ABSTRACT: Literature data relevant to the decision to allow a waiver of in vivo bioequivalence (BE) testing for the approval of immediate release (IR) solid oral dosage forms containing doxycycline hyclate are reviewed. According to the Biopharmaceutics Classification System (BCS), doxycycline hyclate can be assigned to BCS Class I. No problems with BE of IR doxycycline formulations containing different excipients and produced by different manufacturing methods have been reported and hence the risk of bioequivalence caused by these factors appears to be low. Doxycycline has a wide therapeutic index. Further, BCS-based dissolution methods have been shown to be capable of identifying formulations which may dissolve too slowly to generate therapeutic levels. It is concluded that a biowaiver is appropriate for IR solid oral dosage forms containing doxycycline hyclate as the single Active Pharmaceutical Ingredient (API) provided that (a) the test product contains only excipients present in doxycycline hyclate IR solid oral drug products approved in the International Conference on Harmonization (ICH) or associated countries; and (b) the comparator and the test products comply with the BCS criteria for “very rapidly dissolving” or,
INTRODUCTION

A biowaiver monograph for doxycycline hyclate based on literature data, together with some additional experimental data, is presented. The risks of waiving in vivo bioequivalence (BE) testing for the approval of new multisource and/or reformulated immediate release (IR) solid oral dosage forms containing doxycycline hyclate are evaluated under consideration of its biopharmaceutical and clinical properties. This evaluation refers to drug products containing doxycycline hyclate, which is the hemiethanolate hemihydrate form of doxycycline hydrochloride, as the single Active Pharmaceutical Ingredient (API). The purpose and scope of this series of monographs have been previously discussed. Briefly, the aim of these monographs 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 an incorrect biowaiver decision as well as the consequences of the 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 or advise against a biowaiver decision is referred to in the recently published World Health Organization (WHO) Guideline. These monographs do not intend to simply apply the WHO, US FDA, and/or EMEA Guidance, but aim to apply these guidelines and further serve as a critical evaluation of these regulatory documents. Biowaiver monographs have already been published for acetaminophen (paracetamol), acetazolamide, acelovir, amitriptyline hydrochloride, atenolol, chloroquine (phosphate, sulfate, and hydrochloride), cimetidine, diclofenac (sodium and potassium), ethambutol dihydrochloride, ibuprofen, isoniazid, metoclopramide, prednisolone, prednisone, propranolol hydrochloride, pyrazinamide, quinidine sulfate, ranitidine hydrochloride, rifampicin, and verapamil hydrochloride. They are also available online at http://www.fip.org/bcs.

GENERAL CHARACTERISTICS

Name

INN name: Doxycycline; INNM name: Doxycycline hyclate; Chemical name: 4-(Dimethylamino)-3,5,10,12,12a-pentahydroxy-6-methyl-1,11-dioxo-2-naphthacenecarboxamide hydrochloride, compound with ethanol (1:0.5), hemihydrate; 

(4S,4aR,5S,5aR,6R,12aS)-4-(Dimethylamino)-3,5,10,12,12a-pentahydroxy-6-methyl-1,11-dioxo-2-naphthacenecarboxamide hydrochloride, compound with ethanol (1:0.5), hemihydrate; 

6-Deoxy-5β-hydroxytetracycline hydrochloride; 4-(Dimethylamino)-3,5,10,12,12a-pentahydroxy-6-methyl-1,11-dioxo-2-naphthacenecarboxamide monohydrochloride, compound with ethyl alcohol (2:1), monohydrate.

Doxycycline hyclate is official in the JP XV where it is named “doxycycline hydrochloride hydrate.” The Martindale uses the name “doxycycline hydrochloride” for doxycycline hyclate.

The molecular weight of doxycycline hyclate is 512.9 and its melting point is 201°C. The structure of doxycycline hyclate is shown in Figure 1.

Therapeutic Indication and Dose

Doxycycline is bacteriostatic against a wide variety of organisms, both Gram-positive and
Gram-negative. It is used mainly for the treatment of urinary tract, respiratory tract, and gastrointestinal (GI) tract infections. The usual initial dose of doxycycline is the equivalent of 200 mg doxycycline base (equal to 230.8 mg of doxycycline hyclate) as a single dose or in divided doses over the first day. This initial dose is followed by 100 mg (equivalent to 115.4 mg of doxycycline hyclate) daily. For children weighing less than 45 kg an initial dose of approximately 4 mg/kg/day followed by 2 mg/kg/day may be given, whereby the effects of drug on teeth and bones should be taken into consideration. In severe cases, for example, in patients with sensitive gonococcal infections, a dosage of 200 mg doxycycline is maintained throughout the course of treatment. Occasionally, as in the case of syphilis, a daily dose of 300 mg may be given for 15 days.

