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1 **Resistance to tenofovir-based regimens during treatment failure of subtype C HIV-1 in South Africa**

2 **Running Head: Tenofovir resistance in subtype C HIV**

3 Authors: Hoffmann, Christopher J (1, 2); Ledwaba, Johanna (3); Li, Jin-fen (4); Johnston, Victoria (5);
4 Hunt, Gillian (3); Fielding, Katherine L (5), Chaisson, Richard E (1); Churchyard, Gavin J (2, 5, 6); Grant,
5 Alison D (5); Johnson, Jeffrey A (4); Charalambous, Salome (2); Morris, Lynn (3)

6 **Affiliations:**

7 (1) Johns Hopkins University School of Medicine, Baltimore, Maryland, USA

8 (2) Aurum Institute, Johannesburg, South Africa

9 (3) Centre for HIV and STIs, National Institute for Communicable Diseases of the National Health
10 Laboratory Services, Johannesburg, South Africa

11 (4) HIV Drug Resistance and Diagnostics Development Unit; Division of HIV/AIDS Prevention; Centers for
12 Disease Control and Prevention

13 (5) London School of Hygiene and Tropical Medicine, London, United Kingdom

14 (6) School of Public Health, University of the Witwatersrand, Johannesburg, South Africa

15

16 **Corresponding author:** Christopher J. Hoffmann, Johns Hopkins University School of Medicine, Division
17 of Infectious Diseases, 1550 Orleans St, CRB II Rm 1M-07, Baltimore, MD 21231, USA

18 tel: 410-614-4257; fax: 410-955-0740; e-mail: choffmann@jhmi.edu

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1 **Abstract**

2 Background: Tenofovir disoproxil fumarate (TDF) is increasingly available for patients infected with
3 subtype C HIV-1. This subtype is reported to develop the principle TDF resistance mutation in the HIV
4 reverse transcriptase, K65R, with greater propensity than other subtypes. We sought to describe K65R
5 development during TDF use in a cohort of patients infected with subtype C HIV.

6 Methods: Using a prospectively followed cohort with 6 monthly HIV RNA assays, we identified virologic
7 failure (defined as an HIV RNA >1000 c/mL) during treatment that included TDF. Residual serum, stored
8 at the time of the HIV RNA assay, was used for consensus sequencing and allele-specific PCR. We
9 assessed prevalence of resistance at failure during TDF-containing treatment and associated factors.

10 Results: Among 1,682 patients on a TDF-containing regimen, 270 developed failure of which 40 were
11 assessed for resistance. By sequencing, the K65R was identified in 5 (12%), major NNRTI mutations in 24
12 (57%), and the M184V/I in 12 (28%) patients. The K65R was associated with lower HIV RNA at failure
13 (HIV RNA \log_{10} 3.3 versus 4.2 c/mL) and prior stavudine exposure. An additional 5 patients had minority
14 K65R populations identified by allele-specific PCR.

15 Conclusions: These data suggest that the K65R prevalence at virologic failure is moderately higher in our
16 subtype C population than some non-subtype C HIV cohorts. However, we did not find that the K65R
17 was highly selected in HIV-1 subtype C infected patients with up to 6 months of failure of a TDF-
18 containing regimen.

19 **Key Words:** HIV, subtype C, resource limited setting, drug resistance, tenofovir, treatment failure, HIV
20 RNA

1 **Background**

2 Tenofovir disoproxil fumarate (TDF) is recommended as a preferred first-line antiretroviral therapy (ART)
3 agent by the World Health Organization (1). TDF is potent, allows once-a-day dosing, and is well
4 tolerated; however, one of the concerns with its use is the potential for regional variation in the
5 development of HIV drug resistance. Subtype C HIV-1, the subtype that predominates in southern Africa
6 and India, has been reported to develop the principle TDF-associated drug resistance mutation, K65R in
7 the HIV reverse transcriptase, more rapidly than other subtypes during *in vitro* selection (2-4). In
8 addition, there may be a higher percentage of minority K65R quasi-species among ART-naïve individuals
9 infected with subtype C compared to subtype B (5). Furthermore, use of stavudine (d4T) selects for the
10 K65R mutation in a higher proportion of patients with subtype C HIV than may have been expected from
11 the subtype B experience (6-9).

