Purpose of review
HIV treatment has evolved since the introduction of antiretroviral therapy (ART) in the 1990s. Earlier treatment strategies, and the introduction of integrase inhibitors in preferred first-line ART have fundamentally changed cardiovascular side effects due to HIV infection and ART. This review provides an update on cardiovascular toxicity of contemporary ART.

Recent findings
Cardiovascular disease (CVD) risk, including heart failure, is still increased in people living with HIV (PLWH). Exposure to older antiretrovirals, including stavudine and zidovudine, still impact on CVD risk through persistent changes in body fat distribution years after discontinuation. Protease inhibitors (PI) and efavirenz have associated metabolic disturbances and increased risk of CVD, although use is decreasing worldwide. Integrase inhibitors and CCR5 antagonists seem to have negligible immediate CVD toxicity. Weight gain on newer antiretrovirals including integrase inhibitors is a reason for concern.

Summary
CVD risk should be monitored carefully in PLWH who were exposed to first generation ART, efavirenz or to PIs. Registries should capture ART use and CVD events to stay informed on actual clinical risk in the current era of rapid initiation on integrase inhibitor-based ART.

Keywords
antiretroviral therapy, cardiovascular disease, heart failure, HIV, side effects
KEY POINTS

- CVD risk, including heart failure, is increased up to two times in people living with HIV.
- Exposure to older ART regimens including thymidine analogues impacts negatively on CVD risk, even years after discontinuation.
- The increase in CVD risk relies next to ART also on traditional CVD risk factors and duration of untreated HIV infected.
- Contemporary ART seems to have far less cardiovascular toxicity than older regimens, although weight gain is a concern for INSTIs.
- Nationwide registries should capture ART use and CVD events to stay informed on CVD risk in the current era with timely initiation of contemporary ART.

Contemporary antiretroviral therapy

Currently, there are eight categories of marketed ART, including nucleoside reverse transcriptase inhibitors (NRTIs), non-NRTIs (NNRTIs), protease inhibitors (PI), integrase strand transfer inhibitors (INSTIs), CC-chemokine receptor 5 (CCR5) antagonists, fusion inhibitors, CD4-directed postattachment inhibitors and GP120 attachment inhibitors. International guidelines currently recommend first-line ART combinations including 2 NRTIs, usually tenofovir disoproxil fumarate (TDF), or tenofovir alafenamide (TAF), or abacavir (ABC) with either lamivudine (3TC) or emtricitabine (FTC). This should be combined with an INSTI. An NNRTI or PI with a booster such as ritonavir or cobicistat may be used as an alternative to an INSTI [9]. The World Health Organizations first-line recommendation consists of dolutegravir (an INSTI) with a TDF/3TC backbone, and as alternative low-dose efavirenz to dolutegravir [10].

CARDIOMETABOLIC SIDE EFFECTS

Cardiometabolic side effects differ by ART class and sometimes even by individual drug. A comprehensive overview of metabolic side effects by ART drugs has been described by Hsue et al. [11] and by Dominick et al. [12]. Overall, it is difficult to disentangle the exact effects of HIV and different types of ART on CVD risk. Differences between study populations, changes in regimens, altered adherence over time, and distinct risk profiles by gender and race make association and causation assessments complex. In general, ART toxicity can induce new CVD risk factors or exacerbate the negative impact of existing CVD risk factors like hypertension, insulin resistance, diabetes mellitus, lipid disturbances and obesity [2]. HIV and ART both influence the function of adipose tissue, leading to inflammation and metabolic syndrome. ART has been associated with oxidative damage to DNA, also leading to metabolic syndrome [13].

