2 × 12.5-mg were dose in a randomized, three-way, crossover study in
## Table 1. Excipients° Present in Diclofenac° IR Solid Oral Drug Products° With a Marketing Authorization (MA) in Germany (DE), Denmark (DK), Finland (FI), France (FR), The Netherlands (NL), Norway (NO), Spain (ES), Sweden (SE), United Kingdom (UK) and the United States (US)°, and the Minimal and Maximal Amount of that Excipient Present Pro Dosage Unit in Solid Oral Drug Products With an MA in the USA°

<table>
<thead>
<tr>
<th>Excipient</th>
<th>Drug Products Containing that Excipient With an MA Granted by the Named Country</th>
<th>Range Present in Solid Oral Dosage Forms With an MA in the USA (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzoic acid</td>
<td>DK(1) NO(2) SE(3)</td>
<td>No data</td>
</tr>
<tr>
<td>Calcium hydrogen phosphate</td>
<td>DE(4) DK(5–12) FI(13,14) NO(15,16) SE(17,18) UK(19)</td>
<td>104–850</td>
</tr>
<tr>
<td>Calcium phosphate</td>
<td>DE(20) DK(21) NL(23) NO(24) SE(25,26) US(27,28)</td>
<td>21–362</td>
</tr>
<tr>
<td>Carmellose sodium</td>
<td>DK(29) FI(30) NO(31) SE(32)</td>
<td>2.2–160</td>
</tr>
<tr>
<td>Cellulose</td>
<td>DE(20,33–36) DK(1,29,37) ES(38,39) FI(30,40) FR(41) NL(23,42,43) NO(2,31,44,45) SE(3,25,26,46,47) US(27,28,48,49)</td>
<td>4.6–1385°</td>
</tr>
<tr>
<td>Croscarmellose sodium</td>
<td>FI(40) US(48)</td>
<td>2–180</td>
</tr>
<tr>
<td>Crospovidone</td>
<td>DE(50,51)</td>
<td>4.4–792°</td>
</tr>
<tr>
<td>dimeticone</td>
<td>DE(33)</td>
<td>3.7</td>
</tr>
<tr>
<td>Glycerol</td>
<td>DK(29) FI(30,40) NO(31) SE(32)</td>
<td>0.14–198°</td>
</tr>
<tr>
<td>Glycerol dibehenate</td>
<td>DE(50,51)</td>
<td>5.7–14</td>
</tr>
<tr>
<td>Hypromellose</td>
<td>DE(34–36,50,51) DK(1,29,37) ES(38) FI(30,40) FR(41) NO(2,31) SE(3,32) US(28,48,49)</td>
<td>0.8–86</td>
</tr>
<tr>
<td>Lactose</td>
<td>DE(34–36) DK(1,29,37) ES(38,39) FI(30,40) FR(41) NL(42,43) NO(2,31,44,45) SE(3,32,46,47) US(28,48,49)</td>
<td>23–1020°</td>
</tr>
<tr>
<td>Lecithin</td>
<td>DE(4) DK(5–12) FI(13,14) NO(15,16) SE(17,18)</td>
<td>5–15</td>
</tr>
<tr>
<td>Macrogol</td>
<td>DE(20,33–36,50,51) DK(1,37) ES(38) FR(41) NL(23) NO(2) SE(3,25,26) US(27,28,48)</td>
<td>0.12–500°</td>
</tr>
<tr>
<td>Macrogol stearate</td>
<td>DK(1) NO(2) SE(3)</td>
<td>0.15–401°</td>
</tr>
<tr>
<td>Magnesium stearate</td>
<td>DE(4,20,33–36,50,51) DK(1,5–12,21,29,37) ES(38,39) FR(41) NL(23,42,43) NO(15,16) SE(3,17,18,25,26,46,47) US(19) US(27,28,48,49)</td>
<td>0.0004–5.7</td>
</tr>
<tr>
<td>Maltodextrin</td>
<td>DE(35,36) DK(37) FR(41)</td>
<td>0.16–80</td>
</tr>
<tr>
<td>Mannitol</td>
<td>DE(50,51)</td>
<td>33–454</td>
</tr>
<tr>
<td>Octamethylcyclotetrasiloxane</td>
<td>DK(1) NO(2) SE(3)</td>
<td>No data</td>
</tr>
<tr>
<td>Polydextrose</td>
<td>US(48)</td>
<td>3.8–8.1</td>
</tr>
<tr>
<td>Polysorbate®</td>
<td>DK(37)</td>
<td>No data</td>
</tr>
<tr>
<td>Poly(vinylalcohol)</td>
<td>DE(4) DK(5–8) FI(13,14) NO(15,16) SE(17,18)</td>
<td>0.7–20</td>
</tr>
<tr>
<td>Poly(vinylalcohol)</td>
<td>DE(4) DK(5–8) FI(13,14) NO(15,16) SE(17,18)</td>
<td>0.7–20</td>
</tr>
<tr>
<td>Poly(vinylalcohol)</td>
<td>DE(4) DK(5–8) FI(13,14) NO(15,16) SE(17,18)</td>
<td>0.7–20</td>
</tr>
<tr>
<td>Poly(vinylalcohol)</td>
<td>DE(4) DK(5–8) FI(13,14) NO(15,16) SE(17,18)</td>
<td>0.7–20</td>
</tr>
<tr>
<td>Poly(vinylalcohol)</td>
<td>DE(4) DK(5–8) FI(13,14) NO(15,16) SE(17,18)</td>
<td>0.7–20</td>
</tr>
<tr>
<td>Poly(vinylalcohol)</td>
<td>DE(4) DK(5–8) FI(13,14) NO(15,16) SE(17,18)</td>
<td>0.7–20</td>
</tr>
<tr>
<td>Potassium hydrogen carbonate</td>
<td>DE(50,51)</td>
<td>12</td>
</tr>
<tr>
<td>Povidone</td>
<td>DE(4,20,33–36) DK(5–12,21,37) ES(38,39) FI(13,14,22) FR(41) NL(23,42,43) NO(15,16) SE(17,18,25,26,32,46,47) UK(19) US(27,28,48)</td>
<td>0.17–75</td>
</tr>
<tr>
<td>Silica</td>
<td>DE(4,20,33–36) DK(5–12,21,29,37) ES(38,39) FI(13,14,22) FR(41) NL(23,42,43) NO(15,16) SE(17,18,25,26,32,46,47) UK(19) US(27,28,48)</td>
<td>0.65–99</td>
</tr>
<tr>
<td>Simethicone</td>
<td>DK(1) NO(2) SE(3)</td>
<td>0.0004–5.7</td>
</tr>
<tr>
<td>Sodium hydroxide</td>
<td>DE(33)</td>
<td>0.74–6.7</td>
</tr>
<tr>
<td>Sodium lauryl sulphate</td>
<td>DE(50,51) US(48)</td>
<td>0.65–50</td>
</tr>
<tr>
<td>Sodium starch glycolate</td>
<td>DE(4,20,33–36,50,51)</td>
<td>2–876°</td>
</tr>
<tr>
<td>Sorbic acid</td>
<td>DK(1) NO(2) SE(3)</td>
<td>0.94</td>
</tr>
</tbody>
</table>

