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Successful pharmacogenetics-based optimization of unboosted atazanavir plasma exposure in HIV-positive patients: a randomized, controlled, pilot study (the REYAGEN study)

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33 **Successful Pharmacogenetics-based Optimization of Unboosted Atazanavir Plasma Exposure**
34 **in HIV-positive Patients: a Randomized, Controlled, Pilot Study (The REYAGEN Study).**

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38

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86 **Synopsis**

87 **Background:** Atazanavir without ritonavir, despite efficacy and tolerability, shows low plasma
88 concentrations that warrant optimization.

89 **Methods:** In a randomized, controlled, pilot trial, stable HIV-positive patients on
90 atazanavir/ritonavir (with tenofovir/emtricitabine) were switched to atazanavir. In the standard dose
91 arm atazanavir was administered as 400 mg once-daily, while according to patients' genetics (*PXR*,
92 *ABCB1* and *SLCO1B1*) in the pharmacogenetic arm: patients with unfavourable genotypes received
93 atazanavir 200 mg twice-daily.

94 **Results:** Eighty patients were enrolled with balanced baseline characteristics. Average atazanavir
95 exposure was 253 ng/mL (150-542) in the pharmacogenetic arm versus 111 ng/mL (64-190) in the
96 standard arm ($p < 0.001$); 28 patients in the pharmacogenetic arm (75.7%) had atazanavir exposure
97 > 150 ng/mL versus 14 patients (38.9%) in the standard arm ($p = 0.001$). Immunovirological and
98 laboratory parameters had a favourable outcome throughout the study with non-significant
99 differences between study arms.

100 **Conclusions:** Atazanavir plasma exposure is higher when the schedule is chosen according to the
101 patient's genetic profile.

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108 INTRODUCTION

109 In the lifelong perspective of anti-HIV treatment, individual tailoring of the antiretroviral regimen is
110 going to be increasingly required. Although never formally approved in Europe, the use of
111 atazanavir without concurrent intake of ritonavir has been shown to be effective and well tolerated
112 in two induction-maintenance clinical trials of relevant size and several retrospective studies.¹⁻⁴
113 However in a significant proportion of patients the pharmacokinetic (PK) exposure of atazanavir
114 might be potentially insufficient to guarantee long-term HIV inhibition.^{5,6} atazanavir lower
115 exposure when combined with tenofovir disoproxil fumarate has been shown in healthy volunteers
116 but subsequently found to be less relevant in HIV-positive patients.⁷⁻⁹ atazanavir pharmacokinetics
117 is significantly influenced by genetic polymorphisms in the region coding for the pregnane X
118 receptor (*PXR*, controlling the expression of several genes involved in drug metabolism and
119 transport); additionally polymorphisms in *ABCB1* (coding for P-glycoprotein) and *SLCO1B1*
120 (coding for OATP1B1) were shown to have a comparable effect on atazanavir exposure.¹⁰⁻¹²
121 Furthermore we observed that the pharmacokinetic exposure of atazanavir was significantly
122 improved when administered 200 mg twice-daily instead of 400 mg once-daily.¹³

123 We report here the results of a randomized comparative study on the clinical use of unboosted
124 atazanavir with or without pharmacogenetic guide in patients also taking co-formulated
125 tenofovir/emtricitabine.

126

127 METHODS

128 HIV-positive adult patients on treatment with atazanavir/ritonavir (300/100 mg) plus
129 tenofovir/emtricitabine with HIV RNA <50 copies/mL for at least six months were eligible for
130 enrolment at two sites in Italy. Switch to atazanavir was proposed for toxicity/tolerability or for
131 simplification, according to physicians' evaluation in clinical practice. Exclusion criteria were:

132 previous virological failure, genotypic resistance-associated mutations, ongoing opportunistic
133 infections/neoplasias, liver cirrhosis, chronic renal failure, self-reported adherence <90% (Visual
134 Scale) and consumption of potentially interacting drugs.