Of all NRTIs, abacavir has attracted the most clinical concern regarding its CVD risk profile for over a decade. Recent studies show that abacavir is associated with increased risk of myocardial infarction, independent of traditional CVD risk factors [5,14]. This was already seen in the Data Collection on Adverse events of anti-HIV drugs (D:A:D) study in 2010, where use of abacavir, as well as lopinavir (PI), was found to result in altered glucose and lipid metabolism, mitochondrial toxicity, cardiac myopathy and impaired left ventricular function [15]. However, in a pooled analysis of clinical trial data abacavir was not associated with CVD risk in younger people with low CVD risk [16]. This might indicate that the contribution to increased CVD risk is most pronounced in older patients with existing CVD risk factors. The mechanism through which abacavir increases CVD risk is unclear, but may include altered platelet function. Platelet dysfunction is associated with CVD risk. Abacavir is associated with changes in platelet-collagen interaction linked to platelet activation [17,18]. This effect seems to be specific for abacavir as these proinflammatory changes were not observed for TDF and TAF. In the general population, an increased immature platelet fraction has been associated with CVD events. This fraction was increased in ART naïve PLWH but was lower in PLWH on ART, implying that ART reduces CVD risk [19]. More research is needed to unravel the link between ART, platelet function and CVD events.
Toxicity profile of current ART

TAF has been associated with weight gain and treatment related obesity, and TDF wit mitigation of weight gain, although impact on traditional metabolic factors such as glucose or lipids has not been seen [20,21].

Of the NNRTIs efavirenz and rilpivirine are commonly used. Efavirenz is known to increase lipid levels including low-density lipoprotein (LDL) and triglycerides, as well as to promote insulin resistance, with less of an effect by rilpivirine. However, rilpivirine is associated with greater weight gain [21]. Nevirapine, a legacy NNRTI, was regarded to be more lipid friendly as it increased high-density lipoprotein (HDL) to a larger extend than LDL, and did not increase insulin resistance [22].

PI, in general, are associated with an increased risk of CVD including myocardial infarction [23]. The use of PIs has also been linked to increased CVD mortality and 30-day hospital readmission for heart failure [24]. The adverse CVD risk in PIs might partly be caused by disturbances in the lipid metabolism [25]. Atazanavir, unboosted or boosted by ritonavir, is an exception in the PI class as it was not associated with an increased risk of CVD in several studies [23,26]. Compared to darunavir, another PI, and raltegravir (an INSTI), atazanavir had the slowest rate of increase in carotid intima-media thickness (CIMT), an intermediate marker for CVD risk. This effect was hypothesized to be mediated by an increase in bilirubin levels seen in people on atazanavir. Bilirubin is an antioxidant and was found to delay the progression of atherosclerosis [27].

The newer drugs including INSTIs and maraviroc, a virus-entry inhibitor (CCR5 antagonist), have generally, less to no measurable cardiovascular toxicity compared to older ART regimens drugs. Lipid profiles in patients using dolutegravir were significantly better than in people using a ritonavir-boosted PI or efavirenz [28]. In people who switched from a PI based regimen to a raltegravir based regimen lipid levels improved significantly and markers of endothelial damage decreased [29]. However, the main concern for INSTIs is excessive weight gain, and this effect seems to be most pronounced in black women [21]. This topic is discussed in depth in another review in this journal and hence not included in our discussion.

Prolonged use of maraviroc in PLWH was significantly associated with a decline in triglyceride levels and fewer comorbidities compared to nonmaraviroc containing ART over a period of three years, although this was not statistically significant, probably due to the low number of events [30]. However, maraviroc is rarely used in modern ART regimens, due to lack of coformulation and expense, as well as requirements for tropism testing.

ANTIRETROVIRAL THERAPY AND CAROTID INTIMA MEDIA THICKNESS

In multiple publications, ART has been linked to an increase in CIMT, a surrogate outcome marker for CVD. This has been well summarized in a systematic review and meta-analysis by Msoka et al. [31] including publications between 2000 and 2014. In this period ART was initiated when HIV infection had already significantly impaired the immune system, as the CD4 count needed to drop below the preset threshold of 350 or later 500 cells/mm³ before ART could be initiated. Besides, ART regimens in that time were known for mitochondrial toxicity and adverse metabolic effects [2].

The assumption that contemporary ART regimens have less CVD toxicity than older regimens is supported by several recent studies using CIMT. In a multicenter study that was conducted just before the test-and-treat principle was introduced, in a 2 year period CIMT increased more steeply in treatment naïve PLWH than in HIV-negative controls, whereas the rate of CIMT progression for PLWH on ART and HIV-negative controls did not differ. The authors concluded that the increased risk of CVD was due to HIV itself, rather than to side effects of ART [32]. Similarly, our own study from South Africa, which included relatively young PLWH with adequate viral suppression on first-line and second-line therapy, did not find a difference in CIMT nor in carotid distensibility between PLWH and healthy controls [33]. A study from Thailand included PLWH > 45 years, virally suppressed, with a median ART duration of 15 years. They also found no difference in CIMT compared to HIV negative sex and age matched controls [34]. The influence of HIV and ART on CIMT remains a question of debate. A large population survey including participants from different sites in Africa reported a lower CIMT in PLWH on ART compared to HIV negative people [35].

