North-South collaboration in clinical pharmacological research of HIV treatment

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North-South collaboration in clinical pharmacological research of HIV treatment

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AIDS and HIV infection

In 1981, the acquired immunodeficiency syndrome (AIDS) was described for the first time in previously healthy homosexual men [1]. Two years later, the human immunodeficiency virus (HIV) was discovered as the cause of AIDS [2]. HIV belongs to the class of retroviruses, using the enzyme reverse transcriptase to convert viral RNA into DNA [3]. For the process of replication, the virus needs the CD4 cells of the human immune system, leading to destruction of the human immune response [4]. HIV can be transmitted through unprotected sexual intercourse, mother-to-child transmission, transfusion of contaminated blood or the use of contaminated injection needles.

Antiretroviral drugs

Survival of HIV-infected subjects can be prolonged by treatment with antiretroviral drugs [5]. To achieve highly active antiretroviral therapy (HAART), at least three antiretroviral drugs from at least 2 different classes should be combined. The five classes of antiretroviral drugs are shown in Table 1. Each of the classes has a unique target in the life cycle of the virus (Figure 1).

Table 1  Overview of antiretroviral drug classes.

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NRTIs: nucleoside reverse transcriptase inhibitors
NNRTIs: non-nucleoside reverse transcriptase inhibitors

Nucleoside reverse transcriptase inhibitors

Nucleoside reverse transcriptase inhibitors (NRTIs) inhibit the replication of HIV by inhibition of the enzyme reverse transcriptase. NRTIs are prodrugs that require intracellular phosphorylation to the active tri-phosphate metabolites [6]. Tenofovir is the only nucleotide analogue that must be di-phosphorylated as it already contains one phosphate group [7]. The first drug to treat HIV, zidovudine, was introduced in 1987 and belongs to the NRTI class [8].

Non-nucleoside reverse transcriptase inhibitors

Non-nucleoside reverse transcriptase inhibitors (NNRTIs) inhibit the replication of HIV by induction of allosteric changes to the enzyme reverse transcriptase. In contrast to NRTIs, NNRTIs do not require phosphorylation to become active [9]. Nevirapine was the first NNRTI to be approved in 1996 [10].

Protease inhibitors

Protease inhibitors inhibit the reproduction of HIV by inhibition of the enzyme protease. Saquinavir, indinavir and ritonavir were the first protease inhibitors to be approved in 1996 [11].
Integrase inhibitors

A new class of integrase inhibitors can inhibit the reproduction of HIV by inhibition of the enzyme integrase. Raltegravir is the first integrase inhibitor that was recently approved [14].

Epidemiology of HIV infection

Global estimates from the Joint United Nations Programme on HIV/AIDS (UNAIDS) and the World Health Organization (WHO) show that 33.2 million people, of whom 2.5 million children, were living with HIV at the end of 2007 [15]. The numbers of infected adults and children per region are shown in Figure 2. The region most affected by the AIDS epidemic remains Sub-Saharan Africa, where 68% of the adults and nearly 90% of the children infected with HIV live. Of all AIDS deaths in 2007, 76% occurred in Sub-Saharan Africa, illustrating the unmet need for HIV treatment in resource-limited countries.

Clinical pharmacological research of HIV treatment

Although challenging, clinical pharmacological research of HIV treatment in resource-limited countries can be facilitated by sponsorships and North-South collaboration between partners from the developed and developing world. Most of the research in this thesis was funded by the European and Developing Countries Clinical Trials Partnership (EDCTP) and by the Poverty Related Infection Oriented Research (PRIOR) network that was established by a grant from the Netherlands Foundation for the Advancement of Tropical Research (NWO-WOTRO) and the Netherlands Foundation for Health Research and Development (ZonMw). The North-South collaboration consisted of two European institutes (Radboud University Nijmegen Medical Centre, Nijmegen, The Netherlands and the Medical Research Council, Clinical Trials Unit, London, United Kingdom) and two African institutes (University Teaching Hospital, Lusaka, Zambia and Kilimanjaro Christian Medical Centre, Moshi, Tanzania). This thesis focuses on clinical pharmacology in HIV-infected children (Part I), HIV-infected adults (Part II) and HIV-TB co-infection (Part III).

I. Clinical pharmacology in HIV-infected children

A major barrier to scaling up HIV treatment for children in resource-limited areas of the world has been the lack of affordable, accessible and appropriate paediatric...
antiretroviral drug formulations [16]. This has led to the pragmatic approach of prescribing generic adult fixed dose combination (FDC) tablets of nevirapine, stavudine and lamivudine to children. In addition to difficulties with accurate cutting and possible unequal distribution of drugs within tablets, a major problem is that the drug ratios are designed for adult dosing. Pharmacologically speaking, HIV-infected children cannot simply be regarded as small adults. Pharmacokinetics of antiretroviral drugs are highly variable in the paediatric population as children mature and grow rapidly and individually until they are adults [17]. For example, (young) children metabolize the NNRTI nevirapine more rapidly than adults. Chapter 1 focuses on general characteristics related to pharmacokinetic processes in HIV-infected children. Chapter 2 describes the exposure to nevirapine in HIV-infected Malawian and Zambian children treated with divided adult FDC tablets.

Recently, paediatric-friendly generic FDC tablets were developed for HIV-infected children with higher nevirapine to stavudine and lamivudine ratios than adult tablets in accordance with paediatric dose recommendations. We performed an independent pilot bioequivalence study of these paediatric FDC tablets in comparison to the branded products (Chapter 3). Subsequently, we investigated whether the antiretroviral drug ratio in the paediatric FDC tablets results in optimal exposure of nevirapine, stavudine and lamivudine in a target population of Zambian HIV-infected children (Chapter 4).

II. Clinical pharmacology in HIV-infected adults

The access to HIV treatment for adults in resource-poor countries has improved in the past few years, mainly due to global efforts such as the “3 by 5” initiative of WHO [18]. Most of the generic regimens that have become available are nevirapine-based. A disadvantage of NNRTI drugs such as nevirapine is the low genetic barrier for the development of resistance [19]. Patients at risk for virological failure are those with subtherapeutic plasma concentrations of nevirapine [20-22]. Therapeutic Drug Monitoring (TDM) is a well-known tool for the optimization of nevirapine dosing in the developed world [22], but is not often performed in resource-limited settings due to the lack of simple and affordable assays to determine the exposure to nevirapine. Chapter 5 describes the validation of a simple and economical thin layer chromatography method for semi-quantitative detection of nevirapine in saliva of HIV-infected adults.

Complexity and costs of several effective strategies to prevent mother-to-child transmission (MTCT) of HIV have limited large-scale introduction in low-income countries. Administration of a single dose nevirapine to the mother shortly before delivery and to the newborn after birth was found to be a simple and cost-effective strategy to reduce the risk of MTCT in low-income countries by 50% [23]. A major disadvantage is the development of resistance in up to 70% of women [24], which may diminish the effectiveness of nevirapine when a mother becomes pregnant again or acquires an indication for nevirapine-based HAART in the future [25]. It is likely that nevirapine resistance develops due to the combination of a low genetic barrier to resistance [19] and a long half-life [26]. The risk for the development of resistance is increased when subtherapeutic nevirapine concentrations remain in the blood for a long period of time. A short-course of an enzyme inducer may reduce resistance development by increasing metabolism and decreasing half-life of nevirapine. In Chapter 6, a pilot study investigating the effect of enzyme inducers on the elimination half-life of nevirapine is presented. The study was conducted in the Netherlands as prelude to a study in Tanzania to test a suitable intervention for its ability to reduce the development of nevirapine resistance.

III. Clinical pharmacology in HIV-TB co-infection

Tuberculosis (TB) is a common opportunistic infection in HIV-infected subjects, particularly in developing countries [27]. Co-administration of HIV and TB treatment is frequently indicated. Standard of care treatment regimens for TB include rifampicin, which is a strong inducer of cytochrome P450 enzymes, resulting in drug-drug interactions with antiretroviral therapy [28]. Patients on rifampicin are preferably treated with efavirenz-based HAART [27], which does not lead to a clinically relevant interaction [29, 30]. Although rifampicin reduces nevirapine exposure by 20-55% [31], nevirapine is an alternative to efavirenz among non-Caucasian patients [32, 33].

Second-line treatment for patients who have failed NNRTI-based regimens does often include protease inhibitors [27]. Rifampicin, however, causes large decreases
in the exposure to protease inhibitors [34-37]. We previously demonstrated that increased doses of lopinavir/ritonavir soft gel capsules (SGCs) compensate for the interaction with rifampicin [34]. Recently, the SGC formulation was replaced by a new heat-stable tablet formulation that exhibits slightly higher bioavailability irrespective of food intake. This has been a major improvement, especially for resource-limited settings where there may be a lack of options for refrigeration or food. Data from the interaction study with rifampicin and the SGC formulation of lopinavir/ritonavir cannot simply be extrapolated to the new tablet formulation. Chapter 7 describes the subsequent study in healthy volunteers evaluating the pharmacokinetics of two adjusted dose regimens of lopinavir/ritonavir tablets in combination with rifampicin. Clinical experience with the combined use of lopinavir/ritonavir and rifampicin in the Netherlands is described in Chapter 8.

Objectives of this thesis

This thesis presents the first output of a North-South collaboration in clinical pharmacological research of HIV treatment. Part I deals with the optimization of paediatric regimens for the scale-up of HIV treatment in resource-limited countries. Part II focuses on TDM in HIV-infected adults and the optimization of a cost-effective strategy for the reduction of MTCT in low-income countries. In Part III, the challenges of combined treatment with lopinavir/ritonavir and rifampicin for HIV-TB co-infection are described. Finally, a General discussion is presented.

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Part I
Clinical pharmacology in HIV-infected children
Children with HIV are not small adults: what is different in pharmacology?

Chapter 1

Children with HIV are not small adults: what is different in pharmacology?

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Current Opinion in HIV and AIDS 2007; 2:405-9
Purpose of review
Pharmacokinetics of antiretroviral drugs are highly variable among HIV-infected children. This review describes pharmacokinetic processes in children and recent pharmacokinetic data in children with HIV. The general lack of pharmacokinetic data and the potential role of therapeutic drug monitoring (TDM) is being discussed.

Recent findings
It was unexpectedly found that exposure to lopinavir is decreased in the first 6 months of life. Recent findings of subtherapeutic efavirenz concentrations in children suggest that pediatric dose recommendations should be re-evaluated. In addition, recommended dosing of lamivudine leads to lower exposure in children younger than 6 years of age. Preliminary results of pediatric fixed-dose combination (FDC) tablets for HIV-infected children with a higher nevirapine to stavudine and lamivudine ratio than adult FDCs suggest adequate drug exposure. As an alternative to plasma sampling, concentrations of nevirapine can be determined in saliva.

Summary
There is a shortage of pharmacokinetic data in the highly variable population of HIV-infected children. Selected pharmacology studies should be undertaken to improve pediatric dose guidance of existing antiretroviral drugs. TDM is a useful tool to optimize treatment in HIV-infected children. However, more data are needed to establish child-specific reference values.

Keywords
children, HIV, pharmacokinetics

Introduction
HIV-infected children cannot simply be regarded as small adults, pharmacologically speaking. Pharmacokinetics of antiretroviral drugs are highly variable in the pediatric population as children mature and grow rapidly and individually until they are adults. This brief review focuses on general characteristics relating to the processes in pharmacokinetics (absorption, distribution, metabolism, excretion) in the pediatric population, followed by recent examples of antiretroviral drug pharmacokinetics in HIV-infected children. In addition, practical dosing issues of antiretroviral drugs in children are taken into account. Finally, the role of therapeutic drug monitoring for HIV-infected children is being discussed.

Absorption
The gastrointestinal absorption of oral drugs in children is different from that in adults, because of developmental changes of the gastrointestinal tract. During the first 2 years of life, the pH in the stomach of children is high compared with the pH in adults [1**]. Gastric emptying time is delayed in neonates, whereas in infants and older children gastric emptying time is more rapid than in adults [2]. Similarly, intestinal motility is reduced in neonates and increased in older infants [1**]. Furthermore, intestinal drug absorption in neonates may be influenced by increased permeability of the mucosa, immature biliary function, reduced first-pass metabolism, maturation of carrier mechanisms and variable microbial colonisation [1**].

Food restrictions to optimize absorption of some antiretroviral drugs can be problematic in young HIV-infected children who need regular feeding and may not tolerate high-fat meals [2]. The authors of one study supposed that the much higher apparent nelfinavir plasma clearance and volume of distribution found in children below the age of 2 years was due to a decrease in bioavailability [3*]. These results were in agreement with our previous finding that children below 2 years tend to be at higher risk for low plasma concentrations of nelfinavir [4]. The reduced bioavailability in infants can be explained by differences in diet between young infants and older children, as the bioavailability of nelfinavir is influenced by the quantity and type of food with which it is administered [3*, 5]. Moreover,
bioavailability of weakly acidic compounds like nelfinavir may be reduced in the first 2 years of life due to a higher pH in the stomach [3\*]. Atazanavir and indinavir are 2 other examples of antiretroviral drugs that require an acidic gastric medium for adequate absorption [6]. Therefore, absorption of atazanavir and indinavir may also be reduced in the first 2 years of life, when gastric pH is slowly declining towards adult levels. This effect theoretically could abate with concurrent ritonavir use [6]. While there are insufficient data to recommend atazanavir with or without ritonavir or indinavir plus ritonavir in young children [7\*\*], studies have been presented on the use of these antiretroviral drugs in older children. Recently, first data were reported on the pediatric use of ritonavir-boosted atazanavir by 23 children and adolescents with a median age of 16 years (range, 10-19 years) [8*]. The adult dose of 300 mg atazanavir and 100 mg ritonavir in children weighing more than 50 kg and the reduced dose of 200 mg atazanavir and 100 mg ritonavir in children weighing less than 50 kg, grossly gave a satisfactory plasma concentration at random timing in children with good adherence. Nevertheless, virological failure was observed in one third of the children identified as good compliers; the authors claim that this may have been caused by the insufficient antiviral potency of the nucleoside reverse transcriptase inhibitors (NRTIs) that were used as backbone [8\*]. Reduced dosages of indinavir (220-300 mg/m²), when boosting with either 100 mg or with full ritonavir dosages appeared to provide adequate indinavir concentrations in most out of 19 Thai children with median ages of 9.7 and 11.3 years, respectively [9]. It is important to keep in mind that the available pharmacokinetic data for atazanavir and indinavir mentioned above are mainly from older children, in whom the level of gastric pH is not expected to influence absorption.

Distribution

The distribution of drugs in the body changes during childhood, because of age-specific differences in water content and plasma protein concentrations. The volume of total body water and extracellular fluid is high in young infants [1\*\*]. Drugs with a small volume of distribution (Vd <0.4 L/kg in adults) distribute over the extracellular fluid, while drugs with a large Vd (>0.6 L/kg in adults) are extensively tissue bound [1\*\*]. Since body surface area (BSA) correlates with extracellular fluid volume, BSA may be used to predict the dose of drugs with a small Vd in young children. Doses of drugs with a large Vd can be based on body weight, because tissue binding capacity and Vd in children are similar to those in adults [1\*\*]. The fact that protein binding tends to be reduced in neonates may be relevant for drugs with high protein binding capacity in combination with a small Vd. An increase in the unbound drug fraction may result in a larger Vd and increased efficacy and toxicity on short-term. However, stabilization of the unbound drug concentration may be expected due to enhanced clearance of the drug and therefore dose adjustments do not necessarily seem to be indicated [1\*\*].

Enfuvirtide, the first fusion inhibitor for the treatment of HIV-infection, is administered subcutaneously and exhibits a small Vd, low systemic clearance and high plasma protein binding [10]. Body weight adjusted dosing (2.0 mg/kg bid) in 25 HIV-infected children between 5 and 16 years of age resulted in enfuvirtide exposure similar to that obtained in HIV-infected adults receiving a dosage of 90 mg bid [11]. Recently, it was confirmed that pediatric enfuvirtide dosing per body weight is appropriate in children from 6 years of age as enfuvirtide exposure was not affected by age [12\*]. No data are available regarding the use of enfuvirtide in neonates. Another example of a drug with high protein binding capacity in combination with a small Vd is the relatively new antiretroviral tipranavir. The pharmacokinetic profile of tipranavir in pediatric patients is currently under investigation [13].

Metabolism

The rate of drug metabolism in children is influenced by changes in hepatic enzyme activity. Drugs can be metabolized by hepatic enzymes involved in phase 1 (oxidation, reduction and hydrolysis) and phase 2 (conjugation) reactions. Cytochrome (CYP) P450 is an important mixed-function oxidase system with reduced activity in neonates. This explains the fact that most drugs have a prolonged elimination half-life in neonates. The elimination half-life of most substrates approaches adult levels at the age of 2 to 6 months, when a significant amount and activity of enzymes is present [1\*\*]. Activity of liver enzymes exceeds adult levels at 1 to 4 years and declines to adult levels at the end of puberty [2]. Below the age of 2 months it seems wise to start with a very low dose and modify subsequent doses based on response, adverse events and if possible drug
concentrations. Between 2 and 6 months of age careful dosing of drugs based on body weight appears to be appropriate [1**]. After maturation of liver enzymes at the age of 6 months, metabolism is mainly dependent on liver growth, except for metabolism by the enzymes glucuronosyltransferase (UGT) and CYP2D6. As liver volume correlates well with BSA, it seems reasonable to base drug doses in children from the age of half a year on BSA as long as UGT and CYP2D6 are not involved in the pathway of metabolism [1**].

Metabolism of antiretroviral drugs from the protease inhibitor (PI) and non nucleoside reverse transcriptase inhibitor (NNRTI) classes in particular varies markedly with age in children and is also more variable between children of the same age and size compared to adults. In this paragraph, the focus will be on the PI-combination lopinavir/ritonavir and the NNRTIs nevirapine and efavirenz as these are the preferred options to be given in combination with 2 NRTIs as initial therapy for HIV-infected children. Metabolism of lopinavir is predominantly mediated by hepatic CYP3A4. Ritonavir inhibits the activity of CYP3A4 resulting in boosted plasma lopinavir concentrations [14]. Jullien et al have recently shown that lopinavir pharmacokinetics vary greatly during childhood and that children below the age of 6 months and boys above the age of 12 years may have decreased levels of exposure to lopinavir [15**]. The increased ability to eliminate lopinavir in neonates was surprising when looking at the pharmacokinetic process of metabolism alone, as the activity of CYP3A4 is known to be markedly reduced in the first weeks of life [15**]. However, when taking into account the pharmacokinetic processes of absorption and distribution, a decrease in the pharmacokinetic enhancement provided by ritonavir was found to be the most likely explanation [15**]. This example shows us the importance of looking at all aspects of the pharmacokinetic process and the actual testing of our hypotheses in the target population of HIV-infected children. Once daily dosing of lopinavir/ritonavir (460/115 mg/m2) in 19 HIV-infected children between 1.4 and 12.9 years resulted in mean pharmacokinetic parameters comparable to once daily dosing (800/200 mg) in adults, although the variability in trough levels was much higher in children [16**]. Subtherapeutic trough levels were more often experienced in younger children [16**]. In 2003, virologic responses in 74 HIV-infected children (1.6 months to 14.5 years) supported the use of nevirapine doses greater than 300 mg/m2/day, which was higher than recommended by the manufacturers at the time of publication [17]. Recently, in 127 African children aged 8 months to 18 years, subtherapeutic nevirapine concentrations were only observed in 3% of those prescribed ≥ 300 mg/m2/day compared to 23% of those prescribed < 300 mg/m2/day [18**]. Preliminary results in Zambian children of at least 6 months that were dosed according to this 300 mg/m2/day cut-off were promising as few subtherapeutic concentrations were observed [19]. With this knowledge, it is inappropriate to support dosing of nevirapine below 300 mg/m2/day in HIV-infected children at this stage. Ren et al have recently presented data on efavirenz concentrations in children with and without the anti-tuberculous enzyme inducer rifampin [20]. Standard recommended doses were used. Rifampin did not significantly reduce efavirenz concentrations. However, the fact that 50% of the children had a subtherapeutic efavirenz concentration, suggests that recommendations for efavirenz doses should be re-evaluated. An example of reduced first-pass metabolism of the NRTI zidovudine in neonates was published longer ago. After an oral dose of zidovudine, bioavailability was 89% in the first 2 weeks of life and 61% in children that were older than 2 weeks [21].

Excretion

Drug excretion in children is influenced by maturation of the kidney function. Glomerular filtration (GFR) and active tubular secretion (AS) are reduced in neonates and rise to adult values at about 3 and 7 months of age, respectively [22]. In older children, GFR and AS may actually exceed adult values [22]. Peak renal functions occur between the ages of 3 and 5 years [2]. Logically, drug dosing in children should be based on GFR if excretion by GFR is most significant and should be based on AS if excretion by AS is most significant [1**]. In the first week of life GFR may be based on an inert marker or gestational age, while after the first week of life plasma creatinine may be used as a marker for GFR [1**]. In children above 2 years without renal insufficiency drug doses can be based on BSA, since there is a good correlation with GFR [1**]. The NRTI lamivudine is preliminary eliminated by renal excretion of non-metabolized drug. The renal clearance of lamivudine was found to be greater than the glomerular filtration rate, which implies that lamivudine is also actively secreted into the renal tube [23]. A higher dose of lamivudine is recommended in children (4 mg/kg bid).
compared to adults (150 mg: ± 2 mg/kg bid). We have recently demonstrated that recommended dosing of lamivudine in a group of 51 children between 1.7 and 18 years leads to lower plasma exposure and maximum concentration of lamivudine in children younger than 6 years of age when compared with older children or adults [24**]. Part of the explanation could be the use of oral solution in younger children and tablets in older children, as the bioavailability of the solution may be less in children. Another reasonable explanation could be enhanced renal clearance in children between 1.7 and 6 years of age compared to older children.

Practical dosing issues

Adult antiretroviral formulations do not allow doses to be easily adjusted in small increments as the child grows. The development of pediatric friendly liquid formulations of individual antiretroviral drugs has been a good solution for the treatment of HIV-infected children in the developed world. In contrast, liquid formulations are generally no option for children in resource limited settings, where liquids are too expensive and too difficult to transport and store due to large volumes and short shelf-lives. The mainstay of first-line therapy for HIV-infected adults in resource-limited settings is a fixed-dose combination (FDC) of stavudine, lamivudine and nevirapine. Recent findings demonstrate that it is difficult to achieve adequate nevirapine levels with divided adult FDC tablets in young children without the risk of overdosing with stavudine [18**]. However, newly developed small, crushable, dispersible and scored FDC tablets for HIV-infected children with a higher proportion of nevirapine are currently undergoing clinical investigation and preliminary results suggest adequate exposure of all three antiretrovirals over the entire range of ages [19]. Development of solid pediatric formulations containing a PI may be problematic as minimum tablet sizes are expected to be too big for pediatric use.

Role of Therapeutic Drug Monitoring

Treatment of HIV-infected children may be considered as an indication for therapeutic drug monitoring (TDM), because of high inter- and intrapatient variability of antiretroviral drug concentrations [25]. In HIV-infected adults, plasma drug concentrations of PIs and NNRTIs are better predictors of antiretroviral response or toxicity than drug dose is [26]. This is expected to be even more evident in HIV-infected children where guidelines may advise inconsistent categories or wide ranges of drug doses due to the lack of sufficient pharmacokinetic data. For example, the US Food and Drug Administration (FDA) approved lopinavir/ritonavir for HIV-infected children from the age of 6 months even though the dose validation in the lowest weight group was limited to a small number of children, while the European Medicines Agency (EMEA) approved the combination only for children of at least 2 years of age [16**]. It would be helpful to have some guidance on the minimum number of children per weight group that should be used in pharmacokinetic studies to register antiretroviral drugs for the use in children. Since little or no target drug levels are available for children, antiretroviral drug concentrations in children are targeted to adult reference values [25]. Adult references may be insufficient for children because of the unique features of HIV-infection in children such as immature immune systems and high viral loads or may be too high in case of increased sensitivity of children for side effects [2]. In addition to optimization of antiretroviral therapy dosage for children, TDM may be used as a direct and objective instrument to measure non-adherence, which is a substantial problem in pediatric HIV-infected children [2]. A new interest of research is the development of noninvasive, reliable and cost-effective methods for application of TDM in HIV-infected children. As an alternative to plasma sampling, concentrations may be determined in saliva for antiretroviral drugs with low protein binding like nevirapine [27**].

