Virology Journal

CASE REPORT

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Salvage therapy with an Albuvirtide-based antiretroviral regimen for multi-drug resistant HIV and drug-resistant HBV with renal impairment: a case report

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Abstract

Background The clinical management of HIV, particularly in the context of multi-drug resistance (MDR) and co-infections such as hepatitis B virus (HBV), is notably complex. Here we present a case study of a patient with multi-drug resistant HIV who was co-infected with drug-resistant HBV and suffered from renal insufficiency. We employed an optimized regimen based on the fusion inhibitor Albuvirtide (ABT), combined with highly effective, low nephrotoxicity antiviral drugs for HBV. This approach ultimately achieved effective suppression of both HIV and HBV.

Case presentation A 58-year-old male, diagnosed with HIV in 1997 and co-infected with HBV, experienced renal insufficiency. Due to poor adherence, he developed resistance to nucleoside, non-nucleoside reverse transcriptase inhibitors, and protease inhibitors over nearly two decades, necessitating frequent modifications to his ART regimen. In 2019, HIV RNA rebounded to 1120 copies/mL, prompting resistance testing that revealed high-level resistance to Elvitegravir (EVG), intermediate resistance to Raltegravir (RAL), and potential low-level resistance to Bictegravir (BIC) and dolutegravir (DTG). This led to a strategic overhaul of the ART to ABT + Emtricitabine/Tenofovir Alafenamide (FTC/TAF) + double-dose DTG, resulting in a significant suppression of the HIV. Concurrently, HBV suppression and renal function were well-maintained.

Conclusions This case underscores the potential value of individualized treatment strategies for patients with multidrug-resistant HIV and HBV co-infection complicated by renal impairment. The observed virological control following the use of novel agents such as Albuvirtide (ABT), in combination with second-generation integrase strand transfer inhibitors (INSTIs) like DTG, alongside renal-sparing antivirals, highlights the importance of designing optimized regimens based on resistance profiles and renal function. This personalized and adaptive therapeutic approach may offer clinical benefits in similarly complex scenarios.

Keywords HIV, Multi-drug resistance, Albuvirtide, Hepatitis B virus, Renal impairment

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Introduction

The global landscape of HIV treatment is confronted with the escalating challenge posed by the prevalence of drug-resistant HIV strains, threatening the long-term efficacy of ART and jeopardizing efforts to curb the HIV epidemic [1]. Regions across the world are reporting alarming increases in both acquired and transmitted HIV drug resistance, underscoring the urgent need for innovative treatment strategies, including the utilization of long-acting injectable agents and drugs with novel mechanisms of action, to overcome these resistance barriers. The critical role of routine viral load monitoring and adherence support is emphasized, alongside the necessity for timely regimen adjustments in response to emerging resistance patterns.

As the global community grapples with these challenges, the situation is further complicated by the prevalence of HBV co-infections among individuals living with HIV [2–4], particularly in areas like China, where HBV is endemic. Concurrent infections with HBV have been shown to adversely affect HIV therapy outcomes. HIV and HBV can influence each other's disease progression. HBV infection can synergistically increase HIV replication and transcription, thus accelerating the progression of AIDS [5]. HIV can influence the development of HBV infection and increase the risk of chronic liver disease, cirrhosis, and hepatocellular carcinoma (HCC), affecting the prognosis and course of the disease [6, 7].

In the early era of antiviral treatment for HIV/HBV co-infection, there was a lack of potent anti-HBV drugs such as Tenofovir Disoproxil Fumarate (TDF) or Tenofovir Alafenamide (TAF). When regimens contain only lamivudine (3 TC), HBV-related drug resistance develops easily. This has a significant impact on HBV viral control. Current guidelines recommend 3 TC or FTC plus TDF or TAF as the backbone antiviral components for HIV/HBV co-infected patients [8, 9].

Against this backdrop of multidrug resistance and the compounded challenge of HBV coinfection, the introduction of innovative treatments becomes imperative. Albuvirtide (ABT), a novel long-acting injectable antiretroviral therapy approved by the Chinese National Medical Products Administration (NMPA) in 2018, offers a promising alternative for individuals grappling with the complexities of HIV treatment [10]. As a long-acting peptide fusion inhibitor, ABT works by targeting the hydrophobic groove in the N-terminal heptad repeat (HR1) region of HIV-1 gp41 [11, 12]. This binding prevents the formation of the six-helix bundle structure that is essential for viral fusion, thereby blocking viral entry into CD4+T cells [13]. Through this unique mechanism of action, ABT exhibits broad-spectrum anti-HIV-1 activity in vitro against both wild-type and various drug-resistant HIV-1 strains [14]. Its distinctive molecular target and mechanism make it particularly valuable for treating patients with resistance to conventional antiretroviral drugs.

In this intricate case, the patient was confronted with a formidable array of challenges: the presence of multi-drug resistant HIV, HBV resistance, and consequential renal impairment. This case serves as a testament to the pivotal role of a nimble, patient-centric approach in the management of HIV patients facing multi-drug resistance. It also illuminates the complex interdependence between effective viral suppression and the preservation of renal health.