12 However, knowledge related to K65R development during treatment with TDF remains limited in
13 settings in which subtype C HIV predominate and results differ widely (10;11). A recent study conducted
14 in Durban, South Africa reported that among 33 patients with virologic failure while receiving a TDF-
15 containing ART regimen, 23 (70%) had the K65R mutation, suggesting an unusually high prevalence of
16 TDF resistance at treatment failure (11). This is in contrast to a report on K65R prevalence at virologic
17 failure from an international collaboration of mostly European cohorts in which the proportion of
18 subtype C HIV with the K65R was 16.2% (10) and a study from multiple African sites in which the
19 prevalence was 27.7% (12). In addition, it is unclear whether there are specific risk factors for the K65R
20 development during treatment failure while on TDF. In order to further examine the selection of K65R
21 in a subtype C population, we described HIV drug resistance, including the prevalence of minority K65R,
22 K70E, and M184V species, and associations with resistance, including prior receipt of either d4T or
23 zidovudine (AZT), among patients at the time of virological failure on a TDF-containing ART regimen.

24

1 **Methods**

2 Patients in this study were part of a multisite workplace and community-based HIV programme
3 managed by a single organization in South Africa (13;14). ART eligibility was based on CD4 count and
4 WHO clinical stage criteria with a CD4 count threshold of <200 cells/mm³ for much of the study period.
5 HIV RNA and CD4 count were determined before ART initiation and every six months thereafter.
6 Residual plasma, when available, was stored at -80°C. The first-line regimen was a combination of either
7 AZT or d4T, lamivudine, and either efavirenz or nevirapine until mid-2007 in the workplace clinics, and
8 mid-2010 in the community clinics. Subsequent to 2007 and 2010, there was a switch to TDF in the
9 workplace and community programmes, respectively. Inclusion criteria for this study were as follows:
10 patients were aged >17 years old and received a TDF-containing ART regimen along with a non-
11 nucleoside reverse transcriptase inhibitor (NNRTI) greater than six months before the study closer date
12 of March 2011, and had at least one HIV RNA value of <400 c/mL while on ART. Patients who
13 underwent a single drug substitution from another NRTI to TDF, while remaining on an NNRTI, were
14 included if the most recent HIV RNA prior to substitution to TDF was <400 c/mL; however, this HIV RNA
15 assay could have occurred several months prior to the switch. Single drug substitutions generally
16 occurred because of side effects, from either nucleoside reverse transcriptase inhibitor (NRTI) d4T or
17 AZT. Follow-up time was censored after March 2011. All laboratory and treatment data were captured
18 prospectively in a monitoring and evaluation database.

19 We defined treatment failure as an HIV RNA >1000 c/mL while on TDF with a prior HIV RNA <400 c/mL
20 after initiating ART (either on TDF or just prior to substitution to TDF). All data were anonymised prior
21 to analysis. Research conformed to the ethical principles set out in the Declaration of Helsinki. Ethical
22 approval was provided by the University of the Witwatersrand, London School of Hygiene and Tropical
23 Medicine, and Johns Hopkins University.

1 *Laboratory*

2 HIV RNA was assayed by polymerase chain reaction (PCR) (Amplicor HIV-1 Monitor Test, Roche
3 Diagnostics, Nutley, New Jersey, USA) or branched chain DNA analysis (Bayer Versant, New York, USA).
4 Genotyping was performed on a stored plasma sample available at the time of first viremia (HIV RNA
5 >1000 c/mL) while on TDF using a validated in-house assay (15). Samples that failed to amplify were re-
6 tested using a nested PCR to obtain a smaller fragment of 1,084 base pairs, as described elsewhere (16).
7 Subtype C allele-specific PCR (AS-PCR) assays were used to detect low-level K65R, K70E, and M184V
8 mutations. The delta cycle thresholds (Δ CT) and the mutation frequency cutoffs were 8.0 and $\geq 2\%$ for
9 K65R, 7.0 and $\geq 0.3\%$ for K70E, and 8.5 and $\geq 0.5\%$ for M184V (5).

10 *Analysis*

11 We compared characteristics at first ART initiation (on AZT, d4T, or TDF containing regimen) and at
12 virologic failure on a TDF-containing regimen based on the first NRTI the patient had received (AZT, d4T,
13 or TDF). We used the Kruskal-Wallis method, for continuous data, and chi-square test, for proportions.
14 We also used the Kruskal-Wallis method to compare CD4 count, HIV RNA, and duration on TDF prior to
15 failure among patients with and without stored plasma. We used non-parametric methods due to small
16 sample sizes with sequencing data. We described the prevalence of mutations and 95% confidence
17 intervals using the binomial exact method. We included the confidence interval of the prevalence of
18 resistance mutations to provide a range of uncertainty for the true prevalence in our cohort, assuming
19 no bias in which patients had samples available. We assessed for association between treatment site,
20 duration on treatment, CD4 count, HIV RNA, prior NRTI exposure, sex, and age and presence of the
21 K65R, M184V, or any major NNRTI mutation, based on the IAS-USA list of drug resistance mutations
22 (17), using non-parametric methods; either the Wilcoxon rank sum test or Fisher's exact test, as
23 appropriate.