Conclusion

Due to the shortage of pharmacokinetic data in the highly variable population of HIV-infected children, antiretroviral drug dosing remains complicated. Selected pharmacology studies should be undertaken to improve pediatric dose guidance of existing antiretroviral drugs. Furthermore, the new European regulation for pediatric drugs will lead to an obligation for pediatric research for every new drug developed for adults and having a potential use for children, in exchange for a six month extension of the supplementary protection certificate. TDM can be used to optimize treatment for the individual HIV-infected child. However, more data are needed to establish child-specific reference values.
References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as: * of special interest; ** of outstanding interest.

   An excellent and comprehensive review on the influence of developmental changes in absorption, distribution, metabolism and excretion on drug pharmacokinetics during childhood. General pediatric dose recommendations are proposed.


   This population pharmacokinetic analysis shows a decrease in the bioavailability of nelfinavir in infants. The authors conclude that children below the age of 2 months may need higher doses than currently recommended.


   This brief review clearly summarizes the text of the Guidelines for the Use of Antiretroviral Agents in Pediatric HIV Infection that were developed for the US and updated in October 2006.

   The change to a once-daily treatment including ritonavir-boosted atazanavir in 23 extensively pretreated children between 10 and 19 years old was associated with a significant risk of virological failure.


   The results of this population pharmacokinetic analysis confirm the appropriateness of body weight-based pediatric enfuvirtide dosing.


   The unexpected finding of decreased exposure to lopinavir in neonates makes this paper of outstanding interest.

   This study shows higher variability in lopinavir trough levels in children than in adults treated once daily. Subtherapeutic trough levels were more often experienced in younger children.


   An important study demonstrating that it is difficult to achieve adequate nevirapine levels with divided adult FDC antiretroviral tablets in children without the risk of overdosing with stavudine. Development of appropriate pediatric FDC tablets is essential for the treatment of HIV-infected children in resource-limited settings.


   Interestingly, this study shows that recommended dosing of lamivudine leads to lower exposure in children younger than 6 years of age.


   This paper describes the innovative idea of nevirapine determination in saliva as alternative to plasma sampling.
Chapter 2

Nevirapine concentrations in HIV-infected children treated with divided fixed-dose combination antiretroviral tablets in Malawi and Zambia

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Abstract

Objective: To investigate nevirapine concentrations in African HIV-infected children receiving divided Triomune® tablets ( stavudine + lamivudine + nevirapine).

Design: Cross-sectional study.

Methods: Steady-state plasma nevirapine concentrations were determined in Malawian and Zambian children aged 8 months – 18 years receiving Triomune® in routine outpatient settings. Predictors from height-for-age, BMI-for-age, age, sex, post-dose sampling time and dose/m²/day were investigated using centre-stratified regression with backwards elimination (p<0.1).

Results: Of the 71 Malawian and 56 Zambian children (median age 8.4 versus 8.5 years, height-for-age -3.15 versus -1.84 respectively), only 1 (3%) of those prescribed ≥ 300 mg/m²/day nevirapine had subtherapeutic concentrations (<3.0mg/L) compared with 22 (23%) of those prescribed <300 mg/m²/day; most children with subtherapeutic nevirapine concentrations were taking half or quarter Triomune® tablets. Lower nevirapine concentrations were independently associated with lower height-for-age (indicating stunting) (+0.37mg/L per unit higher [95% CI -0.003,+0.74], p=0.05), lower prescribed dose/m² (+0.89mg/L per 50mg/m² higher [+0.32,+1.46], p=0.002) and higher BMI-for-age (indicating lack of wasting) (-0.42mg/L per unit higher [-0.80,-0.04], p=0.03).

Conclusions: Currently available adult fixed dose combination tablets are not well suited for children, particularly at younger ages: Triomune® 30 is preferable to Triomune® 40 because of the higher dose of nevirapine relative to stavudine. Further research is required to confirm that concentrations may be reduced in stunted but increased in wasted children. Development of appropriate paediatric fixed dose combination tablets is essential if antiretroviral therapy is to be made widely available to children in resource-limited settings.

Introduction

There are 2.2 million HIV-infected children in sub-Saharan Africa of whom 370,000 are in urgent need of antiretroviral therapy (ART) [1, 2]. Operational challenges to scaling up ART for children include a lack of HIV diagnostic and monitoring tests for infants and limited expertise of health personnel in caring for HIV-infected children receiving ART. However a major obstacle in resource-limited settings is lack of affordable, accessible and appropriate paediatric antiretroviral drug formulations [3].

In order to provide ART to HIV-infected children, several countries have taken the pragmatic approach of prescribing divided adult fixed dose combination (FDC) antiretroviral tablets of Triomune® 30 or 40 (30 or 40 mg stavudine, 150 mg lamivudine, 200 mg nevirapine) to children. In addition to difficulties with accurate cutting and possible unequal distribution of drugs within tablets, a major problem with such an approach is that the ratios of drugs are designed for adult dosing. Since the rate at which children metabolise drugs is different to that of adults, and this may also vary with age, the ratios required will be different, particularly where dosing recommendations for children are based on surface area, as for nevirapine [4].

There are limited pharmacokinetic and dosing data on nevirapine as part of a FDC in children [5, 6] and how these may vary with ethnicity and degree of malnutrition. Here we aimed to determine steady state plasma concentrations of nevirapine in HIV-infected Malawian and Zambian children receiving divided adult fixed dose combination tablets of Triomune® 30 or 40, many of whom were malnourished.

Methods

Study population
This cross-sectional study took place in the paediatric ART clinics of Queen Elizabeth Central Hospital (QECH), Blantyre, Malawi and the University Teaching Hospital (UTH), Lusaka, Zambia between December 2004 and June 2005. HIV-infected children aged 8 months to 18 years who had received Triomune® 30 or 40 for at least a month were enrolled. Ethical approval was obtained and written informed consent was sought from parents or guardians, and assent from children.
not scored; the pills were split at home at both centres, though QECH provided pill cutters for this purpose. Nevirapine was dose escalated in both centres, with all children receiving half nevirapine dose for 2 weeks before proceeding to full nevirapine dose. During this dose escalation phase, the children at QECH received Triomune® 40 once daily with Lamivir-S® (40 mg stavudine, 150 mg lamivudine) once daily. At UTH, the children received Triomune® 30 once daily only. Once on full dose, the majority of children received Triomune® twice daily.

Single steady state blood samples were collected at routine clinic visits, at variable times post-dose, and plasma was separated and stored at -70°C prior to transportation to the Netherlands. Nevirapine concentrations were assayed at Radboud University Nijmegen Medical Centre, Nijmegen, The Netherlands, using validated HPLC [10]. Data were collected on demographics, growth parameters, last drug dose, timing of sample compared to last intake and co-medication.

Statistical methods
We used height-for-age to capture stunting and BMI-for-age as a pseudo weight-for-height score to capture wasting, calculated using the 1990 British Growth Charts [11] in Stata 9 [12]. CDC weight-for-height [13] could not be used as 50% of the children were outside the height range.

We estimated the effects of height-for-age, BMI-for-age, age, sex, time between last dose and sampling and dose/m²/day using linear regression of nevirapine concentration and logistic regression of therapeutic nevirapine concentration (≥3.0 mg/L or not, chosen as a consensus to be that best reflective of clinical practice [14-16]), stratifying for centre using meta-analysis methods with fixed effects, as centre was strongly confounded with many of the potential predictors. We used backwards elimination (p<0.1) to identify the most important predictors, investigating non-linearity using fractional polynomials [17].

Results
Baseline and pharmacokinetic data were available for 71 children from QECH and 56 children from UTH (Table 1). Although median ages were similar (8.4 versus 8.5

<table>
<thead>
<tr>
<th>Table 1 Baseline characteristics by centre.</th>
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<tr>
<td>QECH (n=71)</td>
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<tr>
<td>Age, years</td>
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<td>Age 0.5-3 years old</td>
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<td>Total daily prescribed stavudine dose</td>
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<td>Time between last dose and sampling, hours</td>
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Values given are median (IQR) and ranksum p-values comparing centres for continuous variables and number (%) and p-value comparing centres using chi-squared test for categorical variables.

* Triomune® 40 at QECH, Triomune® 30 at UTH.
† Date of starting ART missing for one UTH child.
‡ Sampling time missing for 7 UTH children.

where appropriate. At QECH, HIV-infected children were prescribed Triomune® 40 tablets (the only product available in Malawi) according to body weight as per national guidelines [7], either whole (containing 200 mg nevirapine) or divided into quarter (50 mg nevirapine), half (100 mg nevirapine) or three-quarter (150 mg nevirapine) parts. At UTH, children >10kg only, in long term follow-up of a previous trial of cotrimoxazole prophylaxis [8], were prescribed half or whole Triomune® 30 tablets according to surface area as per WHO guidelines [9]; children weighing <10kg received liquids and were excluded from this study. Triomune® tablets are
Nevirapine concentrations with divided tablets

Figure 1  Comparison of nevirapine (NVP) to lamivudine (3TC) and nevirapine to stavudine (d4T) ratios in Triomune® 30 and Triomune® 40 tablets versus ratios of the drugs as recommended for children.

Figure 2  Nevirapine (NVP) dose/m² and concentration by weight. (a) Total daily prescribed nevirapine dose/m² (mg/m²).

Converting kg to m² using standard UK growth charts [11].
Weights of children in this study are plotted along the top of the graph.

years at QECH and UTH respectively), more young children were enrolled from QECH, with 24% aged 0.5-3 years compared to none from UTH. Children from QECH were on average more malnourished by all anthropometric measures (median (IQR) height-for-age -3.15 (-3.82, -2.42) versus -1.84 (-2.98, -1.17) at UTH; BMI-for-age -0.89 (-1.64, 0.07) versus -0.50 (-1.63, 0.27) respectively). Children at UTH had been on ART for on average 3 months longer (median 8.7 (IQR 5.5, 17) [range 1.4, 46] months) compared to those at QECH (5.9 (3.2, 8.1) [2.2, 38] months).

The recommended daily nevirapine dose in children is 300-400 mg/m² [9, 18]. Of note, achieving a daily dose of 300 mg/m² requires a much higher ratio of nevirapine to lamivudine and nevirapine to stavudine for the lightest children than the ratio of these drugs in adult Triomune® 30 or Triomune® 40 tablets. This is illustrated in figure 1, and the weights of children in the study are shown at the top of this figure. All but four of the 27 children weighing <15kg were from QECH; for a fixed dose of lamivudine, children under 15kg have recommended nevirapine doses over 25% greater than that in Triomune®. Uneven dosing and provision of one-quarter and three-quarter tablets occurred at QECH, but not at UTH, where only half or whole Triomune® tablets taken twice daily were used. The median nevirapine dose received was lower at QECH than at UTH (median (IQR) dose/m²/day 243 (217, 270) mg/m²/day at QECH versus 288 (250, 344) mg/m²/day at UTH). Of note, age and nevirapine dose/m²/day were strongly
respectively) and were excluded from subsequent analyses, since these high concentrations did not seem to be explained by the stated prescribed dose. Other characteristics of these two children were comparable to the cohort (age 3 and 7 years, BMI-for-age +1.00 and +0.61, height-for-age -3.70 and -2.53, daily dose/m2 285 and 253 mg/m2/day respectively). Neither child was taking fluconazole prophylaxis or therapy, which is known to increase nevirapine exposure [19].

Of the remaining 125 children, the median (IQR) nevirapine concentrations were 4.8 (2.8, 6.5) and 7.0 (5.4, 10.5) mg/L at QECH and UTH respectively. Nineteen (27%) of the remaining children had nevirapine concentrations estimated at over 20 mg/L (22 and 31 mg/L respectively) and were excluded from subsequent analyses, since these high concentrations did not seem to be explained by the stated prescribed dose. Other characteristics of these two children were comparable to the cohort (age 3 and 7 years, BMI-for-age +1.00 and +0.61, height-for-age -3.70 and -2.53, daily dose/m2 285 and 253 mg/m2/day respectively). Neither child was taking fluconazole prophylaxis or therapy, which is known to increase nevirapine exposure [19].

Two patients with nevirapine concentrations >20 mg/L excluded.
Therapeutic nevirapine concentration ≥ 3.0 mg/L.
Quarter tablet = 50 mg nevirapine; half tablet = 100 mg nevirapine; whole tablet = 200 mg nevirapine.
OD = once a day; BD = twice a day.

Values given are median (IQR) for continuous variables and number (%) for categorical variables.
† Excluding two patients with nevirapine concentrations >20 mg/L.
of the QECH children and 4 (7%) of the UTH children had subtherapeutic nevirapine concentrations (defined as <3.0 mg/L; median age 8.1 years). Five of these had concentrations below 0.2 mg/L and 11 below 1 mg/L. Thirty-two (26%) children had concentrations over 8 mg/L and 20 (16%) had concentrations over 10 mg/L.

The majority (100 (87%) of the 125) of children were either on no other medications or cotrimoxazole alone. None of the concomitant medications used are known to interact with nevirapine, except isoniazid, which could inhibit the liver enzyme CYP3A4 [20] and potentially increase nevirapine concentrations. However, the three children on isoniazid (all at QECH) all had nevirapine concentrations below the 75th centile (2.3, 5.6 and 8.1 mg/L).

Only 2 (7%) of the 28 children prescribed ≥350 mg/day nevirapine (three-quarter/whole Triomune® tablets; median dose/m² 337 (range 274, 454) mg/m²) had subtherapeutic nevirapine concentrations compared with 10 (15%) of the 65 children prescribed 200–<350 mg/day (quarter/half tablets; dose/m² 214 (120, 297) mg/m²) (Figure 2b). Only 1 (3%) of the 30 children prescribed a nevirapine dose adjusted for body surface area of ≥300 mg/m²/day had a subtherapeutic concentration compared with 22 (23%) of the 95 children prescribed <300 mg/m²/day.

Age and nevirapine dose received were strongly confounded, as expected (Table 2). However, because younger children have a higher surface area relative to weight, this also led to strong confounding with dose adjusted for surface area: the youngest children received the lowest doses and also received the lowest doses adjusted for surface area compared with the recommended 300-400 mg/m²/day [9]. Reflecting underlying variation in surface area adjusted dosing, 38% (6 of 16) in the youngest age group (0.5-3 years old) had subtherapeutic concentrations compared with 12% (3 of 26), 25% (10 of 40) and 9% (4 of 43) in the age groups 4-6, 7-10 and 11+ years respectively.

Children with higher dose/m², higher height-for-age but lower BMI-for-age had higher nevirapine concentrations in univariable and multivariable models (Table 3a). A 50 mg/m² higher daily dose of nevirapine was independently associated with a
0.89 [0.32, 1.46] mg/L higher nevirapine concentration (p=0.002). A one unit higher height-for-age was independently associated with a 0.37 (95% CI [-0.003, 0.74]) mg/L higher nevirapine concentration (p=0.05), but a one unit lower BMI-for-age was independently associated with a 0.42 [0.04, 0.80] mg/L higher nevirapine concentration (p=0.03). There was no evidence that the effect of any of these variables was non-linear. Of note, whilst age and dose/m² were both significant univariable predictors, age was a confounder of dose/m², and only dose/m² had an independent effect on nevirapine concentration. There was no evidence of an effect of sex on nevirapine concentration (full multivariable model, p=1.0).

We examined the above variables with respect to the likelihood of achieving nevirapine concentrations above the therapeutic threshold. A one unit increase in height-for-age was independently associated with a 48 [7, 106] % increase in the odds of achieving a therapeutic nevirapine concentration (p=0.02, Table 3b). There was no evidence of an association between achieving a therapeutic nevirapine concentration and BMI-for-age, nor dose/m² (univariable OR=0.90 [0.64, 1.27], p=0.6; 1.14 [0.71, 1.82], p=0.6 respectively), but power was low and height-for-age and dose/m² were confounded, with 70% of those with height-for-age z-score< -4 prescribed <250 mg/m² daily, compared to just 35% of those with height-for-age z-score ≥ -4.

Discussion

In the absence of appropriate paediatric antiretroviral drug formulations in resource-limited settings, divided adult fixed dose combination (FDC) antiretroviral tablets are often prescribed for use in children. In addition to limited information on the uniformity of distribution of the component drugs in the tablet and difficulties in cutting the unscored tablets accurately, the drugs are in a fixed dose ratio that is not appropriate for children. For example, national guidelines drawn up in 2003 for the delivery of ART to HIV-infected children in Malawi needed to reconcile dosing recommendations for three drugs: two with dosing recommendations based on weight, the third on either surface area or on weight with a step down in dose at age 8 years, reflecting the fact that nevirapine is metabolised more rapidly in younger children. The guidelines needed to be applied in District units (or smaller health centres) where staff training and facilities would be extremely limited. Provision of individual syrups and dosing by surface area were considered impossible on a national basis. Triomune® 40 (but not 30) was already in use and about to be recommended for adults in the national programme, but it was clearly not possible to dose all 3 components according to individual recommendations using Triomune® 40 for children. Given a choice between separate paediatric formulations, underdosing nevirapine (particularly in younger children) or overdosing lamivudine and stavudine, a pragmatic decision was made to base Triomune® 40 recommendations on doses for lamivudine and stavudine, i.e. on a mg/kg basis, with a linear relationship between weight and dose, and accepting that nevirapine was likely to be underdosed in the youngest children.

Our results indicate that using divided Triomune® tablets in this way can lead to subtherapeutic nevirapine concentrations at any age and body weight when these are associated with low nevirapine doses/m²/day. Younger, smaller children who are more likely to receive quarter tablets and have higher surface area for weight are at particular risk, with nearly half of those receiving quarter tablets either once or twice daily having subtherapeutic concentrations. Because of the higher viral loads and faster metabolism in young children, the potential for development of drug resistant virus is significant [21, 22]. Therefore quarter Triomune® tablets should be avoided where appropriate alternative ART formulations exist. We did not measure lamivudine or stavudine levels in plasma; although this is not the active moiety of these drugs, which act intracellularly, the doses prescribed suggest that subtherapeutic levels of these drugs could also have occurred in some children. This is of particular concern for lamivudine given the low genetic barrier to development of the M184V mutation, and recent findings that 8 mg/kg/day dosing may also be too low in children under 6 years of age [23].

We found that the strongest predictor of nevirapine level was the dose prescribed in mg/m²/day and subtherapeutic concentrations were infrequently observed in those children receiving a nevirapine dose of ≥ 300 mg/m²/day. Body surface area measurements are difficult to calculate and errors have been reported [24]. A recent paper describing underdosing of many antiretrovirals in children points out non-concordance of dosing when calculated using mg/kg versus mg/m² recommendations for nevirapine in particular [4]. In collaboration with leading HIV
Nevirapine concentrations with divided tablets

Nevirapine concentrations with divided tablets

paediatric pharmacologists, WHO has recently developed standardised weight-band based dosing tables for all antiretrovirals used in children, using surface area dose calculations as the basis for conversion into weight bands. This should simplify dosing of antiretrovirals in resource-limited settings [9]. Of note, over a quarter of the children in our study had plasma nevirapine concentrations over 8 mg/L and 16% had concentrations over 10 mg/L, although overt toxicity was not observed.

Our results suggest that nevirapine concentrations may be reduced in stunted but increased in wasted children, with lower height-for-age (a pseudo-measure for stunting) independently associated with lower nevirapine concentrations and lower BMI-for-age (a pseudo-measure for wasting) independently associated with higher nevirapine concentrations. One possible explanation is that wasted children will be older than well-nourished children of the same weight, and so will metabolise the same dose of nevirapine more slowly. As malnutrition is common in HIV-infected children in sub-Saharan Africa and is often used as a clinical criteria of eligibility to access ART, these results carry important implications for clinical practice. Further pharmacokinetic studies in a larger number of children taking a range of antiretroviral drugs is required to confirm these findings. It is possible that different recommendations for dosing malnourished children may be required, although in general if food is available, weight gain and growth after starting ART is rapid. Doses also need to be monitored carefully with any rapid changes in height and/or weight. However, children in this study remained stunted and wasted 3 or more months after starting ART.

Although samples were on average taken later post-dose at QECH compared to UTH (median 8.9 vs 3.5 hours), the long half-life of nevirapine (median 25.5, range [12.1, 105.2] hours in children [5], similar to median 24.3 hours observed in adults [25]) leads to only a minimal difference between nevirapine peak and trough concentrations at steady state. Indeed we observed no effect of dose timing in the multivariable analysis. In addition, the lower limit of the therapeutic range for nevirapine (3.0 mg/L) is based on a study in which samples were taken at random times [14]. Two children (one from each centre) had nevirapine concentrations estimated at over 20 mg/L and were excluded from the main analysis. These high concentrations did not seem to be explained by the stated prescribed dose, which was comparable to the other children, or by concomitant medications. Further, children had been on nevirapine for median 6.5 months, so gastrointestinal problems which could affect absorption are unlikely. An alternative explanation is a possible pharmacogenomic or -genetic effect, as the CYP2B6 T/T genotype at position 516 is more common in African-Americans than in European-Americans and is associated with greater efavirenz exposure [26] and, to a lesser extent, with greater nevirapine exposure [27]. Misunderstanding instructions about how many pieces of tablet or tablets to give could also have occurred. A limitation of our study is that we did not measure adherence, nor were any drugs taken under direct observation; nevirapine concentrations may therefore reflect adherence as well as prescribed dose. Those children with very low nevirapine concentrations are unlikely to have taken ART for several days, emphasising the difficulties of administering drugs to young children. In addition, we did not have viral loads to be able to relate nevirapine levels to treatment success or failure.

Nevirapine pharmacokinetics have been studied recently in 34 Thai children (median age 8.4 years) who similarly received divided tablets (GPO-VIR S30®, equivalent to Triomune® 30) [5]. In this study 33 of the 34 children achieved therapeutic concentrations (defined as ≥ 3.4 mg/L). However none were receiving quarter tablets and the mean daily nevirapine dose was considerably higher at 328 mg/m², compared to 265 mg/m² in our study. A recent comparison of the pharmacokinetics of liquid formulations versus split Triomune® 40 in 18 Malawian children (median age 7 years) concluded that although quartered multiples of FDC tablets are reasonable for use in larger children, liquid formulations are better for smaller children [6].

Our findings demonstrate that it is difficult to achieve adequate nevirapine levels [28] in young children with divided Triomune® tablets without a risk of overdosing with stavudine, especially when using Triomune® 40. Therefore, for young children, paediatricians currently face a difficult decision, as increasing the Triomune® dose to ensure adequate nevirapine will consequently increase the dose of lamivudine and stavudine. Higher doses of stavudine in particular may lead to toxicity; its main side effect, peripheral neuropathy, can be difficult to identify in children and may be irreversible. Use of Triomune® 30 rather than Triomune® 40 would enable higher doses of nevirapine and lamivudine to be given and, as higher doses of lamivudine may anyway be beneficial in younger children, this would be preferable [23]. An alternative strategy would be to supplement quarter Triomune® tablets with...
additional nevirapine syrup, although this may not always be available and would be more difficult for caregivers. Of note, despite the low nevirapine levels achieved and the potential for development of resistance, the children in this cohort continue to go to school, put on weight and come to clinic, in contrast to the high mortality observed in the cohort when ART was not available [8]. As a result of these data and also because Triomune 30 is now available in Malawi, national paediatric ART dosing guidelines have been amended: the Triomune® dose has been increased in younger children such that few children now receive less than 300 mg/m² nevirapine, while accepting a modest increase in the doses of lamivudine and stavudine.

Cipla Pharmaceuticals are developing FDC antiretroviral tablets in two formulations suitable for infants and children with a higher proportion of nevirapine, Pedimune® Baby (6 mg stavudine, 30 mg lamivudine, 50 mg nevirapine) and Pedimune® Junior (twice Baby dose). Tablets are scored to enable dividing for accurate dosing and are dispersible. They are currently undergoing clinical investigation but are not yet pre-qualified by WHO and therefore so far not accessible to national ART programmes. The availability of these and other paediatric generic FDC tablets for resource-limited settings is eagerly awaited and long overdue. It is a high priority for successful scaling up ART for children.