135 The study was approved by the institutional review board at both participating centres, and each
136 participant provided signed informed consent before enrolment; the procedures were in accordance
137 with the ethical standards of the Helsinki Declaration of 1975 (as revised in 1983).

138 The study was a randomized, controlled, open-label, pilot trial. Patients were randomized 1:1
139 (block randomization) to either standard-dose arm ["SD"; atazanavir 400 mg *once daily*] or
140 pharmacogenetic-based arm ["PG"; atazanavir 400 mg *once daily* in patients with favourable
141 genetic profile or atazanavir 200 mg *twice daily* in patients with unfavourable genetic profile]. At
142 enrolment genomic DNA was extracted using QIAamp whole blood mini kit (Qiagen, Valencia,
143 CA, USA) and genotyping was conducted by real time-based allelic discrimination with the use of
144 standard methods (BIORAD, Milano, Italy). The following single nucleotide polymorphisms were
145 analysed: C63396T in *PXR* (rs2472677), C3435T in *ABCB1* (rs1045642) and C521T in *SLCO1B1*
146 (rs4149056). *PXR* 63396 TT, *ABCB1* 3435 CT/TT and *SLCO1B1* 521 TT were codified as 1
147 (associated with lower plasma concentrations). On the basis of the PG results patients were given a
148 score (min zero - max three) and a different dosing schedule according to favourable (≤ 1) or
149 unfavourable genetic profiles (≥ 2).

150 Primary end point was the prevalence of atazanavir average trough concentrations (geometric mean
151 of the first three determinations at weeks 4, 8 and 12) above 150 ng/mL (suggested target plasma
152 level) in the two arms. Secondary end points were the comparison of the proportion of patients with
153 HIV RNA <50 copies/mL and of the changes in indirect bilirubin, total cholesterol, LDL-
154 cholesterol, HDL-cholesterol and triglycerides at 48 weeks.

155 atazanavir trough plasma concentrations [12/24 hours after drug intake according to drug schedule
156 (\pm two hours)] were measured by a previously validated HPLC-PDA (Photo Diode Array) method
157 and performed in Torino.¹⁴

158 A sample size of 80 patients (40 per group) was calculated to provide a statistical power of at least
159 80%, in order to identify a difference in mean atazanavir Ctrough below the MEC of 150 ng/mL
160 between the two study arms. It was assumed a 20% of atazanavir Ctrough under MEC in the PG
161 arm, and a 50% in the control arm from previous studies results.¹⁰⁻¹² Standard non-parametric tests
162 were used for all analysis and performed using SPSS 20.0 software for Mac (SPSS, IBM Inc.).

163

164 **RESULTS**

165 Eighty patients were enrolled (2009-2011): demographic and immunovirological characteristics
166 were well balanced between study arms (Table 1). Patients' disposition is shown in Figure S1: no
167 subject dropped out of the study due to toxicity, virological failure or major clinical events. The
168 prevalence of single nucleotide polymorphisms is reported in Table 1; all variants were in Hardy-
169 Weinberg equilibrium. 27 patients in the PG arm received atazanavir 200 mg twice daily.

170 Atazanavir plasma trough concentrations are shown in Figure S2 and Table S1. Atazanavir Ctrough
171 was slightly higher at baseline in the PG arm [1034 ng/mL (592-1935) versus 587 ng/mL (77-
172 1290), Mann-Whitney $p=0.06$] as compared to SD arm; it was significantly higher at every time
173 point after randomization ($p<0.001$ for all comparisons, Mann-Whitney) in the PG arm.

174 Geometric mean of week 4 to 12 atazanavir Ctroughs was 253 ng/mL (150-542) in the PG arm
175 versus 111 ng/mL (64-190) in the SD arm, favouring the former ($p<0.001$, Mann-Whitney). As for
176 the primary endpoint 28 patients in the PG arm (75.7%) had an average atazanavir Ctrough above
177 150 ng/mL versus 14 patients (38.9%) in the SD arm ($p=0.001$, RR 4.89, 95%CI 1.79-13.38) (Fig.
178 1).