According to the Essential Medicines List of the WHO (EML, 15th ed., March 2007), 100 mg doxycycline (hydrochloride) capsules or tablets can be used as an antibacterial. In case of malaria, 100 mg doxycycline as capsules (hydrochloride) or dispersible tablets (monohydrate) can be used in combination with quinine for curative treatment, and for malarial prophylaxis 100 mg doxycycline (hydrochloride) capsules or tablets can be prescribed.

Therapeutic Index and Toxicity

Doxycycline is considered to be a wide therapeutic index drug according to the US FDA definition, and there is generally no need to monitor blood levels. An LD₅₀ of 262 mg/kg was reported in rats. No serious adverse effects of doxycycline have been reported. Disturbances of the GI tract are commonly observed following oral administration of tetracycline antibiotics in therapeutic doses; however, doxycycline shows the least GI adverse effects among the tetracycline antibiotics. On the other hand, all of the tetracycline antibiotics, doxycycline hyclate, especially in capsule form, is most likely to cause esophageal ulceration. Doxycycline monohydrate may be an alternative to doxycycline hyclate in patients with high risk of suffering from esophageal lesions because it has less acidic properties than the hyclate salt.

As for other tetracycline antibiotics, doxycycline can accumulate in calcium-rich tissues such as bones and teeth during their formation, and may cause yellow and brown discoloration and enamel hypoplasia in developing teeth in children. Photosensitivity reactions (mostly phototoxic and in rare cases photoallergic) due to accumulation of doxycycline in the skin have also been reported.

In general, tetracycline antibiotics should not be used in patients who have renal disease, specifically, renal insufficiency or renal failure. However, if therapy with a tetracycline proves necessary for such a patient, doxycycline or minocycline are preferred due to their minimal renal clearance. Studies to date have indicated that at usual recommended doses of doxycycline, the drug does not accumulate in patients with renal impairment.

It is contraindicated to give doxycycline to patients with porphyria. Symptoms including nausea, vomiting, and diarrhea are commonly observed with overdosage of tetracycline antibiotics including doxycycline. Occasionally, overdosage of doxycycline has led to liver and kidney damage as well as pancreatitis. Treatment for overdosage with the oral preparation of doxycycline should be symptomatic and gastric lavage may be considered.

PHYSICOCHEMICAL PROPERTIES

Salt, Stereoisomers, and Polymorphs

Salts of doxycycline for pharmaceutical preparations listed in the pharmacopoeias include doxycycline monohydrate (free base), doxycycline hyclate (in some pharmacopoeias under the name “hydrochloride,” see above), and doxycycline calcium. The USP 32 has monographs for doxycycline monohydrate, doxycycline hyclate and doxycycline calcium, although the latter salt is used only for oral solutions. The European Pharmacopoeia (Ph.Eur., 5th ed.) has monographs on doxycycline monohydrate and doxycycline hyclate. The International Pharmacopoeia (Ph.Int., 4th ed.) and the British Pharmacopoeia (BP 1993) include only doxycycline hyclate. Oral products with Marketing Authorizations (MAs) in Germany (DE) contain either the hyclate or the monohydrate. This monograph pertains only to the hyclate salt.

No polymorphism of doxycycline hyclate has been reported.
Solubility

Doxycycline hyclate is classified as soluble or freely soluble in water. An aqueous solubility of 50 mg/mL has been reported, but without specifying the temperature. Doxycycline hyclate aqueous solution, containing 1% doxycycline, has a pH of 2–3. Solubility of doxycycline hyclate in SGFsp, pH 1.2 and in SIFsp, pH 6.8 at room temperature was reported as about 40 and 28 mg/mL (based on a 230.8 mg dose of doxycycline hyclate), respectively. The values are far less than the D/S cut-off of 250 mL for the “high solubility” biowaiver criterion.

To confirm the “high solubility” properties of doxycycline hyclate, further experimental data for doxycycline hyclate solubility in compendial buffers pH 1.0, 1.2, 4.5, 6.8, and 7.5 were obtained at 37°C using the standard shake-flask method. The experiment was performed by adding 461.6 mg doxycycline hyclate powder, equivalent to 400 mg doxycycline, to 250 mL buffer. In all cases the powder went immediately into solution, demonstrating that doxycycline hyclate has “high solubility” at all five pHs representing the GI conditions at 37°C.

Partition Coefficient

Log P values of −1.90 and 0.63 were reported for doxycycline hyclate and doxycycline free base, respectively. Calculations using fragmentation methods based on atomic contributions to lipophilicity and by using the ClogP program (version 3.0, Biobyte Corp., Claremont, CA, http://www.biobyte.com) yielded values of −0.60 (Clog P) and −3.66 (log P).

pKₐ

Doxycycline is an amphoteric compound with three pKₐ values. At 20°C, pKₐ values of 3.5 (tricarbonyl system), 7.7 (ketophenolic system), and 9.5 (dimethylammonium group) have been reported.

