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Pharmacokinetic Study of Tenofovir Disoproxil Fumarate Combined with Rifampin in Healthy Volunteers

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Tenofovir disoproxil fumarate (tenofovir DF) was studied in combination with rifampin in 24 healthy subjects in a multiple-dose, open-label, single-group, two-period study. All subjects were given tenofovir DF at 300 mg once a day (QD) from days 1 to 10 (period 1). From days 11 to 20 the subjects received tenofovir DF at 300 mg combined with rifampin at 600 mg QD (period 2). The multiple-dose pharmacokinetics of tenofovir (day 10 and 20) and rifampin (day 20) were assessed. The drug-related adverse events (AEs) experienced during this study were mostly mild. Only one grade 3 AE possibly or probably related to the treatment (raised liver enzyme levels) occurred during period 2; the subject was withdrawn from the study. Pharmacokinetic data for 23 subjects were thus evaluable. Point estimates for the mean ratios of tenofovir with rifampin versus tenofovir alone for the area under the concentration-time curve from time zero to 24 h (AU(Cmax)0-24), the maximum concentration of drug in plasma (Cmax), and the minimum concentration of drug in plasma (Cmin) were 0.88, 0.84, and 0.85, respectively. The 90% classical confidence intervals for AU(Cmax)0-24, Cmax, and Cmin were 0.84 to 0.92, 0.78 to 0.90, and 0.80 to 0.91, respectively, thus suggesting pharmacokinetic equivalence. Similarly, coadministration of rifampin and tenofovir DF did not result in changes in the values of the tenofovir pharmacokinetic parameters. For rifampin, the values of the pharmacokinetic parameters found in this study were comparable to those found in the literature, indicating that tenofovir DF has no effect on the pharmacokinetics of rifampin. In conclusion, adaptation of either the rifampin or the tenofovir DF dose for the simultaneous treatment of tuberculosis and human immunodeficiency virus (HIV) infection in HIV-infected patients is probably not required.

Coinfection with Mycobacterium tuberculosis and human immunodeficiency virus (HIV) is frequent, particularly in Africa and Asia (3, 14, 18). Simultaneous treatment of tuberculosis and HIV infection may lead to complex combination therapy. Rifampin is a drug of choice for the treatment of tuberculosis. Rifampin is known to have major pharmacokinetic interactions with HIV protease inhibitors and nonnucleoside reverse transcriptase inhibitors (8, 10, 12, 13, 16, 17). Tenofovir disoproxil fumarate (tenofovir DF) is the first drug from a new class of anti-HIV agents (nucleotide reverse transcriptase inhibitors) that has been recently approved for use for the treatment of HIV infections in adults. However, no data are available regarding its pharmacokinetics in combination with tuberculosatic drugs, in particular, rifampin. No influence of rifampin on the pharmacokinetics of tenofovir is expected, because both drugs are metabolized and eliminated in different ways. Tenofovir is eliminated unchanged by glomerular filtration and active tubular secretion (1, 6), while rifampin is extensively metabolized by intestinal and hepatic metabolism (4). However, a pharmacokinetic interaction cannot be excluded.

The clinical trial described here was designed to explore the pharmacokinetics of tenofovir DF with and without rifampin in an effort to establish whether there is a need to adjust the dosage of either medication when the two medications are used for the treatment of patients coinfected with M. tuberculosis and HIV.