(Continued)
<table>
<thead>
<tr>
<th>Excipient</th>
<th>Drug Products Containing that Excipient With an MA Granted by the Named Country</th>
<th>Range Present in Solid Oral Dosage Forms With an MA in the USA (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch</td>
<td>DE(4,20,33–36) DK(1,5–12,21,29,37) ES(38,39)</td>
<td>0.44–1135f</td>
</tr>
<tr>
<td></td>
<td>FI(13,14,22,30,40) FR (41) NL(23,42,43)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NO(2,15,16,24,31,44,45) SE (3,17,18,25,26,32,46,47) UK(19) US (27,28)</td>
<td></td>
</tr>
<tr>
<td>Starch, pregelatinized</td>
<td>US (49)</td>
<td>6.6–600</td>
</tr>
<tr>
<td>Sucrose</td>
<td>DE(20,33) NL(23) SE (25,26) US (27)</td>
<td>12–900</td>
</tr>
<tr>
<td>Talc</td>
<td>DE(4,20,33,34) DK(1,5–12) ES(38) FI(13,14) NL(23)</td>
<td>0.26–220f</td>
</tr>
<tr>
<td></td>
<td>NO(2,15,16) SE (3,17,18,25,26)</td>
<td></td>
</tr>
<tr>
<td>Triacetin</td>
<td>US (48)</td>
<td>0.72–15</td>
</tr>
<tr>
<td>Xanthan gum</td>
<td>DE(4) DK(5–12) FI(13,14) NO(15,16) SE (17,18)</td>
<td>14</td>
</tr>
</tbody>
</table>