Dosage Form Strengths

Dosage form strengths of doxycycline are expressed as mg free base. The WHO EML lists 100 mg doxycycline (capsules or tablets). Table 1 shows IR doxycycline hyclate tablets with MAs in Germany (DE), Denmark (DK), Finland (FI), France (FR), the Netherlands (NL), Norway (NO), Spain (ES), Sweden (SE), the United Kingdom (UK), and the United States (US). These MAs cover a range of strengths corresponding to 20, 50, 100, and 200 mg doxycycline base.

PHARMACOKINETIC PROPERTIES

Absorption and Bioavailability

Among tetracycline antibiotics, doxycycline is reported to have the best absorption. The absolute bioavailability (BA) of doxycycline administered orally at a dose of 100–200 mg is 90–100%. The average percent fraction doxycycline absorbed in humans (Fₐ%) was reported to be 95%. Doxycycline is rapidly absorbed; it can be detected in the blood within 15 min of administration. Linear pharmacokinetics of orally administered doxycycline have been demonstrated in the dose range 100–600 mg. A peak plasma doxycycline concentration of about 2.6 µg/mL is reached within approximately 2–3.5 h after a dose of 200 mg. Different salt forms demonstrated no significant influences on doxycycline absorption.

Unlike tetracycline, food only slightly reduces the area under the plasma concentration–time curve (AUC) and the mean plasma concentrations of doxycycline. The mean serum concentrations of doxycycline obtained during a multiple-dosage regimen of 200 mg/day in the fasted and fed states (regardless of the meal type) were found to be in the therapeutic range (4.4 µg/mL vs. 4.0 µg/mL), indicating little or no clinical significance of the food effect. Although milk and dairy products reduce the exposure of several tetracycline antibiotics significantly, this is not the case for doxycycline. Dairy products have at most a minor influence on doxycycline absorption. Nevertheless, it is recommended to take doxycycline product separately from drugs containing di- and/or trivalent cations, for example, antacids.
<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 US (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia</td>
<td>ES(1)</td>
<td>5–156&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Acetylated monoglycerides</td>
<td>ES(2–4)</td>
<td>0.3–3.7</td>
</tr>
<tr>
<td>Alginic acid</td>
<td>ES(5) NL(6)</td>
<td>32–80</td>
</tr>
<tr>
<td>Aluminium hydroxide</td>
<td>DE(7,8)</td>
<td>15</td>
</tr>
<tr>
<td>Beeswax</td>
<td>ES(1) NL(6,9)</td>
<td>0.44–2</td>
</tr>
<tr>
<td>Calcium hydrogen phosphate</td>
<td>ES(10,11)</td>
<td>109–636</td>
</tr>
<tr>
<td>Carnauba wax</td>
<td>ES(1) NL(6,9) US(12,13)</td>
<td>0.15–58&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Castor oil hydrogenated</td>
<td>DE(14) FI(15)</td>
<td>0.93–37.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cellulose</td>
<td>DE(14,16) ES(17–19) FR(20–23) NL(6,9,24–26) UK(27) US(12,13,28–38)</td>
<td>4.6–1385&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Croscarmellose sodium</td>
<td>DE(16) NL(9) US(12,13,28,30,31)</td>
<td>2–180</td>
</tr>
<tr>
<td>Crospovidone</td>
<td>DE(39) DK(40) ES(41) FR(20,22,23) NL(42)</td>
<td>4.4–792&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dimethicone</td>
<td>FR(21) NL(25)</td>
<td>3.7</td>
</tr>
<tr>
<td>Ethylcellulose</td>
<td>US(38)</td>
<td>1.0–121&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fucellaran</td>
<td>NL(25)</td>
<td></td>
</tr>
<tr>
<td>Gelatin</td>
<td>DE(7,8,16,39,43) DK(40) ES(2,3,5,10,11,17–19,41) UK(44) US(29,31,37)</td>
<td>1–756&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Hydroxypropylcellulose</td>
<td>NL(9)</td>
<td>4–132</td>
</tr>
<tr>
<td>Hypromellose</td>
<td>FR(21) NL(6,24,25) US(12,13,30,33,36,38)</td>
<td>0.8–537</td>
</tr>
<tr>
<td>Hypromellose phthalate</td>
<td>ES(2,3)</td>
<td>13–104</td>
</tr>
<tr>
<td>Lactose</td>
<td>DE(7,8,14,16,43) ES(1,5,10,11,18,19,45) FI(15) FR(21) NL(6,9) US(12,13,31–36)</td>
<td>23–1020&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Macrogol</td>
<td>DE(7,8,16,43) ES(18) FR(20,21,23) NL(24) US(12,13,30,33–35)</td>
<td>0.12–500&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Magnesium stearate</td>
<td>DE(7,8,14,16,43) ES(1,5,10,11,17–19,45) FI(15) FR(20–23) NL(6,9,24–26) UK(27,44) US(12,13,28–38)</td>
<td>0.15–401&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Magnesium trisilicate</td>
<td>ES(10,11)</td>
<td>20–77</td>
</tr>
<tr>
<td>Methylcellulose</td>
<td>NL(9) US(33,34)</td>
<td>2.8–184</td>
</tr>
<tr>
<td>Polydextrose</td>
<td>US(13)</td>
<td>3.8–8.1</td>
</tr>
<tr>
<td>Polysorbate 80</td>
<td>US(12,30)</td>
<td>2.2–418&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Poly(vinylalcohol)</td>
<td>US(35)</td>
<td>0.7–20</td>
</tr>
<tr>
<td>Povidone</td>
<td>ES(1–4) NL(6,9,25)</td>
<td>0.17–80</td>
</tr>
<tr>
<td>Propylene glycol</td>
<td>NL(6,9,25) US(38)</td>
<td>1.5–52</td>
</tr>
<tr>
<td>Shellac</td>
<td>ES(5) NL(9) UK(44)</td>
<td>4.4–25</td>
</tr>
<tr>
<td>Silica</td>
<td>DE(7,8,14,16,43) ES(17,18) FR(20,21) NL(6,9,24–26) UK(28,29,33–35)</td>
<td>0.65–99</td>
</tr>
<tr>
<td>Sodium hydrogen carbonate</td>
<td>FI(15)</td>
<td>2–125</td>
</tr>
<tr>
<td>Sodium lauryl sulphate</td>
<td>ES(5) FR(20) NL(6) UK(44) US(29,30,37,38)</td>
<td>0.65–50</td>
</tr>
<tr>
<td>Sodium starch glycolate</td>
<td>DE(14) NL(24) US(33,34)</td>
<td>2–876&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Starch</td>
<td>DE(7,8,14,16,39) DK(40) ES(1–5,10,11,18,41) NL(6,9,42) UK(44)</td>
<td>0.44–1135&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>US(33,34)</td>
<td>0.9–72&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sucrose</td>
<td>DE(39) DK(40) ES(1–4,41) NL(42)</td>
<td>12–900</td>
</tr>
</tbody>
</table>