Case presentation

A 58-year-old male with a diagnosis of HIV in 1997 and concurrent HBV co-infection has been under our meticulous care. He started ART in 1999, but over the past 20 years, his condition has fluctuated due to poor adherence, resulting in resistance to multiple antiviral drugs (including NNRTI, NRTI, and PI). This was confirmed by genotypic resistance testing using the Stanford HIVDB program to identify DRMs and infer resistance to antiretroviral drugs, with sequences classified as susceptible (< 15, including potential resistance) or resistant (15 < = low-level resistance < 30, 30 < = intermediate-level resistance < 60, or high-level resistance ≥ 60) based on their mutation scores [15]. The patient's ART regimen underwent frequent changes, particularly during 2007–2011 when he received 6 different regimens comprising a total of 11 different antiretroviral drugs due to poor adherence.

From 2011 to 2018, his condition stabilized with a consistent regimen of TDF/3 TC/ATV/r/RPV/RAL. In 2018, despite viral suppression, his regimen was changed to FTC/TAF/EVG/c + DRV/r due to concerns about long-term renal function and the availability of more kidney-friendly options. Subsequent regimen changes occurred in 2019 and 2023, with each modification guided by resistance testing results and clinical considerations including his renal status.

In May 2019, while on a regimen of FTC/TAF/EVG/c + DRV/r, his clinical course worsened with a rebound in HIV RNA to 1120 copies/mL and CD4 + T lymphocyte count of 156 cells/μL, moderate RAL resistance, and high EVG resistance, as detailed in Table 1. After careful and thorough consideration, the antiretroviral regimen was changed to ABT (320 mg/dose weekly injection), double-dose DTG (50 mg twice daily), and FTC/TAF (200 mg/25 mg once daily). The choice of double-dose DTG was based on the presence of INSTI resistance mutations. By January 3, 2020, his HIV RNA levels had decreased to below the detectable limit (< 20 copies/mL), and his CD4 + T lymphocyte count had

Table 1 Summary of drug resistance

Test Date	Drug Class	Resistance Mutations	Resistance Level Changes
Jul 2009	NRTI	M41L, E44D, M184 V, L210 W, T215 F	- 3TC: High-Level Resistance - ABC: Intermediate Resistance - AZT: Intermediate Resistance - D4 T: Intermediate Resistance - DDI: Intermediate Resistance - FTC: High-Level Resistance - TDF: Low-Level Resistance
	NNRTI	V106L, Y188L	- DLV: Intermediate Resistance - EFV: High-Level Resistance - ETR: Low-Level Resistance - NVP: High-Level Resistance
	PI	M46I, I47 V, L76 V, V82 F, L10I, E35G, Q58E, I85 V	- ATV: Intermediate Resistance - DRV: Intermediate Resistance - FPV: High-Level Resistance - IDV: High-Level Resistance - LPV: High-Level Resistance - NFV: High-Level Resistance - SQV: Potential Low-Level Resistance - TPV: Intermediate Resistance
Aug 2010	NRTI	M41L, E44D, M184 V, L210 W, T215 F, **K70 AEKT**	- ABC: High-Level Resistance ↑ - AZT: High-Level Resistance ↑ - D4 T: High-Level Resistance ↑ - DDI: High-Level Resistance ↑ - TDF: Intermediate Resistance ↑
	NNRTI	V106L, Y188L	- ETR: Potential Low-Level Resistance ↓
	PI	M46I, I47 V, L76 V, V82 F, **V32I**, L10I, E35G, Q58E, I85 V, **T74ST**	No change reported
May 2019	NRTI	M41L, E44D, M184 V, L210 W, T215 F, K70 AEKT	No change reported
	NNRTI	Y188L	- DOR: High-Level Resistance ↑
	PI	M46I, I47 V, L76 V, V82 F, **V32I**, L10 F, K20 T, Q58E	- ATV: High-Level Resistance ↑ - DRV: High-Level Resistance ↑ - SQR: Intermediate Resistance ↑
	INSTI	E92Q	- BIC: Potential Low-Level Resistance - DTG: Potential Low-Level resistance - EVG: High-Level Resistance - RAL: Intermediate Resistance

Newly developed mutations are highlighted in bold. All resistance interpretations were analyzed using the Stanford HIV Drug Resistance Database algorithm at the time of genotypic testing. The resistance levels shown reflect the interpretations provided by the algorithm at each testing timepoint. The arrow symbols indicate: ↑ increase in resistance level, ↓ decrease in resistance level

Abbreviations: *3 TC* for Lamivudine, *ABC* for Abacavir, *AZT* for Zidovudine, *D4 T* for Stavudine, *DDI* for Didanosine, *FTC* for Emtricitabine, *TDF* for Tenofovir Disoproxil Fumarate, *DLV* for Delavirdine, *EFV* for Efavirenz, *ETR* for Etravirine, *NVP* for Nevirapine, *DOR* for Doravirine, *ATV* for Atazanavir, *DRV* for Darunavir, *FPV* for Fosamprenavir, *IDV* for Indinavir, *LPV* for Lopinavir, *NFV* for Nelfinavir, *SQV* for Saquinavir, *TPV* for Tipranavir, *BIC* for Bictegravir, *DTG* for Dolutegravir, *EVG* for Elvitegravir, *RAL* for Raltegravir, *NRTI* for Nucleoside Reverse Transcriptase Inhibitors, *NNRTI* for Non-nucleoside Reverse Transcriptase Inhibitors, *PI* for Protease Inhibitors, and *INSTI* for Integrase Strand Transfer Inhibitors

improved to 302 cells/μL. HBV therapy was initiated with lamivudine (3 TC) in 1999 concurrent with HIV treatment. After seven years of treatment, HBV developed YMDD resistance mutations in 2006, leading to a switch from 3 TC to a TDF-containing regimen. During the initiation of TDF therapy in early 2007, there was a transient but significant fluctuation in renal function parameters, with SCr rising sharply and eGFR declining correspondingly. This acute change was likely related to the initial adaptation to TDF treatment, which is known to potentially affect renal function [16, 17]. The patient's renal parameters subsequently stabilized with continued monitoring and supportive care, though a gradual decline in renal function was observed over the following years, eventually necessitating the switch to TAF in 2019.