1. Eeze, filmovertrukne tabletter
2. Ezze 25 mg filmdragsjerte tabletter
3. Eeze 25/50 mg, filmdragerade tabletter
4. Diclac\textsuperscript{R} Dolo 12.5 mg Filmttabletten (Mono)
5. Diclofenac Rapid “Actavis”, filmovertrukne tabletter
6. Diclofenac Rapid “Copyfarm”, filmovertrukne tabletter
7. Diclon Rapid, filmovertrukne tabletter
8. Diclopax, filmovertrukne tabletter
9. Fenaco, filmovertrukne tabletter
10. Dictavis, filmovertrukne tabletter
11. Diclium, filmovertrukne tabletter
12. Fenacta, filmovertrukne tabletter
13. Diclofenac Rapid Actavis 25/50 mg tabletti, kalvopäälysteinein
14. Diclofenac Rapid Copyfarm 25/50 mg tabletti, kalvopäälysteinein
15. Diclofenackalium Actavis 25/50 mg tabletter, filmdragsjerte
16. Diclofenackalium Copyfarm 25/50 mg filmdragerade tabletter
17. Diklofenak T Actavis 25/50 mg filmdragerade tabletter
18. Diklofenak T Copyfarm 25 mg och 50 mg filmdragerade tabletter
19. Diclofenac potassium 12.5 mg tablets
20. Voltaren\textsuperscript{R} K Migraine 50 mg överzogene Tabletten (Mono)
21. Voltaren Rapid, overtrukne tabletter
22. Voltaren Rapid 25/50 mg tabletti, päällystetty
23. Cataflam 25/50, omhulde tabletten 25/50 mg
24. CATAFLAM 50 mg dragsjerte tabletter
25. Diklofenak T Sandoz 25/50 mg, tabletter
26. Voltaren T 25/50 mg, dragerade tabletter
27. Cataflam\textsuperscript{R} tablet 50 mg, sugar-coated [Novartis Pharmaceuticals Corporation]
28. Diclofenac potassium tablets 50 mg, film-coated [TEVA Pharmaceuticals USA]
29. Diclofenac ratiopharm Rapid, filmovertrukne tabletter
30. Diclofenac ratiopharm Rapid 25/50 mg tabletti, kalvopäälysteinein
31. Diclofenackalium ratiopharm tabletter, filmdragsjert
32. Diclofenac T ratiopharm 25/50 mf filmdragerade tabletter
33. Diclofenac PB 50 mg Tablettten (Mono)\textsuperscript{h}
34. Diclodoc\textsuperscript{R} 50 Tabletten (Mono)\textsuperscript{h}
35. Optalidon\textsuperscript{R} Zahnschmerz mit Diclofenac Filmttabletten (Mono)
36. Voltaren\textsuperscript{R} Dolo 12. mg Filmttabletten (Mono)
37. Voltaren Dolo, filmovertrukne tabletter
38. DICLOPENACO PENSA 50 mg comprimidos EFG\textsuperscript{h}
39. Vontalgin 12.5 mg comprimidos

(Continued)
The systemic absorption of diclofenac as a function of the dose is proportional within the range 25–150 mg, which suggests that the low drug solubility at low pH is not limiting absorption.