MATERIALS AND METHODS

Study design. The present study was designed to evaluate the effect of 600 mg of rifampin on the pharmacokinetics of 300 mg of tenofovir DF and also to assess whether tenofovir DF has a substantial impact on steady-state exposure to rifampin. This study was a multiple-dose, open-label, single-group, two-period study with 24 healthy volunteers. First, the subjects received tenofovir DF at 300 mg once daily (QD) for 10 days (period 1). At study day 10, a steady-state 24-h pharmacokinetic curve was obtained for tenofovir. During the second period of the study (period 2), tenofovir DF at 300 mg was combined with rifampin at 600 mg QD, again for 10 days. At study day 20, 24-h steady-state pharmacokinetic curves were obtained for tenofovir and rifampin. During the study both tenofovir DF and rifampin had to be taken with breakfast. On the days prior to study days 9 and 19, the subjects reported to the study center for direct observation of dosing with the medications with a standardized breakfast. Subsequently, on the evening of study days 9 and 19 the subjects remained at the study center for two overnight stays and remained at the study center until the morning of study days 11 and 21, respectively. On days 9, 10, 11, 19, and 20 the subjects received a standardized breakfast of 550 kcal (two slices of whole bread, 15 g of low-fat margarine, 14 g of jelly, 150 ml of orange juice, and 150 ml of skim milk). The medication was administered immediately after breakfast with 200 ml of tap water. All other meals and snacks on the pharmacokinetic study days were also standardized. When the subjects took the medication at home, study drugs were administered with breakfast (at least two and at most three slices of whole bread).

No crossover design was used in this study because rifampin could lead to considerable carryover effects, due to its long-lasting cytochrome P450-inducing effect. To eliminate this effect a longer washout period would be necessary, but this would have significantly prolonged the duration of the study and would have
led to difficulties with subject recruitment and retention. This study was reviewed and approved by the independent ethics committee Arnhem-Nijmegen. Written informed consent was obtained from each study subject prior to the conduct of any study-related activity.

**Study subjects.** Twenty-four healthy male and female subjects were eligible for inclusion in the study. The subjects could be between 18 and 65 years of age with a body weight of at least 50 kg and in good age-appropriate health condition, as established by the individual’s medical history; a physical examination; electrocardiography; and the results of biochemistry, hematology, and urine analyses within the 3 weeks prior to administration of the first dose. Other inclusion criteria were an ability to sign informed consent voluntarily and a willingness to refrain from the use of contact lenses during the treatment with rifampin. Exclusion criteria were as follows: positive tests for HIV, hepatitis B virus, or hepatitis C virus; a tuberculin skin test reaction of more than 15 mm in diameter; a severity of tuberculosis; pregnancy; breast-feeding; the lack of adequate contraception (e.g., hormonal; bilateral tubal ligation; the use of an intrauterine device, total abstinence, or double-barrier methods; or a postmenopausal state for 2 years) among female subjects of childbearing potential; a creatinine clearance rate <50 ml/min; or a serum creatinine level above 133 μmol/liter.

**Sampling for pharmacokinetic studies.** For determination of the tenofovir and rifampin concentrations in blood plasma, samples of 5 ml of blood, recovered to obtain at least 2 ml of plasma, were collected in heparinized hard plastic tubes at the following times: just before drug intake (predosing); on day 10 and day 20; and at 1, 2, 3, 4, 6, 8, 10, 12, 16, 20, and 24 h after drug intake. The blood samples were centrifuged at 2,500 × g for 10 min at 4°C. The plasma was divided into equal portions, transferred to polypropylene tubes, and stored at −80°C for sampling until analysis. From these samples containing rifampin, plasma samples containing tenofovir were obtained to determine the concentrations of the quality controls used were 2.85, 9.5, and 24 mg/liter. The intra- and interassay coefficients of variation were less than 1.1% for all quality controls. The lower limit of quantification was 0.50 mg/liter. Samples from the same subject were analyzed by use of the same standard curve.

**Pharmacokinetic analysis.** Pharmacokinetic parameters for tenofovir and rifampin were calculated by noncompartmental methods by use of the WinNonlin software package (version 4.1; Pharsight Corporation, Mountain View, Calif.) and the log-linear trapezoidal rule. On the basis of the individual plasma concentration-time data, the following pharmacokinetic parameters were determined: the area under the plasma concentration-time curve (AUC) from time zero to 24 h (AUC0–24; in milligram · hour per liter), the maximum concentration of drug in plasma (Cmax; in milligrams per liter), the area under the concentration-time curve from 10 up to 24 h (AUC10–24; in milligram · hour), the apparent elimination half-life (t1/2), and the apparent oral clearance (CL/F; in liters per hour). AUC0–24, where C* is the last quantifiable concentration, was calculated for rifampin. Cmax and CL/F were not calculated for rifampin.