On March 1, 2007, HBV DNA was controlled to less than 1000 IU/mL. However, there was a notable increase in HBV DNA levels in late 2015, which was successfully managed through continued adherence to the TDF-containing regimen. Due to deteriorating renal function (eGFR decreased to 56 mL/min/1.73 m2 and serum creatinine increased to 132 μmol/L in 2019), the HBV treatment was once again adjusted, settling on a TAF/FTC regimen, which by January 3, 2020, effectively suppressed HBV DNA to below 100 IU/mL.

Throughout his treatment, as depicted in Fig. 1, plasma HIV RNA levels were closely monitored, with significant improvements observed following the introduction of Albuvirtide and the subsequent maintenance of an optimized regimen. Figure 2 details the patient's $CD4^+$T and $CD8^+$T cell counts, demonstrating immunological recovery, while Fig. 3 shows HBV DNA levels, reflecting the effective management of both HIV and HBV infections in light of his complex drug resistance profile. Additionally, Fig. 4 showcases the changes in renal function over time and the impact of therapeutic choices aimed at minimizing further nephrotoxicity.

With sustained HIV and HBV viral suppression maintained for more than three years on the ABT + FTC/TAF + DTG regimen, and considering the patient's improved adherence and stability, the treatment team decided to simplify the regimen by switching from double-dose DTG to Biktarvy (BIC/FTC/TAF) in combination with ABT in 2023. This decision was supported by the absence of virological failure during the previous three years and the low resistance potential to BIC shown in earlier resistance testing (Table 1). The patient has remained stable on the current regimen, demonstrating the effectiveness of our individualized and multidisciplinary approach.

Discussion

The management of multi-drug resistant (MDR) HIV, compounded by HBV co-infection and renal impairment, presents a formidable challenge in clinical practice. This case underscores the critical importance of a comprehensive, multidisciplinary approach, guided by a thorough understanding of resistance patterns and informed by current treatment guidelines. The World Health Organization and the Department of Health and Human Services recommend initial resistance testing and the strategic use of integrase strand transfer inhibitors (INSTIs) or ritonavir-boosted protease inhibitors (PIs) in settings with prevalent non-nucleoside reverse transcriptase inhibitors (NNRTIs) resistance [18, 19]. Tailoring antiretroviral therapy based on individual resistance profiles, ensuring the inclusion of at least two fully active agents, is paramount for achieving and maintaining viral suppression [20].

In this case, the patient's 20-year treatment history, characterized by suboptimal adherence and sequential virologic failures, highlights the profound impact of prolonged antiretroviral therapy exposure on the development of MDR [21]. The emergence of resistance mutations across multiple drug classes, including the