Administration with food can extend the lag time ($t_{lag}$) of drug absorption, thereby increasing the time to maximum concentration ($t_{max}$) and decreasing the maximum concentration ($C_{max}$). Food does not have a significant effect on the extent of oral absorption of diclofenac sodium or diclofenac potassium. Diclofenac's rapid and complete absorption suggests a high permeability through the intestinal membrane. This observation of high permeability throughout the intestinal tract is also supported by reports of rapid absorption of diclofenac from effervescent tablets and the high permeability of diclofenac in the colon after administration of the drug as a suppository.

In a Caco-2 cell monolayer experiment, the permeability of diclofenac from apical-to-basolateral ($P_{A-B}$) and basolateral-to-apical ($P_{B-A}$) directions were $20.2 \times 10^{-6}$ and $21.3 \times 10^{-6}$ cm/s, respectively, while metoprolol permeability was $43.4 \pm 0.7 \times 10^{-6}$ and $34.1 \pm 0.6 \times 10^{-6}$ cm/s in the two directions, respectively. Metoprolol is 90–95% absorbed from the intestinal tract and is often used as a reference for the lower limit of a highly permeable drug. In an artificial membrane model, $P_{am}$ of diclofenac, metoprolol, and propranolol were $53.3 \times 10^{-6}$, $5.67 \times 10^{-6}$, and $13.7 \times 10^{-6}$ cm/s, respectively.

**Distribution**

The apparent volume of distribution is 1.3 L/kg for diclofenac potassium and 1.4 L/kg for diclofenac sodium. Circulating diclofenac is known to be greater than 99% bound to human serum protein, primarily to albumin. However, this binding has been described as pharmacokinetically insignificant due to the rapid association–dissociation of diclofenac to albumin, such that the drug readily dissociates and permeates across the vascular membrane to the tissues.
Metabolism

Diclofenac undergoes extensively hepatic biotransformation involving aromatic hydroxylations and conjugations.53,54 Five diclofenac metabolites have been identified.22,41,54 One metabolite has a very weak pharmacological activity.22

Excretion

Approximately 65% of diclofenac is excreted in the urine, largely as metabolites, and 35% in bile as conjugates of unchanged diclofenac and metabolites.22 Very little drug is eliminated in the unchanged form in urine.44 The terminal half-life of unchanged diclofenac is approximately 2 h.22,30
**Table 3.** Solubility of Diclofenac Sodium from Literature Data and the Corresponding Dose/Solubility (D/S) Ratio’s for Three Tablet Strengths

<table>
<thead>
<tr>
<th>pH</th>
<th>Medium</th>
<th>Solubility (mg/mL) (23 ± 2°C)</th>
<th>12.5 mg</th>
<th>25 mg</th>
<th>50 mg²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>0.1 N HCl</td>
<td>0.0012</td>
<td>12500⁶</td>
<td>25000⁶</td>
<td>50000⁶</td>
</tr>
<tr>
<td>2.0</td>
<td>0.01 N HCl</td>
<td>0.0017</td>
<td>7535⁶</td>
<td>14706⁶</td>
<td>29412⁶</td>
</tr>
<tr>
<td>3.0</td>
<td>0.001 N HCl</td>
<td>0.28</td>
<td>45</td>
<td>89</td>
<td>179</td>
</tr>
<tr>
<td>4.1</td>
<td>Acetate buffer</td>
<td>0.0033</td>
<td>3788⁶</td>
<td>7576⁶</td>
<td>15152⁶</td>
</tr>
<tr>
<td>4.5</td>
<td>Acetate buffer</td>
<td>0.0036</td>
<td>3472⁶</td>
<td>6944⁶</td>
<td>13889⁶</td>
</tr>
<tr>
<td>5.5</td>
<td>Acetate buffer</td>
<td>0.036</td>
<td>347⁷</td>
<td>694⁷</td>
<td>1389⁷</td>
</tr>
<tr>
<td>5.8</td>
<td>Phosphate buffer</td>
<td>0.14</td>
<td>89</td>
<td>179</td>
<td>357</td>
</tr>
<tr>
<td>6.0</td>
<td>Phosphate buffer</td>
<td>0.15</td>
<td>83</td>
<td>167</td>
<td>333</td>
</tr>
<tr>
<td>6.8</td>
<td>Phosphate buffer</td>
<td>0.67</td>
<td>19</td>
<td>37</td>
<td>75</td>
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<tr>
<td>7.0</td>
<td>Phosphate buffer</td>
<td>1.36</td>
<td>9</td>
<td>18</td>
<td>37</td>
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<tr>
<td>7.4</td>
<td>Phosphate buffer</td>
<td>5.15</td>
<td>2</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>7.8</td>
<td>Phosphate buffer</td>
<td>12.00</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>8.0</td>
<td>Phosphate buffer</td>
<td>12.14</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