Acknowledgements and sources of support

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References


Chapter 3

Pharmacokinetics of two generic fixed-dose combinations for HIV-infected children (Pedimune Baby & Pedimune Junior) are similar to the branded products in healthy adults

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Abstract

Objectives: Cipla Pharmaceuticals have developed generic fixed-dose combinations of stavudine, lamivudine and nevirapine for HIV-infected children (Pedimune Baby and Junior). We determined the pharmacokinetic profiles of stavudine, lamivudine and nevirapine in Pedimune and compared these with the branded products.

Methods: This phase-I, comparative, single-center, open-label, three-period, single-dose study was designed as a pilot study to exclude large differences in pharmacokinetics. Six healthy males were randomized to the following regimen sequences: ABC; ACB; BCA; BAC; CAB; CBA (A = reference, B = Pedimune Baby, C = Pedimune Junior). Single doses of medication were administered at 3 time points 4 weeks apart. An 8h pharmacokinetic curve was recorded at day 1 of every cycle after medication intake. In addition, blood samples were taken on day 2, 3, 4, 8 and 15.

Results: Nonparametric statistical tests revealed no statistically significant differences in C_{max} (0.173 ≤ P ≤ 0.753) and T_{max} (0.317 ≤ P ≤ 1.000) of stavudine, lamivudine and nevirapine between the 2 Pedimune formulations and the branded drugs. Also, there were no significant differences in AUC_{0-∞} of stavudine, lamivudine and nevirapine between Pedimune Junior and the branded drugs (0.345 ≤ P ≤ 0.600) and between Pedimune Baby and the branded drug for nevirapine (P=0.463). In contrast, the AUC_{0-∞} of stavudine (mean change: +21%; P=0.046) and lamivudine (mean change: +14%; P=0.028) differed significantly between Pedimune Baby and the branded drugs, but these changes were considered not clinically significant.

Conclusions: The pharmacokinetic profiles of stavudine, lamivudine and nevirapine in Pedimune Baby and Junior are comparable to the branded products. Based on these results, it is acceptable to test the pharmacokinetics and dosing requirements of Pedimune in HIV-infected children.

Introduction

In well resourced countries, Anti-Retroviral Therapy (ART) with three or more potent drugs has resulted in major reductions in morbidity and mortality of HIV-infected adults and children [1, 2].

There are now intensive efforts by governments and non-governmental organizations to increase the number of people being treated with ART in resource-limited parts of the world where 90% of infected individuals live. For HIV-infected adults in these settings, pharmaceutical companies have reduced drug costs through separate pricing, and generic manufacturers have been allowed to produce ART combinations at lower costs without facing patent claims.

Cipla Pharmaceuticals is an India-based generic manufacturer that has produced a fixed-dose combination (FDC) tablet for HIV-infected adults, (Triomune - 30 or 40mg stavudine, 150mg lamivudine, 200mg nevirapine), to be taken twice-daily without food restriction. Bioequivalence and clinical efficacy have been demonstrated [3-5]. At a price of less than 1 euro/day, Triomune is now a reasonable option for many adult patients, and is frequently used in access-to-care programs.

In 2005, it was estimated that at least 660,000 children were in need of ART [6], of whom 90% live in sub-Saharan Africa. However, fewer than 4% of individuals receiving ART in 2005 were children. There are several reasons for this including difficulties in making an early diagnosis of HIV in HIV-exposed infants and lack of personnel trained in paediatric ART management. However, arguably the biggest barrier is lack of appropriate formulations of ART, including FDC tablets, and simple dosing tables. Paediatric brand liquid formulations are expensive, may require water for reconstitution, which is not always available in good quality, and may require refrigeration, which is a particular problem in rural areas. Further, until recently, there were no FDC tablets for children. Triomune is sometimes prescribed dosed as half or quarter tablets. However, lack of scoring can result in inaccurate breaking and hence inaccurate dosing. Of more concern are preliminary data from a study in Malawian and Zambian children which showed that nevirapine underdosing was common, particularly in the youngest children receiving quarter tablets of Triomune [7].
To address this issue, Cipla Pharmaceuticals have recently developed two generic fixed-dose combinations for HIV-infected children (Pedimune Baby and Pedimune Junior) including the same agents as in Triomune, but in a different dose ratio, with higher dose of nevirapine. Pedimune Baby contains 6mg stavudine, 30mg lamivudine and 50mg nevirapine, while Pedimune Junior contains double the dose. Pedimune tablets are small, dispersible or crushable, and scored.

The primary objective of this pilot study was to determine the pharmacokinetic profile of stavudine, lamivudine and nevirapine in Pedimune Baby and Pedimune Junior after single-dose in healthy males, and to compare this to the individual branded products. The study was conducted in the Netherlands as a prelude to a pharmacokinetic study of Pedimune in HIV-infected children in Zambia which has recently started.

Materials and methods

This phase-I, comparative, single-center, open-label, three-period, single-dose study was not designed as a bioequivalence study but as a pilot study to exclude large differences in pharmacokinetic profiles. Healthy male subjects aged 18 to 65 years were eligible for enrollment after pre-entry and laboratory evaluation. Subjects who tested positive for HIV and/or hepatitis B or C and subjects with abnormal clinical laboratory test results were excluded. Subjects were not allowed to take any concomitant drug (for two weeks preceding dosing), except for paracetamol and loperamide. The study protocol was reviewed and approved by the Ethics Committee of the Radboud University Nijmegen Medical Centre, Nijmegen, The Netherlands. Informed consent was obtained from all subjects before enrollment.

Subjects were randomized to one of the following regimen sequences: ABC; ACB; BAC; CAB; CBA:

Regimen A (reference): 24mg stavudine (24mL Zerit powder for suspension 1 mg/mL, Bristol-Myers Squibb), 120mg lamivudine (12mL Epivir solution 10mg/mL, GlaxoSmithKline) and 200mg nevirapine (one Viramune tablet of 200mg, Boehringer Ingelheim).

Regimen B (test 1): 4 combined-formulation tablets consisting of 6mg stavudine, 30mg lamivudine, and 50mg nevirapine (Pedimune Baby, Cipla Pharmaceuticals).

Regimen C (test 2): 2 combined-formulation tablets consisting of 12mg stavudine, 60mg lamivudine, and 100mg nevirapine (Pedimune Junior, Cipla Pharmaceuticals).

Single doses of medication, normalized to 200mg of nevirapine, were administered at 3 time points 4 weeks apart. Medication was taken orally after a minimum fast of 3 hours. One of the investigators directly observed medication ingestion. Breakfast and lunch were standardised on the day of medication ingestion and were administered 2 and 5 hours after intake, respectively.

Blood was collected just before and 0.5, 1, 1.5, 2, 2.5, 3, 4, 5, 6, 8, 24, 48, 72, 168 and 336 hours after intake. Blood samples were stored at 2-8°C for maximum 8 hours until being centrifuged. Immediately after centrifugation, plasma was separated and stored at –40°C until analysis. Plasma concentrations of stavudine and lamivudine were determined in all samples up to 24 hours after intake by a validated HPLC assay with ultraviolet (UV) detection [8]. Plasma concentrations of nevirapine were determined in all samples by a validated HPLC assay with UV detection, modified from a method published by Hollanders et al [9]. The lower and upper limits of quantification for the modified assay were 0.03 and 15 mg/L, respectively. The intraday precision ranged from 0.4% to 11.4%, while additional variation as a result of performing the assay on different days ranged from 0.0% to 2.1%. The accuracy of the assay ranged from 100.1% to 104.8%.

The pharmacokinetic (PK) parameters C_max and T_max were calculated directly from observations of plasma concentrations. Non compartmental pharmacokinetic analysis was performed by using WinNonlin software package (version 4.1; Pharsight Corporation, Mountain View, Calif.) to determine the PK parameter AUC_0-∞.

Wilcoxon’s signed rank test was used to compare C_max, AUC_0-∞ and T_max between the generic and branded formulations. Descriptive statistics were carried out by using SPSS, software version 12.0 [SPSS Inc., 1989-2003].
Nonparametric statistical tests revealed no statistically significant differences in the Cmax (0.173 ≤ P ≤ 0.753) and Tmax (0.317 ≤ P ≤ 1.000) of stavudine, lamivudine and nevirapine between the two Pedimune formulations and the branded drugs. Furthermore, no statistically significant differences in the AUC0-∞ of stavudine, lamivudine and nevirapine were found between Pedimune Junior and the branded drugs (0.345 ≤ P ≤ 0.600). The AUC0-∞ of stavudine (P = 0.046) and lamivudine (P = 0.028) differed significantly between Pedimune Baby and the branded formulations, while there was no significant difference in the AUC0-∞ of nevirapine (P = 0.463). For Pedimune Baby the mean AUC0-∞ of stavudine and lamivudine was 21% and 14% higher compared to the branded drugs, respectively.

Treatments were generally well tolerated. No adverse events were reported after intake of Pedimune Junior. Reported mild adverse events, possibly related to treatment, were diarrhoea (1 out of 6 subjects on branded products and 1 out of 6

Results

Six healthy white male subjects were enrolled in the protocol. The median age, height, and body weight (range) were 43 (21-63) years, 1.84 (1.74-1.98) m, and 86.5 (69.0-100.0) kg, respectively. All 6 males completed the study.

Plasma concentrations of stavudine, lamivudine and nevirapine after single doses of the branded drugs (A), Pedimune Baby (B) and Pedimune Junior (C) are illustrated in Figures 1, 2 and 3, respectively. There are no large differences between the different plasma concentration-time curves.

Primary pharmacokinetic (PK) parameters of stavudine, lamivudine and nevirapine after single doses of the branded drugs (A), Pedimune Baby (B) and Pedimune Junior (C) are shown in Table 1.
Although the formulations are designed for HIV-infected children, it is generally not accepted to study pharmacokinetics of new agents or new formulations in healthy children. Therefore, healthy adults were included. Due to a possible effect of endogenous or exogenous estrogenic hormones on the pharmacokinetics of nevirapine, the effect of nevirapine on oral contraceptives, more toxicity of nevirapine in healthy females, and the small sample size, we only included male subjects.

Nonparametric statistical tests revealed no statistically significant differences in the C_{max} and T_{max} of stavudine, lamivudine and nevirapine between the two Pedimune formulations and the branded drugs. Moreover, no statistically significant differences were found for the AUC_{0-\infty} of stavudine, lamivudine and nevirapine between Pedimune Junior and the branded drugs. While there was no significant difference in the AUC_{0-\infty} of nevirapine between Pedimune Baby and Viramune, the AUC_{0-\infty} of stavudine and lamivudine was significantly higher (21 and 14%, respectively) after subjects on Pedimune Baby) and nausea (2 out of 6 subjects on branded products). All adverse events resolved spontaneously.

Discussion

The present pilot study shows that the pharmacokinetic profiles of stavudine, lamivudine and nevirapine in Pedimune Baby and Junior are comparable to the individual branded products after intake of single doses.

A bioequivalence study is typically conducted as a single-dose, crossover trial. With three different formulations a minimum number of 6 subjects was needed for this pilot study to test all possible sequences. The study was not powered to prove bioequivalence, but to exclude large differences (> 50%) in pharmacokinetic parameters.
intake of Pedimune Baby when compared to the individual branded formulations. However, we do not consider these differences in AUC\(_{0-\infty}\) (far below 50%) to be large and find the pharmacokinetic profiles of stavudine, lamivudine and nevirapine in Pedimune Baby and Junior comparable to the individual branded products. In addition, it would be more worrisome when AUC\(_{0-\infty}\) of stavudine and/or lamivudine were lower instead of higher, as observed here. In general, virological failure is much more difficult to manage than toxicity.

Cipla Pharmaceuticals is currently conducting a formal bioequivalence study on Pedimune prior to applications for registration, and to meet prequalification criteria set by the WHO. Prior to results being available from this, we believe that the information from this independent pilot study showing comparable pharmacokinetic profiles of the three agents (stavudine, lamivudine and nevirapine) between the newly-developed Pedimune tablets and the branded products, is sufficient for us to start a larger pharmacokinetic study in African HIV-infected children in Zambia who are a key target population for use of Pedimune. The children in our trial are closely monitored for potential toxicity and virological failure, because bioequivalence of the Pedimune tablets still needs to be proven. Given that large numbers of children are either receiving no Anti-Retroviral Therapy (ART), or inappropriate ART doses from part Triomune tablets, it is imperative that fixed-dose combinations of appropriate formulations and doses are tested urgently and then become available and licensed for children as soon as possible.

In conclusion, the pharmacokinetic profiles of stavudine, lamivudine and nevirapine in Pedimune Baby and Junior are comparable to the individual branded products. Based on the results of this pilot study, it is acceptable to start testing the pharmacokinetics and dosing requirements of Pedimune Baby and Junior in HIV-infected children, while monitoring closely for potential toxicity and virological failure.

Acknowledgements

We would like to thank the laboratory technicians of the Department of Clinical Pharmacy, Radboud University Nijmegen Medical Centre, for the analysis of the samples.

References

Chapter 4
Nevirapine, stavudine and lamivudine pharmacokinetics in African children on paediatric fixed-dose combination tablets

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Abstract

Objective: Triomune Baby and Junior have been developed in response to the urgent need for appropriate paediatric fixed-dose combination antiretroviral tablets, with higher nevirapine to stavudine and lamivudine ratios than adult tablets in accordance with paediatric recommendations. We determined whether this ratio results in optimal exposure in the target population.

Methods: Seventy-one Zambian children were treated with Triomune Baby or Junior dosed according to weight-bands. After 4 weeks or more, a 12-hour pharmacokinetic curve was recorded. Antiretroviral plasma concentrations were assayed by high-performance liquid chromatography.

Results: Six children were excluded because of poor adherence. Of the remaining 65, 24 (37%) were female, 24 (37%) weighed less than 15kg and most were malnourished. Mean (range) nevirapine C_{12h}, C_{max} and AUC_{12h} of 6.0 (1.4,16.9) mg/L, 10.0 (3.8,22.5) mg/L and 94.4 (32.1,232) h.mg/L were higher than those reported in adults. Nevirapine C_{12h} was subtherapeutic (<3.0 mg/L) in four (6%) children. Mean stavudine and lamivudine C_{12h}, C_{max}, AUC_{12h} (<0.015 mg/L, 0.45 mg/L, 1.05 h.mg/L and 0.09 mg/L, 1.33 mg/L, 5.42 h.mg/L) were comparable to adults. There was no evidence of a difference in nevirapine AUC_{12h} across weight-bands (p=0.2), while the difference in stavudine (p=0.0003) and lamivudine AUC_{12h} (p=0.01) was driven by the single weight-band with unequal dosing.

Conclusions: Nevirapine concentrations were higher but more variable than those in adults; pharmacokinetic parameters of stavudine and lamivudine were comparable to adults. As nevirapine underdosing is of greater concern than overdosing, the Triomune Baby and Junior ratio appears to be appropriate for children weighing 6kg and over. Further research is required for children under 6kg.

Introduction

Of 2.3 million children living with HIV in 2006, almost 90% in sub-Saharan Africa, an estimated 780,000 urgently require antiretroviral (ARV) therapy [1]. Where liquids are available, they are costly, have short shelf-lives, and are difficult to transport and store [2]. Due to lack of availability of affordable and appropriate paediatric ARV drug formulations, divided adult fixed-dose combination tablets (FDCs) are frequently provided for children. However, adult FDCs do not allow easy dose adjustment as a child grows. Further, and more importantly, drug ratios in these adult FDCs are not correct for children. Our previous study in 127 HIV-infected Malawian and Zambian children receiving divided adult FDCs (Triomune; Cipla Pharmaceuticals, India; 200mg nevirapine, 30 or 40mg stavudine, 150mg lamivudine) demonstrated a risk of nevirapine underdosing [3], due to children, particularly the youngest, metabolizing nevirapine more rapidly than adults. Underdosing is a major threat to long-term success of ARV therapy, as lack of potency in suppressing viral replication will result in development of mutations, particularly against drugs with a low genetic barrier to resistance such as nevirapine and lamivudine, and limit subsequent treatment options [4, 5]. This is of particular concern for children facing a life-time requirement of ARV therapy.

To address this problem, Cipla Pharmaceuticals have developed small, dispersible, crushable, scored FDCs for HIV-infected children in two sizes (Triomune Baby and Junior) with relatively higher nevirapine versus stavudine and lamivudine dose ratios compared to the adult FDC, in accordance with paediatric dosing recommendations [6]. In our independent pilot bioequivalence study, the pharmacokinetics (PK) of Triomune Baby and Junior were similar to branded products in six healthy males [7]. Formal bioequivalence was demonstrated by Cipla Pharmaceuticals (data on file).

Here we studied the PK of nevirapine, stavudine and lamivudine in Zambian HIV-infected children prescribed Triomune Baby or Junior twice daily according to surface-area derived weight-bands, to determine whether the dose ratio results in optimal ARV exposure in the target population.
Methods

Study population and design

CHAPAS1 is an open, randomised, controlled, phase I/II trial designed to assess the appropriate dosing of, and adherence to, Triomune Baby (50mg nevirapine, 6mg stavudine, 30mg lamivudine) and Junior (double Baby dose). Two hundred HIV-infected children aged 3 months to 14 years weighing <30kg who fulfill WHO criteria for initiating ARV therapy have been enrolled at the University Teaching Hospital, Lusaka, Zambia. Children were randomised in a 1:1 ratio to take Triomune Baby or Junior either immediately at full dose in a twice-daily schedule, or in a once-daily dose escalation schedule with an additional stavudine/lamivudine tablet (Lamivir-S, Cipla Pharmaceuticals) for the first 14 days, followed by full dose. Children previously treated with ARVs, including for prevention of mother-to-child HIV transmission, were excluded. Further exclusion criteria were severe laboratory abnormalities, active opportunistic infection, and treatment with any medication known to be contra-indicated in combination with nevirapine, stavudine and/or lamivudine.

The first 64 children enrolled in CHAPAS1 were to participate in the PK substudy, with 16 per age-group <3, 3-6, 7-10 and 11-14 years. These children had to fulfill all enrolment criteria for CHAPAS1 and also not suffer from illnesses that could influence the PK of the ARVs such as diarrhea, vomiting, renal or liver disease, and not be taking concomitant medication with interactions to the ARVs.

Full nevirapine dosing was chosen to aim for daily doses of 300-400 mg/m² [6] using estimated body surface area (BSA) for weight converted into weight-bands (3-<6, 6-<10, 10-<15, 15-<20, 20-<25, 25-<30kg) [8]. Daily stavudine and lamivudine doses were targeted to 2 and 8 mg/kg respectively. Nevirapine dose ranges in mg/m² and stavudine and lamivudine dose ranges in mg/kg (Table 1) are the result of the same dose in mg being given over weight (and BSA) ranges. Of note, one weight-band (15-<20kg) has unequal morning and evening doses.

The protocol was reviewed and approved by the Ethics Committees of the University of Zambia, Lusaka and University College London. Written informed consent was obtained from parents or guardians, and children where appropriate.

Blood collection and drug concentration assays

At least four weeks after starting Triomune Baby or Junior, a 12-hour PK curve was undertaken, following directly observed medication ingestion. Non-breast-fed children fasted for ≥3 hours before intake, and standardized meals were given 1-2, 4-6 and 8-12 hours after intake. Two mL of blood was collected just before and 1, 2, 4, 6, 8 and 12 hours after intake. Plasma was separated and stored at -80°C until transportation to the Netherlands on dry-ice.

Plasma concentrations of nevirapine, stavudine and lamivudine were assayed at the Department of Clinical Pharmacy of the Radboud University Nijmegen Medical Centre, Nijmegen, The Netherlands, using two validated HPLC assays with ultraviolet detection [9, 10]. The plasma drug concentration 12 hours post-dose (C12h) and maximum concentration (Cmax) were determined directly from concentration-time data. The area under the concentration-time curve 0-12 hours post dose (AUC12h) was evaluated using the linear-log trapezoidal rule.

Children were excluded if there was evidence of non-adherence, i.e. if the ratio between nevirapine C12h and predose concentration was more than 2 and...
non-adherence was independently suspected by the study team, or if this ratio was more than 4 without suspected non-adherence.

**Statistical methods**

Weight-for-age, height-for-age and body mass index (BMI)-for-age z-scores were calculated using the 1990 British Growth Charts [11] in Stata 9 [12] and CD4-for-age using published age-related reference ranges [13]. Nevirapine, stavudine and lamivudine AUC\(_{12h}\) were compared across weight-bands and age groups using analysis of variance adjusted for randomisation.

**Results**

Of the 71 children enrolled in the PK substudy, six were excluded due to evidence of non-adherence. These six, aged 10 months to 12 years, had similar weights and CD4% to the rest of the cohort, and daily prescribed nevirapine doses of 363-424 mg/m\(^2\).

Of the remaining 65 children, 16, 18, 16 and 15 were aged <3, 3-6, 7-10 and 11-14 years respectively. The majority were malnourished and moderately to severely immunodeficient (Table 2). The mean (range) daily prescribed nevirapine dose at enrolment was 370 (317, 486) mg/m\(^2\). Of note, two children who were dosed at enrolment according to screening weight (10 and 11kg) had experienced weight loss (both to 9.8kg) by the time of enrolment, and therefore received doses equating to 427 and 416 mg/m\(^2\) respectively at enrolment. Thirty-one (48%) and 34 (52%) were randomised to the full dose and dose escalation arms of CHAPAS1 respectively.

The median (range) time from ARV therapy initiation to PK day was 27 (26, 56) days. Seven children gained and one lost weight after enrolment such that they were in the next higher (three 6-<10kg, one 10-<15kg, two 15-<20kg and one 20-<25kg at enrolment) or next lower (one 15-<20kg) weight-band on PK day. Doses were adjusted after the end of the PK day.

Nevirapine concentrations were higher than those previously reported in adults (Table 3), though C\(_{12h}\) was subtherapeutic (<3.0 mg/L) [4, 14] in four (6%) children: one in each of the weight-bands 3-<6kg (1 of 2 children), 10-<15kg (1 of 9), 20-<25kg (1 of 12) and 25-<30kg (1 of 10); aged 9 months, 6, 10 and 10 years; and

<table>
<thead>
<tr>
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<th>3-&lt;6</th>
<th>6-&lt;10</th>
<th>10-&lt;15</th>
<th>15-&lt;20</th>
<th>20-&lt;25</th>
<th>25-&lt;30</th>
<th>All</th>
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<tbody>
<tr>
<td>Sex, female</td>
<td>2 (100%)</td>
<td>4 (31%)</td>
<td>5 (56%)</td>
<td>6 (32%)</td>
<td>4 (33%)</td>
<td>3 (30%)</td>
<td>24 (37%)</td>
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<tr>
<td>Age, years</td>
<td>0.8 (0.7, 0.8)</td>
<td>1.3 (0.5, 4.2)</td>
<td>5.2 (2.2, 6.8)</td>
<td>7.7 (4.6, 12.6)</td>
<td>11.2 (6.5, 16.5)</td>
<td>15.0 (10.0, 19.0)</td>
<td>6.9 (0.5, 14.9)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>4.3 (3.4, 5.2)</td>
<td>7.7 (6.0, 8.8)</td>
<td>11.2 (10.0, 13.0)</td>
<td>15.0 (10.0, 19.0)</td>
<td>21.5 (16.5, 26.0)</td>
<td>27.0 (15.0, 34.0)</td>
<td>16.0 (6.6, 19.0)</td>
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<td>Weight-for-age z-score</td>
<td>-7.0 (-9.5, -4.6)</td>
<td>-3.7 (-5.8, -1.3)</td>
<td>-3.8 (-7.0, -1.4)</td>
<td>-3.1 (-6.2, -1.2)</td>
<td>-2.8 (-5.0, -0.9)</td>
<td>-3.0 (-4.3, -1.1)</td>
<td>-3.4 (-9.5, -0.9)</td>
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<td>-2.1 (-4.1, -0.7)</td>
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<td>-3.2 (-4.6, -0.7)</td>
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<td>-9.6 (-12.4, 0.2)</td>
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<td>-5.3 (-6.2, -3.1)</td>
<td>-4.3 (-5.0, -3.1)</td>
<td>-2.2 (-2.8, -1.9)</td>
<td>-2.2 (-2.8, -1.9)</td>
<td>-3.2 (-4.3, -1.7)</td>
<td>-3.4 (-4.3, -1.7)</td>
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<td>CD4%</td>
<td>23 (22, 23)</td>
<td>14 (3, 27)</td>
<td>13 (2, 24)</td>
<td>12 (2, 24)</td>
<td>12 (2, 24)</td>
<td>1 (1, 38)</td>
<td>13 (2, 24)</td>
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<td>WHO stage</td>
<td>3 (50%)</td>
<td>11 (85%)</td>
<td>9 (100%)</td>
<td>18 (95%)</td>
<td>10 (83%)</td>
<td>8 (80%)</td>
<td>57 (88%)</td>
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<td>Daily prescribed nevirapine dose, mg/m(^2)</td>
<td>391 (355, 427)</td>
<td>415 (349, 486)</td>
<td>376 (326, 459)</td>
<td>358 (317, 391)</td>
<td>353 (326, 372)</td>
<td>405 (372, 421)</td>
<td>370 (317, 486)</td>
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<tr>
<td>Daily prescribed stavudine dose, mg/kg</td>
<td>2.9 (2.3, 3.5)</td>
<td>2.5 (1.9, 3.0)</td>
<td>2.2 (1.8, 2.4)</td>
<td>1.8 (1.6, 2.0)</td>
<td>1.7 (1.5, 1.8)</td>
<td>1.8 (1.5, 1.8)</td>
<td>1.8 (1.5, 1.8)</td>
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<tr>
<td>Daily prescribed lamivudine dose, mg/kg</td>
<td>14.6 (11.5, 17.6)</td>
<td>12.3 (9.5, 15.0)</td>
<td>10.9 (7.5, 12.0)</td>
<td>9.1 (7.5, 12.0)</td>
<td>8.8 (7.5, 12.0)</td>
<td>8.9 (7.5, 12.0)</td>
<td>8.9 (7.5, 12.0)</td>
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</tbody>
</table>
| Values are n (%) for categorical variables and median (range) for continuous variables.
Pharmacokinetics of paediatric fixed-dose combinations

Figure 1  Mean (a) nevirapine, (b) stavudine and (c) lamivudine concentrations (mg/L) by weight-band.