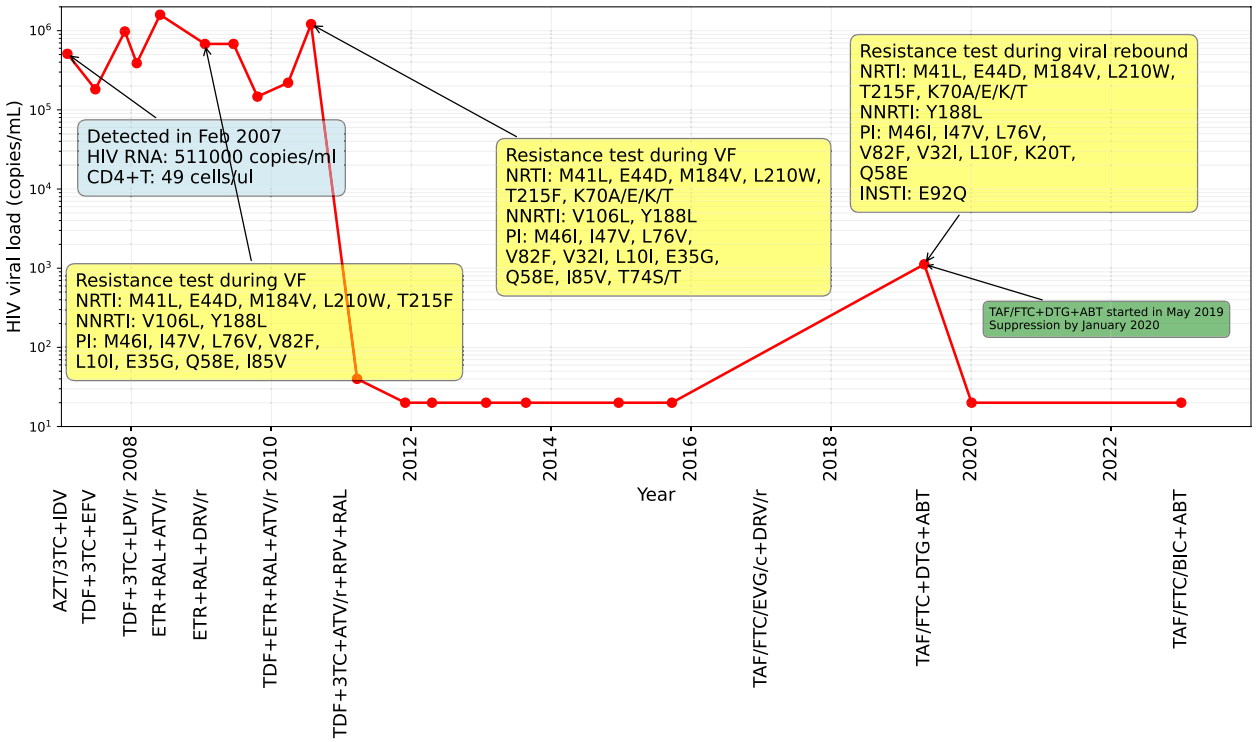

Fig. 1 Temporal Evolution of HIV RNA Levels and Antiretroviral Treatment History This figure illustrates the patient's HIV RNA levels (copies/mL) over time (2007–2023) on a logarithmic scale. Resistance test results during virologic failure (VF) and viral rebound events are indicated in yellow boxes, showing key mutations in NRTI, NNRTI, PI, and INSTI classes. Sequential antiretroviral regimens are shown at the bottom, with significant changes marked by transition points. The initial diagnosis data (Feb 2007) is highlighted in blue, showing baseline HIV RNA and $CD4^+$ T cell counts

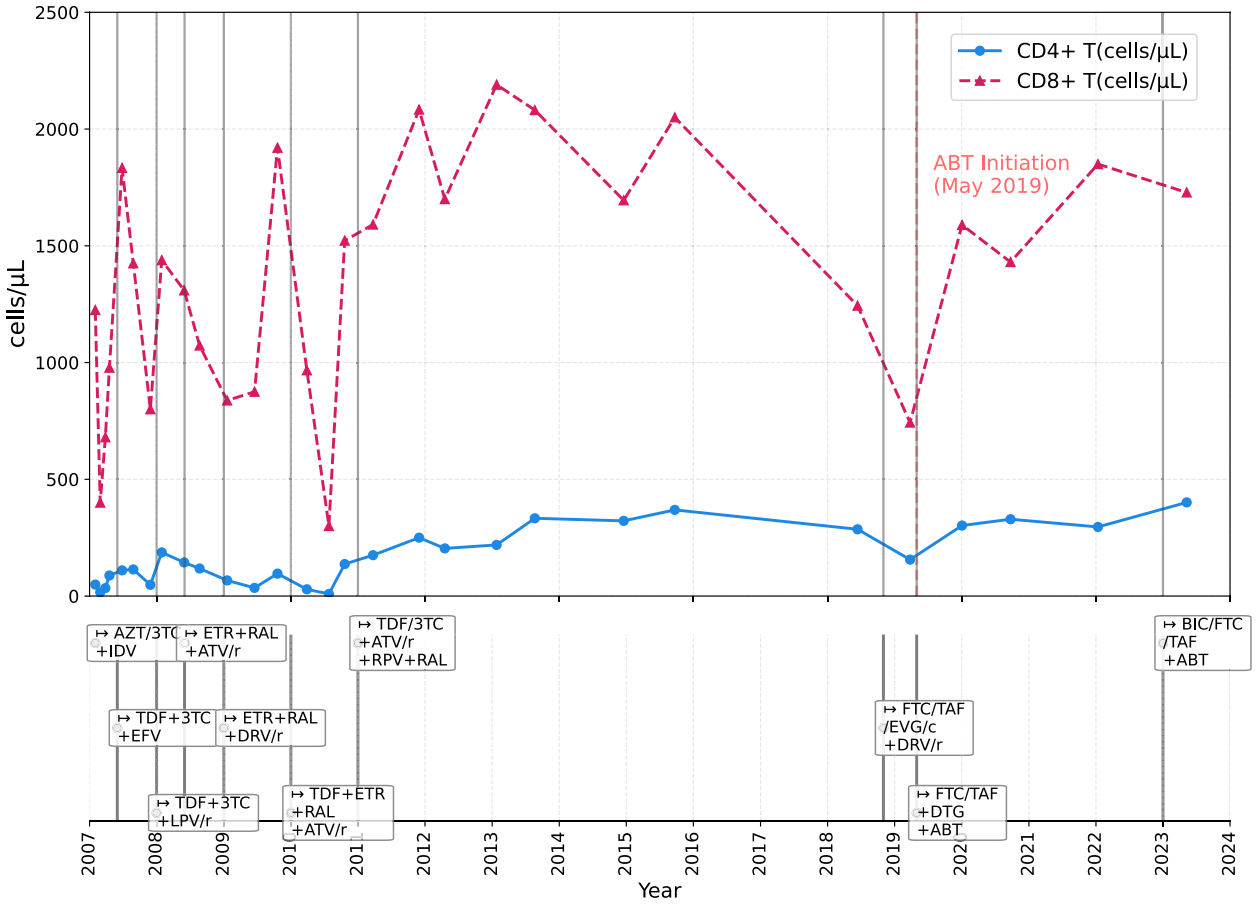

Fig. 2 Dynamics of $CD4^+$ T and $CD8^+$ T Cell Populations. The graph depicts changes in $CD4^+$ T cell (solid blue line with circles) and $CD8^+$ T cell (dashed pink line with triangles) counts (cells/μL) from 2007 to 2023. The vertical dashed line marks the initiation of ABT in March 2019. The bottom panel shows the chronological progression of antiretroviral regimens, demonstrating the evolution of treatment strategies over time