⁵Critical limit: <250 mL²⁴.  
⁶Highest tablet strength of IR solid oral dosage forms on USA and EU market.  
⁷Exceeds critical limit.

**DOSAGE FORM PERFORMANCE**

**Excipients and/or Manufacturing Variations**

Excipients present in diclofenac sodium and diclofenac potassium IR solid oral drug products with an MA in the US and some European countries are shown in Table 1. These products are “plain” tablets and are intended to be swallowed intact. In Table 2, the same information is shown for IR soluble tablets, dispersible tablets and powders for oral solution. In view of the MAs, it is presumed that these drug products successfully met the in vivo BE criteria. Unlike other APIs, diclofenac products were not exempted from in vivo BE studies for some time by the German Regulatory Authorities. More-over, diclofenac is not on the list of except APIs from in vivo BE studies by the Dutch Regulatory Authorities.

**In Vivo Bioequivalence**

Several studies demonstrated BE among diclofenac potassium IR products. In a randomized, single dose, two-way crossover study in 66 subjects, a 12.5 mg diclofenac potassium tablet formulation was shown to be bioequivalent in terms of log transformed Cmax, AUC0−t and AUC0−∞ to its reference, Voltarol Dolo 12.5 mg tablets (Novartis, Basel, Switzerland). Dissolution profiles of test product were reported to be similar to the reference products marketed in various European countries.

**Table 4.** Solubility of Diclofenac Potassium at Room Temperature and the Corresponding Dose/Solubility (D/S) Ratio’s for Three Tablet Strengths

<table>
<thead>
<tr>
<th>pH</th>
<th>Medium</th>
<th>Solubility (mg/mL)⁶</th>
<th>12.5 mg</th>
<th>25 mg</th>
<th>50 mg²</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>Acetate buffer</td>
<td>0.0014 (0.0001)</td>
<td>8929⁷</td>
<td>17857⁷</td>
<td>35714⁷</td>
</tr>
<tr>
<td>6.8</td>
<td>Phosphate buffer</td>
<td>0.7167 (0.0165)</td>
<td>17</td>
<td>35</td>
<td>70</td>
</tr>
<tr>
<td>7.4</td>
<td>Phosphate buffer</td>
<td>2.341 (0.016)</td>
<td>5</td>
<td>11</td>
<td>21</td>
</tr>
</tbody>
</table>

⁵Between brackets: standard deviation of mean.  
⁶Critical limit: <250 mL²⁴.  
⁷Highest tablet strength of IR solid oral dosage forms on USA and EU market.  
⁸Exceeds critical limit.
In another single dose study in 24 healthy volunteers, a diclofenac potassium 50 mg sachet formulation containing excipients such as potassium hydrogen carbonate, mannitol, aspartame, saccharin sodium, glyceryl dibehenate, and flavors proved to be bioequivalent to the reference tablet formulation Voltfast in terms of $\text{AUC}_{0-\infty}$, although $\text{C}_{\text{max}}$ was twofold larger from the sachet formulation.\textsuperscript{58} No dissolution studies were performed because the test formulation is a powder for oral solution.