**Statistical analysis.** Statistical analyses were performed with SPSS software (version 11.0; SPSS Inc., 1989 to 1999). Descriptive statistics were calculated with Excel 2000 software (Microsoft Corporation, 1985 to 1999). Evaluation of the AUC0–24 and the Cmax of tenofovir was the main objective of this trial. These parameters are considered the primary characteristics for the extent and the rate of drug absorption, respectively. The bioequivalence of tenofovir was determined by comparing the values of the relevant pharmacokinetic parameters obtained with the test treatment (tenofovir DF and rifampin on study day 20) to those obtained with the reference treatment (tenofovir DF alone on study day 10) by using the following statistical methods. The AUC0–24, Cmax and Cmax of tenofovir were reported for study day 10 and study day 20 together by use of the ratios of the values on study day 20/ratios on study day 10. The arithmetic means and standard deviations are given for study day 20 and study day 10. The geometric mean ratios and 90% classical confidence intervals for AUC0–24, Cmax and Cmax were calculated. Treatments were considered bioequivalent if the respective 90% confidence intervals for AUC0–24 and Cmax were included within the predefined bioequivalence range of 80 to 125% (20). The values of the pharmacokinetic parameters for rifampin were compared with data from the literature by the use of descriptive statistics. The study was powered for the tenofovir Cmax by using nQuery software, and a sample size of 15 was required to achieve an 80% power to reject the null hypothesis that the two treatments are not equivalent in favor of the alternative hypothesis that the means of the two treatments are equivalent when the expected difference is 0.000. By this approach, a sample size of 15 would provide a 93% power for AUC0–24. By considering the possibility that the subjects would drop out and/or that some difficulties with sample or pharmacokinetic analysis with some subjects would occur, 24 subjects were enrolled in this study.

**RESULTS**

**Demographics.** Twenty-four subjects (13 males, 11 females) were enrolled in this trial. One male subject was black; all other subjects were Caucasian. The mean age of the subjects was 41 years (range, 20 to 63 years). The mean body weight was 77 kg (range, 58 to 97 kg), and the mean height was 1.75 m (range, 1.59 to 1.88 m).

**Pharmacokinetics.** The pharmacokinetic evaluation was based on data sets for subjects that completed the study on both study days (study days 10 and 20). Data for 23 subjects were included in the pharmacokinetic analysis of tenofovir and rifampin. Table 1 provides a summary of the values of the pharmacokinetic parameters for tenofovir, including the arithmetic means, geometric mean ratios, and 90% confidence interval estimates for the pharmacokinetic parameters for tenofovir alone (study day 10) and tenofovir in combination with rifampin (study day 20). The tenofovir AUC0–24, Cmax, and Cmin were lower in period 2 when tenofovir DF was coadministered with rifampin. However, the magnitudes of these differences were small, with geometric mean ratios (90% confidence intervals) of 0.88 (0.84 to 0.92), 0.84 (0.78 to 0.90), and
The combination of tenofovir DF with rifampin was generally well tolerated, as only one patient prematurely discontinued treatment with rifampin. The most common AEs that were reported during treatment with tenofovir DF were fatigue, headache, and gastrointestinal disorders. During period 2 one subject was withdrawn from the study due to several complaints, which were rash, headaches, abdominal disorders, fatigue, somnolence, and dizziness. The study medications were stopped on study day 15. At the follow-up visit, 5 days later, the subject developed elevated liver enzyme levels, which were judged to be a grade 3 AE. Nine days after the first follow-up visit the liver enzyme levels returned to normal. The AEs that occurred during the combination treatment with tenofovir DF and rifampin consisted mainly of flu-like symptoms (e.g., fatigue, headache, and gastrointestinal disorders) and urine discoloration, which are well-known AEs of rifampin.