INSTI E92Q mutation, further complicated the therapeutic landscape. The presence of the E92Q mutation in this case presented an interesting clinical interpretation challenge. While this mutation primarily affects elvitegravir susceptibility, its impact on bictegravir (BIC) and dolutegravir (DTG) remains less definitive. According to the Stanford HIV Drug Resistance Database, E92Q confers potential low-level resistance to BIC and DTG, although direct phenotypic evidence for this effect is limited. This discrepancy between algorithmic interpretation and clinical significance influenced our decision to use double-dose DTG initially, following a conservative approach to managing potential resistance. The successful viral suppression achieved with this strategy, and subsequent maintenance with BIC-containing regimen, suggests that the clinical impact of E92Q on second-generation INSTI may be limited when these drugs are used appropriately in optimized regimens. This underscores the critical role of routine viral load monitoring, adherence support, and timely adjustment of treatment regimens based on the evolution of resistance [22].

The strategic introduction of ABT, a long-acting fusion inhibitor, in combination with an optimized background regimen comprising TAF/FTC and DTG, proved pivotal in navigating this complex resistance scenario. ABT's unique mechanism of action, targeting the HIV-1 gp41 glycoprotein, coupled with its high genetic barrier to resistance and lack of cross-resistance to other antiretroviral therapy classes [23], make it a valuable tool in the management of MDR HIV. The sustained viral suppression achieved for two years following the initiation of the ABT-based regimen, despite the patient's history of extensive resistance and suboptimal adherence, underscores the therapeutic promise of this approach [24].

The concurrent presence of HBV infection and renal impairment added layers of complexity to the therapeutic approach. The incorporation of TDF or TAF as part of the antiretroviral therapy regimen has demonstrated efficacy in controlling both HIV and HBV infections,

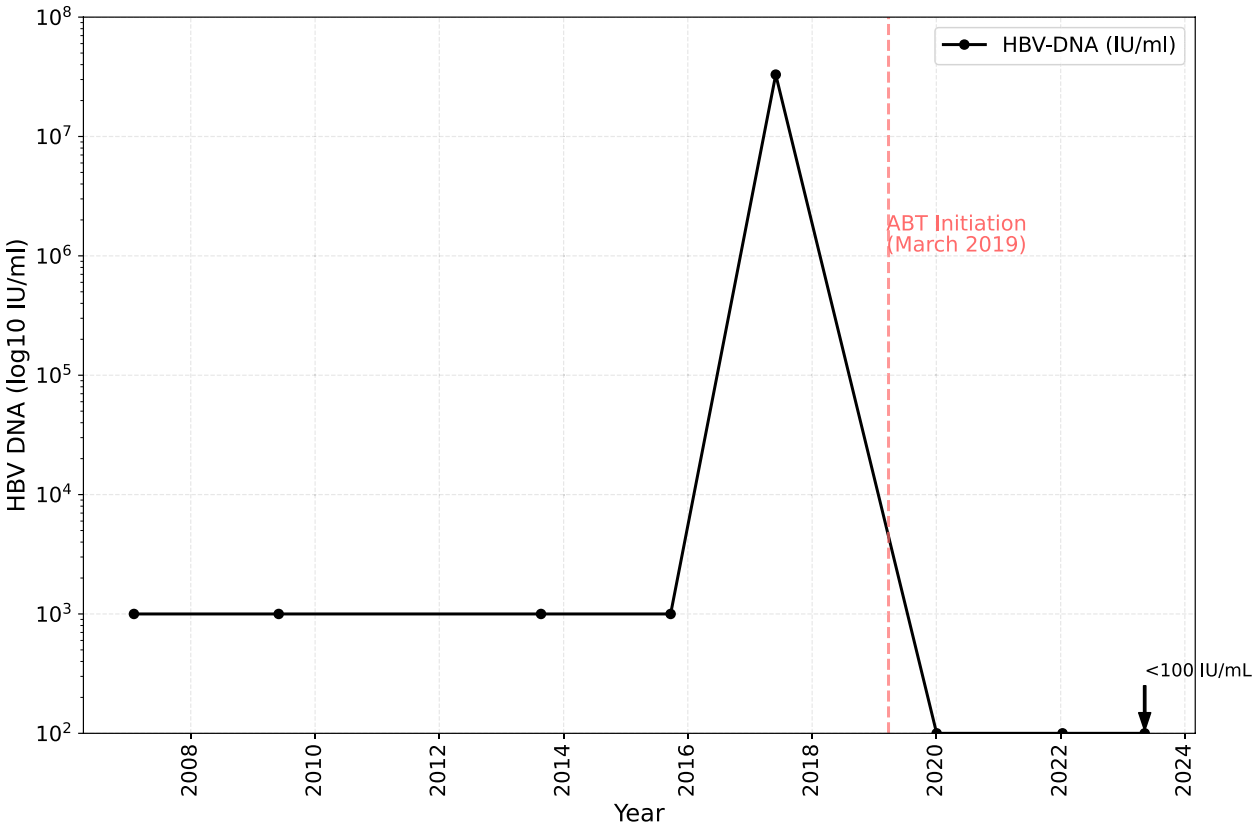

Fig. 3 Longitudinal Monitoring of HBV DNA Levels. Changes in HBV DNA levels (IU/ml) are tracked from 2007 to 2023. The vertical dashed line indicates the initiation of ABT therapy in March 2019. The figure demonstrates periods of viral suppression and a notable peak in viral load, followed by successful suppression after treatment adjustments