24

1 **Results**

2 A total of 1,682 patients met the inclusion criteria, of whom 843 (50%) were male; the median age was
3 37 years (interquartile range [IQR]: 32, 45), and the median CD4 count prior to ART initiation was 194
4 cells/mm³ (IQR: 108, 328; Table 1). TDF was part of the initial regimen for 640 (38%) patients, whereas
5 206 (12%) were switched from AZT, and 836 (50%) were switched from d4T (Table 1). Initial NRTI
6 groups differed by proportion male, age, and CD4 count at ART initiation (all p <0.05). In addition, the
7 median time on ART prior to switching to a TDF-containing regimen was longer for patients started on
8 d4T (791 days) versus started on AZT (639 days; p=0.005).

9 Virologic failure was identified among 270 of the 1,682 patients (16%) while on TDF. The median CD4
10 count, HIV RNA, and time on TDF at virologic failure were similar across the three starting-NRTI groups
11 (Table 1; all p ≥0.1). The overall cohort median time on TDF at virologic failure was 152 days, CD4 count
12 at failure was 199 cells/mm³, and HIV RNA level was 4.3 log₁₀ c/mL. Of the 270 patients with virologic
13 failure, 44 (16%) had stored plasma from the date of first detection of virologic failure. We compared
14 the CD4 count, HIV RNA, and duration on TDF at the time of failure between patients with stored plasma
15 and those without stored plasma. Time on TDF at failure was longer for those with stored samples (261
16 days versus 140 days, p<0.001); whereas CD4 count and HIV RNA at failure were similar between
17 patients with and without stored serum (p>0.1). The median time from the prior suppressed HIV RNA
18 for patients with samples was 177 days (IQR: 124, 209).

19 *Drug Resistance Mutations*

20 Of the 44 patients with available samples from the time of virologic failure, HIV RNA could not be
21 amplified from 4 due to low volume. The 40 patients with amplified HIV RNA were all infected with
22 subtype C HIV-1; 22 (55%) of whom had drug resistance mutations detected by population sequencing
23 (Table 2). NNRTI mutations were the most common (21; 52%), followed by the M184V/I mutation (11,

1 28%; 10 with M184V and 1 with M184I). Five (12%; 95% confidence interval: 4.1-27%) patients had the
2 K65R mutation, four of whom also had the M184V mutation. No patients had the K70E by population
3 sequencing.

4 AS-PCR was completed on 39 of the 40 samples. One sample had insufficient volume for AS-PCR; a
5 sample that contained the K65R and M184V mutations by consensus sequencing. AS-PCR identified the
6 presence of M184V in 10 patients (9 identified by sequencing and one additional patient). Four of the
7 five samples that had the K65R mutation by sequencing also had the K65R mutation detected by AS-PCR
8 (the fifth had insufficient volume for AS-PCR); in addition, five patients who were negative for the K65R
9 by sequencing were positive by AS-PCR. Among individuals with positive AS-PCR for the K65R mutation
10 and with negative consensus sequencing, the median ΔC_T value was 7.4 (IQR: 6.9, 7.4); close to the
11 threshold representing 2% of quasi-species. No K70E mutations were detected by AS-PCR.

12 We evaluated for associations between the presence of the K65R, M184V, or major NNRTI mutations as
13 identified through consensus sequencing. We identified an association between lower HIV RNA at
14 virologic failure and the presence of resistance mutations (Table 3). This was especially notable for
15 patients with the K65R mutation; the HIV RNA IQR was 3.2-3.7 \log_{10} c/mL when this mutation was
16 present compared to 3.1-3.9 \log_{10} c/mL when the M184V mutation was present and 3.2-4.5 \log_{10} c/mL
17 when major NNRTI mutations were present. The five patients with the K65R by sequencing had all
18 received d4T before switching to TDF. Among those with the K65R identified only with AS-PCR, two had
19 received prior d4T, one prior AZT, and two had no history of ART prior to TDF initiation. There was no
20 evidence for associations between HIV drug resistance and sex, age, HIV RNA prior to ART initiation, CD4
21 prior to ART initiation, or workplace versus community program (all $p > 0.1$), although numbers were
22 small leading to a very low power to detect an association.