(Continued)
Table 1. (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 Oral Dosage Forms with an MA in the US (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talc</td>
<td>DE(7,8,16,39) DK(40) ES(1–4,17,18,41,45) FR(20,23) NL(24,35,42) US(35,38)</td>
<td>0.25–220°</td>
</tr>
<tr>
<td>Triacetin</td>
<td>US(13,36)</td>
<td>1–15</td>
</tr>
</tbody>
</table>

(1) DOXICICLINA NORMON 100 mg Grageas. (2) DOXIPIL 100 mg cápsulas duras. (3) MEDEDOXI 50 mg cápsulas duras. (4) PELEDOX 50. (5) VIBRACINA 100 mg cápsulas duras. (6) Doxycycline ratiopharm 100 mg, omhulde tabletten. (7) Aknefug® Doxyliefilmtabletten (Mono). (8) Doxy-Wolf® 100/200 Filmtabletten (Mono). (9) Doxycycline 100, omhulde tabletten 100 mg. (10) Doxil, cápsulas. (11) Doxil emzínico, cápsulas. (12) Doxycycline hyclate (doxycycline hyclate) tablet (100 mg), coated [Mutual Pharmaceutical Company, Inc.]. (13) Doxycycline hyclate (doxycycline hyclate) tablet (20 mg), film coated [Mutual Pharmaceutical Company, Inc.]. (14) Doxycycline AL 100 T/150 mg Tabletten (Mono). (15) Doxycycline AL 100 T/200 T Tabletten (Mono). (16) Doxycycline STADA® 100 mg/200 mg Filmtabletten (Mono). (17) DOXITEN BIO, cápsulas. (18) DOXITEN ENZIMÁTICO, cápsulas. (19) RETENS® cápsulas. (20) DOXY 100 mg cp pellic. (21) DOXYCYCLINE ARROW 100 mg cp pellic. (22) DOXYCYCLINE BIOGARAN 200 mcg cp pellic. (23) SPANOR 100 mg cp pellic. (24) Doxycycline 100 PCH, omhulde tabletten 100 mg. (25) Doxycycline Lagap, tabletten 100 mg. (26) Periostat 20 mg filmomhulde tabletten, filmomhulde tabletten. (27) PERIOSTAT® 20 mg film-coated tablets. (28) Doxycycline (doxycycline hyclate) tablet (100 mg), coated [West-Ward Pharmaceutical Corp.]. (29) Doxycycline hyclate (doxycycline hyclate) capsule (50/100 mg) [Watson Laboratories, Inc.]. (30) Doxycycline hyclate (doxycycline hyclate) tablet (100 mg) [Watson Laboratories, Inc.]. (31) Doxycycline hyclate (doxycycline hyclate) capsule (50/100 mg) [Mutual Pharmaceutical Company, Inc.]. (32) Doxycycline hyclate (doxycycline hyclate) capsule (50/100 mg) [West-Ward Pharmaceutical Corp.]. (33) Doxycycline hyclate (doxycycline hyclate) tablet (100 mg), film coated [IVAX Pharmaceuticals, Inc.]. (34) Doxycycline hyclate (doxycycline hyclate) capsule (50/100 mg) [IVAX Pharmaceuticals, Inc.]. (35) Doxycycline hyclate (doxycycline hyclate) tablet (20 mg), film coated [Lannett Company, Inc.]. (36) Periostat (doxycycline hyclate) tablet (20 mg) [CollaGenex Pharmaceuticals, Inc.]. (37) Vibramycin hyclate (doxycycline hyclate) capsule (50/100 mg) [Pfizer Labs]. (38) Vibra-tabs (doxycycline hyclate) tablet (100 mg), film coated [Pfizer Labs]. (39) Antodox® 100 mg/200 mg Hartkapseln (Mono). (40) Doxycycline “EthypHarm,” kapsler, hårde. (41) PRODERMA 50 mg/100 mg/200 mg cápsulas duras. (42) Ethypharm doxycycline 50 mg/100 mg/200 mg, capsules. (43) Doxy 200 mg Kapseln (Mono). (44) Doxycycline capsules 50, 100 mg (Actavis UK Ltd). (45) DOXICICLINA VALOMED.