with necessary adjustments based on renal function [25]. In this case, the patient presented with early YMDD mutation, leading to HBV drug resistance. TDF and TAF, as potent anti-HBV drugs, have not reported any HBV-related drug resistance to date [26]. Therefore, when the patient developed HBV resistance after 3 TC treatment, switching to TDF, then to TAF due to concomitant renal impairment, maintaining high anti-HBV activity while addressing renal dysfunction was crucial to ensure sustained HBV suppression. Notably, ABT, as a peptide fusion inhibitor that acts extracellularly, does not undergo renal metabolism or excretion, and no significant impact on renal function was observed in this patient during the treatment period, making it a particularly suitable choice for patients with renal impairment.

This case demonstrates that in the face of multiple challenges such as HIV multi-drug resistance, HBV resistance, and renal impairment, the use of ABT for treating HIV infection, concomitant anti-HBV treatment, and renal function protection is key to successful outcomes. Furthermore, enhancing patient education and management to improve treatment adherence is an integral part of the treatment process. ABT is administered as a once-weekly intravenous injection, with fewer injection site reactions and good tolerability [27]. In this case, poor adherence in the early stages was primarily due to the high pill burden. The combination of the single-tablet regimen Biktarvy (BIC/FTC/TAF) with ABT significantly reduced the pill burden, improving adherence and playing a key role in achieving virological suppression. This case provides valuable experience and reference for the treatment of similar complex cases. ABT, as an extracellular fusion inhibitor for treating HIV infection, holds a broad application prospect. Nonetheless, further research into its efficacy, safety, and cost-effectiveness is essential to better serve a wider patient population.

Conclusion

This case demonstrates the potential utility of incorporating long-acting injectable antiretroviral agents such as ABT into individualized treatment strategies for multidrug-resistant HIV, particularly in patients with additional clinical challenges such as HBV resistance and renal insufficiency. In this case, the regimen combining ABT