No clinically significant hematology or urinalysis values were observed in this study.

**DISCUSSION**

This study was designed to investigate whether rifampin influences the pharmacokinetics of tenofovir. The study showed that bioequivalence could be suggested for tenofovir DF combined with rifampin and tenofovir DF given alone and that the combination of tenofovir DF with rifampin was generally well tolerated, as only one patient prematurely discontinued from study.

The confidence intervals for AUC and $C_{\text{min}}$ were 0.84 to 0.92 and 0.80 to 0.91, respectively, while the confidence interval was 0.85 (0.80 to 0.91) for $\text{AUC}_{0-24}$, $C_{\text{max}}$, and $C_{\text{min}}$, respectively, suggesting pharmacokinetic equivalence when tenofovir DF was dosed with or without rifampin.

Figure 1 illustrates the effects of rifampin on the mean concentration-time profiles of tenofovir. Table 1 presents the pharmacokinetic parameters of rifampin from the literature (4, 15). The values of the pharmacokinetic parameters for rifampin when it was combined with tenofovir are comparable to those in the literature when rifampin is administered with food, suggesting pharmacokinetic equivalence when tenofovir DF was dosed with or without rifampin.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value on day 20 (this study) $(n = 23)$</th>
<th>Value in the literature $(n = 14^a)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{max}}$ (h)</td>
<td>2.4 (0.6) $^b$</td>
<td>4.43 (1.11)</td>
</tr>
<tr>
<td>$C_{\text{max}}$ (mg/liter)</td>
<td>10.9 (3.0)</td>
<td>7.27 (2.25)</td>
</tr>
<tr>
<td>$\text{AUC}_{0-12}$ (mg h/liter)</td>
<td>43.27 (15.28)</td>
<td>50.97 (14.27)</td>
</tr>
<tr>
<td>$t_{1/2}$ (h)</td>
<td>1.5 (0.3)</td>
<td></td>
</tr>
</tbody>
</table>

$^a$ The data are from reference 15 and are for subjects who received rifampin with breakfast.

$^b$ Values are means (standard deviations).

**TABLE 1. Pharmacokinetics of tenofovir**

<table>
<thead>
<tr>
<th>Study day and statistics</th>
<th>$\text{AUC}_{0-24}$ (mg h/liter)</th>
<th>$C_{\text{max}}$ (mg/liter)</th>
<th>$C_{\text{min}}$ (mg/liter)</th>
<th>$T_{\text{max}}$ (h)</th>
<th>$t_{1/2}$ (h)</th>
<th>CL/F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 10</td>
<td>3.56 ± 0.77 (3.48) $^b$</td>
<td>0.36 ± 0.080 (0.36)</td>
<td>0.071 ± 0.016 (0.069)</td>
<td>1.0 (1.0–3.0)</td>
<td>13.8 ± 4.53 (13.2)</td>
<td>88.1 ± 19.0 (86.2)</td>
</tr>
<tr>
<td>Day 20</td>
<td>3.11 ± 0.57 (3.06)</td>
<td>0.30 ± 0.060 (0.30)</td>
<td>0.060 ± 0.011 (0.059)</td>
<td>1.0 (1.0–2.0)</td>
<td>11.6 ± 2.77 (11.2)</td>
<td>99.8 ± 20.3 (98.0)</td>
</tr>
<tr>
<td>Geometric mean ratio for day 20/day 10 (90% CI)</td>
<td>0.88 (0.84–0.92)</td>
<td>0.84 (0.78–0.90)</td>
<td>0.85 (0.80–0.91)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$ $n = 23$, CI, confidence interval.

$^b$ Values are arithmetic means ± standard deviations (geometric means), unless indicated otherwise.