Table 3  Pharmacokinetic parameters of nevirapine, stavudine and lamivudine.

<table>
<thead>
<tr>
<th></th>
<th>3–&lt;6 (n=2)</th>
<th>6–&lt;10 (n=13***)</th>
<th>10–&lt;15 (n=9)</th>
<th>15–&lt;20 (n=19)</th>
<th>20–&lt;25 (n=12)</th>
<th>25–&lt;30 (n=10)</th>
<th>All (n=65***)</th>
<th>Literature data adults**</th>
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<tbody>
<tr>
<td><strong>Nevirapine</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>C_{12h} (mg/L)</td>
<td>5.7 (1.8, 9.7)</td>
<td>6.4 (3.5, 16.9)</td>
<td>5.0 (2.2, 10.5)</td>
<td>5.6 (3.2, 8.9)</td>
<td>5.6 (2.9, 11.0)</td>
<td>7.9 (1.4, 14.9)</td>
<td>6.0 (1.4, 16.9) [3.0]</td>
<td>3.7</td>
</tr>
<tr>
<td>C_{max} (mg/L)</td>
<td>8.5 (5.3, 11.7)</td>
<td>10.7 (5.6, 22.5)</td>
<td>101 (41.1, 168)</td>
<td>80.8 (5.5, 15.3)</td>
<td>90.6 (4.1, 17.6)</td>
<td>85.9 (3.8, 21.2)</td>
<td>118 (3.8, 22.9) [3.8]</td>
<td>5.7</td>
</tr>
<tr>
<td>AUC_{12h}, h.mg/L</td>
<td>76.1 (40.4, 112)</td>
<td>102 (55.3, 232)</td>
<td>80.8 (42.0, 158)</td>
<td>61.3 (41.3, 169)</td>
<td>65.9 (31.2, 208)</td>
<td>85.9 (31.2, 232)</td>
<td>94.4 (31.2, 232) [39.4]</td>
<td>54.5</td>
</tr>
<tr>
<td><strong>Stavudine</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>C_{12h} (mg/L)</td>
<td>&lt;0.015 (&lt;0.015, &lt;0.015)</td>
<td>&lt;0.015 (&lt;0.015, 0.03)</td>
<td>&lt;0.015 (&lt;0.015, 0.03)</td>
<td>&lt;0.015 (&lt;0.015, 0.03)</td>
<td>&lt;0.015 (&lt;0.015, 0.03)</td>
<td>0.02 (&lt;0.015, 0.11)</td>
<td>&lt;0.015 (&lt;0.015, 0.11)</td>
<td>0.009</td>
</tr>
<tr>
<td>C_{max} (mg/L)</td>
<td>0.38 (0.09, 0.68)</td>
<td>0.44 (0.29, 0.89)</td>
<td>0.3 (0.21, 0.84)</td>
<td>0.53 (0.19, 0.53)</td>
<td>0.37 (0.33, 0.64)</td>
<td>0.43 (0.39, 0.82)</td>
<td>0.57 (0.09, 0.89) [0.15]</td>
<td>0.54</td>
</tr>
<tr>
<td>AUC_{12h}, h.mg/L</td>
<td>0.86 (0.4, 1.31)</td>
<td>1.04 (0.58, 2.13)</td>
<td>1.20 (0.54, 1.46)</td>
<td>0.8 (0.35, 1.49)</td>
<td>0.84 (0.73, 1.69)</td>
<td>1.00 (0.79, 2.13)</td>
<td>1.44 (0.35, 2.16) [0.41]</td>
<td>1.28</td>
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<tr>
<td><strong>Lamivudine</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>C_{12h} (mg/L)</td>
<td>0.11 (0.07, 0.15)</td>
<td>0.09 (0.05, 0.17)</td>
<td>0.09 (&lt;0.05, 0.15)</td>
<td>0.07 (&lt;0.05, 0.20)</td>
<td>0.08 (&lt;0.05, 0.17)</td>
<td>0.13 (&lt;0.06, 0.23)</td>
<td>0.09 (&lt;0.05, 0.23)</td>
<td>0.09</td>
</tr>
<tr>
<td>C_{max} (mg/L)</td>
<td>0.81 (0.20, 1.42)</td>
<td>1.42 (0.62, 2.23)</td>
<td>1.86 (0.69, 3.42)</td>
<td>1.34 (0.32, 2.66)</td>
<td>1.70 (0.86, 2.52)</td>
<td>1.47 (0.88, 2.74)</td>
<td>1.47 (0.20, 3.42) [0.69]</td>
<td>1.2</td>
</tr>
<tr>
<td>AUC_{12h}, h.mg/L</td>
<td>4.94 (1.59, 6.69)</td>
<td>6.76 (3.28, 10.28)</td>
<td>6.76 (4.15, 10.16)</td>
<td>6.76 (1.80, 11.45)</td>
<td>6.76 (3.21, 8.04)</td>
<td>6.76 (3.65, 9.39)</td>
<td>6.76 (1.59, 11.45) [2.26]</td>
<td>4.7</td>
</tr>
</tbody>
</table>

* Values are mean (range) [SD].
** Values are median for nevirapine and mean for stavudine and lamivudine [16, 24, 25].
*** Stavudine and lamivudine analysis failed for one child in 6–<10kg weight-band.
weeks were detected in a small number of children (grade 3 anaemia (n=3), bilirubin (n=1); grade 4 bilirubin (n=1), creatinine (n=1), thrombocytopenia (n=1); all single measurements). One further child had grade 4 bilirubin at week four which was not known to have resolved by death from pneumonia (HIV-related) at nine weeks.

Discussion

In Zambian HIV-infected children receiving the recently developed paediatric FDCs Triomune Baby or Junior, nevirapine plasma concentrations were higher and more variable than historical data in adults, while overall PK parameters of stavudine and lamivudine were comparable.

Triomune Baby and Junior are small, dispersible, crushable, scored tablets with ARV ratios designed to best fit recommended paediatric doses of individual drugs according to WHO guidelines [6]. Importantly, the nevirapine dose in these FDCs has been increased relative to the dose in the adult FDCs (Triomune) to compensate for higher metabolism of nevirapine in children. We developed weight-band-based dosing tables for Triomune Baby and Junior to simplify dosing in resource-limited settings. We aimed to achieve daily nevirapine doses $\geq 300 \text{ mg/m}^2$, converted into weight-bands, to minimise the risk of subtherapeutic plasma concentrations [3, 14] and virological failure [5].

Since no paediatric reference drug concentrations are available for these ARV doses and ratios, we compared our results with adult reference values. In these 65 children, nevirapine plasma concentrations were higher than in adults. However, nevirapine $C_{12h}$ was subtherapeutic (<3.0 mg/L) [4, 14] in 6% of children and the inter-patient variability was greater than in adults [15]. Therefore we would not recommend a lower nevirapine dose in children, who are at greater risk of underdosing for several reasons [17]. Further, in spite of higher average exposure, nevirapine-related adverse reactions were transient with only temporary treatment interruptions, and nevirapine $C_{max}$ and $AUC_{12h}$ were comparable between children with and without nevirapine-related toxicities. This reflects the lack of a well-defined upper limit of the therapeutic range. The higher average nevirapine exposure minimised the percentage of children with subtherapeutic concentrations and
therefore the related risk for the development of resistance, without any evidence of increased toxicity. There was no evidence of a difference in nevirapine AUC$_{12h}$ by weight-band ≥ 6 kg or age group.

We determined stavudine and lamivudine plasma concentrations as surrogates of intracellular concentrations of the pharmacologically active triphosphate metabolites, because obtaining adequate blood volumes for determination of intracellular concentrations of nucleoside reverse transcriptase inhibitor triphosphates is ethically, logistically and technically difficult in children [18]. Our assumption was that comparable plasma concentrations between children and adults would reflect comparable intracellular concentrations. Unlike nevirapine, the plasma concentration parameters of stavudine and lamivudine were comparable to those reported in adults, with no differences across pre-specified age groups. A previous study reported that recommended daily lamivudine dosing (8 mg/kg) [6] leads to lower AUC$_{12h}$ and C$_{max}$ in younger compared to older children [19]. However, of note, in our study younger children received relatively higher lamivudine doses per kg compared to older children, as a consequence of optimising dosing of three ARVs across six weight-bands, resulting in adequate plasma exposures across all ages.

There was a difference in stavudine and lamivudine AUC$_{12h}$ by weight-band, which appeared to be driven by the single weight-band with unequal dosing. However, the reduced plasma exposure to stavudine and lamivudine after the lower morning dose would not be representative of the average 24-hour exposure; in addition the long intracellular half-life of lamivudine may not be reflected in plasma concentrations. Nevirapine exposure appears to be less affected by unequal dosing, most likely because of its long elimination half-life. Although unequal dosing should be avoided where possible for drugs with a short elimination half-life, this may be preferable to increasing complexity and hence risking lower adherence by administering larger numbers of lower dose tablets equally per dosing interval. We plan to investigate adherence, in particular between equal and unequal dosed weight-bands, using detailed adherence data collected in CHAPAS1.

WHO recently recommended Triomune 30 for all adults irrespective of body size because of increasing concerns about stavudine-associated lipoatrophy and data suggesting that the lower dose may be adequate in adults. It is particularly important not to overdose stavudine in young children who will have long-term exposure to ARVs by virtue of therapy initiation early in life. However, when using stavudine as part of a FDC, it is also crucial not to underdose nevirapine and lamivudine, which have low genetic barriers to resistance. Our previous study in 127 HIV-infected Malawian and Zambian children receiving divided adult Triomune 30 or 40 (30 or 40 mg stavudine respectively) demonstrated that it is impossible to achieve adequate nevirapine concentrations in young children without risking overdosing with stavudine, especially when using Triomune 40, but even when using Triomune 30 [3]. In that study, 18% of children had a subtherapeutic random nevirapine plasma concentration (<3.0 mg/L), compared to only 6% with a subtherapeutic trough nevirapine plasma concentration in this current study. Further, the difference in the proportion of subtherapeutic nevirapine concentrations may have been larger if we had evaluated nevirapine C$_{12h}$ in our previous study, though smaller if we had directly observed medication intake in that study. In a Thai study, only 3% (1 of 34) of children who received divided adult FDCs (GPO-VIR S30, GPO, Thailand; equivalent to Triomune 30) had subtherapeutic nevirapine concentrations (defined as < 3.4 mg/L) [20] and the average nevirapine dose was considerably higher at 326 mg/m$^2$ [20] compared to 265 mg/m$^2$ in our previous study [3]. However, the average age was higher and none were <3 years (compared with 13% in our previous study), nor did any receive quarter or three-quarter tablets (compared with 42%) [3].

To avoid overdosing with stavudine while aiming to achieve therapeutic nevirapine concentrations in children taking adult FDCs, liquid formulations allow for more accurate dosing of the smallest children where there are no alternatives [21]. However, liquid formulations are costly, difficult to transport and store, and are complicated for carers to administer (for example, three syrups each of different volume rather than low numbers of whole or divided FDCs). Further, frequent changes in volumes of separate liquid ARVs as a child grows presents considerable challenges for both carers and medical providers. Paediatric FDCs in an appropriate ratio for children, such as Triomune Baby and Junior, are attractive alternatives, especially in resource-limited settings. It is hoped that in the future alternative FDCs, such as Atripla, Truvada and Kivexa, which do not contain stavudine, will become available for children. One disadvantage of FDCs is less flexibility of dosing, exemplified by the common practice of dose escalation of the auto-inducing drug nevirapine during the first two weeks of treatment to avoid high plasma...
additional PK sampling is needed in children <6kg. Following successful review of this study in African HIV-infected children, who are a key target population, WHO now recommend the Triomune Baby and Junior ratios and these FDCs have been approved by the United States Food and Drug Administration. It is hoped they will now be made accessible to national ARV therapy programs at low cost, and that future efforts will be made to develop other solid paediatric FDCs which do not contain stavudine.

Acknowledgements and sources of support

The authors would like to thank the families and children, and staff from the University Teaching Hospital and School of Medicine, Lusaka, Zambia. Technicians from the Department of Clinical Pharmacy, Radboud University Nijmegen Medical Centre, Nijmegen, The Netherlands are kindly acknowledged for the analysis of the plasma ARV concentrations. Marthe Le Prevost is acknowledged for help in training on pharmacokinetic techniques for the study. The study medication was supplied by Cipla Pharmaceuticals, India. The CHAPAS1 study was funded by the European and Developing Countries Clinical Trials Partnership (grant CHINTU 2004.01.H.d2.33011) and sponsored by the Medical Research Council, UK.

We assessed the PK of the antiretroviral drugs based on observed intake. Six (of 71, 8%) children did not meet our strict adherence criteria; this raises potential cause for concern regarding adherence, which we will investigate further in our planned adherence analyses. Exclusion of these children allowed reliable estimation of the PK parameters.

Since there were only two children in the lowest weight-band (3-<6kg), there are insufficient data to draw conclusions about dosing for children weighing <6kg at this stage. In light of critical interim results from the CHER trial [23] suggesting the importance of early treatment of infants, this extension to children <6kg is crucial.

The children in our PK substudy will continue to be followed in CHAPAS1. Further analyses are planned to evaluate possible predictors of ARV plasma concentrations, in particular the impact of malnutrition; we previously demonstrated lower nevirapine concentrations in stunted African children and higher concentrations in wasted children for the same dose per BSA [3]. In addition, analyses are planned to investigate the impact of predictors on subsequent changes in CD4%, viral load and resistance, in particular with respect to the lower plasma exposure of stavudine and lamivudine observed in the weight-band with unequal dosing.

We conclude that the ARV ratio of nevirapine, stavudine and lamivudine in the paediatric FDCs Triomune Baby and Junior is appropriate for children ≥ 6kg; concentrations and possible toxicity. In the case of Triomune Baby and Junior, this means provision of an additional stavudine/lamivudine tablet during the first two weeks to allow full dosing of these ARVs. CHAPAS1 is currently investigating whether increased complexity of dose escalation outweighs the possible reduction of adverse events. Of note, nevirapine dose escalation in 52% of children in this PK substudy would not have influenced our results as sampling was carried out at steady state [22] and this was confirmed by sensitivity analyses unadjusted for randomisation results not shown). Our PK data suggest no effect of drug concentrations on the rate of adverse events. Co-medications used in our study would not be expected to influence outcomes.

We are currently enrolling into a further substudy to estimate 4-sample PK curves of the three ARVs in children aged ≥1 month weighing 3-<6kg at enrollment who are receiving Triomune Baby.
References


16. EMEA. Viramune; Summary of Product Characteristics.
25. EMEA. Epivir; Summary of Product Characteristics.
Part II
Clinical pharmacology in HIV-infected adults
Chapter 5
Therapeutic drug monitoring of nevirapine in resource-limited settings

Rafaela L’homme1,2, Eva Muro3, Jacqueline Droste1,2, Liselotte Wolters3, Noor van Eijk-Benneken Kolmer1,2, Werner Schimana1, David Burger1,2

1 Department of Clinical Pharmacy, Radboud University Nijmegen Medical Centre, Nijmegen, The Netherlands; 2 Nijmegen University Centre for Infectious diseases (NUCID), Nijmegen, The Netherlands; 3 Kilimanjaro Christian Medical Centre, Moshi, Tanzania

Clinical Infectious Diseases 2008; in press
Abstract

Background: We developed a simple and inexpensive thin layer chromatography (TLC) assay for semi-quantitative detection of nevirapine saliva concentrations in resource-limited settings. The method was validated in an African target population.

Methods: Paired plasma and saliva nevirapine concentrations were assayed by high-performance liquid chromatography (HPLC); saliva concentrations were also assayed by TLC. The false positive rate was the proportion of subtherapeutic nevirapine saliva and plasma concentrations by HPLC reported as being therapeutic in saliva by TLC. The false negative rate was the proportion of therapeutic nevirapine saliva and plasma concentrations by HPLC reported as subtherapeutic in saliva by TLC. The extent of agreement in TLC readings between 5 technicians and 2 batches of TLC sheets was evaluated.

Results: Twenty-five (9%) of 286 African adults had a subtherapeutic plasma nevirapine concentration. The median saliva/plasma nevirapine concentration ratio was 0.51. The false positive rate by TLC was 0.00 (none out of 23) compared to HPLC saliva result and 0.08 (2 out of 25) compared to HPLC plasma result. The false negative rate by TLC was 0.01 (3 out of 263) compared to HPLC saliva result and 0.01 (3 out of 261) compared to HPLC plasma result. The extent of agreement in TLC result was substantial between 5 technicians (Fleiss’ kappa 0.77) and 2 batches of sheets (Cohen’s kappa 0.80).

Conclusions: The TLC assay was found to be sensitive, specific and robust in detection of subtherapeutic nevirapine concentrations in saliva of African HIV-infected adults. It is an attractive alternative to HPLC for therapeutic drug monitoring of nevirapine in resource-limited settings.

Introduction

Nevirapine is widely prescribed in combination with nucleoside reverse transcriptase inhibitors for the treatment of HIV-infection in resource-limited countries. Adequate plasma concentrations of nevirapine are required to achieve a successful response, whereas subtherapeutic concentrations (defined as <3.0mg/L) are related to development of mutations and virological failure [1-3]. Even in the case of perfect adherence to standard doses, some patients will remain at risk for underdosing because of interpatient variability in nevirapine exposure or drug-drug interactions.

In the developed world, Therapeutic Drug Monitoring (TDM) [3] is a well-known tool for the optimization of nevirapine dosing in HIV-infected patients. Due to the lack of simple and affordable methods to determine the exposure to nevirapine, TDM is hardly ever performed in resource-limited settings. Previous studies suggest that saliva may be used as an alternative body fluid for TDM of nevirapine [4, 5]. Saliva nevirapine concentrations in HIV-infected [4] and healthy [5] Caucasians are approximately half of the values observed in plasma. We recently developed a thin layer chromatography (TLC) method to provide a simple and economical tool for semi-quantitative measurement of nevirapine in saliva.

The primary objective of this study was to validate our newly developed TLC method for TDM of nevirapine in saliva of HIV-infected Africans. Secondary objectives were to determine the relation between saliva and plasma nevirapine concentrations and the proportion of subtherapeutic nevirapine concentrations in an African population.

Methods

Study population

Three hundred HIV-infected adults on a nevirapine (Viramune® or a generic formulation) containing regimen for at least 4 weeks were eligible for enrolment at a routine visit to the adult HIV clinic of the Kilimanjaro Christian Medical Centre (KCMC), Moshi, Tanzania. Patients suffering from oral lesions or ulcers and those who were unable to self-report date and time of last nevirapine ingestion were excluded. The protocol
Therapeutic drug monitoring of nevirapine in saliva

Saliva. The intraday precision of the assays ranged from 0.4% to 3.2% for plasma and from 1.3% to 4.1% for saliva. Additional variation as a result of performing the assays on different days ranged from 0.0% to 0.4% for plasma and from 0.8% to 2.2% for saliva. The accuracy of the assays ranged from 102% to 105% for plasma and from 99% to 102% for saliva. Saliva/plasma ratios of nevirapine concentrations and the proportion of subjects with a subtherapeutic nevirapine plasma concentration below 3.0 mg/L [3] were determined. In addition, saliva concentrations of nevirapine were semi-quantitatively analysed at the Biotechnology Laboratory of KCMC, Moshi, Tanzania, using a newly developed TLC method.

Experimental TLC method
A reference solution of 1.75 mg/L nevirapine (Boehringer Ingelheim) was obtained by dilution of a stock solution (0.875 mg/mL nevirapine in dimethylsulfoxide, DMSO, Merck 102931) in blank saliva; both were kept at -80°C.

The reference solution and saliva samples were thawed at room temperature, mixed (1 minute) and centrifuged (9000 g, 1 minute). Of the reference and samples, 1.0 mL was transferred into a 10 mL glass test tube. After addition of 0.5 mL 0.2 M ammonia (diluted from 25% ammonia, Labopharma) and 5 mL tert-butylmethylether (Riedel-de Haën), tubes were closed, mixed (1 minute), centrifuged (1150 g, 5 minutes) and kept at -80°C until the lower layer was frozen completely (20 minutes). The organic layer was poured into a 10 mL glass test tube and was dried in two days.

An eluent (or mobile phase) was prepared (toluene:ethyl acetate = 1:1, ACME Chemicals and Unilab, respectively) and poured into a TLC container. The container was closed and left for 1 hour. After addition of 50 µL methanol to the dried test tubes, they were closed and mixed (1 minute). One µL of the reference and samples was slowly pipetted in small dense dots at least 1.5 cm from the side and 2.0 cm from the bottom of a silica gel TLC sheet (height 10.0 cm; width 20.0 cm, Merck), as shown in Figure 1. After drying, spots were checked for similarity of size and shape under UV light (254 nm, CAMAG 022.9120). The TLC sheet was placed in the container with eluent for approximately 12 minutes (Figure 2). It was marked for the distance the eluent had moved and was dried in the air. The intensity of the spots was determined under UV light and compared to the reference spot (Figure 3). A spot that was less intense than the reference was considered subtherapeutic (see was reviewed and approved by the Ethics Committee of Tumaini University, Moshi, Tanzania. Written informed consent was obtained from all subjects before enrolment.

Sample collection and drug concentration assays
At a routine visit to the clinic, unannounced paired blood and saliva samples were collected within 5 minutes. Stimulated saliva was obtained by a salivette (Sartstedt, Etten-Leur, the Netherlands) using a dental cotton roll impregnated with citric acid (20 mg), which stimulates the salivary flow. Study subjects were asked to chew on the roll for approximately 1 minute. Blood and saliva samples were stored at 2-8°C for a maximum of 8 hours. Plasma was separated and stored at -80°C until transportation to the Netherlands on dry-ice. Saliva was obtained by centrifugation of the cotton roll at 800 g for 10 minutes. Two aliquots were stored at -80°C: one for analysis by TLC in Tanzania and one for transportation to the Netherlands and analysis by high-performance liquid chromatography (HPLC).