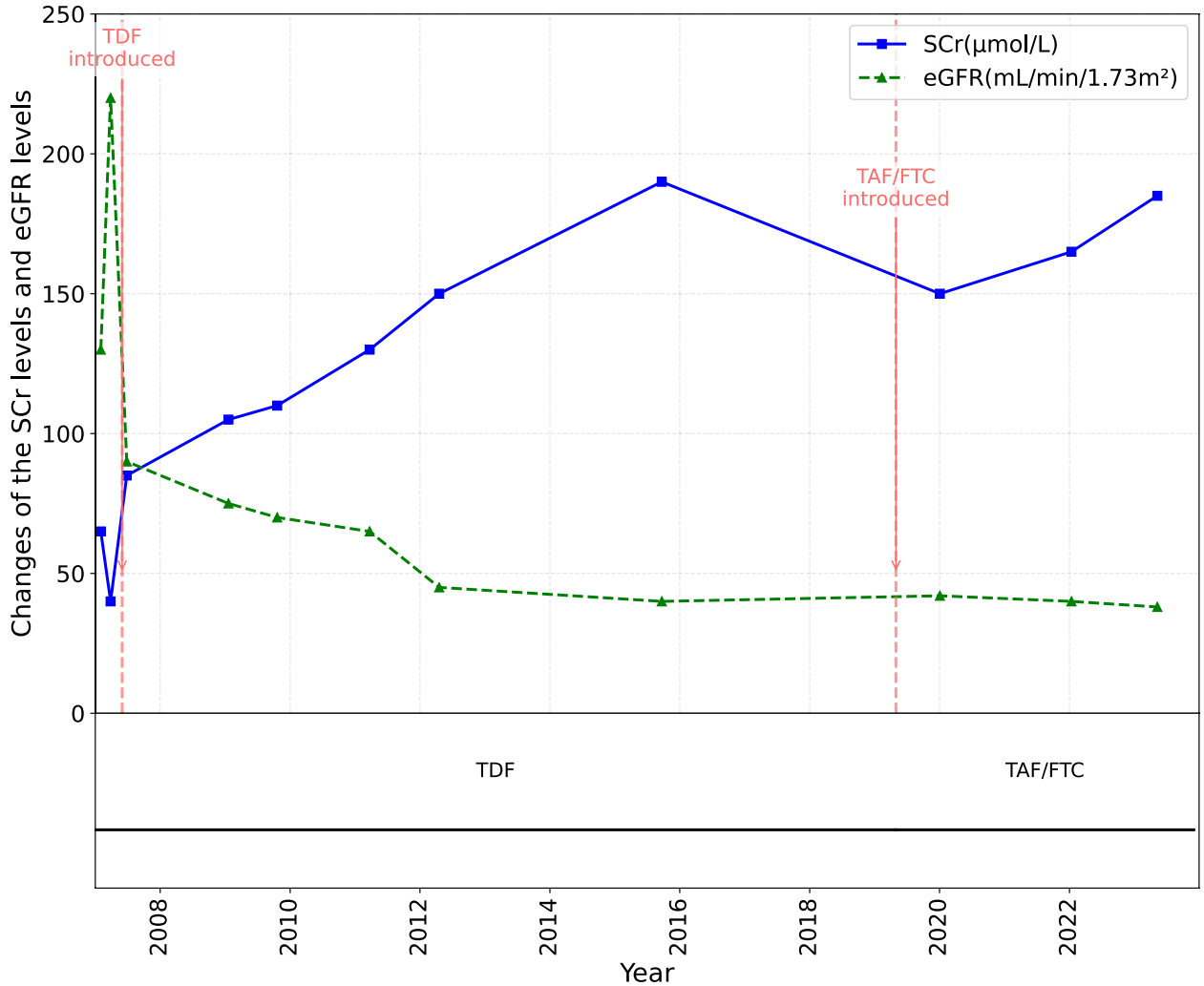

Fig. 4 Evolution of Renal Function Parameters. This figure shows the changes in serum creatinine (SCr, solid blue line with squares) and estimated glomerular filtration rate (eGFR, dashed green line with triangles) from 2007 to 2023. Vertical dashed lines mark the introduction of TDF and TAF/FTC, highlighting the impact of antiretroviral medication changes on renal function. The bottom panel indicates the periods of TDF and TAF/FTC usage

with TAF/FTC and DTG, guided by resistance testing and the patient's overall condition, achieved durable viral suppression and immune recovery without significant adverse effects. These findings highlight the importance of personalized therapy, close monitoring, and timely regimen optimization in the management of complex HIV cases.

Abbreviations

ART	Antiretroviral treatment
VF	Virological failure
PR	Protease
NRTIs	Nucleoside reverse transcriptase inhibitors
RTV	Ritonavir
3 TC	Lamivudine
ABC	Abacavir
ABT	Albuvirtide
ATV/r	Atazanavir/ritonavir
AZT	Zidovudine
BIC	Bictegravir
D4 T	Stavudine
DDI	Didanosine
DLV	Delavirdine
DOR	Doravirine
DRV/R	Darunavir/ritonavir
DTG	Dolutegravir
EFV	Efavirenz
ETR	Etravirine
ETV	Entecavir
EVG	Elvitegravir
FPV/r	Fosamprenavir/ ritonavir
FTC	Emtricitabine
IDV/r	Indinavir/ritonavir
INSTIs	Integrase strand transfer inhibitors
LPV/r	Lopinavir/ritonavir
NFV	Nelfinavir
NNRTIs	Non-nucleoside reverse transcriptase inhibitors
NRTIs	Nucleoside reverse transcriptase inhibitors
NVP	Nevirapine

PIs	Protease inhibitors
RAL	Raltegravir
SQR/r	Saquinavir/ritonavir
TAF	Tenofovir alafenamide
TDF	Tenofovir disoproxil fumarate
TPV/r	Tipranavir/ritonavir

Acknowledgements
We express our sincere gratitude to the patient for consenting to the publication of this case report. We also extend our deep appreciation to the entire medical team involved in the patient's care for their tireless efforts and dedication.
Special thanks go to Frontier Biotechnologies Inc. (Nanjing) for their invaluable support and provision of the novel drug Albuvirtide used in this case. Their commitment to advancing HIV treatment options has been instrumental in achieving the positive outcomes reported here.

Authors' contributions
Y.Z.H was responsible for data collection and analysis, and drafting the initial manuscript. B.L.L. assisted with data collection and analysis and participated in discussions and revisions of the paper. W.P.C. and L.H.L. were responsible for research design, providing literature support and research direction suggestions, and contributed to the writing and revision of the research background and discussion sections. All authors have read and agreed to the published version of the manuscript.

Funding
This work was supported by grants from the National Natural Science Foundation of China (Grant No. 82072265), the Science and Technology Project of Guangzhou (Grant No. 2023 A03 J0792 and 2024 A03 J0880), and the National Key Research and Development Program of China (Grant No.2022YFC2304800).

Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This study was approved by the Ethics Committee of Guangzhou Eighth People's Hospital (approved number: 202033166) and was conducted in accordance with the guidelines of the Declaration of Helsinki and the principles of good clinical practice. We hereby declare that informed consent was obtained from the patient for the publication of all images, clinical data, and other data included in this manuscript. The patient has agreed and fully understands the nature of our study, as well as the use and publication of their data.

Competing interests
The authors declare no competing interests.