*Colorants, flavors, and ingredients present in the printing ink are not included. Coating substances are excluded if in the SmPC the constituents of core and coating are stated separately.

**Excluded are: soft gelatin capsules filled with a solution and oral suspensions.

***Sources of data: see text, Dosage Form Strengths Section.


The upper range value reported is unusually high for solid oral dosage forms and the authors doubt its correctness.

since the absorption of doxycycline may be impaired.65

Permeability

An apparent permeability coefficient (P_app) of doxycycline of 17.5 × 10–6 cm/sec using the Caco-2 monolayer system was reported.70 In the same study a high permeability internal standard suggested by the US FDA,3 antipyrine, demonstrated a P_app of 45.3 × 10–6 cm/sec.70 By comparing the drug permeability between Caco-2 and PAMPA assay, it was demonstrated that transcellular but not paracellular permeation is the main transport pathway of doxycycline.70

Distribution

The volume of distribution of doxycycline at steady-state (Vss) varies between approximately 53 and 134 L and the volume of the central compartment (Vc) is 22 L.40 These values can vary slightly according to the doxycycline salt.65 In the elderly, the volume of distribution is higher than in young patients.71 Doxycycline distributes effectively into the body tissues especially liver, kidneys, and digestive tract.26,40 Doxycycline as well as other tetracycline antibiotics can be retained at the sites of new bone formation and impair calcification in developing teeth, and in some injured soft tissues.26 The plasma protein binding of doxycycline is the highest among some injured soft tissues.26 The plasma protein binding of doxycycline is the highest among some injured soft tissues.26

Metabolism and Excretion

No problems with instability of doxycycline in the GI tract have been reported.

Although it has been demonstrated that no metabolites of doxycycline are found in blood, urine, or feces,40 some reference sources indicate that some metabolism does occur.42,71,72 Additionally, a decrease in the area under the plasma...
concentration–time curve (AUC) of doxycycline was observed during concomitant treatment with drugs that induce hepatic enzymes, for instance, alcohol (chronic use), rifampicin, carbamazepine, phenobarbital, phenytoin, and primidone, owing to the increased metabolism of doxycycline.26,73

Doxycycline is slowly eliminated via the kidneys to an extent of approximately 30–40% in patients with normal renal function.26,40 A renal clearance of 1.8–2.1 L/h was reported.40 The rest of the dose is eliminated through the digestive tract and excreted in the feces, probably due to partial biliary elimination in addition to diffusion through the intestinal wall and subsequent chelation with the metal ions, for example, Ca\(^{2+}\), Mg\(^{2+}\) present in the small intestine.26,40 The nonchelated doxycycline is reabsorbed and undergoes enterohepatic cycling.26,40

The elimination half-life (t\(_{1/2}\)) of doxycycline varies from about 12 to 25 h 26,40,42,74,75 after single dosing and between 17 and 24 h after multiple dosing.76 These values do not change in the elderly patients although the serum and tissue concentrations are higher than those observed in young adults.40 In renal failure patients, the t\(_{1/2}\) and AUC remain unchanged and no accumulation is observed even after repeated doses in anuric patients.40 At first glance, these results appear to be inconsistent with renal elimination as the major route of doxycycline elimination. However, a decrease in the fraction of doxycycline bound to plasma proteins in renal failure patients appears to result in an increase in nonrenal clearance, which then compensates for the decrease in renal clearance.77