23

1 Discussion

2 The K65R mutation was present among 12% (confidence interval of 4.1 – 27) of individuals at first
3 detection of virologic failure of a TDF-containing regimen. This prevalence is similar to some prior
4 studies based in clinical cohorts from subtype C or mixed subtype infections, in which the K65R
5 mutations ranged from 0 to 27% and duration on a TDF-containing regimen ranged from 324 to 1000
6 days (8;10;12;18-21). Notably, our results are consistent with a modest increase in K65R associated with
7 subtype C HIV, similar to the 16% prevalence reported in a multi-national analysis of subtype C HIV (10)
8 and with overlapping confidence intervals with another study in Africa in which 27.7% of the 47
9 participants receiving TDF developed the K65R mutation (12). It is notable that our finding is markedly
10 lower than the 70% reported from a study from Durban, South Africa (11) and predictions from some *in*
11 *vitro* studies (2;3;5).

12 Differences in the prevalence of resistance identified in our study and from the Durban study may have
13 arisen for a variety of reasons. Duration on ART at the time of failure is one possibility; however, this is
14 an unlikely explanation as the difference in median time on ART between the studies was small (173 for
15 the Durban study versus 152 days overall for this study and 261 days for those with sequencing) (11). It
16 is plausible that participants who developed virologic failure in our study had stopped taking ART and
17 thus did not maintain a predominant quasi-species that included resistance to TDF, lamivudine, or
18 efavirenz. To further assess the prevalence of K65R with this scenario, we excluded patients without
19 resistance mutations and only included the 22 patients with any mutations. This increased the K65R
20 proportion to 5/22 (23%). This is higher than reports from clinical trials with subtype B (22-24) but still
21 considerably lower than the Durban study. Another approach is to include the low-level K65R mutants
22 detected by AS-PCR, making the assumption that these minority quasi-species were on the way to
23 becoming dominant and were not detected by our consensus sequencing. However, this approach only

1 leads to a prevalence of 25% (10/40). Another possibility could be the use of alternative resistance
2 pathways that may have antagonism toward the K65R, such as TAMS and the K70E (25-27). However,
3 only four patients developed TAMS and no K70E mutations were detected by either population
4 sequencing or AS-PCR, making this an unlikely explanation. Finally, it is possible that a greater
5 proportion of patients in the Durban study had previously received d4T; however, the authors reported
6 that only 10 of the 35 patients had received d4T prior to TDF.

7 Several limitations need to be considered regarding our study. It is likely that some patients took little
8 ART, leading to a high HIV RNA and no resistance mutations. However, we lacked reliable adherence
9 data to assess this. Another limitation is the small number of samples available for resistance assays.
10 We doubt bias influenced which patients had residual stored plasma as samples were missing either
11 because insufficient specimen was sent to the laboratory for plasma storage following HIV RNA assay,
12 samples were stored but were not able to be retrieved, or laboratory personnel failed to store specimen
13 on a given day. The patients with and without stored residual plasma were also similar by CD4 count
14 and HIV RNA, although time on TDF at the time of virologic failure was longer among those with
15 sequencing. A longer duration on a regimen could lead to a higher proportion with resistance
16 mutations. It is also possible that some patients had already developed virologic failure while on a d4T-
17 based regimen and were not virologically suppressed at the time of TDF substitution. Where this
18 occurred, some of the identified mutations, including K65R, may have developed during d4T exposure. It
19 is unclear how this affected our results; however, if d4T did select for the K65R mutation, we may have
20 overestimated the effect of TDF on K65R prevalence. Finally median duration on ART was relatively
21 short. A longer time on ART may lead to an increase in K65R, especially if patients with virologic failure
22 were maintained on a failing regimen for an extended period of time. Despite these limitations, we
23 believe our analysis provides additional valuable information on K65R development in subtype C HIV.

1 In our cohort of patients with subtype C HIV who were receiving regular HIV RNA monitoring while on a
2 TDF-containing ART, NNRTI and M184V mutations predominated while resistance to TDF occurred less
3 frequently. Indeed, it appeared that prior d4T use was a risk for the K65R mutation in this cohort,
4 possibly because the mutation was already being selected during prior d4T use. If prior enrichment is
5 the case, it needs to be considered in selecting second-line agents or alternative first-line agents for
6 individuals with d4T exposure in need of another agent. In the setting of prior d4T exposure, AZT may
7 be a better option than TDF; however, studies are needed comparing second-line treatment options.
8 For patients without prior ART exposure we did not identify any K65R mutations by population
9 sequencing; while re-assuring that this mutation does not appear to develop rapidly, our small sample
10 size and relatively short duration of failure requires circumspection. Our overall finding of a moderately
11 higher prevalence of the K65R mutation among patients with subtype C HIV and virologic failure on a
12 TDF-containing regimen adds to evidence for differences in the development of HIV drug resistance by
13 HIV-1 genotype but is also re-assuring in that we did not find a markedly higher prevalence of the K65R
14 that could have greater clinical importance.