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Received: 17 September 2024 Accepted: 14 May 2025
Published online: 19 May 2025

References

1. Gökengin D, Noori T, Alemany A, et al. Prevention strategies for sexually transmitted infections, HIV, and viral hepatitis in Europe. Lancet Reg Health Eur. 2023;34:100738.
2. Yeh ML, Huang CF, Huang CI, et al. Hepatitis B-related outcomes following direct-acting antiviral therapy in Taiwanese patients with chronic HBV/HCV co-infection. J Hepatol. 2020;73(1):62–71.
3. Gobran ST, Ancuta P, Shoukry NH. A Tale of Two Viruses: Immunological Insights Into HCV/HIV Coinfection. Front Immunol. 2021;12:726419.
4. Arora U, Garg P, Agarwal S, et al. Complexities in the treatment of coinfection with HIV, hepatitis B, hepatitis C, and tuberculosis. Lancet Infect Dis. 2021;21(12):e399–406.
5. Gómez-gonzalo M, Carretero M, Rullas J, et al. The hepatitis B virus X protein induces HIV-1 replication and transcription in synergy with T-cell activation signals: functional roles of NF-kappaB/NF-AT and SP1-binding sites in the HIV-1 long terminal repeat promoter. J Biol Chem. 2001;276(38):35435–43.
6. Gruevska A, Moragrega AB, Cossarizza A, et al. Apoptosis of hepatocytes: relevance for hiv-infected patients under treatment. Cells. 2021;10(2):410.
7. Kim HN, Newcomb CW, Carbonari DM, et al. Risk of HCC with hepatitis B viremia among HIV/HBV-coinfected persons in North America. Hepatology (Baltimore, MD). 2021;74(3):1190–202.
8. Council A. Guidelines for the use of antiretroviral agents in adults and adolescents with HIV. J Org Chem. 2021;86(1):693–708.
9. SOCIETY EAC. EACS Guidelines, Version 12.0, October 2023. 2021.
10. Nie J, Sun F, He X, et al. Tolerability and adherence of antiretroviral regimens containing long-acting fusion inhibitor albuvirtide for HIV post-exposure prophylaxis: a cohort study in China. Infect Dis Ther. 2021;10(4):2611–23.
11 Pu J, Wang Q, Xu W, et al. Development of protein- and peptide-based HIV entry inhibitors targeting gp120 or gp41. Viruses. 2019;11(8):705.
12. Chong H, Yao X, Zhang C, et al. Biophysical property and broad anti-HIV activity of albuvirtide, a 3-maleimimidopropionic acid-modified peptide fusion inhibitor. PLoS One. 2012;7(3):e32599.
13 Helmy NM, Parang K. The role of peptides in combatting HIV infection: applications and insights. Molecules. 2024;29(20):4951.
14. Shimura K, Kodama E, Sakagami Y, et al. Broad antiretroviral activity and resistance profile of the novel human immunodeficiency virus integrase inhibitor elvitegravir (JTK-303/GS-9137). J Virol. 2008;82(2):764–74.
15. Rhee SY, Jordan MR, Raizes E, et al. HIV-1 drug resistance mutations: potential applications for point-of-care genotypic resistance testing. PLoS One. 2015;10(12):e0145772.
16. Cooper RD, Wiebe N, Smith N, et al. Systematic review and meta-analysis: renal safety of tenofovir disoproxil fumarate in HIV-infected patients. Clin Infect Dis. 2010;51(5):496–505.
17. Fux CA, Christen A, Zgraggen S, et al. Effect of tenofovir on renal glomerular and tubular function. AIDS (London, England). 2007;21(11):1483–5.
18. World Health Organization. Update of recommendations on first- and second-line antiretroviral regimens: policy brief. Geneva, Switzerland: WHO; 2019. WHO/CDS/HIV/19.15. Available at: https://apps.who.int/iris/handle/10665/325892. Accessed 15 July 2024.
19. Panel on Antiretroviral Guidelines for Adults and Adolescents. Guidelines for the use of antiretroviral agents in adults and adolescents with HIV. Department of Health and Human Services. 2024. Available at: https://clinicalinfo.hiv.gov/en/guidelines/adult-and-adolescent-arv. Accessed 30 Jan 2025.
20. Gupta RK, Gregson J, Parkin N, et al. HIV-1 drug resistance before initiation or re-initiation of first-line antiretroviral therapy in low-income and middle-income countries: a systematic review and meta-regression analysis. Lancet Infect Dis. 2018;18(3):346–55.
21. Lan Y, Li L, He X, et al. Transmitted drug resistance and transmission clusters among HIV-1 treatment-naïve patients in Guangdong, China: a cross-sectional study. Virol J. 2021;18:1–9.
22 Chimukangara B, Lessells RJ, Rhee SY, et al. Trends in pretreatment HIV-1 drug resistance in antiretroviral therapy-naive adults in South Africa, 2000–2016: a pooled sequence analysis. EClinicalMedicine. 2019;9:26–34.
23 Cunha RF, Simões S, Carvalheiro M, et al. Novel antiretroviral therapeutic strategies for HIV. Molecules. 2021;26(17):5305.
24. Aberg JA, Mills A, Moreno S, et al. The evolution of clinical study design in heavily treatment-experienced persons with HIV: a critical review. Antivir Ther. 2023;28(3):13596535231174774.
25. Singh KP, Crane M, Audsley J, et al. HIV-hepatitis B virus coinfection: epidemiology, pathogenesis, and treatment. AIDS. 2017;31(15):2035–52.

26. Liu T, Sun Q, Gu J, et al. Characterization of the tenofovir resistance-associated mutations in the hepatitis B virus isolates across genotypes A to D. Antiviral Res. 2022;203:105348.
27. Su B, Yao C, Zhao QX, et al. Efficacy and safety of the long-acting fusion inhibitor albuvirtide in antiretroviral-experienced adults with human immunodeficiency virus-1: interim analysis of the randomized, controlled, phase 3, non-inferiority TALENT study. Chin Med J (Engl). 2020;133(24):2919–27.

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