**DOSAGE FORM PERFORMANCE**

**Bioavailability and Bioequivalence**

Several reports in the literature have demonstrated BE of doxycycline products.37,65,67,74,75,78–87 The study details, BE criteria, and results of the pharmacokinetic studies conducted from 1975 to 2007 are summarized in Table 2. All studies reported the pharmacokinetic parameters between doxycycline hyclate products, various doxycycline salt forms and different dosage forms of doxycycline to be “bioequivalent” or “not significantly different.” It should be noted that doxycycline can be regarded as a borderline “highly variable drug” based on the data from Kitzes-Cohen et al.86 Indeed, the Central Labora-
Table 2. Summary of the Bioequivalence Studies of Doxycycline Products

<table>
<thead>
<tr>
<th>Refs.</th>
<th>Formulations Studied</th>
<th>Composition</th>
<th>Subjects</th>
<th>Prandial</th>
<th>Study Design</th>
<th>Pharmacokinetic Parameters</th>
<th>Bioequivalence Criteria, Statistics</th>
<th>Results</th>
<th>In Vitro Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antal et al.</td>
<td>200 mg doxycycline hyclate capsules, oral solution except for suspension which contained doxycycline base</td>
<td>An oral solution contained 480 mg ascorbic acid</td>
<td>6 male volunteers (21–30 yo)</td>
<td>Fasted (meal after 3 h)</td>
<td>Randomized, five-way, crossover/washout 1 week</td>
<td>AUC, Cmax, T_{max}</td>
<td>ANOVA then Tukey's or Student's t-test</td>
<td>Three capsules — bioequivalent to each other and to the oral solution</td>
<td>Basket, 25 rpm, 0.1N HCl.</td>
</tr>
<tr>
<td>Welling et al.</td>
<td>200 mg doxycycline hyclate capsules and oral solution (dissolved capsules)</td>
<td>Not reported</td>
<td>4 male and 2 female volunteers (19–36 yo)</td>
<td>Fasted (meal after 4 h)</td>
<td>Six-way, single dose, crossover/washout 2 weeks</td>
<td>Serum level comparison, paired t-test</td>
<td>Not specified but comparing the mean serum level</td>
<td>Not significantly different in terms of clinical effects</td>
<td>No</td>
</tr>
<tr>
<td>Saux et al.</td>
<td>200 mg doxycycline polyphosphate, hyclate, and base capsules</td>
<td>Not reported</td>
<td>2 male and 4 female volunteers (20–28 yo)</td>
<td>Fasted (meal after 5 h)</td>
<td>Single dose, subjects received two of three products/washout 2 weeks</td>
<td>AUC, Cmax, T_{max}</td>
<td>Not specified</td>
<td>Not significantly different</td>
<td>No</td>
</tr>
<tr>
<td>Malmborg et al.</td>
<td>100 mg doxycycline monohydrate and hydrochloride tablets</td>
<td>Not reported</td>
<td>10 male and 2 female volunteers (24–36 yo)</td>
<td>Fed (breakfast)</td>
<td>Two-way, single dose, crossover/washout 1 week</td>
<td>AUC, Cmax</td>
<td>Student's t-test (no significance level specified)</td>
<td>Not significantly different</td>
<td>No</td>
</tr>
<tr>
<td>Campistron et al.</td>
<td>200 mg doxycycline hyclate solutions, capsules, and tablets</td>
<td>Not reported</td>
<td>10 male and 2 female volunteers (23–32 yo)</td>
<td>Fasted (meal after 4 h)</td>
<td>Randomized, three-way, single dose, crossover/washout 1 week</td>
<td>AUC, Cmax, T_{max}</td>
<td>ANOVA (Westlake CI)</td>
<td>Not significantly different</td>
<td>No</td>
</tr>
<tr>
<td>Linberg et al.</td>
<td>200 mg doxycycline hyclate tablets and capsules</td>
<td>Not reported</td>
<td>8 male yersiniosis patients (20–30 yo)</td>
<td>Not specified</td>
<td>Oral administration in 6 patients, i.v. for 2 patients</td>
<td>Absorption rate constant, serum level comparison</td>
<td>Not specified</td>
<td>Not significantly different</td>
<td>No</td>
</tr>
<tr>
<td>Kees et al.</td>
<td>2 brands, 100 mg doxycycline hyclate tablets</td>
<td>Not reported</td>
<td>16 male volunteers (22–27 yo)</td>
<td>Fasted (meal after 4 h)</td>
<td>Randomized, two-way, single dose, crossover/washout 2 weeks</td>
<td>AUC, Cmax, T_{max}, 1/2</td>
<td>95% CI</td>
<td>Bioequivalent</td>
<td>No</td>
</tr>
<tr>
<td>Saano et al.</td>
<td>150 mg doxycycline hydrochloride tablets, dissolved hydrochloride tablets, and dissolved monohydrate tablets</td>
<td>Not reported</td>
<td>8 male and 7 female volunteers (21–25 yo)</td>
<td>Standard low-fat breakfast was given after 30 min of drug administration</td>
<td>Randomized, three-way, single dose, crossover/washout 1 week</td>
<td>AUC, Cmax, T_{max}</td>
<td>ANOVA</td>
<td>Not significantly different</td>
<td>No</td>
</tr>
<tr>
<td>Study Authors</td>
<td>Formulations</td>
<td>Subjects</td>
<td>Prandial Study Design</td>
<td>Pharmacokinetic Parameters</td>
<td>Bioequivalence</td>
<td>Notes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------------------------------</td>
<td>---------------------------</td>
<td>----------------------------------------</td>
<td>----------------------------</td>
<td>----------------</td>
<td>-------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balogh et al.</td>
<td>2 brands, 100 mg doxycycline hyclate capsules</td>
<td>Not reported</td>
<td>19 male and 1 female volunteers (21–26 yo)</td>
<td>Randomized, two-way, single dose, crossover/washout 1 week</td>
<td>AUC, C&lt;sub&gt;max&lt;/sub&gt;, 95% CI, 70–130%</td>
<td>Bioequivalent</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saket et al.</td>
<td>2 brands, 100 mg doxycycline hyclate capsules</td>
<td>Not reported</td>
<td>18 male volunteers (19–26 yo)</td>
<td>Randomized, two-way, single dose, crossover/washout 1 week</td>
<td>AUC, C&lt;sub&gt;max&lt;/sub&gt;, T&lt;sub&gt;max&lt;/sub&gt;</td>
<td>Student’s t-test</td>
<td>Not significantly different</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kites-Cohen et al.</td>
<td>100 mg doxycycline monohydrate and hydrochloride tablets</td>
<td>Not reported</td>
<td>22 male volunteers (18–32 yo)</td>
<td>Randomized, two-way, single dose, crossover/washout 1 week</td>
<td>AUC, C&lt;sub&gt;max&lt;/sub&gt;, T&lt;sub&gt;max&lt;/sub&gt;, t&lt;sub&gt;1/2&lt;/sub&gt;, MRT</td>
<td>90% CI</td>
<td>Bioequivalent</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Akarra et al.</td>
<td>2 brands, 100 mg doxycycline hyclate capsules</td>
<td>Not reported</td>
<td>24 male volunteers (24–43 yo)</td>
<td>Randomized, two-way, single dose, crossover/washout 2 weeks</td>
<td>AUC, C&lt;sub&gt;max&lt;/sub&gt;, T&lt;sub&gt;max&lt;/sub&gt;</td>
<td>ANOVA, 90% CI, 80–125%</td>
<td>Bioequivalent</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Gschwend et al.</td>
<td>2 brands, 100 mg doxycycline hyclate capsules</td>
<td>Not reported</td>
<td>24 male volunteers (18–43 yo)</td>
<td>Randomized, two-way, single dose, crossover/washout 2 weeks</td>
<td>AUC, C&lt;sub&gt;max&lt;/sub&gt;, T&lt;sub&gt;max&lt;/sub&gt;, t&lt;sub&gt;1/2&lt;/sub&gt;</td>
<td>90% CI, 80–125%</td>
<td>Bioequivalent</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