179 No difference in plasma HIV-RNA <50 copies/mL was observed in 37 patients (100%) in the PG
180 arm versus 33 patients (97%) in the SD arm at week 48. Three patients (8.1%) and 4 patients
181 (11.7%) in the PG and SD arm presented a viral blip during the study (p=0.703, Fisher's exact test).
182 Patients in both arms had similar CD4+ T lymphocytes recovery at week 48: 39 cells/mm³ in the
183 PG versus 53 cells/mm³ in the SD arm (p=0.744, Mann-Whitney).

184 At 48 weeks significant decreases (all p<0.05, Wilcoxon's) in safety markers were noted as
185 compared to baseline: no significant differences between study arms were found (Mann-Whitney),
186 (Table S2).

187

188 **DISCUSSION**

189 In this pilot, randomized and controlled study we found that the pharmacokinetic exposure of
190 atazanavir, when co-administered with tenofovir/emtricitabine was significantly higher and closer
191 to the desired target concentration when the frequency of administration was chosen according to
192 the patient's genetic profile. The proportion of patients with atazanavir C_{trough} above the cut-off
193 concentration rose from 40% (previous studies and the standard arm) to 75.7% (study arm) when
194 the frequency of atazanavir administration (400 mg once daily or 200 mg twice daily) was decided
195 on the basis of the individual genotypic profile.¹⁰⁻¹² Although not all patients had a C_{trough} level
196 above the pre-specified cut-off value of 150 ng/mL, the pharmacokinetic exposure in the study arm
197 was found significantly more appropriate than in patients in the control arm. In the PG arm baseline
198 atazanavir levels were higher than those recorded in the SD arm: it is possibly due to unbalanced
199 factors between study arms (such as *CYP3A5* genotype and adherence levels) and unexpected
200 atazanavir exposures according to genotype (Supp.Tab.1) may support this hypothesis.¹⁵ It must
201 however be considered that the 150 ng/mL threshold resulted from the analysis of a moderately
202 experienced population of HIV-infected patients that was no longer formally re-assessed in

203 treatment-naïve patients: it appears possible that it could be lower in patients not harbouring virus
204 with resistance associated mutations and after achieving viral suppression.^{6,16,17} The documented
205 higher intracellular accumulation of atazanavir as compared to other PIs might also support this
206 hypothesis.^{18,19} No significant difference in the prevalence of viral control or in the changes in
207 safety markers between study arms was seen: it is possible the longer follow-up may be required to
208 observe the effect of improved pharmacokinetic exposure or that lower atazanavir concentrations
209 may be adequate.

210 Independently of study arm atazanavir-based regimens were well tolerated and associated with
211 improved safety profiles. Even if the drug is nowadays less used given the availability of safe and
212 very compact antiretroviral regimens it may be very useful in the long-term treatment of HIV-
213 positive patients. The absence of ritonavir (associated with side effect even at low doses) and the
214 uncommon incidence of hyperbilirubinmia (being the main determinant of atazanavir/ritonavir
215 inferior performance in naïve patients) support the attractiveness of atazanavir-containing
216 regimens.²⁰ Even if the need for genetic testing prior to start atazanavir might not be commonly
217 accepted it can be a tool for avoiding unnecessary treatment interruptions and side effects.²¹
218 Although some patients (those with unfavourable genetic profile) would necessitate to take the drug
219 twice daily instead of once daily, the advantage in terms of side effects reduction might compensate
220 the higher frequency of administration.

221 We have to recognize some limitations of this study: the limited sample size, the restricted number
222 of included genetic polymorphisms as well as a casual impaired factors distribution between the
223 study arms, the potential need for therapeutic drug monitoring even in the PG-based arm.

224 Once in a lifetime performed genetic testing offers the possibility to know in advance the likelihood
225 of an individual patient to achieve a more appropriate atazanavir pharmacokinetic exposure and to

226 choose the frequency of administration accordingly; if confirmed, this observation supports the use
227 of pharmacogenetics for treatment tailoring in atazanavir-receiving HIV-positive patients.