Neuvonen\textsuperscript{59} reported no significant change in the pharmacokinetics of diclofenac when coadministered with magnesium hydroxide, but this study was carried out with enteric coated tablets and hence of very limited value for IR dosages forms.

### Dissolution and In Vitro/In Vivo Correlation

For diclofenac potassium tablets, the USP30 dissolution specification is not less than 80% (Q) of the labeled amount to be dissolved within 60 min in 900 mL simulated intestinal fluid (without enzyme) at 50 rpm in the paddle apparatus.\textsuperscript{27} The Ph.Eur and the BP do not contain monographs for IR diclofenac tablets. No in vitro/in vivo correlations were identified in the literature for diclofenac IR solid oral dosage forms.

### DISCUSSION

#### Solubility

Tables 3 and 4 show the dose/solubility ratio ($D/S$) of each salt at pH 6.0 and above to be less than the critical limit of 250 mL for highly soluble according to the present BCS Guidances.\textsuperscript{2,3,60} The solubility reported by Kincl et al.\textsuperscript{29} at pH 3.0 in 0.001 N HCl appears unexplainably high. All other data show diclofenac to be below pH 4.5 (or pH 5.8, depending on the tablet strength) to be not highly soluble. Although most solubility data have been collected at room temperature, it is unlikely that solubility values would be much different at 37°C to change the interpretation in terms of the BCS classification.

#### Absorption and Permeability

The complete 100% absorption classifies diclofenac as highly permeable.\textsuperscript{2,3,60} This classification is supported by in vitro data. Some reports indicate that a permeability coefficient of more than $1 \times 10^{-6}$ cm/s in Caco-2 model is considered to imply high permeability and/or complete absorption.\textsuperscript{49,61,62} Others report that a permeability coefficient over $10 \times 10^{-6}$ cm/s implies high permeability\textsuperscript{11} or $>70\%$ absorption in humans.\textsuperscript{63} Diclofenac exceeds both criteria. The artificial membrane permeability data and the partitioning data further support the classification of diclofenac as being highly permeable.

### BCS Classification

According to all Guidances, the data presented above classify diclofenac in BCS Class II.\textsuperscript{2-4} Using the disposition characteristics of the API as an estimate for its permeability, Wu and Benet\textsuperscript{64} assigned diclofenac to Class II in a Biopharmaceutics Drug Disposition Classification System (BDDCS).

#### Risk for Drug Products to be Bioequivalent

Tables 1 and 2 show excipients and their quantity limits used in diclofenac IR products with MAs in a number of countries. By virtue of their MAs, it may be assumed that these drug products passed in vivo BE studies. Hence, it is inferred that none of the excipients tabulated in these tables has had a significant effect on the extent nor the rate of diclofenac absorption. It is worthy of note that some drug products contain sodium lauryl sulfate, which has been reported to improve drug dissolution of poorly soluble drugs.\textsuperscript{65} However, it appears that even if there was improved dissolution, sodium lauryl sulfate did not lead to the drug product to be bioequivalent. It is deduced that these excipients in these reported limits do not cause interactions that result in bioequivalence for diclofenac.

We conclude that the low solubility of diclofenac at pH values of 4.5 and below does not pose a substantial risk for bioequivalence. This may be the result of diclofenac high permeability, as well as the dynamic character of the uptake processes.\textsuperscript{66}

#### Surrogate Techniques for In vivo BE Testing

The rate-limiting step in the absorption of diclofenac from a drug product is gastric emptying, disintegration in vivo or dissolution in vivo. Comparative in vitro dissolution testing in
Discriminatory media is a sensible technique to detect significant differences in disintegration in vivo or dissolution in vivo between a test drug product and comparator. In vitro dissolution testing in SIF (pH 6.8) without enzyme is suggested by USP and FDA for IR diclofenac potassium drug products as the quality control test. SIF without pancreatin and SIF without pancreatin with 1% (w/v) Tween 20 has been suggested as discriminatory dissolution media for diclofenac sodium prolonged release tablets. Dissolution in these media can be considered as discriminatory dissolution test for IR dosage forms. The BCS Guidance prescribes comparative in vitro dissolution testing between test and comparator in pH 1.2, 4.5, and 6.8 buffers and also provides criteria for the assessment of dissolution profile similarity. In media pH 1.2 and pH 4.5, no dissolution is expected, providing evidence that no dissolution enhancers are present.