yo, years old.
which investigated the possible influence of pirenzepine, an antimuscarinic drug, and ranitidine, an H₂-receptor antagonist, on the BA of doxycycline. These two drugs modified the GI tract conditions, with pirenzepine changing the motility and ranitidine increasing the upper GI pH. No changes in Cₘₐₓ and AUC were observed either with pirenzepine or ranitidine coadministrations, although the Tₘₐₓ was prolonged in both cases. It was concluded that physical interactions via chelation rather than changes in the GI environment are responsible for the decrease in the BA of doxycycline when administered with antacids.

**DISCUSSION**

**Solubility**

Doxycycline hyclate is “highly soluble” according to all BCS criteria⁵ and no solubility problems in the upper GI milieu are expected.

**Permeability and Absorption**

Doxycycline hyclate is “highly permeable” according to all BCS criteria⁵ since the BA of doxycycline is nearly complete following oral administration.⁴⁰ Caco-2 studies support this classification.⁴⁸

**Risks Associated with Biowaiving**

With any positive biowaiver decision there is, statistically speaking, a risk that the decision reached is incorrect. Therefore the risk of reaching such an incorrect decision needs to be assessed. Risk is defined as the combination of the probability of occurrence of harm and the severity of that harm.⁹³ Therefore, the overall risk of a positive biowaiver decision can be defined as the probability that the test product, after passing the surrogate BE testing, is actually bioequivalent and the therapeutic consequences for the patient, if such a situation should occur. Each of these possibilities is discussed below.