Plasma and saliva concentrations of nevirapine were assayed at the Department of Clinical Pharmacy of the Radboud University Nijmegen Medical Centre, Nijmegen, The Netherlands, using validated HPLC assays with ultraviolet (UV) detection, modified from a method published by Hollanders et al [6]. Pre-treatment of plasma samples remained the same [6] and did not differ from the preparation of saliva samples. Briefly, 150 µL of saliva or plasma was mixed with 150 µL of perchloric acid, vortexed for 20 seconds and centrifuged for 5 minutes at 11,000 rpm. Subsequently, 200 µL of the clear supernatant was transferred to insert vials and placed in the autosampler. The lower and upper limits of quantification of the modified assays were 0.167 and 16.7 mg/L for plasma and 0.158 and 15.8 mg/L for saliva. The intraday precision of the assays ranged from 0.4% to 3.2% for plasma and from 1.3% to 4.1% for saliva. Additional variation as a result of performing the assays on different days ranged from 0.0% to 0.4% for plasma and from 0.8% to 2.2% for saliva. The accuracy of the assays ranged from 102% to 105% for plasma and from 99% to 102% for saliva. Saliva/plasma ratios of nevirapine concentrations and the proportion of subjects with a subtherapeutic nevirapine plasma concentration below 3.0 mg/L [3] were determined. In addition, saliva concentrations of nevirapine were semi-quantitatively analysed at the Biotechnology Laboratory of KCMC, Moshi, Tanzania, using a newly developed TLC method.

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HPLC [6] (<1.5 mg/L) that was reported as therapeutic in saliva by TLC. The false negative rate was defined as the proportion of therapeutic nevirapine saliva concentrations by HPLC [6] (≥1.5 mg/L) that was reported as subtherapeutic in saliva by TLC.

Twenty-five saliva samples with nevirapine concentrations by HPLC [6] closest to the TLC reference were selected to test the robustness of the TLC method. The extent of agreement in TLC result between 5 different technicians (Fleiss’ kappa [7]) and 2 different batches of TLC sheets (Cohen’s kappa [8]) was evaluated in these 25 saliva samples.

The stability of the stock solution (nevirapine in DMSO) was tested after storage at -40 °C for 50 months. The stability of the reference solution (nevirapine in blank saliva) was tested after storage at room temperature for 17 hours, after storage at -40 °C for 2 months, and after freezing and thawing twice. Interference of possible co-medications was evaluated by comparison of the retention factor (Rf: distance travelled by compound divided by distance travelled by eluent front) of extractable and detectable (UV light, 254 nm) compounds with the Rf value of nevirapine. In addition, blank saliva samples from at least 6 subjects not taking nevirapine were tested for interference by endogenous substances.

Biological validation of TLC method

All plasma and saliva samples were used to determine the biological sensitivity and specificity of the TLC method. The false positive rate was defined as the proportion of subtherapeutic nevirapine plasma concentrations by HPLC [6] (<3.0 mg/L [3]) that was reported as therapeutic in saliva by TLC. The false negative rate was defined as the proportion of therapeutic nevirapine plasma concentrations by HPLC [6] (≥3.0 mg/L [3]) that was reported as subtherapeutic in saliva by TLC.

Results

Of the 300 subjects enrolled in the study, 14 were excluded because of problems with labelling, too little volume of saliva or lost saliva. The mean (range) age of the remaining 286 African subjects (200 women) was 41 (17, 71) years. All subjects were
reference was substantial between 5 technicians (Fleiss’ kappa of 0.77) and 2 batches of TLC sheets (Cohen’s kappa of 0.80).

The stock solution for the TLC method (nevirapine in DMSO) was stable at –40 °C for at least 50 months (mean ± SD recovery 99.7 ± 0.3%). The reference solution (nevirapine in blank saliva) was stable at room temperature for at least 17 hours (recovery 107.6 ± 5.8%) and at –40 °C for at least 2 months (recovery 94.3 ± 3.2%). Freezing and thawing twice had no effect on the stability of nevirapine in blank saliva (recovery 95.1 ± 1.1%). The average nevirapine Rf value was 0.29; none of the possible co-medications that were extractable and detectable had a similar Rf value. Also, no interference by endogenous substances was observed in the blank saliva samples from subjects not taking nevirapine.

Two of the 25 subtherapeutic (<3.0 mg/L) nevirapine plasma concentrations (2.61 and 2.91 mg/L) according to HPLC were reported as therapeutic by TLC (false positive rate of 0.08); the biological sensitivity of the TLC method was 92% (Table 1). Three of the 261 therapeutic (≥3.0 mg/L) nevirapine plasma concentrations (3.41, 3.52 and 4.28 mg/L) according to HPLC were reported as subtherapeutic by TLC (false negative rate of 0.01); the biological specificity of the TLC method was 99% (Table 1).

**Discussion**

Twenty-five out of 286 (9%) HIV-infected African adults had a subtherapeutic nevirapine plasma concentration <3.0 mg/L [3]. Saliva nevirapine concentrations were approximately half of the values observed in plasma. A TLC method for semi-quantitative detection of nevirapine in saliva was found to be sensitive, specific and robust. This simple and economical tool is a good option for TDM of nevirapine in resource-limited settings.

Using saliva instead of plasma for TDM of nevirapine implies painless and non-invasive sampling with diminished risk of HIV-transmission to health care workers at a lower cost [4]. TLC is a relatively inexpensive assay technique compared to HPLC [9], which is commonly used in the developed world for TDM of

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**Table 1** Number of (sub)therapeutic nevirapine concentrations by Thin layer chromatography (TLC), compared to High-performance liquid chromatography (HPLC), sensitivity and specificity of TLC assay.

<table>
<thead>
<tr>
<th></th>
<th>HPLC - Subtherapeutic</th>
<th>HPLC - Therapeutic</th>
<th>TLC - Saliva</th>
<th>TLC - Saliva</th>
<th>Sensitivity</th>
<th>Specificity</th>
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<td></td>
<td>Subtherapeutic</td>
<td>Therapeutic</td>
<td>Subtherapeutic</td>
<td>Therapeutic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPLC - Saliva</td>
<td>23</td>
<td>0</td>
<td>23</td>
<td>0</td>
<td>100%</td>
<td>99%</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>260</td>
<td>3</td>
<td>258</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPLC - Plasma</td>
<td>23</td>
<td>2</td>
<td>23</td>
<td>3</td>
<td>92%</td>
<td>99%</td>
</tr>
</tbody>
</table>

Subtherapeutic concentrations were defined as < 1.75 mg/L (saliva, TLC), < 1.5 mg/L (saliva, HPLC) and < 3.0 mg/L (plasma, HPLC). Therapeutic concentrations were defined as higher values than these cut-off values.
nevirapine in plasma. An HPLC system for TDM of nevirapine costs approximately €40,000 and the costs for consumables per sample are estimated at €15. In contrast, the estimated initial set-up cost of a new TLC method for semi-quantitative measurement of nevirapine in saliva are €800 and the costs for consumables per sample are approximately €1.60. Since this simple and inexpensive method was developed to perform TDM of nevirapine in resource-limited settings, it was validated in an African target population in the current study.

The percentage of HIV-infected adults with a subtherapeutic nevirapine plasma concentration <3.0 mg/L [3] according to HPLC [6] in our Tanzanian population (9%) was low compared to the percentage in a previous report from Malawi (16%) [10]. This may be due to the unreliable drug supply during the time of the Malawian study (2003), which explained more than one-third of the total reported non-adherence [10]. The fact that 18 of the 25 subtherapeutic nevirapine plasma concentrations in our Tanzanian population were undetectable indicates non-adherence, since nevirapine is generally detected up to weeks after termination of drug intake due to its long elimination half-life [11].

The median saliva/plasma nevirapine concentration ratio of 0.51 according to HPLC [6] in our population of HIV-infected Africans was comparable to the ratios observed in HIV-infected [4] and healthy [5] Caucasians. It has been suggested that thorough rinsing of the mouth is required prior to saliva sampling, because remnants of orally administered medicines may contaminate saliva specimens and yield spuriously high values [12]. Indeed, 6 of the 286 subjects in the current study had an unexpectedly high saliva/plasma nevirapine concentration ratio above 1 [4, 12], which may be due to chewing tablets without rinsing the mouth prior to sampling. This explanation is supported by our observation that the time between last ingestion and sampling was shorter for those subjects with an unexpectedly high nevirapine concentration in saliva compared to plasma.

Since saliva nevirapine concentrations by HPLC were approximately half of the values observed in plasma, they were defined as subtherapeutic if below 1.5 mg/L rather than below the cut-off value for plasma of 3.0 mg/L [3]. The main requirement of our TLC method for semi-quantitative detection of nevirapine in saliva was appropriate sensitivity, meaning detection of nevirapine concentrations that were subtherapeutic according to HPLC, in order to pick out those subjects at risk for nevirapine resistance. During the development of our TLC method, subtherapeutic saliva concentrations just below 1.5 mg/L were sufficiently distinguishable from a TLC reference of 1.75 mg/L, but not from a reference of 1.5 mg/L. For the validation of our TLC method we have therefore chosen a reference of 1.75 mg/L, which has led to an excellent technical sensitivity (100%) and specificity (99%). None of the subtherapeutic nevirapine saliva concentrations according to HPLC were reported as therapeutic by TLC and the few therapeutic saliva concentrations that were reported as subtherapeutic by TLC were all close to the cut-off value for saliva (1.5 mg/L).

The biological validation comparing nevirapine saliva concentrations by TLC to plasma concentrations by HPLC (subtherapeutic or therapeutic) resulted in an acceptable sensitivity (92%) and excellent specificity (99%). False positive and negative results were all close to the cut-off value for plasma (3.0 mg/L). The somewhat lower biological sensitivity can be explained by the fact that some subjects with a subtherapeutic plasma concentration according to HPLC had a therapeutic saliva concentration according to both HPLC and TLC. Although these subjects had a higher saliva/plasma ratio than average, none of them had a ratio above 1.

As expected, it was found to be most difficult to interpret nevirapine saliva concentrations closest to the TLC reference. To test the worst-case scenario robustness of the TLC method we selected 25 samples closest to the reference. The fact that the extent of agreement in TLC results between 5 technicians and 2 batches of TLC sheets was substantial provides an indication that the outcome of our TLC method is reliable during normal use.

At this moment we are planning to roll out the TLC method in various African countries as well as in Indonesia. This will make it possible to further evaluate its robustness and practical application to monitor adherence. Potentially, the assay could be further developed commercially.

In conclusion, we developed a simple and economical TLC method for semi-quantitative detection of nevirapine saliva concentrations. The assay was found to be sensitive, specific and robust in the detection of subtherapeutic nevirapine
concentrations in an African population. It is an attractive alternative to HPLC for therapeutic drug monitoring of nevirapine in resource-limited settings.

Acknowledgements and sources of support

We would like to thank the patients for their participation in this study. Laizer Leshoki Salitory of the Kilimanjaro Christian Medical Centre (KCMC), Moshi, Tanzania is kindly acknowledged for the screening of study subjects. The study nurses at KCMC are thanked for the collection of study samples. The study was funded by Poverty Related Infection Oriented Research (PRIOR), a research network sponsored by the Netherlands Foundation for the Advancement of Tropical Research (NWO-WOTRO) and the Netherlands Foundation for Health Research and Development (ZonMw).

References

Enzyme inducers reduce elimination half-life after a single dose of nevirapine in healthy women

Chapter 6

Enzyme inducers reduce elimination half-life after a single dose of nevirapine in healthy women

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Abstract

Objective: Single-dose nevirapine to prevent mother-to-child transmission of HIV is associated with development of nevirapine resistance, probably due to its long half-life in combination with a low genetic barrier to resistance. The objective of this study was to find enzyme inducers to reduce nevirapine half-life.

Design: The design of this phase-I pharmacokinetic study was single-center, open-label, two-period, nine-group.

Methods: After administration of a single 200-mg dose of nevirapine to HIV-seronegative non-pregnant women in both period 1 and 2, blood was sampled twice-a-week for 21 days. In period 2 additional interventions (single dose carbamazepine, phenobarbital or phenytoin; phenytoin for 3 or 7 days; St John’s Wort, vitamin A or cholecalciferol for 14 days) were administered to all subjects except for the control group.

Results: Thirty-six subjects participated. In three intervention groups T-half ratio (nevirapine half-life in period 2 / half-life in period 1) differed significantly from the control group: single 400-mg dose of carbamazepine (P = 0.021), 184mg phenytoin once daily for 3 (P = 0.021) or 7 days (P = 0.021). The median decrease in nevirapine half-life was 18.8, 19.0 and 16.9 hours, respectively.

Conclusion: Interventions with a single dose of 400mg carbamazepine or phenytoin 184mg for 3 or 7 days effectively reduced nevirapine half-life. Appropriately powered safety and feasibility endpoint studies are warranted before these interventions can be tested in the setting of single-dose nevirapine for prevention of mother-to-child transmission of HIV to reduce the development of nevirapine resistance.

Introduction

Without treatment, the risk to transmit HIV to the child during pregnancy or delivery is approximately 25 to 48%. Complexity and costs of several effective strategies to prevent mother-to-child transmission (MTCT) of HIV presently limit large-scale introduction in low-income countries. However, the administration of a single dose of the antiretroviral drug nevirapine (NVP) to the mother shortly before delivery and to the newborn within the first 24 to 72 hours after birth [1] is simple and affordable for low-income countries. This so-called single dose NVP (SD-NVP) strategy reduces the risk of MTCT by 50%.

Aside from the suboptimal effectiveness of the SD-NVP strategy, an important disadvantage is that in approximately 20 to 70% of the women the virus develops resistance against NVP [2, 3]. This can have a great impact. First, the effectiveness of SD-NVP may be diminished in a following pregnancy. Second, efficacy can be diminished when the mother herself has an indication for NVP-based highly active antiretroviral therapy (HAART) in the future [4]. Third, there is a possibility to transmit resistant HIV to others. NVP resistance can develop due to the long elimination half-life of NVP in combination with a low genetic barrier to resistance. In one study, women who developed the K103N mutation after intake of a single NVP dose had a significantly longer elimination half-life of NVP than those in whom no resistance was detected (74.8 vs. 51.8 hours; P = 0.01) [5].

A short-course of an enzyme inducer may prevent the development of resistance by decreasing elimination half-life of NVP. The primary elimination pathway for NVP appears to be the oxidative metabolism by cytochrome P-450 enzymes CYP3A4 and CYP2B6 [6]. Several potent CYP3A inducers have been described in literature. Long-term treatment with anticonvulsants such as carbamazepine, phenobarbital and phenytoin increased the clearance of antipyrine, which is a broad marker of enzyme induction, on average to a similar extent [7]. St John’s Wort increased the clearance of NVP with 35% [8]. PXR-mediated up-regulation of CYP3A4/CYP3A7 and CYP3A5 by retinol and β-carotene points to a potential interference on the metabolism of xenobiotic and endogenous relevant compounds [9]. Finally, the fully active dihydroxylated metabolite of cholecalciferol, 1α,25-(OH)2D3, was shown to induce the expression of CYP3A4 and, to a lesser extent, CYP2B6 and CYP2C9 genes in normal differentiated primary human hepatocytes [10].
validated immunoassay TDxFLx (Abbott, Amsterdam, the Netherlands). In addition, trough levels of phenytoin were determined in the blood samples of day 3 (group 5-6) and day 7 (group 6). Concentrations of retinol (group 8) and 25(OH)D (group 9) were determined in the blood sampled 8 hours after intake on day 0 by validated HPLC assay. Furthermore, trough levels of retinol (group 8) and 25(OH)D (group 9) were determined in the blood samples of day 7 and 14.

Results

Thirty-six non-pregnant healthy women were enrolled in the protocol. The median age, height, and body weight (interquartile range) were 22 (20-24) years, 1.71 (1.67-1.75) m, and 64.5 (60.0-73.0) kg, respectively. All women were white. One woman randomized to group 7 dropped out of the study during period 1 for personal reasons.

The median elimination half-life of NVP (range) in period 1 was 53.9 (34.2-104.2) hours. Pharmacokinetic parameters of NVP in period 1 and 2 are illustrated per

Table 1

<table>
<thead>
<tr>
<th>Study design.</th>
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<tbody>
<tr>
<td><strong>Period 1</strong></td>
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<tr>
<td>• Group 1-9: SD NVP 200mg</td>
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<tr>
<td><strong>Period 2</strong></td>
</tr>
<tr>
<td>• Group 1: SD NVP 200mg</td>
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<tr>
<td>• Group 2: SD NVP 200mg + SD carbamazepine 400mg</td>
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<tr>
<td>• Group 3: SD NVP 200mg + SD phenobarbital 200mg</td>
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<tr>
<td>• Group 4: SD NVP 200mg + SD phenytoin 184mg</td>
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<tr>
<td>• Group 5: SD NVP 200mg + phenytoin 184mg, 3 days</td>
</tr>
<tr>
<td>• Group 6: SD NVP 200mg + phenytoin 184mg, 7 days</td>
</tr>
<tr>
<td>• Group 7: SD NVP 200mg + St John’s Wort tea**, 14 days</td>
</tr>
<tr>
<td>• Group 8: SD NVP 200mg + SD retinyl palmitate 200000 IU + 8-carotene 30mg &amp; retinyl palmitate 4000 IU, 13 days</td>
</tr>
<tr>
<td>• Group 9: SD NVP 200mg + cholecalciferol 2000 IU, 14 days</td>
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</tbody>
</table>

* Each group consisted of 4 participants. NVP was taken with water during a standardised breakfast on day 0 of period 1 and 2 (with an interval of 4 weeks). First doses of interventions were taken simultaneously with NVP in period 2. ** One cup (tea bag of 2g St John’s Wort & 150mL boiling water, 10 minutes).

NVP (nevirapine)
medication group in Table 2. Non-parametric statistical tests (Mann-Whitney) were performed on T-half ratio (NVP half-life in period 2 divided by NVP half-life in period 1). T-half ratios of three intervention groups differed significantly from group 1 (control): single 400-mg dose of carbamazepine (group 2; P = 0.021), 184mg phenytoin once daily for 3 days (group 5; P = 0.021) and 184mg phenytoin once daily for 7 days (group 6; P = 0.021). In these 3 intervention groups, the median [range] decrease in NVP half-life in period 2 ranged from 11.9 [0.0-37.4] to 19.0 [14.0-17.0] hours, respectively. The decrease in NVP half-life has led to faster undetectable NVP levels in group 2, 5 and 6 with carbamazepine single dose, phenytoin 3 and 7 days, respectively. In these 3 intervention groups, the median [range] decrease in time to undetectable NVP levels in period 2 was 4.0 [3.0-7.0], 7.0 [7.0-7.0] and 8.5 [7.0-11.0] days, respectively. There are no large differences between maximum NVP plasma levels eight hours after intake in the two periods.

Eight hours after intake of a single dose, carbamazepine levels in group 2 ranging from 3.78 to 6.03 mg/L were all close to the lowest level of the therapeutic range of 4-10 mg/L. Phenobarbital levels in group 3 eight hours after intake of a single dose ranged from 5.10 to 5.83 mg/L and were thus below the therapeutic range of 10-40 mg/L. Phenytoin levels in group 4-6 ranging from 2.36 to 6.27 mg/L were all below the therapeutic range of 8-20 mg/L. Retinol and 25(OH)D levels were all within the normal range of 0.70-3.00 µmol/L and 25-100 nmol/L, respectively.

One out of 36 women in period 1 and 2 out of 36 women in period 2 showed mild elevation of the liver enzyme ALAT (84, 95 and 114 U/L, respectively). Two out of 4 women taking carbamazepine and 5 out of 12 women taking phenytoin experienced mild vertigo. All 4 women in the phenobarbital group experienced mild somnolence. Adverse events were transient and did not influence the activities of daily living.

**Discussion**

The present pilot study shows that NVP elimination half-life can be effectively decreased by interventions with a single 400-mg dose of carbamazepine or 184mg phenytoin for 3 or 7 days, most likely due to enzyme induction. Enzyme inducers reduce nevirapine half-life

Table 2  Pharmacokinetic parameters of NVP in period 1 & 2, and values in period 2 minus values in period 1 (median, range).

<table>
<thead>
<tr>
<th></th>
<th>NVP half-life, T ½ (hours)</th>
<th>Time to first undetectable NVP level, Tundetect (day)</th>
<th>NVP concentration 8 hours after intake, C8h (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Period 1 Period 2 Period 2-1</td>
<td>Period 1 Period 2 Period 2-1 Period 1 Period 2 Period 2-1</td>
<td>Period 1 Period 2 Period 2-1</td>
</tr>
<tr>
<td>1</td>
<td>48.4 [44.4, 58.9] 46.3 [37.9, 62.5] -11.9 [-15.9, -8.8]</td>
<td>15.0 [14.0, 17.0] 14.0 [14.0, 17.0] 0.0 [0.0, 0.0]</td>
<td>2.19 [1.35, 2.24] 2.02 [1.72, 2.78] -0.16 [-0.27, +0.60]</td>
</tr>
<tr>
<td>2</td>
<td>52.5 [46.9, 104.2] 33.8 [31.3, 66.2]</td>
<td>15.5 [14.0, 28.0] 12.0 [10.0, 21.0] [-4.0, -7.0, -3.0]</td>
<td>2.24 [1.71, 2.46] 2.03 [1.73, 2.65] +0.07 +0.93</td>
</tr>
<tr>
<td>3</td>
<td>49.4 [34.2-69.4] 39.7 [30.3-68.3]</td>
<td>14.0 [10.0, 21.0] 14.0 [10.0, 14.0] 0.0 [0.0, 0.0]</td>
<td>1.98 [1.89, 2.12] 1.91 [1.67, 2.01] -0.05 -0.05</td>
</tr>
<tr>
<td>4</td>
<td>58.5 [25.3, 66.5] 50.4 [27.7, 70.8]</td>
<td>17.0 [10.0, 21.0] 15.5 [10.0, 21.0] [-1.5, -4.0, +4.0]</td>
<td>1.89 [1.72, 2.12] 2.00 [1.66, 2.29] +0.11 +0.11</td>
</tr>
<tr>
<td>6</td>
<td>55.3 [37.6-59.9] 34.5 [30.6-50.3]</td>
<td>14.0 [10.0, 21.0] 8.5 [7.0, 10.0] [-11.0, -7.0, -10.0]</td>
<td>1.83 [1.43, 2.29] 1.75 [1.25, 2.25] +0.23 +0.23</td>
</tr>
<tr>
<td>7</td>
<td>55.3 [37.6-59.9] 54.2 [38.2, 74.2]</td>
<td>14.0 [10.0, 70.10] 17.0 [17.0, 17.0] 0.0 [0.0, 0.0]</td>
<td>2.02 [1.34, 2.50] 1.84 [1.24, 1.92] -0.18 -0.18</td>
</tr>
<tr>
<td>8</td>
<td>53.0 [46.2, 66.1] 56.1 [44.4, 66.9]</td>
<td>15.5 [14.0, 21.0] 17.0 [17.0, 17.0] +1.5 [0.0, +4.0]</td>
<td>1.96 [1.60, 2.26] 1.94 [1.53, 2.04] +0.15 +0.23</td>
</tr>
<tr>
<td>9</td>
<td>62.2 [54.4, 62.8] 54.8 [52.7, 60.8]</td>
<td>17.0 [14.0, 21.0] 17.0 [17.0, 17.0] -4.0 [-4.0, +3.0]</td>
<td>2.01 [1.53, 2.52] 1.99 [1.58, 2.79] -0.22 -0.22</td>
</tr>
</tbody>
</table>

* Group.

NVP (nevirapine)
This study with small groups was not designed to perform statistical tests. However, because of large and very consistent decreases in NVP half-life, we decided to perform a non-parametric statistical test on the primary parameter T-half ratio to see whether the effect was actually significant.