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Table 1: Characteristics by initial ART regimen

	Whole cohort n (%) or median (IQR)	Initial NRTI prior to switch to TDF			p*
		n (%) or median (IQR)			
		AZT	d4T	TDF	
N	1682	206	836	640	
Men	843 (50)	131 (59)	202 (24)	510 (80)	0.0001
Age (years), median	37 (32, 45)	40 (33, 47)	36 (31, 42)	39 (33, 47)	0.0001
CD4 count at ART initiation, cells/mm ³	194 (108, 328)	206 (128, 347)	160 (80, 256)	261 (152, 394)	0.0001
HIV RNA at ART initiation, log ₁₀ c/mL	4.7 (4.5, 4.9)	4.7 (4.4, 4.8)	4.7 (4.6, 4.8)	4.7 (4.5, 5.0)	0.2
Median time on initial NRTI prior to TDF, days		639 (352, 1,005)	791 (445, 1,187)-		0.005
Virologic failures, n	270	56	66	148	
Time on TDF at failure, median, days	152 (97, 222)	152 (106, 222)	160 (93, 219)	141 (91, 224)	0.6
CD4 count at TDF failure, median, cells/mm ³	199 (121, 303)	174 (124, 239)	215 (125, 356)	205 (120, 308)	0.1
HIV RNA at failure on TDF, median, log ₁₀ c/mL	4.3 (3.6, 4.9)	4.4 (4.1, 4.8)	4.1 (3.4, 4.8)	4.3 (3.6, 5.0)	0.2
Number of failures with genotyping	40	8	19	13	
K65R	5	0	5 (26)	0	0.06
M184V	11	2 (25)	7 (37)	2 (15)	0.4

NNRTI	22	6 (62)	11 (58)	5 (38)	0.5
AS-PCR K65R	9	1 (12)	6 (32)	2 (15)	0.5
AS-PCR M184V	10	2 (25)	5 (28)	3 (23)	1.0

NRTI: nucleoside reverse transcriptase inhibitor; AZT: zidovudine; d4T: stavudine; TDF: tenofovir disoproxil fumarate; AS-PCR: allele-specific polymerase chain reaction.

* p for difference between initial NRTI. Comparison of continuous variables using the Kruskal-Wallis method and proportions using the chi-square test.

Table 2: Resistance Mutations

	Population Sequencing	Mutations <i>only</i>
	Number (%; 95% Confidence Interval)	identified by Allele- specific PCR
N	40	
Major NNRTI mutation	21 (52; 36-68)	
K101E	1	
K103N	15	
V106M	4	
V108I	3	
V179D	1	
Y181C	3	
G190A	3	
P225H	3	
F227L	1	
M230L	1	
M184V/I	11 (28; 15-44)	1
K65R	5 (12; 4.1-27)	5
Any TAM	4 (10; 2.8-24)	
M41L	1	
D67N	2	
K70R	1	
L210W	1	
T215Y	1	
K219Q	1	

Table 3: Associations with resistance (identified by sequencing) by mutation

	K65R			M184V			Major NNRTI resistance		
	n or median (IQR)		P*	n or median (IQR)		P*	n or median (IQR)		P*
Mutation present (n)	No (35)	Yes (5)		No (29)	Yes (11)		No (19)	Yes (21)	
Prior ART regimen (n)									
No	12	0	0.3	11	1	0.08	8	4	0.1
Yes	23	5		18	10		11	17	
Prior d4T (n)									
No	21	0	0.02	17	4	0.3	11	10	0.5
Yes	14	5		12	7		8	11	
Total ART duration, days: median (IQR)	935 (624, 1291)	744 (515, 1100)	0.5	840 (536, 1115)	1136 (744, 1515)	0.3	825 (492, 1115)	1064 (700, 1290)	0.2
TDF duration, days, median (IQR)	224 (163, 402)	178 (112, 219)	0.3	235 (151, 402)	198 (168, 262)	0.7	235 (168, 438)	198 (122, 324)	0.5
CD4 at failure, cells/mm ³ , median (IQR)	218 (102, 331)	337 (233, 366)	0.2	159 (58, 350)	163 (79, 218)	0.4	250 (112, 327)	218 (107, 348)	0.9
HIV RNA at genotyping, log ₁₀ c/mL, median (IQR)	4.2 (3.8, 5.0)	3.3 (3.2, 3.7)	0.02	4.3 (3.8, 5.1)	3.4 (3.1, 3.9)	0.004	4.5 (3.8, 5.2)	3.7 (3.2, 4.5)	0.02