228

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251 SB, SR, MS, AD and GDP designed the study and contributed to data collection. AC performed
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253 OV, ML, AT, LM contributed to data collection. AC and MB drafted the first version of the
254 manuscript and finalized the manuscript. JC, MS and AD performed the pharmacokinetic and
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256 contributed to study design, supervision and critical revision of the manuscript for intellectual
257 content. All authors read and approved the final manuscript.

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Characteristic	Standard arm (n= 40)	dose Pharmacogenetic arm (n= 40)	p values
Age (years): median (IQR)	43 (37-47)	44 (38-50)	0.424
Male gender: n (%)	28 (70%)	30 (75%)	0.783
Ethnicity: n (%)			
White	37 (92.5%)	34 (85%)	0.487
Black	1 (2.5%)	3 (7.5%)	
Other	2 (5%)	3 (7.5%)	
BMI (Kg/m ²): median (IQR)	22.9 (20.2-25.3)	23.9 (21-26.2)	0.421
Duration of HIV infection (years): median (IQR)	5.9 (3.7-12.4)	7.3 (3.7-12.3)	0.665
CD4+ T lymphocytes (cells/mm ³): median (IQR)	541 (428-628)	467 (320-600)	0.063
CD4+/CD8+ T lymphocytes ratio: median (IQR)	0.65 (0.53-1.1)	0.60 (0.5-1.29)	0.864
Hepatitis B surface antigen positive: n (%)	6 (15%)	1 (2.5%)	0.049
Hepatitis C antibody positive: n (%)	8 (20%)	8 (20%)	0.823
Single nucleotide polymorphisms: n (%)			
<i>PXR 63396</i> TT	12 (30%)	10 (25%)	0.848
<i>ABCB1 3435</i> CT/TT	28 (70%)	29 (72.5%)	0.364
<i>SLCO1B1 521</i> TT	30 (75%)	33 (82.5%)	0.848
Favorable pharmacogenotypic score (<=1): n (%)	14 (35%)	13 (32.5%)	0.797

348

349 **Table 1. Demographics, immunovirological and pharmacogenetic characteristics of**
350 **randomized patients.** Values were compared between the two arms using Chi-square (Fisher's
351 exact test where appropriate) for categorical values and Mann-Whitney test for continuous variable;
352 two-sided p values are shown in the last column. "IQR": interquartile range.

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370 **Figures:**

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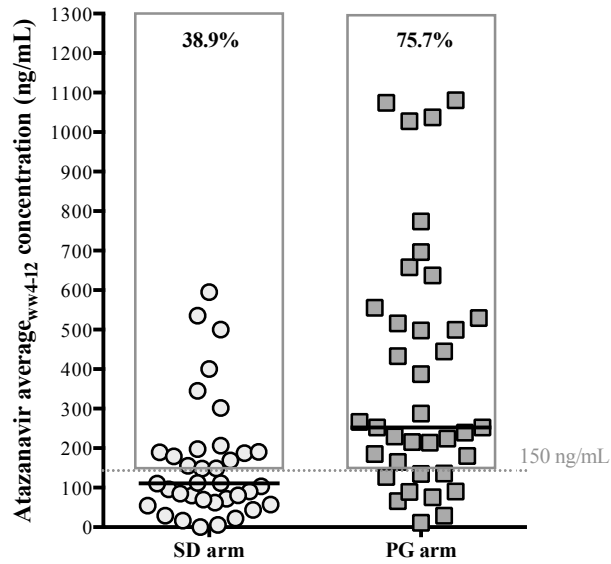
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378 **Figure 1. Atazanavir average concentration (weeks 4 to 12) according to study arm.** Symbols
 379 indicate geometric mean of trough concentration obtained at weeks 4, 8 and 12; the horizontal lines
 380 represent median values. The gray boxes represent the percentage of patients with average exposure
 381 above 150 ng/mL.

382