The interventions with St. John’s Wort tea, vitamin A and D for 14 days did not show a decrease in NVP half-life. For St. John’s Wort this may be explained by the fact that the product used in this study (tea) contains a relatively low amount of hyperforine [11], which is the constituent likely responsible for enzyme induction [12]. For vitamin D, one explanation might be that after intake of cholecalciferol by healthy women without vitamin D deficiency, in vivo conversion to the fully active dihydroxylated metabolite 1α,25-(OH)2D3 is not optimal. A single 200-mg dose of phenobarbital was not enough to substantially reduce NVP half-life. Lengthening treatment would not be wise, because of slow elimination by the nursing infant. It seemed to be necessary to take 184mg of phenytoin once daily for at least three days to significantly reduce NVP half-life. In the African setting of PMTCT it should be safe to use phenytoin during breast feeding [13], because of its poor passage into breast milk. Surprisingly, the simple intervention with a single 400-mg dose of carbamazepine appeared to effectively reduce NVP half-life. It is unknown whether this effect is due to enzyme activation, enzyme induction or the up-regulation of the efflux transporter P-glycoprotein (P-gp) [14], although data being conflicting about this effect is due to enzyme activation, enzyme induction or the up-regulation of the efflux transporter P-glycoprotein (P-gp) [14], although data being conflicting about whether the effect was actually significant.

It is clear that our study population of healthy non-pregnant Dutch women of child-bearing age is not similar to the setting in sub-Saharan African countries, where HIV-infected pregnant women are black and will have different dietary habits, body weights, and concomitant medications. The CYP2B6 T/T genotype at position 516 is more common in African-Americans than in European-Americans and is associated with greater efavirenz exposure [16] and, to a lesser extent, also to greater NVP exposure [17]. However, the median NVP half-life in our group of 36 white women (53.9 hours) does not differ much from the mean NVP half-life in a smaller group of pregnant HIV-infected Ugandan women receiving SD-NVP (61.3 hours) [18]. The results from this pilot study are valuable, since we were able to identify three potential interventions (single 400-mg dose of carbamazepine, 184mg phenytoin for 3 or 7 days) to be studied in the setting of PMTCT to confirm our finding that NVP half-life will be diminished and to test the hypothesis that hereby development of NVP resistance will decrease. The most rational intervention to start with is a single dose of carbamazepine, because of its simplicity.

Addition of other antiretroviral agents after delivery to cover the window of opportunity for the virus to select for nevirapine resistance is a different approach. Recently, preliminary data were presented that short courses (4-7 days) of zidovudine plus lamivudine (Combivir®) added to SD-NVP in the prevention of MTCT, significantly reduced the development of NVP resistance when compared with no intervention [19]. However, the substantial increase in costs and complexity is not desirable. Recent data from a study in Zambia showed that it is already difficult to accurately carry out the simple SD-NVP intervention [20].

It is currently unknown at what plasma level NVP selects for resistance. NVP levels that are either undetectable or, in the context of HAART, greater than 3.0-3.4 mg/L [21, 22], do not have selective pressure. The intervention with 4-7 days Combivir® covers the potential zone of selective pressure below 3.0-3.4 mg/L only partially, which explains that NVP resistance was not fully absent in the intervention arms [19]. A significant decrease in NVP half-life by addition of an enzyme inducer will reduce the duration of the potential zone of resistance, but may also not be sufficient to prevent development of all NVP mutations. It might be interesting to study if combining these two approaches of decreasing NVP half-life and co-administering other antiretroviral agents will be of additional value.
In conclusion, the interventions with a single 400-mg dose of carbamazepine, 184mg phenytoin once daily for 3 or 7 days effectively reduced NVP half-life after intake of a single 200-mg dose of NVP, leading to faster undetectable NVP levels. Appropriately powered safety and feasibility endpoint studies are warranted before these interventions can be tested in the setting of SD-NVP for PMTCT in Africa to confirm our finding of decreased NVP half-life and to test the hypothesis that hereby the development of NVP resistance will be reduced.
Chapter 7
High incidence of adverse events in healthy volunteers receiving rifampicin and adjusted doses of lopinavir/ritonavir tablets

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Abstract

Objective: Previous research in healthy volunteers has demonstrated that rifampicin and adjusted doses of lopinavir/ritonavir soft-gel capsules resulted in adequate exposure to lopinavir. Our objective was to study the combined use of rifampicin and the newly introduced lopinavir/ritonavir tablets.

Methods: A total of 40 healthy subjects was planned to start with 600 mg rifampicin once daily from day 1–5. From days 6-15, subjects were randomized to receive lopinavir/ritonavir tablets dosed as either 600/150 mg or 800/200 mg twice daily, both in addition to 600 mg rifampicin once daily. A 12h pharmacokinetic curve was planned on day 15. Safety assessments were conducted regularly throughout the study period.

Results: Eleven subjects started as the first group in this study. No major complaints occurred during day 1–5 (rifampicin only). After addition of lopinavir/ritonavir, eight subjects suffered from both nausea and vomiting, one from nausea only, and one from vomiting only. On day 7 increases in AST/ALT levels were reported in all subjects and on day 8 the study was prematurely terminated. The AST/ALT levels continued to rise and peaked (grade 2: n=2, grade 3: n=1, grade 4: n=8) on days 9-10. All values returned to normal within six weeks.

Conclusions: This study showed a high incidence of adverse events when a higher than standard dose of the new lopinavir/ritonavir tablets was combined with rifampicin. In the future, this drug combination should not be given to healthy volunteers. Liver function should be carefully monitored when rifampicin and lopinavir/ritonavir are combined in patients.

Introduction

Approximately one-third of the 40 million people living with HIV/AIDS worldwide are co-infected with tuberculosis (TB) [1]. Rifampicin is the most powerful component of current TB treatment, but is also a strong inducer of cytochrome P450 enzymes, resulting in drug-drug interactions with antiretroviral therapy [2, 3], in particular non-nucleoside reverse transcriptase inhibitors (NNRTIs) and protease inhibitors (PIs).

The World Health Organization (WHO) recommends to combine rifampicin-based TB treatment with efavirenz-based antiretroviral therapy in TB-HIV co-infected patients [3]. The modest decrease in concentrations of the NNRTI efavirenz is not expected to be clinically relevant [4, 5]. Although rifampicin reduces concentrations of the NNRTI nevirapine by 20-55% [6], collected experience is sufficient to make nevirapine an alternative to efavirenz among non-Caucasian patients receiving rifampicin [7, 8]. A disadvantage of NNRTI drugs is the low genetic barrier for the development of resistance; only one point mutation is required to confer high-level cross-class resistance [9].

One alternative for patients with NNRTI-resistant HIV or those unable to take NNRTIs would be triple nucleoside regimens without interaction to rifampicin. However, these regimens are associated with less antiretroviral activity [10] and therefore not advisable. An equally active alternative to NNRTI-based therapy among patients being treated with rifampicin may be PI-based antiretroviral therapy. However, standard PI doses, whether boosted with ritonavir or not, cannot be given with rifampicin because of large decreases in PI concentrations [11-14].

In HIV infected adults without active tuberculosis, WHO recommends lopinavir/ritonavir at 400/100 mg twice daily (BID) in combination with two nucleosides as PI-based therapy [15]. We have previously evaluated the pharmacokinetics of two adjusted dose regimens of lopinavir/ritonavir (800/200 mg BID and 400/400 mg BID) soft gel capsules when combined with rifampicin in healthy volunteers [11]. Because of more variable pharmacokinetics of lopinavir in the better tolerable arm of 800/200 mg lopinavir/ritonavir, therapeutic drug monitoring (TDM) appeared to be indicated. In the absence of TDM, 400/400 mg lopinavir/ritonavir could be combined with rifampicin, while closely monitoring for liver enzyme elevations.
Recently, a new tablet formulation of lopinavir/ritonavir has become available. Compared to the soft gel capsule, the novel tablet formulation shows reduced pharmacokinetic variability and exhibits slightly higher (18%) bioavailability, irrespective of concomitant food intake [16].

The aim of this study was to evaluate the pharmacokinetics of two adjusted dose regimens of lopinavir/ritonavir tablets in combination with rifampicin in healthy volunteers. Due to an unexpectedly high incidence of adverse events, this study was terminated prematurely.

Methods

Study design
The study was designed as an open-label, sequential, 2-period, phase IV multiple dose trial in healthy volunteers. From day 1 until day 5, subjects received 600 mg rifampicin once daily (QD). From day 6 until day 15, subjects were randomized to receive either three (600/150 mg) or four (800/200 mg) of the new lopinavir/ritonavir (Kaletra®) tablets BID, combined with 600 mg rifampicin QD. On days 1, 3, 5, 6, 7, 9, 11, 13 and 15 study medication was planned to be taken under observation and immediately after a standardized breakfast (± 350 kcal, ± 13 g. of fat). The other drug doses were taken at home. All subjects gave written informed consent and the Ethical Review Board of Radboud University Nijmegen Medical Centre, The Netherlands, approved the study.

Subjects
Healthy subjects, aged 18-55 years were eligible for enrolment after pre-entry and laboratory evaluation. The main exclusion criteria were: positive HIV test result; positive hepatitis B or C test result; positive Mantoux test result; abnormal clinical laboratory test results and abnormal ECG.

Pharmacokinetic assessment
Blood samples of 5 ml were planned to be collected at the following time points; on day 5 just before and two hours post-dose (C2h) for the determination of rifampicin (and desacetylrifampicin) plasma concentrations; on day 7, 9, 11 and 13 pre-dose for the determination of plasma concentrations of lopinavir and ritonavir; and on day 15 pre-dose until 12 hours post-dose for the analysis of all three drugs. Blood samples were stored in the refrigerator immediately and centrifuged at 2,500 g for 10 minutes. Plasma was separated and stored below -40°C (for the determination of lopinavir and ritonavir) or -80°C (for the determination of rifampicin and desacetylrifampicin) within 4 hours after collection. All procedures concerning collection and storage of drug samples have been validated.

Bioanalysis
Plasma lopinavir, ritonavir, rifampicin and desacetylrifampicin concentrations were determined by validated high-performance liquid chromatography (HPLC) methods [17, 18].

Safety and tolerability
We planned to perform clinical chemistry and hematology tests and to ask subjects about the occurrence of adverse events at each study visit on day 1, 3, 5, 6, 7, 9, 11, 13 and 15. Adverse events, clinical chemistry and hematology test results were graded according to the grading system of the Division of AIDS [19]. After termination of the study, hepatitis B and C tests were repeated. In addition, Epstein-Barr virus and cytomegalovirus antibody tests were performed to exclude acute viral infection.

Results

Subjects
Forty healthy volunteers were enrolled in the study. The first group consisted of eleven subjects of whom eight were Caucasians, two were Caucasian-black and one was black. The median (range) age, body weight and body mass index were 24 (19-51) years, 63 (53-92) kg and 22 (19-30) kg/m², respectively. Five subjects (three females) received 600/150 mg lopinavir/ritonavir BID and six (four females) received 800/200 mg lopinavir/ritonavir BID in addition to rifampicin 600 mg. The remaining 29 subjects were withdrawn from the study after receiving only one dose of rifampicin (n=10) or no study medication at all (n=19).
Pharmacokinetics
The geometric mean (range) of rifampicin and desacetylrifampicin C_{2h} on day 5 (rifampicin only) was 11.3 (6.8-17.4) and 1.12 (0.74-2.37) mg/L, respectively (n=11).

In five subjects, plasma concentrations of lopinavir and ritonavir were undetectable in the morning of day 7 due to vomiting after the evening dose on day 6. In the remaining six subjects, the geometric mean (range) of the lopinavir and ritonavir trough concentrations on day 7 were 7.9 (6.6-10.3) mg/L and 0.71 (0.35-1.61) mg/L in the 600/150 mg group (n=3) and 10.9 (8.3-13.8) mg/L and 1.20 (0.64-1.85) mg/L in the 800/200 mg group (n=3). The median (range) of the rifampicin and desacetylrifampicin trough concentrations in the morning of day 7 were 0.41 (0.0-1.13) mg/L and 0.40 (0.0-0.83) mg/L in the 600/150 mg group (n=3) and 10.9 (8.3-13.8) mg/L and 1.20 (0.0-1.12) mg/L in the 800/200 mg group (n=6).

Tolerability
No major complaints or abnormal AST/ALT levels occurred during day 1–5, when rifampicin was given only (Table 1). After addition of lopinavir/ritonavir, eight

### Table 1 Distribution of adverse events (n, %) in eleven healthy volunteers. Medication was stopped on day 7 or 8.

<table>
<thead>
<tr>
<th>Adverse event</th>
<th>Day 1-11 (overall)</th>
<th>Day 1-5 (rifampicin)</th>
<th>Day 6-11 (day 6-7/8: rifampicin and lopinavir/ritonavir)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flatulence</td>
<td>1 (9%)</td>
<td>0</td>
<td>1 (9%)</td>
</tr>
<tr>
<td>Headache</td>
<td>1 (9%)</td>
<td>0</td>
<td>1 (9%)</td>
</tr>
<tr>
<td>Rash</td>
<td>1 (9%)</td>
<td>1 (9%)</td>
<td>0</td>
</tr>
<tr>
<td>Grade 1 Fever</td>
<td>1 (9%)</td>
<td>0</td>
<td>1 (9%)</td>
</tr>
<tr>
<td>Grade 1 Myalgia</td>
<td>1 (9%)</td>
<td>0</td>
<td>1 (9%)</td>
</tr>
<tr>
<td>Grade 2 Joint pain</td>
<td>1 (9%)</td>
<td>0</td>
<td>1 (9%)</td>
</tr>
<tr>
<td>Grade 1 Fatigue</td>
<td>2 (18%)</td>
<td>2 (18%)</td>
<td>0</td>
</tr>
<tr>
<td>Grade 1 Diarrhoea</td>
<td>2 (18%)</td>
<td>1 (9%)</td>
<td>2 (18%)</td>
</tr>
<tr>
<td>Grade 2 Nausea</td>
<td>0</td>
<td>0</td>
<td>1 (9%)</td>
</tr>
<tr>
<td>Grade 1 Vomiting</td>
<td>3 (18%)</td>
<td>1 (9%)</td>
<td>2 (18%)</td>
</tr>
<tr>
<td>Grade 2 Vomiting</td>
<td>8 (73%)</td>
<td>2 (18%)</td>
<td>7 (64%)</td>
</tr>
<tr>
<td>Pruritis Grade 1</td>
<td>3 (27%)</td>
<td>3 (27%)</td>
<td>3 (27%)</td>
</tr>
<tr>
<td>Pruritis Grade 2</td>
<td>6 (55%)</td>
<td>0</td>
<td>6 (55%)</td>
</tr>
<tr>
<td>Headache ALT Grade 2</td>
<td>8 (73%)</td>
<td>0</td>
<td>8 (73%)</td>
</tr>
<tr>
<td>Headache ALT Grade 3</td>
<td>8 (73%)</td>
<td>0</td>
<td>8 (73%)</td>
</tr>
<tr>
<td>Headache ALT Grade 4</td>
<td>8 (73%)</td>
<td>0</td>
<td>8 (73%)</td>
</tr>
<tr>
<td>AST Grade 2</td>
<td>2 (18%)</td>
<td>0</td>
<td>2 (18%)</td>
</tr>
<tr>
<td>AST Grade 3</td>
<td>1 (9%)</td>
<td>0</td>
<td>1 (9%)</td>
</tr>
<tr>
<td>AST Grade 4</td>
<td>8 (73%)</td>
<td>0</td>
<td>8 (73%)</td>
</tr>
<tr>
<td>GGT Grade 1</td>
<td>4 (36%)</td>
<td>0</td>
<td>4 (36%)</td>
</tr>
<tr>
<td>GGT Grade 2</td>
<td>2 (18%)</td>
<td>0</td>
<td>2 (18%)</td>
</tr>
<tr>
<td>GGT Grade 3</td>
<td>1 (9%)</td>
<td>0</td>
<td>1 (9%)</td>
</tr>
<tr>
<td>Bilirubin Grade 2</td>
<td>3 (27%)</td>
<td>0</td>
<td>3 (27%)</td>
</tr>
<tr>
<td>Bilirubin Grade 3</td>
<td>5 (45%)</td>
<td>0</td>
<td>5 (45%)</td>
</tr>
</tbody>
</table>

* * Probably related to excessive metoclopramide usage.

ALT (alanine aminotransferase), AST (aspartate aminotransferase), GGT (gamma glutamyl transferase).
arm in which rifampicin usage was followed by the combination of rifampicin and the PI [20], analogous to the current study. However, this sequence is a reflection of the clinical situation of TB-HIV co-infected patients as TB is preferably treated first. Besides, TB-HIV co-infected patients seem to tolerate the combination of rifampicin and saquinavir/ritonavir well in both sequences [14, 21], suggesting a yet unidentified difference between patients and healthy volunteers. It has not been investigated so far, whether TB-HIV co-infected patients tolerate the combination of rifampicin and lopinavir/ritonavir better than healthy volunteers.

With respect to the second difference, the absence of a dose escalation scheme for the adjusted dose of lopinavir/ritonavir may have contributed to the high incidence of adverse events in the current study. We decided to omit dose escalation because the liver enzymes had been induced by rifampicin already. The efflux transporter P-glycoprotein (P-gp) can mediate the transport of lopinavir and ritonavir [22, 23] as well as rifampicin [24]. A time-dependent effect by lopinavir/ritonavir on P-gp was previously suggested; inhibition after single-dose and induction after repeated administration [25]. The immediate administration of the high dose of lopinavir/ritonavir in the current study may have resulted in inhibition of the efflux transporter P-gp and therefore to the relatively high trough concentrations of the study medication observed. This may explain part of the adverse events.

Finally, unidentified toxic excipients of the new tablet formulation and its slightly higher bioavailability may have played a role. Studies show that this slight increase in bioavailability of lopinavir/ritonavir tablets may compensate for the inductive effect of efavirenz [26]. This same compensation may occur when combined with rifampicin, as in the current study in which we found relatively high non steady-state lopinavir trough levels compared to the steady-state levels in the previous study [11]. In short, data from interaction studies with one formulation cannot be extrapolated to another formulation.

In conclusion, this study demonstrates the challenging character of the compatibility of rifampicin and PIs in TB-HIV therapy. We advise that further studies investigating the interaction between rifampicin and lopinavir/ritonavir tablets be performed in the actual target population of TB-HIV co-infected patients rather than in healthy volunteers. Awaiting these results, simultaneous treatment with rifampicin and
lopinavir/ritonavir should not be applied. In case no alternatives are available, extreme caution and close monitoring of liver enzymes and plasma drug concentrations is warranted.

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References


Chapter 8
Clinical experience with the combined use of lopinavir/ritonavir and rifampicin

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Submitted
Abstract

Objective: A retrospective study was conducted to describe the clinical experience in the Netherlands with the combined use of lopinavir/ritonavir and rifampicin.

Methods: Adult HIV-infected patients treated concomitantly with lopinavir/ritonavir and rifampicin were selected from the Dutch ATHENA cohort and evaluated with regard to 6 items: lopinavir/ritonavir dose and formulation, sequence of drug administration, lopinavir trough plasma concentration, plasma viral load and tolerability.

Results: Thirty-four patients with a median age of 36 years were included. Overall, only 15% used the recommended increased dose of lopinavir/ritonavir. Of the 23 patients on a non-adjusted dose of lopinavir/ritonavir, 4 out of 6 (67%) had a subtherapeutic lopinavir trough plasma concentration and 3 out of 8 (38%) had a detectable viral load after at least 4 months of concomitant treatment. Two out of 5 (40%) patients on a recommended increased dose of lopinavir/ritonavir prematurely stopped the drug combination because of adverse events vs. 4 out of 23 (17%) on a non-adjusted dose and 1 out of 6 (17%) on a slightly increased dose.

Conclusions: Combined use of lopinavir/ritonavir and rifampicin is challenging as it implies balancing between suboptimal efficacy and toxicity. An adequately powered prospective study in HIV-infected patients is needed to investigate the consequences of inferior exposure to lopinavir due to non-adjusted doses of lopinavir/ritonavir versus the tolerability of recommended increased doses.

Introduction

Tuberculosis (TB) is the most prevalent opportunistic infection among HIV-infected patients worldwide [1]. Rifampicin is an important drug in the treatment of TB and has strong liver enzyme inducing capacity, resulting in drug-drug interactions with antiretroviral therapy [2].

Rifampicin-based TB treatment can be combined with antiretroviral therapy based on the non-nucleoside reverse transcriptase inhibitor (NNRTI) efavirenz [1], since the decrease in exposure to efavirenz due to co-administration of rifampicin is not expected to be clinically relevant [3, 4]. However, efavirenz cannot be used in case of pregnancy, intolerance or resistance to the drug [5]. The NNRTI nevirapine is considered to be an alternative to efavirenz among non-Caucasian patients receiving rifampicin [6, 7], despite the fact that rifampicin reduces the exposure to nevirapine by 20-55% [8].

An alternative for patients with NNRTI-resistant HIV who are treated with rifampicin would be protease inhibitor (PI)-based antiretroviral therapy [1]. However, rifampicin has been shown to cause large decreases in exposure to PIs [9-12]. We have previously performed two studies in healthy volunteers to evaluate whether adjustment of the standard lopinavir/ritonavir dose of 400/100 mg twice daily (BID) could compensate for the drug interaction with rifampicin [9, 13].

Our first study demonstrated that, on average, rifampicin and increased doses of lopinavir/ritonavir soft gel capsules (SGCs; 800/200 mg BID and 400/400 mg BID) resulted in adequate exposure to lopinavir in healthy volunteers [9]. However, therapeutic drug monitoring (TDM) was advised when combining rifampicin with 800/200 mg lopinavir/ritonavir BID and close monitoring for liver enzyme elevations was advocated when combined with 400/400 mg BID.

A new tablet formulation of lopinavir/ritonavir became available in 2006 to replace the former SGC formulation. In our second study, we aimed to evaluate the pharmacokinetics of two adjusted dose regimens of lopinavir/ritonavir tablets (600/150 mg BID and 800/200 mg BID) in combination with rifampicin in healthy volunteers [13]. However, the study was terminated prematurely due to an unexpectedly high incidence of nausea, vomiting and liver enzyme elevations.
For patients who used the drug combination of lopinavir/ritonavir and rifampicin for at least 4 months, plasma viral load data were collected until the end of concomitant treatment. Viral loads were classified as undetectable (HIV-RNA <50 copies/ml) or detectable (≥50 copies/ml). The proportion of patients with an undetectable plasma viral load at baseline and at the end of concomitant treatment was determined in those on a non-adjusted, slightly adjusted or recommended dose of lopinavir/ritonavir.

Acute, premature termination of lopinavir/ritonavir and rifampicin was defined as stopping concomitant treatment within 4 weeks from the start. Reported adverse events and grade of liver toxicity expressed by elevation of aspartate and alanine aminotransferase (AST/ALT) were collected for patients who prematurely stopped and for those who continued the drug combination [18]. The clinicians of patients who prematurely terminated the drug combination were asked to review the patient file and report the reason for stopping. We calculated the proportion of patients with premature stops because of adverse events overall and according to the 3 dose groups. In addition, we identified the formulations and lead-in drugs that were used by the patients who prematurely stopped the drug combination because of adverse events.

Results

The 34 patients (8 women, 26 men) who were included in the study originated from Sub-Saharan Africa (n=12), The Netherlands (n=8), Latin America (n=7), The Netherlands Antilles (n=3), South East Asia (n=2) or Middle East / North Africa (n=2). Combined treatment with lopinavir/ritonavir and rifampicin was initiated between October 2000 and February 2007. 32 Patients (94%) were treated for TB. Antiretroviral co-medication consisted of zidovudine and lamivudine (n=12), stavudine and lamivudine (n=4), lamivudine and tenofovir (n=4), zidovudine, lamivudine and abacavir (n=4) or alternative combinations (n=10). Median (interquartile range) age, weight, CD4 cell count and plasma viral load at baseline were 36 (32, 43) years, 62 (55, 70) kg, 105 (27, 248) cells/µl and 75,750 (<50, 204,085) copies HIV-RNA/ml.
slightly adjusted dose and 2 of 5 (40%) patients on a recommended dose. Four of 6 (67%) patients on a non-adjusted dose of lopinavir/ritonavir had a subtherapeutic lopinavir trough plasma concentration, whereas the 2 patients on a recommended dose had a therapeutic concentration.

Viral load data were available for all 11 patients who used lopinavir/ritonavir and rifampicin concomitantly for at least 4 months. In Figure 1, the proportion of patients with an undetectable plasma viral load at baseline and at the end of concomitant treatment is shown according to lopinavir/ritonavir dose group.