$^c$ Values are medians (ranges).

FIG. 1. Plasma tenofovir concentrations. □, tenofovir concentration on study day 10 $(n = 23)$ after administration of 300 mg QD; ○, tenofovir concentration on study day 20 $(n = 23)$ after administration of 300 mg combined with rifampin at 600 mg QD. Data are presented as means, and error bars indicate standard deviations.
0.78 to 0.90 for $C_{\text{max}}$. By definition, bioequivalence was proven for AUC and $C_{\text{min}}$ but was only suggested for $C_{\text{max}}$.

The tenofovir DF dose used in this study (300 mg QD) is the dose recommended for the treatment of HIV infection in adults (11). The rifampin dose used (600 mg QD) is an accepted regimen for the treatment of tuberculosis in patients weighing more than 50 kg (7). A previous study (2) has shown that steady-state conditions for rifampin are generally achieved after the sixth daily dose of rifampin at 600 mg. To ensure the achievement of steady-state pharmacokinetics, subjects were given tenofovir DF combined with rifampin for 10 days before pharmacokinetic assessment.

The reason for the lowered observed tenofovir levels is unknown. Several mechanisms could contribute to this interaction. Because tenofovir is not metabolized and is eliminated unchanged by a combination of glomerular filtration and active tubular secretion (1, 6), it is unlikely that the inducing effect of rifampin on hepatic and intestinal cytochrome P450 enzymes (especially CYP3A4) (8) is the mechanism responsible for this effect. This is supported by no apparent changes in the tenofovir $t_{1/2}$ and no clinically relevant effects of rifampin on the tenofovir $C_{\text{min}}$.

Similarly, as tenofovir minimally binds to proteins in human plasma or serum (<0.7 and 7.2%, respectively) (11), altered distribution is also probably not the mechanism responsible for the pharmacokinetic differences observed. As the decrease in the tenofovir $C_{\text{max}}$ was 16% while the decrease in $C_{\text{AUC}}$ was 12%, the cause may be in the process of tenofovir DF or tenofovir absorption. Rifampin has been shown to be an inducer of the efflux transporter P glycoprotein (9). No information exists in the literature that P glycoprotein plays a role in the process of absorption of tenofovir in vivo. However, van Gelder et al. (19) have described the transport of tenofovir DF by a P-glycoprotein-related efflux mechanism in the Caco-2 system.

AEs led to one discontinuation in this study; grade 3 elevations in hepatic enzyme levels were reported after the medication was stopped during period 2, when tenofovir DF was combined with rifampin. Liver disturbance is a well-known side effect of rifampin. Gastrointestinal disorders are well-known AEs of both tenofovir and rifampin and occurred in a total of 46% of the study subjects during both study periods. During period 2 all subjects reported discoloration of their urine, which is a well-known AE of rifampin (7).

Some additional considerations are important for the extrapolation of the results of this study to patients. First, it should be noted that all the participants in this study were healthy subjects. It cannot be excluded that the pharmacokinetics of tenofovir and rifampin are different in HIV-infected patients coinfected with *M. tuberculosis* due to one or both of the diseases. Second, 23 of the 24 subjects of this study were Caucasian. Race might have an effect on the values of the pharmacokinetic parameters for tenofovir, although the available pharmacokinetic data do not indicate substantial differences with regard to race (11). Finally, the subjects in this study were given tenofovir DF and rifampin only, while HIV-infected patients coinfected with *M. tuberculosis* are treated with other antiretroviral and tuberculous drugs, which can cause interactions.

In conclusion, the data from this study demonstrate that the addition of rifampin to tenofovir DF is well tolerated, and the small decrease in plasma tenofovir levels during combination treatment suggests that these drugs can be coadministered without the need for dose adjustments. This implies that standard doses should be a starting point for the use of these medications by HIV-infected patients. Additional pharmacokinetic studies in a clinical setting are warranted to confirm the findings of this study.

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