**Probability of Occurrence of Bioinequivalence**

One report has identified an effect of antacids on the BA of doxycycline.⁹¹ Seemingly contradictory to this finding, two doxycycline hyclate products with an MA in DE contain Al(OH)₃, see Table 1, however, the amount of Al(OH)₃ present in these drug products is likely far lower than used in the study cited. No other reports of BE problems were identified and hence it can be concluded that salt forms of doxycycline in various media at 25°C it was found that the hyclate form is less sensitive to the common ion effect than the other salts.⁹² Insensitivity to the common ion effect of doxycycline hyclate in terms of dissolution is important, especially for *in vivo* dissolution in the GI tract, due to the high chloride level in the human gastric juice, and thus justifies the widespread use of this salt form in doxycycline oral dosage forms.

**Dissolution**

According to the USP 32,⁴³ the same dissolution test conditions are used for doxycycline hyclate capsules and doxycycline hyclate tablets: USP Apparatus 2 (paddle method), rotational speed 75 rpm, 900 mL water as a dissolution medium, temperature 37°C. The dissolution specification for the capsules is “not less than 80% (Q) dissolves within 30 min” and for the tablets is “not less than 80% (Q) dissolves within 90 min.”⁴³ The Ph.Int. 4th ed. describes the dissolution test conditions for doxycycline capsules and doxycycline tablets as: paddle method, rotational speed 75 rpm, 500 mL pH 6.8 buffer as a dissolution medium, temperature 37°C.⁴⁸ The dissolution specification for both tablets and capsules is “not less than 80% (Q) dissolves within 30 min.”⁴⁸

Recently, dissolution of five marketed doxycycline hyclate IR products in DE was tested using both the WHO and the US FDA “BCS-conform” methods.⁵⁰ The dissolution test conditions consisted of the paddle method, medium volume 500 mL, rotational speed 75 rpm (WHO)² or 50 rpm (US FDA),³ and temperature 37°C. The products were tested in three different dissolution media: SGFₚ — pH 1.2; acetate buffer — pH 4.5; and SIFₚ — pH 6.8. The results indicated that *in vitro* BE evaluation based on the WHO test procedure is more appropriate than the US FDA³ testing method and that *in vitro* BE evaluation based on comparative dissolution testing tends to be over-discriminating compared to *in vivo* evaluation, as some products that had successfully passed an *in vivo* BE evaluation failed to pass the *in vitro* BE evaluation.

Using the static pellet method to assess the dissolution performance of the hyclate and other
doxycycline hyclate, formulated in solid IR dosage forms, appears to exhibit very little risk in terms of bioinequivalence. This is in line with its BCS Class I classification.

Probability of False Positives of Surrogate BE Testing

Comparative dissolution testing, especially based on the WHO method, appears to assure detection of bioinequivalence caused by poor in vivo disintegration and in vivo dissolution, should such an unlikely situation arise.

Although comparative dissolution testing will not elucidate excipients and formulation effects on the absorption of doxycycline, the “highly permeable” characteristic of doxycycline hyclate combined with lack of excipient effects on BE would indicate that excipient effects on permeability are unlikely. By using only excipients which are listed in Table 1 in the formulation, the probability of occurrence of an excipient effects on permeability is further reduced.

Patient’s Risks Associated with Bioinequivalence

Doxycycline hyclate has a wide therapeutic index and is mainly used as an antibacterial and for prophylaxis of malaria. Moreover, according to the draft “Science-based criteria for BE in vivo and in vitro, biowaivers, and strategic framework for implementation” of the Pan American Health Organization, doxycycline is classified as having “Intermediate Health Risk,” which basically means that when the plasma concentrations of doxycycline are outside the therapeutic window, adverse (but not necessary serious) reactions may occur.

However, the risk that a bioinequivalent drug product could be formulated, and the further risk that this product would pass all the criteria for accepting BE on the basis of in vitro data, and yet give rise to supra- or subtherapeutic plasma levels, or a $C_{\text{max}}$ different from the comparator, is minimal.

CONCLUSION

A biowaiver for IR solid oral dosage forms containing doxycycline hyclate is scientifically justified, provided that the test product contains only excipients present in a number of doxycycline hyclate IR solid oral drug products approved in ICH or associated countries, for instance as presented in Table 1; and that both the test and comparator products either (a) are both “very rapidly dissolving,” or (b) are both “rapidly dissolving” with similarity of the dissolution profiles demonstrated at pH 1.2, 4.5, and 6.8, as described in the WHO test procedure. When not all of these conditions can be fulfilled, BE should be established on the basis of in vivo pharmacokinetic study.

ACKNOWLEDGMENTS

Kik Groot, RIVM is acknowledged for assembling the data in Table 1. Tanja Ranzinger, Emilia Kastreva, Matthias Hentschel, Reham Abdel-Kader, Charlotte Depalle, Rebekka Heymach, Anke Voskamp, and Elisabeth Herbert are gratefully acknowledged for their assistance in experimental parts and literature search.

REFERENCES