In Table 1, the reported adverse events and toxicity grade of AST/ALT elevations are shown for the 12 (35%) patients who prematurely stopped concomitant lopinavir/ritonavir and rifampicin within 4 weeks and for the 22 (65%) who continued the drug combination. Nausea and malaise were the most experienced adverse events, but were only reported in the group that prematurely discontinued the drug combination. Grade 2 AST/ALT elevations were more often reported in the group that continued the drug combination. Overall, 7 of 34 (21%) patients prematurely stopped the combination within 4 weeks because of acute adverse events; this was 4 of 23 (17%) on a non-adjusted dose, 1 of 6 (17%) on a slightly adjusted dose and 2 of 5 (40%) on a recommended dose of lopinavir/ritonavir (Table 2).

Twenty-eight of 34 (82%) patients were on the SGC formulation, 4 (12%) on the tablet formulation and 2 (6%) on the liquid formulation of lopinavir/ritonavir. Twenty-three (68%) patients had a rifampicin lead-in, 10 (29%) had a lopinavir/ritonavir lead-in and 1 (3%) initiated both drugs simultaneously. The formulations and lead-in drugs that were used by the 7 patients who prematurely stopped the drug combination because of adverse events are shown in Table 2; none of them was using tablets and the proportion of lead-in drugs was comparable to the overall proportion.

Discussion

This retrospective study demonstrates that the dose of lopinavir/ritonavir was usually not increased when combined with rifampicin in Dutch HIV-infected patients. This may have led to the relatively high proportion of subtherapeutic lopinavir trough...
plasma concentrations and detectable viral loads. The low adherence to this particular dose recommendation is in line with a recent study demonstrating that a minority of patients received dose adjustments to compensate for interactions between antiretroviral therapy and rifabutin [19].

Recommendations of lopinavir/ritonavir dose increment when combined with rifampicin [1, 15] have been based on one of our previous pharmacokinetic interaction studies [16]. Although the uptake of this dose recommendation was noticed to some extent after presentation of the particular study [16], general adherence to the recommendation was low. This may be due to clinicians not being aware of the recommendation at the time of prescription, because of slow integration into guidelines [1, 15] and medication monitoring systems. Another reason may be that clinicians did not follow this recommendation as it was only based on a pharmacokinetic interaction study in healthy volunteers [9] without evidence based confirmation of clinical relevance and tolerability of dose increments in HIV-infected patients.

### Table 1
Distribution of adverse events and grade of AST\(^a\)/ALT\(^b\) in those who prematurely terminated (<4 weeks) and those who continued (≥4 weeks) co-administration of lopinavir/ritonavir and rifampicin.

<table>
<thead>
<tr>
<th>Category</th>
<th>Adverse event and grade of AST(^a)/ALT(^b)</th>
<th>&lt;4 weeks n=12</th>
<th>≥4 weeks n=22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiovascular</td>
<td>Sinus tachycardia</td>
<td>1 (5%)</td>
<td></td>
</tr>
<tr>
<td>Chemistries</td>
<td>Slightly elevated LDH(^c)/ALP(^d)</td>
<td>1 (8%)</td>
<td></td>
</tr>
<tr>
<td>Dermatological</td>
<td>Rash</td>
<td>2 (9%)</td>
<td></td>
</tr>
<tr>
<td>Gastrointestinal</td>
<td>Nausea</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diarrhoea</td>
<td>2 (17%)</td>
<td>1 (5%)</td>
</tr>
<tr>
<td></td>
<td>Bad taste mouth</td>
<td>1 (8%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vomiting</td>
<td>1 (8%)</td>
<td></td>
</tr>
<tr>
<td>Genitourinary</td>
<td>Renal disorder</td>
<td>1 (5%)</td>
<td></td>
</tr>
<tr>
<td>Infection</td>
<td>Candidiasis genital</td>
<td>1 (5%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cerebral toxoplasmosis</td>
<td>1 (5%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Conjunctivitis</td>
<td>1 (5%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Herpes zoster</td>
<td>1 (5%)</td>
<td></td>
</tr>
<tr>
<td>Metabolic</td>
<td>Diabetes Mellitus</td>
<td>1 (5%)</td>
<td></td>
</tr>
<tr>
<td>Neurologic</td>
<td>Parasthesia</td>
<td>1 (8%)</td>
<td>1 (5%)</td>
</tr>
<tr>
<td></td>
<td>Peripheral neuropathy</td>
<td>1 (5%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Malaise</td>
<td>1 (8%)</td>
<td>1 (5%)</td>
</tr>
<tr>
<td></td>
<td>Fatigue</td>
<td>1 (8%)</td>
<td>1 (5%)</td>
</tr>
<tr>
<td></td>
<td>Fever</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cachexia</td>
<td>1 (8%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Liver toxicity</td>
<td>1 (8%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pain upper abdomen</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2
Adverse events responsible for premature termination of concomitant treatment with lopinavir/ritonavir and rifampicin in 7 out of 34 patients.

<table>
<thead>
<tr>
<th>Patient</th>
<th>LPV/rtv(^a) dose</th>
<th>Adverse event</th>
<th>LPV/rtv(^a) Formulation</th>
<th>Lead-in drug</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Non-adjusted(^b)</td>
<td>Liver toxicity; malaise; nausea; vomiting</td>
<td>SGO(^c)</td>
<td>Rifampicin</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Nausea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Diarrhoea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Immune reconstitution syndrome</td>
<td></td>
<td>Rifampicin</td>
</tr>
<tr>
<td>5</td>
<td>Slightly adjusted(^c)</td>
<td>Pain upper abdomen</td>
<td></td>
<td>Rifampicin</td>
</tr>
<tr>
<td>6</td>
<td>Recommended(^d)</td>
<td>Bad taste mouth; diarrhoea; nausea; paraesthesia</td>
<td>LPV/rtv(^e)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Nausea; slightly elevated LDH(^e), ALP(^f) and ALT(^g)</td>
<td>liquid</td>
<td>None</td>
</tr>
</tbody>
</table>

\(^{a}\) lopinavir/ritonavir

\(^{b}\) 400/100 mg twice daily

\(^{c}\) 533/133 mg twice daily

\(^{d}\) 400/400 mg (n=1) or 800/200 mg (n=1) twice daily

\(^{e}\) lactate dehydrogenase

\(^{f}\) alkaline phosphatase

\(^{g}\) alanine aminotransferase

\(^{h}\) soft gel capsule

Values given are n (%)
Secondly, the fact that the current study was performed in HIV-infected patients rather than healthy volunteers may have led to the better tolerability of the combination lopinavir/ritonavir and rifampicin. This explanation is supported by other studies demonstrating that HIV patients tolerate another PI-combination, saquinavir/ritonavir, and rifampicin better than healthy volunteers [12, 20, 21]. Although the magnitude of toxicity in our previous studies in healthy volunteers was more severe when using tablets [13] rather than SGCs [9], in the present study we did not find any support that this may be caused by the formulation itself. In another study, without rifampicin, it is even claimed that the new tablet formulation of lopinavir/ritonavir is better tolerated than the SGC [22].

Previous studies in healthy volunteers suggest that the rifampicin lead-in before the introduction of protease inhibitors may have contributed to the high incidence of toxicity observed [13, 20, 23]. However, we could not confirm that the sequence of drug administration may have led to the overall better tolerability in HIV-infected patients.

Several limitations of our study need to be mentioned. This was a retrospective analysis of an observational cohort. Data were not collected on prespecified time points and were not always available. However, the quality of the data in the ATHENA cohort is independently monitored [14]. In case of missing or possible inaccuracy of data, we contacted the treating physician for clarification. As the design of the study was observational and not a randomized study, observed findings may have been confounded. Also, the number of patients involved in this evaluation was limited. Therefore, statistical analyses were not performed.

In conclusion, a small minority of HIV-infected patients in the Netherlands has been treated with the recommended increased dose of lopinavir/ritonavir in combination with rifampicin. This resulted in inferior exposure to lopinavir and possibly related virological failure. The overall tolerability of the drug combination was better than previously reported in healthy volunteers, whereas a higher proportion of those on a recommended increased dose prematurely stopped the combination because of adverse events. Concomitant use of lopinavir/ritonavir and rifampicin remains challenging. An adequately powered prospective study in HIV-infected patients is necessary to further investigate the tolerability of this combination.
References


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We would like to thank all physicians for providing additional clinical information.


General discussion
Introduction

This thesis presents the first output of a North-South collaboration in clinical pharmacological research of HIV treatment in which the Department of Clinical Pharmacy of the Radboud University Nijmegen Medical Centre was involved. Sub-Saharan Africa continues to be the region most affected by HIV. Although the access to adult HIV treatment in resource-poor countries is being improved and an increasing amount of data is generated on treatment efficacy, limited data are available on clinical pharmacology. In this thesis, a collaboration between partners from The Netherlands, United Kingdom, Zambia and Tanzania has led to clinical pharmacological research of HIV treatment that is specifically relevant for resource-limited countries.

Part I deals with the optimization of paediatric regimens for the scale-up of HIV treatment in resource-limited countries. Part II focuses on therapeutic drug monitoring in HIV-infected adults and the optimization of a cost-effective strategy for the reduction of mother-to-child transmission in low-income countries. Part III describes the challenges of combined treatment with lopinavir/ritonavir and rifampicin for HIV-TB co-infection. Overviewing the presented studies, five topics that are relevant for developing countries were selected for discussion: (1) access to HIV treatment; (2) monitoring of HIV treatment; (3) prevention of mother-to-child transmission of HIV; (4) treatment of HIV-TB co-infection; and (5) North-South collaboration in clinical pharmacological research. This general discussion is concluded with future perspectives.

1. Access to HIV treatment

The recent improvement in the access to HIV treatment in developing countries has largely depended on the introduction of cheap generic fixed dose combination (FDC) tablets with standard doses of antiretroviral drugs for adults. The lack of affordable and appropriate paediatric antiretroviral drug formulations has led to prescription of generic adult FDC tablets to children. Several reasons may have contributed to the delay in development of generic paediatric formulations for HIV-infected children in developing countries.

Firstly, the incorrect assumption that there is no need of a generic paediatric formulation may have hindered its development. HIV-infected children cannot simply be regarded as small adults, pharmacologically speaking (Chapter 1).

For example, children metabolize the antiretroviral drug nevirapine more rapidly than adults. Chapter 2 demonstrates that it is impossible to achieve adequate nevirapine concentrations without risking overdosing with stavudine in HIV-infected children receiving divided adult FDC tablets (Triomune, Cipla Ltd., India; 200mg nevirapine, 30 or 40 mg stavudine, 150 mg lamivudine). This is of concern, as children with subtherapeutic nevirapine concentrations are at risk of virological failure and development of resistance [1, 2].

Secondly, the incorrect assumption that a generic paediatric FDC formulation should be liquid may have tempered the enthusiasm for its development by generic manufacturers. The development of liquid formulations can be complex due to problems with stability, solubility and taste. For example, no liquid formulations have been marketed for the insoluble drugs indinavir and saquinavir, and the liquid formulations of efavirenz, ritonavir and lopinavir/ritonavir all have an unpleasant taste. The current development of a lopinavir/ritonavir tablet with half the strength of the adult formulation will offer an attractive alternative to older children in the near future. The time and energy spent trying to develop liquid paediatric FDC formulations is better used in the manufacture of small, dispersible, crushable and scored FDC tablets, which are easier to develop, dispense, transport, store and administer [3]. The development of separate tablet formulations for young and older children would minimize the number of tablets to be taken per dosing interval. On the other hand, management of stocks would be facilitated by the introduction of only one paediatric formulation.

Thirdly, the fact that generic paediatric FDC formulations may be less lucrative for commercial institutions could also explain the delay in development. Only 2.5 million children out of 33.5 million people were estimated to be living with HIV at the end of 2007 [4], indicating a relatively small market for generic paediatric FDC formulations. In addition, developed countries that can afford to pay a higher price for paediatric formulations may not be as interested in generic paediatric FDC tablets as resource-poor countries.

Finally, the fact that global efforts such as the “3 by 5” initiative of the World Health Organization (WHO) have mainly focussed on the access to HIV treatment for adults [5] may have contributed to the delay in development of generic paediatric formulations.
It was only recently that a WHO paediatric antiretroviral working group (PAWG) started to encourage the development of paediatric-friendly FDC tablets and the universal access to safe treatment for HIV-infected children [6]. PAWG identified a prioritized list of paediatric products and used a generic dosing tool, assessing the intended dose delivered, to arrive at recommended doses. Weight-band based dosing tables were developed to simplify dosing of antiretroviral drugs in resource-limited settings. For drugs that should be dosed by body surface area, such as nevirapine, doses were converted into weight bands. PAWG advised a higher nevirapine to stavudine and lamivudine dose ratio for the paediatric version of the adult FDC Triomune investigated in Chapter 2. In addition to the initiatives of WHO [6], the new European paediatric regulation has led to an obligation for paediatric research for every new drug developed for adults and having a potential use for children, in exchange for a six month extension of the supplementary protection certificate.

In response to the urgent need for generic paediatric FDC tablets, Cipla Ltd. has developed Triomune Baby and Junior with higher nevirapine to stavudine and lamivudine ratios than adult Triomune tablets, in accordance with paediatric recommendations. Bioequivalence studies are of importance as products of poor quality should not reach the market. Formal bioequivalence of Triomune Baby and Junior was demonstrated by Cipla Ltd. at the end of 2006 (data on file). Our independent pilot bioequivalence study demonstrated similar pharmacokinetics to the branded products in 2005 already (Chapter 3). This has led to an earlier start of our subsequent study in HIV-infected Zambian children (Chapter 4), which was of benefit for those children in urgent need of Triomune Baby and Junior. The fact that we received funding from the European and Developing Countries Clinical Trials Partnership (EDCTP) for our research in the actual target population of HIV-infected African children (Chapter 4) underlines the high relevancy of the issue. Although the Triomune Baby and Junior antiretroviral drug ratios were shown to be appropriate for children weighing over 6 kg (Chapter 4) and even for those under 6 kg (unpublished data), it is of importance that the children in our trial remain to be followed for investigation of long-term safety and efficacy of the FDCs.

The correctness of WHO PAWG recommendations for drug ratios of prioritized paediatric FDCs [6] can only be confirmed by pharmacokinetic research in the actual target population of HIV-infected children. Therefore, we were invited to present our data for Triomune Baby and Junior (Chapter 4) at one of the PAWG meetings in Geneva. Following successful review, WHO now recommend the antiretroviral drug ratios and the weight-band based dosing table that we used. Triomune Baby and Junior were the first paediatric FDC tablets to be approved by the United States Food and Drug Administration (FDA) and to become available for distribution under the Presidents Emergency Plan For AIDS Relief (PEPFAR) and Clinton Foundation programmes. The accessibility of Triomune Baby and Junior will drastically improve the necessary scale-up of appropriate HIV treatment for children in resource-limited countries.

It is hoped that future efforts will be made to expand the development of generic paediatric formulations with the guidance of PAWG recommendations [6]. The use of the nucleoside reverse transcriptase inhibitor (NRTI) stavudine may lead to toxicities such as lipodystrophy and peripheral neuropathy, which can be difficult to identify in children and may be irreversible. Therefore, paediatric FDCs that do not contain stavudine should be developed. Most of the generic regimens that are being developed contain the non-nucleoside reverse transcriptase inhibitor (NNRTI) nevirapine, while NNRTIs have a low genetic barrier for the development of resistance [7]. For those children who fail first-line NNRTI-based regimens, second-line protease inhibitor-based regimens should become available. Because it can be challenging to develop an FDC with two NRTIs and one protease inhibitor, co-packaging may be indicated.

2. Monitoring of HIV treatment

Provision of adequate HIV care in developing countries can be hindered by a shortage of trained personnel, complexity and costs of laboratory equipments and unreliable drug supply, especially in remote settings [8]. Staff training is required to improve the general quality of care. Patients who are not identified in time to be eligible for antiretroviral treatment remain at risk of dying from AIDS. Facilities to perform CD4 counts are needed to indentify the patients eligible for treatment and to monitor the response to treatment [9]. At a large tertiary referral hospital in the northern zone of Tanzania, the Kilimanjaro Christian Medical Centre (KCMC), facilities to perform CD4 counts have recently been introduced through the National AIDS programme. Furthermore, patients on antiretroviral treatment are at risk of
As an alternative to HPLC, a relatively inexpensive thin layer chromatography (TLC) technique has been investigated for the detection of nevirapine in plasma [15]. We developed a cheap and simple TLC method for semi-quantitative detection of nevirapine in saliva. The assay was validated in HIV-infected Tanzanian adults on nevirapine treatment at KCMC and was found to be sensitive, specific and robust in the detection of subtherapeutic nevirapine concentrations (Chapter 5).

Enough capacity has been built to implement this TLC method as a tool for TDM at the HIV clinic of KCMC. In the light of cost-efficiency, it would be wise to focus on those patients suspected of inappropriate response or non-adherence to nevirapine-based treatment. Counselling of patients with a subtherapeutic nevirapine concentration should include the importance of improved adherence or an increased dose to prevent virological failure and resistance development. The effect of such interventions could be checked by repetition of TDM. Global provision of HIV care would benefit from the transfer of this TLC technique to other developing countries.

3. Prevention of mother-to-child transmission of HIV

Without antiretroviral treatment, the risk to transmit HIV to a baby during pregnancy or delivery is 25-48%. The introduction of highly active antiretroviral therapy (HAART) has reduced the rate of mother-to-child transmission (MTCT) to 1-2% in the developed world [16]. The mainstay of prevention of MTCT (PMTCT) programmes in low-resource settings have focussed on a single dose nevirapine to the mother shortly before delivery and to the baby after birth [17]. This simple and inexpensive intervention, reducing the risk of MTCT by 50%, is less effective than combination antiretroviral therapy [18], but was found to be cost-effective. A major disadvantage is the development of resistance in up to 70% of women [19], which may diminish the response to nevirapine in the future [20].

It is sad that combination antiretroviral therapy in pregnancy is not yet feasible in many resource-limited settings. Even the coverage of a simple PMTCT intervention such as single dose nevirapine remains low [21]. Only 30% of seropositive mother-infant pairs in a city-wide PMTCT programme in Lusaka, Zambia, received both a maternal and infant dose of nevirapine [22]. For as long as PMTCT programmes in the developing world will have to depend on the single dose

side effects and laboratory abnormalities [10], but at KCMC clinical chemistry and haematology testing is only being performed for those patients who can afford to pay a small fee.

Many key anti-HIV drugs are not yet marketed in cheap generic versions. Most of the generic antiretroviral regimens that have become available in developing countries combine the NNRTI nevirapine with two NRTIs. A disadvantage of nevirapine is the low genetic barrier for the development of resistance [7]. Resistant strains against nevirapine-based regimens provided in national programmes of developing countries could be spread through the population. This is of concern, as there are few second-line options for antiretroviral therapy in resource-limited countries, where the national expenditure to health-care is restricted. Patients at risk for virological failure and resistance are those with subtherapeutic plasma concentrations of nevirapine [1, 2], which can be caused by intersubject variability in pharmacokinetics, missed doses due to inadequate drug supply, or non-adherence.

The risk of resistance development could be reduced in several ways. First of all, drug supply should be improved to prevent treatment interruptions [8]. Viral load testing would certainly help to identify those patients with an inappropriate response to treatment and thus at risk for resistance development [11], but is often unaffordable. At KCMC, viral load testing is mainly reserved for determination of the HIV status of babies that were born to HIV-positive mothers. From a pharmacological point of view, therapeutic drug monitoring (TDM) would be an important tool to identify those patients with an inappropriate exposure to drugs such as nevirapine and thus at risk for virological failure and resistance development. However, the assay technique high-performance liquid chromatography (HPLC) which is commonly used for TDM of nevirapine in the developed world [12] is too expensive for resource-poor settings. Furthermore, the required sampling technique to obtain plasma may be too complicated. To facilitate the implementation of TDM in developing countries, alternative options for sampling and assay technique are needed.

Previous studies suggest that saliva may be used as an alternative body fluid to plasma for TDM of nevirapine, implying painless and non-invasive sampling with diminished risk of HIV-transmission to health care workers, and at a lower cost [13, 14]. As an alternative to HPLC, a relatively inexpensive thin layer chromatography (TLC) technique has been investigated for the detection of nevirapine in plasma [15]. We developed a cheap and simple TLC method for semi-quantitative detection of nevirapine in saliva. The assay was validated in HIV-infected Tanzanian adults on nevirapine treatment at KCMC and was found to be sensitive, specific and robust in the detection of subtherapeutic nevirapine concentrations (Chapter 5).
significant decrease in nevirapine half-life by addition of an enzyme inducer will reduce the duration of the potential zone of resistance development, but may also not be sufficient to prevent development of all nevirapine mutations. We are planning for a subsequent VITA-2 study to investigate if combining these two approaches of decreasing nevirapine half-life and co-administering other antiretroviral agents will be of added value. Our study proposal should comply with new national and WHO [26] PMTCT guidelines advising to combine the single dose of nevirapine at delivery with zidovudine from 28th week of gestation and zidovudine/lamivudine intrapartum until 1 week after delivery, if feasible.

The PMTCT field is dynamic as preferred interventions with higher activity, such as HAART, are likely to be more complex and thus less feasible for resource-limited settings. The design of future VITA studies will depend on further adjustments to PMTCT guidelines and the capacity that has been built in the mean time to implement guidelines and to perform clinical trials.

4. Treatment of HIV-TB co-infection

The poverty-related communicable disease tuberculosis (TB) is the most common opportunistic infection among HIV-infected subjects worldwide, but particularly in developing countries [27]. Although co-administration of HIV and TB treatment is frequently indicated, there is a lack of knowledge about drug-drug interactions and overlap in toxicity profiles, particularly for the combination of rifampicin and protease inhibitors. When designing pharmacological trials for the optimization of HIV-TB treatment, several issues should be considered.

An international code of ethics for clinical research, the Declaration of Helsinki, has been established to assure that trials are performed in an ethical manner [28]. The declaration of Helsinki states that medical research involving human subjects should only be conducted if the importance of the objective outweighs the inherent risks and burdens to the subject. As healthy volunteers do not benefit from a drug trial, the risks to which they are exposed can be justified only by the value of the knowledge gained by their participation [29, 30]. However, despite adequate risk estimation, it cannot be excluded that the magnitude of drug toxicity during the actual trial may be higher than expected. Outside the scope of HIV-TB research, a
Phase I trial with a new anti-CD28 monoclonal antibody (TGN1412) resulted in serious adverse events and even hospital admittance for all 6 healthy male subjects in March 2006 [31]. Within the scope of HIV-TB research, several studies in healthy volunteers were carried out to evaluate if adjusted doses of protease inhibitors would compensate for the interaction with rifampicin. Among healthy volunteers receiving once-daily rifampicin, addition of saquinavir/ritonavir [32], increased lopinavir/ritonavir doses (Chapter 7) and twice-daily atazanavir/ritonavir [33] resulted in an unexpectedly high incidence of adverse events. All studies were terminated prematurely. The rifampicin lead-in may have contributed to the toxicity observed. However, the studied sequence is a reflection of the clinical situation of HIV-TB co-infected patients as TB is preferably treated first.

A disadvantage of drug-drug interaction studies in HIV-infected patients is the risk for the development of subtherapeutic plasma concentrations of antiretroviral drugs. For patients who develop resistance as a result of subtherapeutic antiretroviral drug concentrations during a trial, there will be less treatment options in the future. Particularly in resource-limited settings, it will be difficult to select those patients at risk for resistance development, because of the lack of TDM facilities to monitor for subtherapeutic drug concentrations. The fact that there is no network to perform clinical drug trials in HIV-TB co-infected patients in Europe has limited the outcome of our study evaluating the clinical experience with the combined use of lopinavir/ritonavir and rifampicin (Chapter 8). As only a minority of physicians appeared to follow recommendations and treatment was not standardised across the institutions involved, it was difficult to draw conclusions. We would have learned more from Chapter 8 if expertise had been gathered.