Since diclofenac permeability is high, intestinal absorption is not limiting. An excipient interaction with the permeation process is unlikely. This risk of interaction is even lower if the test product contains excipients that are known to exert no such influence, that is, the excipients tabulated in Tables 1 and 2.

**Patient’s Risks Associated With Bioinequivalence**

Bioinequivalence with respect to AUC can cause subtherapeutic drug level, resulting in low analgesic efficacy, or supra-bioavailability, which may lead to cardiovascular and gastrointestinal side-effect risks. However, diclofenac products are used for non-life-threatening conditions, which require achieving minimal effective plasma concentration. The issue of supra-bioavailability is not critical, as diclofenac is a relatively safe drug with wide therapeutic range. Most diclofenac drug products carry a leaflet in which patients are advised to observe and report back any signs or symptoms related to cardiovascular and gastrointestinal events to the physician.

**CONCLUSION**

According to the current FDA and EMEA BCS Guidances, only BCS class I APIs are eligible for the biowaiver, and diclofenac would not qualify for such a biowaiver. However, the recent WHO Guidance opens a possibility for biowaiving of drug products containing BCS Class II APIs with weak acidic properties. This viewpoint for highly permeable acidic APIs has been supported for NSAIDS generally. Certain conditions must be fulfilled, such as requirements with respect to in vitro dissolution; the excipients should be critically evaluated; and the risk of an incorrect biowaiver decision need to be assessed in terms of public health and risks to individual patients. Diclofenac fulfills these criteria.

The question regarding the acceptability of biowaiving between pharmaceutical alternatives requires further discussion. Pharmaceutical alternatives are drug products containing the same molar amount of the same API, but differing in dosage form (e.g., tablet vs. capsule; “plain” tablet vs. dispersible tablet), or chemical form (e.g., different salts, different esters), delivering the same active moiety by the same route of administration. In in vivo BE testing, different salt forms of the API present in test and comparator are potentially allowed if there is no safety concerns. However, in in vitro BE testing, a more conservative approach is prudent in granting biowaivers between different salt forms of an API. Moreover, these two salts sometimes have different therapeutic indications, as diclofenac potassium is sometimes claimed to be absorbed faster than the sodium salt and hence recommended for the treatments that need short onset of action. Hence, we recommend against a biowaiver when the test and comparator do not contain the same salt form of diclofenac.

The FDA, EMEA, and WHO Guidance provide some possibility for in vivo BE testing between pharmaceutical alternatives that differ in dosage form, such as IR tablets versus IR capsules. Available diclofenac IR solid oral dosage forms include plain tablets, dispersible tablets, and powders for solution which are different dosage forms. As above, a more conservative approach is prudent in granting biowaivers between different solid oral dosage forms of an API. We recommend against a biowaiver when the test and comparator do not contain the same dosage form of diclofenac.

In summary, a biowaiver for IR solid oral dosage forms of diclofenac potassium and diclofenac sodium are scientifically justified, provided that: (a) test and comparator contain the same diclofenac salt; (b) the dosage form of the test and comparator is identical; (c) the test product contains only excipients present in diclofenac drug products approved in ICH or associated
countries in the same dosage form, such as those shown in Tables 1 and 2, in amounts that are usual for that dosage form; (d) test drug product and comparator dissolve 85% in 30 min or less in 900 mL buffer pH 6.8, using the paddle apparatus at 75 rpm or the basket apparatus at 100 rpm; and (e) test product and comparator show dissolution profile similarity in pH 1.2, 4.5, and 6.8.

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REFERENCES