Taking into account these experiences, it would be best to investigate the combination of rifampicin and antiretroviral drugs in HIV-TB co-infected patients in the developing world. A requirement would be that patients with an inappropriate exposure to antiretroviral drugs and thus at risk for resistance development will be identified in time. In case there is not enough funding or capacity to implement current methods for TDM in developing countries, efforts should be made to develop alternative methods that are feasible. A simple and inexpensive TLC method has already been developed for the determination of nevirapine (Chapter 5), but not yet for the determination of protease inhibitors. In 2008, a study investigating the combination of rifampicin-containing tuberculostatic treatment and first-line antiretroviral treatment (tenofovir, emtricitabine and efavirenz) will be started at a large referral hospital for HIV-TB co-infected patients, Kibon’goto National Tuberculosis Hospital (KNTH), in the northern zone of Tanzania. It is hoped that hereby capacity is being built for future studies investigating the combination of rifampicin and second-line antiretroviral treatment, which is often based on protease inhibitors. As a follow-up of Chapters 7 and 8 it would be interesting to study a rifampicin lead-in followed by addition of standard lopinavir/ritonavir doses in HIV-TB co-infected patients. This should happen under online TDM of lopinavir/ritonavir concentrations to be able to increase the dose if necessary.

5. North-South collaboration in clinical pharmacological research

Clinical pharmacological research questions that are specifically relevant to developing countries are not always addressed in countries with a high-standard of health care. A North-South collaboration between partners from the developed and developing world can facilitate pharmacological research in resource-poor countries. Research institutes from the developed world can contribute their experience and institutes from the developing world are needed for the provision of ethics approval, study personnel and patients. The collaboration between two European and two African institutes in this thesis was achieved by networking. One of the preceding pharmacology PhD students at the Radboud University Nijmegen Medical Centre (RUNMC) in the Netherlands, Alina Bergschoeff, was involved in the paediatric European network for treatment of AIDS (PENTA). Within this PENTA network, RUNMC has collaborated with the Medical Research Council (MRC), Clinical Trials Unit (CTU) in London, United Kingdom. MRC CTU was also collaborating with the University Teaching Hospital (UTH) in Lusaka, Zambia and asked the RUNMC to join the network. Nijmegen University has a history of 37 years of collaboration with the Tanzanian Health system. A decade ago, RUNMC was very closely involved in the development of the Medical College at KCMC in Moshi, Tanzania. This has been the basis for a research collaboration between the two institutes.

When looking at the output of this thesis, it can be said that the collaboration between European and African institutes has been successful. The large pharmacokinetic trial in Zambian HIV-infected children (Chapter 4) has benefitted from the pharmacological
success of a North-South collaboration in clinical pharmacological research of HIV treatment is the complementary contribution of different partners. Adequate funding is required to build the capacity to perform clinical trials in the developing world and experienced scientists are needed to train and supervise the local study staff.

experience of our department at RUNMC and from the clinical trial experience of MRC CTU. When this so-called CHAPAS1 study was started in Zambia, the infrastructure to perform clinical trials was already in place. The same study clinic and nurses were involved in the previous so-called CHAP trial (Chapter 2, [34]). In contrast, execution of the VITA-1 study, as a follow-up to Chapter 6, trying to optimize PMTCT in Tanzania, appears to be much more complicated. There was a general lack of clinical trial capacity when VITA-1 was started. In addition, MRC CTU with a lot of clinical trial experience in resource-limited settings has not been involved so far.

Pharmaceutical industries that are traditional sponsors of drug trials in the developed world are often not interested to sponsor research for developing countries. Sponsorships should come from international governmental organisations such as the European Union, The Bill Gates Foundation, G8, WHO and the Joint United Nations Programme on HIV/AIDS (UNAIDS). Most of the research in this thesis was funded by EDCTP and by the Poverty Related Infection Oriented Research (PRIOR) network that was established by a grant from the Netherlands Foundation for the Advancement of Tropical Research (NWO-WOTRO) and the Netherlands Foundation for Health Research and Development (ZonMw).

Conclusions and future perspectives

In conclusion, our North-South collaboration between research partners from the developed and developing world has improved the knowledge about clinical pharmacology of HIV treatment that is specifically relevant for resource-limited countries. Although the first affordable and appropriate paediatric FDC tablets recently became available for HIV-infected children in developing counties, future efforts should be made to expand the development of generic paediatric formulations. It is hoped that the cheap and simple TLC method that was developed for the detection of nevirapine in saliva is implemented as a tool for TDM in resource-limited countries. For as long as PMTCT programmes in the developing world will have to depend on the single dose nevirapine intervention, the search for interventions to reduce the risk of resistance development should be continued. Moreover, future research is needed in HIV-TB co-infected patients in the developing world to investigate the co-administration of HIV and TB treatment. The key to
References


Introduction

This thesis presents the first output of a North-South (Europe-Africa) collaboration in clinical pharmacological research of HIV treatment. **Part I** deals with the optimization of paediatric regimens for the scale-up of HIV treatment in resource-limited countries. **Part II** focuses on therapeutic drug monitoring (TDM) in HIV-infected adults and the optimization of a cost-effective strategy for the reduction of mother-to-child transmission (MTCT) of HIV in low-income countries. **Part III** describes the challenges of combined treatment with lopinavir/ritonavir and rifampicin for HIV-tuberculosis (TB) co-infection.

I. Clinical pharmacology in HIV-infected children

The brief review in Chapter 1 focuses on general characteristics relating to pharmacokinetic processes (absorption, distribution, metabolism, excretion) in the paediatric population, followed by recent examples of antiretroviral drug pharmacokinetics in HIV-infected children. Pharmacokinetics of antiretroviral drugs are highly variable in the paediatric population as children mature and grow rapidly and individually until they are adults. It was unexpectedly found that exposure to lopinavir is decreased in the first 6 months of life. In addition, recommended dosing of lamivudine leads to lower exposure in children younger than 6 years of age. Recent findings of subtherapeutic efavirenz concentrations in children suggest that paediatric dose recommendations should be re-evaluated. There is a general shortage of pharmacokinetic data in HIV-infected children. Selected pharmacology studies should be undertaken to improve paediatric dose guidance of existing antiretroviral drugs. TDM is a useful tool to optimize treatment in HIV-infected children. However, more data are needed to establish child-specific reference values.

Chapter 2 describes the exposure to nevirapine in HIV-infected African children treated with divided adult fixed dose combination (FDC) tablets (Triomune) in routine outpatient settings. Of the 127 children, 23 (18%) had a subtherapeutic random nevirapine plasma concentration (<3.0 mg/L). Only 1 (3%) of those prescribed ≥300 mg/m²/day nevirapine had subtherapeutic concentrations compared with 22 (23%) of those prescribed <300 mg/m²/day. Lower nevirapine concentrations were independently associated with lower prescribed dose/m², lower height-for-age, and higher body mass index-for-age. Most children with subtherapeutic nevirapine concentrations were taking half or quarter FDC tablets. It was concluded that currently available adult FDC tablets are not well suited for children, particularly at younger ages. Development of appropriate paediatric FDC tablets is essential if antiretroviral therapy is to be made widely available to children in resource-limited settings.

Two generic paediatric FDC tablets (Triomune Baby & Junior) were developed with higher nevirapine to stavudine and lamivudine ratios than the adult FDC tablet (Triomune) in accordance with paediatric dose recommendations. In Chapter 3, the pharmacokinetics of Triomune Baby & Junior were compared to the branded products. This pilot study in six healthy males shows that the pharmacokinetic profiles of stavudine, lamivudine and nevirapine in the generic paediatric FDC tablets are similar to the branded products. Based on these results, it is acceptable to test the pharmacokinetics and dosing requirements of Triomune Baby & Junior in HIV-infected children.

Chapter 4 describes the pharmacokinetics of the two generic paediatric FDC tablets Triomune Baby & Junior in a target population of 71 African HIV-infected children. After treatment of the children according to weight-bands for at least 4 weeks, a 12-hour pharmacokinetic curve was recorded. Nevirapine plasma concentrations were higher but more variable than those in adults. The nevirapine trough concentration was subtherapeutic (<3.0 mg/L) in four (6%) children. Pharmacokinetic parameters of stavudine and lamivudine were comparable to those in adults. There was no evidence of a difference in nevirapine exposure across weight-bands, while the difference in stavudine and lamivudine exposure was driven by the single weight-band with an unequal morning and evening dose (15–<20kg). As nevirapine underdosing is of greater concern than overdosing, it was concluded that the Triomune Baby & Junior ratio is appropriate for children weighing 6kg and over. Further research is required for children under 6kg.

II. Clinical pharmacology in HIV-infected adults

In Chapter 5, the option to perform TDM of nevirapine in resource-limited settings was explored. A simple and inexpensive thin layer chromatography (TLC) assay was developed for semi-quantitative detection of nevirapine saliva concentrations. The method was validated in a target population of 300 African HIV-infected adults.
Paired plasma and saliva nevirapine concentrations were assayed by high-performance liquid chromatography (HPLC). Saliva concentrations were also assayed by TLC. Nine percent of the subjects had a subtherapeutic plasma nevirapine concentration. The median saliva/plasma nevirapine concentration ratio was 0.51. The TLC assay was found to be sensitive, specific and robust in detection of subtherapeutic nevirapine concentrations in saliva of African HIV-infected adults. It is an attractive alternative to HPLC for TDM of nevirapine in resource-limited settings.

Single-dose nevirapine to prevent MTCT of HIV is associated with the development of nevirapine resistance, probably due to its long elimination half-life in combination with a low genetic barrier to resistance. The pilot study in Chapter 6 aimed to identify enzyme inducers to reduce the half-life of nevirapine. After administration of a single 200-mg dose of nevirapine to 36 healthy non-pregnant women in both period 1 and 2, blood was sampled twice-a-week for 21 days to determine concentrations of nevirapine. In period 2 additional interventions (single dose carbamazepine, phenobarbital or phenytoin; phenytoin for 3 or 7 days; St John’s Wort, vitamin A or cholecalciferol for 14 days) were administered to all subjects except for the control group. In three intervention groups T-half ratio (nevirapine half-life in period 2 / half-life in period 1) differed significantly from the control group: single 400-mg dose of carbamazepine, 184mg phenytoin once daily for 3 or 7 days. The mean decrease in nevirapine half-life in period 2 was 35.3, 38.2 and 35.9%, in these groups respectively. It was concluded that these interventions should be tested in the setting of single-dose nevirapine for the prevention of MTCT (PMTCT) of HIV to reduce the development of nevirapine resistance.

III. Clinical pharmacology in HIV-TB co-infection

Previous research in healthy volunteers has demonstrated that increased doses of lopinavir/ritonavir soft gel capsules compensate for the interaction with rifampicin. The pharmacokinetic interaction study in Chapter 7 shows a high incidence of adverse events in 11 healthy volunteers treated with a higher than standard dose of the new lopinavir/ritonavir tablets in combination with rifampicin. No major complaints occurred when 600 mg rifampicin was given only. However, the study had to be terminated prematurely after addition of 600/150 or 800/200 mg lopinavir/ritonavir twice daily. Eight subjects suffered from both nausea and vomiting, one from nausea only, and one from vomiting only. Moreover, increases in AST/ALT levels were reported in all subjects. All levels returned to normal within six weeks. The observed toxicity may be explained by three facts. Firstly, rifampicin was introduced prior to lopinavir/ritonavir; secondly, the adjusted dose of lopinavir/ritonavir tablets was not escalated; and thirdly, the new lopinavir/ritonavir tablet formulation was used instead of the capsule formulation. It was advised that further studies investigating the interaction between rifampicin and lopinavir/ritonavir tablets be performed in the actual target population of HIV-TB co-infected patients rather than in healthy volunteers.

Chapter 8 describes the clinical experience with the combined use of lopinavir/ritonavir and rifampicin in the Netherlands. Thirty-four adult HIV-infected patients on combined treatment were selected from the Dutch ATHENA cohort for retrospective analysis. Overall, 15% used a recommended increased dose of lopinavir/ritonavir, 82% were on the soft gel capsule formulation of lopinavir/ritonavir and 68% had a lead-in with rifampicin. Of the 23 patients on a non-adjusted dose of lopinavir/ritonavir, 4 out of 6 (67%) had a subtherapeutic lopinavir trough plasma concentration (<1.0 mg/L) and 3 out of 8 (38%) had a detectable viral load (≥50 copies/ml) after at least 4 months of concomitant treatment. Two out of 5 (40%) patients on a recommended increased dose of lopinavir/ritonavir prematurely stopped the drug combination because of adverse events vs. 4 out of 23 (17%) on a non-adjusted dose and 1 out of 6 (17%) on a slightly increased dose. An adequately powered prospective study in HIV-TB co-infected patients is needed to investigate the consequences of inferior lopinavir exposure due to non-adjusted doses of lopinavir/ritonavir and to determine the tolerability of recommended increased doses.

General discussion

In the general discussion the following issues that are relevant for developing countries are discussed: access to HIV treatment, monitoring of HIV treatment, PMTCT of HIV, treatment of HIV-TB co-infection, and North-South collaboration in clinical pharmacological research.

Although the first affordable and appropriate paediatric FDC tablets recently became available for HIV-infected children in developing counties, future efforts
should be made to expand the development of generic paediatric formulations. It is hoped that the cheap and simple TLC method that was developed for the detection of nevirapine in saliva will soon be implemented in resource-limited countries. For as long as PMTCT programmes in the developing world will have to depend on the single dose nevirapine intervention, the search for interventions to reduce the risk of resistance development should be continued. Moreover, future research is needed in HIV-TB co-infected patients in the developing world to investigate the co-administration of HIV and TB treatment. The key to success of a North-South collaboration in clinical pharmacological research of HIV treatment is the complementary contribution of different partners.
Samenvatting
Introductie

Dit proefschrift laat de eerste resultaten zien van een Noord-Zuid samenwerking tussen Europa en Afrika met betrekking tot klinisch farmacologisch onderzoek van HIV behandeling. **Deel I** gaat over de optimalisering van preparaten om kinderen met HIV in ontwikkelingslanden te kunnen behandelen. De focus van **Deel II** ligt bij het monitoren van geneesmiddelconcentraties (therapeutic drug monitoring, TDM) in volwassenen met HIV. Daarnaast is er aandacht voor de optimalisering van een kosteneffectieve strategie voor de vermindering van HIV overdracht van moeder op kind (mother-to-child transmission, MTCT) in ontwikkelingslanden. **Deel III** beschrijft de uitdagingen van gecombineerde behandeling met lopinavir/ritonavir en rifampicine in geval van HIV-tuberculose (TB) dubbelinfectie.

I. Klinische farmacologie in HIV geïnfecteerde kinderen

**Hoofdstuk 1** geeft een beknopt overzicht van de algemene kenmerken van farmacokinetische processen (opname, verdeling, afbraak, uitscheiding) in kinderen, gevolgd door recente voorbeelden van het farmacokinetiek van antiretrovirale geneesmiddelen in HIV geïnfecteerde kinderen. De farmacokinetiek van antiretrovirale geneesmiddelen in kinderen is sterk variabel aangezien kinderen zich individueel ontwikkelen en groeien totdat ze volwassen zijn. Er is onverwacht aangetoond dat de blootstelling aan lopinavir is verminderd in kinderen jonger dan 6 maanden. Daarnaast leidt de aanbevolen dosering van lamivudine tot een lagere blootstelling in kinderen jonger dan 6 jaar. Recente bevindingen van te lage, oftewel subtherapeutische, efavirenz concentraties in kinderen laten zien dat de aanbevolen kinderdoserings van efavirenz opnieuw geëvalueerd zou moeten worden. Er is een algemeen tekort aan farmacokinetische data in kinderen met HIV. Zorgvuldig gekozen farmacologische onderzoeken zouden uitgevoerd moeten worden om de aanbeveling van kinderdosering af te wichten.

**Hoofdstuk 2** beschrijft de blootstelling aan nevirapine in HIV geïnfecteerde Afrikaanse kinderen in de thuissituatie behandeld met gedeelde vaste dosis combinatietabletten (fixed dose combination, FDC) voor volwassenen (Triomune). Van de 127 kinderen hadden er 23 (18%) een subtherapeutische willekeurige nevirapine bloedconcentratie (<3.0 mg/L). Slechts 1 (3%) van de kinderen die ≥ 300 mg/m² nevirapine per dag kregen had een subtherapeutische concentratie in vergelijking met 22 (23%) van de kinderen die <300 mg/m² nevirapine per dag gebruikten. Lagere nevirapine concentraties waren onafhankelijk geassocieerd met een lagere voorgeschreven dosering per m². Er zijn twee generieke FDC kindertabletten (Triomune Baby & Junior) ontwikkeld die voldoen aan de aanbevolen kinderdoserings. Deze kindertabletten bevatten relatief meer nevirapine en relatief minder stavudine en lamivudine in vergelijking tot de FDC tablet voor volwassenen (Triomune). In **Hoofdstuk 3** werd de farmacokinetiek van Triomune Baby & Junior vergeleken met de merkpreparaten. Dit proefonderzoek in zes gezonde mannen laat zien dat de farmacokinetische profielen van stavudine, lamivudine en nevirapine in de generieke kindertabletten vergelijkbaar zijn met de merkpreparaten.

**Hoofdstuk 4** beschrijft de farmacokinetiek van de twee generieke FDC kindertabletten Triomune Baby & Junior in een doelpopulatie van 71 Afrikaanse HIV geïnfecteerde kinderen. Na behandeling van de kinderen aan de hand van gewichtsgroepen voor tenminste 4 weken werden er diverse bloedmonster afgenomen gedurende 12 uur. Nevirapine concentraties waren hoger en meer wisselend dan die in volwassenen. De nevirapine dalconcentratie was subtherapeutisch (<3.0 mg/L) in vier (6%) kinderen. De farmacokinetische parameters van stavudine en lamivudine waren vergelijkbaar met die in volwassenen. Er was geen bewijs voor een verschil in nevirapine blootstelling tussen de gewichtsgroepen, terwijl het verschil in blootstelling aan stavudine en lamivudine werd veroorzaakt door de enige gewichtsgroep met ongelijke ochtend- en avonddoserings (15-<20kg).
Omdat nevirapine onderdosering van grotere zorg is dan overdosering, werd geconcludeerd dat de geneesmiddelenvoedertijd in Triomune Baby & Junior geschikt is voor kinderen van tenminste 6 kg. Meer onderzoek is nodig voor kinderen met een gewicht van minder dan 6 kg.

II. Klinische farmacologie in HIV geïnfecteerde volwassenen

In Hoofdstuk 5 werd bekeken of er een mogelijkheid bestaat om concentraties van nevirapine te monitoren (therapeutic drug monitoring, TDM) in een omgeving met beperkte middelen. Een eenvoudige en goedkope dunne laag chromatografie (DLC) methode werd ontwikkeld voor semikwantitatieve detectie van nevirapine speekselconcentraties. De methode werd gevalideerd in een doelpopulatie van 300 Afrikaanse volwassenen met HIV. Gepaarde bloed- en speekselconcentraties van nevirapine werden gemeten met HPLC (high-performance liquid chromatography). Speekselconcentraties werden tevens bepaald met DLC. Negen procent van de patiënten had een subtherapeutische bloedconcentratie van nevirapine. De mediane speeksel/bloed concentratiemiddel van nevirapine was 0.51. De ontwikkelde DLC is een gevoelige, specifieke en robuuste methode voor de detectie van subtherapeutische nevirapine concentraties in speeksel van Afrikaanse HIV geïnfecteerde volwassenen. Het is een aantrekkelijk alternatief voor HPLC om TDM van nevirapine in ontwikkelingslanden mogelijk te maken.

Een éénmalige dosis nevirapine, zoals gebruikt in Afrika ter voorkoming van moeder-op-kind transmissie van HIV, is geassocieerd met de ontwikkeling van resistentie tegen nevirapine. Dit is waarschijnlijk het gevolg van de lange eliminatiehalfwaardetijd van nevirapine in combinatie met een lage barrière tegen resistentie. Het proefonderzoek in Hoofdstuk 6 was gericht op de zoektocht naar enzyminductoren om de eliminatiehalfwaardetijd van nevirapine te bekorten. Na toediening van een éénmalige 200-mg dosis van nevirapine aan 36 gezonde, niet-zwangere vrouwen in zowel periode 1 als 2, werd twee maal per week gedurende 21 dagen bloed afgenomen ter bepaling van nevirapine concentraties. In periode 2 werden additionele interventies (éénmalige dosis van carbamazepine, fenobarbital of fenytoïne; fenytoïne gedurende 3 of 7 dagen; St Janskruid thee, vitamine A of vitamine D gedurende 14 dagen) toegediend aan alle personen behalve de controlegroep. In drie interventiegroepen verschilde T-half ratio (nevirapine halfwaardetijd in periode 2 / halfwaardetijd in periode 1) significant van de controlegroep: éénmalige 400-mg dosis van carbamazepine, 184 mg fenytoïne één maal daags gedurende 3 dagen of 7 dagen. De gemiddelde daling in nevirapine halfwaardetijd in periode 2 was respectievelijk 35.3, 38.2 en 36.9% in deze groepen. Deze interventies zouden in Afrika getest moeten worden in de setting van een éénmalige dosis nevirapine ter preventie van moeder-op-kind transmissie met het doel de ontwikkeling van nevirapine resistentie te verminderen.

III. Klinische farmacologie bij HIV-TB dubbelinfectie


Hoofdstuk 8 beschrijft de klinische ervaring met het gecombineerd gebruik van lopinavir/ritonavir en rifampicine in Nederland. Vierendertig volwassenen HIV geïnfecteerde patiënten behandeld met bovenstaande combinatie werden voor retrospectieve analyse geselecteerd uit het Nederlandse ATHENA cohort. Van de 34 patiënten, gebruikte 15% een aanbevolen verhoogde dosering van lopinavir/ritonavir en 82% de capsulesformulering van lopinavir/ritonavir. In 68% van de
patiënten werd rifampicine eerder geïntroduceerd dan lopinavir/ritonavir. Van de 23 patiënten op een niet-aangepaste dosering van lopinavir/ritonavir, hadden 4 van de 6 (67%) een subtherapeutische lopinavir dalconcentratie (<1.0 mg/L) en 3 van de 8 (38%) een detecteerbare virale load (≥50 kopieën/ml) na gecombineerde behandeling voor tenminste 4 maanden. Twee van de 5 (40%) patiënten op een aanbevolen verhoogde dosering van lopinavir/ritonavir stoppen vroegtijdig met de geneesmiddelcombinatie in verband met bijwerkingen vs. 4 van de 23 (17%) op een niet-aangepaste dosering en 1 van de 6 (17%) op een licht verhoogde dosering. Een groot prospectief onderzoek in HIV-TB geïnfecteerde patiënten is nodig naar de consequenties van te lage lopinavir blootstelling door niet-aangepaste doseringen van lopinavir/ritonavir en naar de verdraagbaarheid van aanbevolen verhoogde doseringen.

**Algemene discussie**

Het proefschrift wordt afgesloten met een discussie over punten die relevant zijn voor ontwikkelingslanden: toegang tot HIV behandeling, monitoren van HIV behandeling, preventie van moeder-op-kind transmissie van HIV (PMTCT), behandeling van HIV-TB dubbelinfectie, en Noord-Zuid samenwerking met betrekking tot klinisch farmacologisch onderzoek.

Ondanks het feit dat sinds kort de eerste goedkope en adequate FDC kindertabletten beschikbaar zijn voor HIV geïnfecteerde kinderen in ontwikkelingslanden, is het van groot belang dat de ontwikkeling van generieke kinderformuleringen in de toekomst wordt voortgezet. Het is te hopen dat de eenvoudige en goedkope DLC methode die werd ontwikkeld voor de detectie van nevirapine in speeksel binnenkort zal worden geïmplementeerd in ontwikkelingslanden. Voor zolang PMTCT programma’s in ontwikkelingslanden afhankelijk zijn van een éénmalige dosis nevirapine, zou de zoektocht naar interventies voor het verkleinen van het risico opresistenteontwikkeling moeten voortduren. Daarnaast zou er een plek moeten zijn voor verder onderzoek in HIV-TB geïnfecteerde patiënten in ontwikkelingslanden naar de gecombineerde behandeling van HIV en TB. De sleutel tot succes van een Noord-Zuid samenwerking met betrekking tot klinisch farmacologisch onderzoek van HIV behandeling is de complementaire bijdrage van verschillende onderzoekspartners.
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List of publications


Curriculum Vitae