In summary, contemporary ART does not seem to induce relevant cardiovascular toxicity as measured with CIMT. The association between increased CIMT and ART use in older publications may be explained by the then used, more toxic ART regimens, or by significant immune deficiency before ART initiation, with prolonged exposure to a high viral load and hence direct toxicity of HIV on endothelial cells [11].

ANTIRETROVIRAL THERAPY AND METABOLIC CHANGES

Older ART regimens were known to result in lipodystrophy and a change from subcutaneous adipose tissue (SAT) to visceral adipose tissue (VAT). An increase in VAT is strongly associated with insulin resistance.
resistance, metabolic syndrome and CVD. A study from Denmark showed that previous exposure to thymidine analogues, like stavudine and zidovudine, and didanosine, was associated with an increase in VAT compared to PLWH who were never exposed to these drugs. This effect was still visible 9 years after discontinuation of these drugs [36]. Newer ART seems to have a more favourable metabolic profile than older ART, but it is important to consider the ART history when assessing someone’s CVD risk profile.

A study from India, before the introduction of dolutegravir in 2019, reported a prevalence of metabolic syndrome in PLWH of 21.3%, with the highest prevalence in people on a PI-based regimen with a tenofovir backbone [37]. A study from Ethiopia had the same findings: metabolic syndrome was present in 23.5% of all HIV positive participants. Use of ART for more than 6 years and use of older ART regimens, that included stavudine, were both significantly associated with the occurrence of metabolic syndrome [38]. In a study from the United States of America (USA), metabolic syndrome was present in 34% of PLWH, all treated with ART. The prevalence increased with age and was higher in women than in men [39]. The introduction of the INSTIs has raised a new concern as INSTIs, and particularly dolutegravir and bictegravir, are associated with excessive weight gain and fat accumulation, mainly in the trunk, and more in women than in men [21]. The long term impact of weight gain on the occurrence of metabolic syndrome, diabetes mellitus type 2 and CVD risk has yet to be established, but is reason for concern [40].

**ANTIRETROVIRAL THERAPY AND HEART FAILURE**

In the pre-ART period cardiomyopathy with clinically manifest heart failure was frequently observed, and this was strongly linked to early mortality. This changed drastically with the introduction of ART. However, PLWH still have an up to 2 times higher risk of heart failure, both with preserved and reduced ejection fraction, compared to HIV-negative individuals [12]. Sudden cardiac death is also reported more often in PLWH and both heart failure and sudden cardiac death have been associated with low nadir CD4 count and peak viral load levels [41]. The prevalence of systolic dysfunction among PLWH decreased with increasing ART coverage [42]. No specific class of ART was associated with risk of heart failure in a nationwide cohort study in Taiwan [43]. For PLWH who are virally suppressed on ART the risk of sudden cardiac death levels out to the risk seen in the general population [44].

For older ART regimens mitochondrial toxicity impacted negatively on the myocardium and in a cardiac magnetic resonance imaging study in 2012, cardiac steatosis and cardiac fibrosis was seen frequently. Myocardial lipid levels were almost double in PLWH compared to healthy controls and about 75% of PLWH had any degree of myocardial fibrosis [45]. In a recent study, the level of intramyocardial triglycerides was three times higher in women living with HIV who were virally suppressed on ART (42% PI use, 63% INSTI use) than in HIV-negative women, although lipid levels in the blood did not differ. Intramyocardial triglyceride content was adversely related to diastolic function, as well as to viral load and CD4/CD8 ratio but no association with ART duration was seen [46]. A study in South Africa included 134 PLWH virally suppressed on ART and 95 uninfected people. Almost all participants (92%) used an NRTI/NRTI based ART regimen. PLWH had more myocardial fibrosis on cardiac magnetic resonance imaging than HIV-negative people, although in subgroup analysis this effect was only seen in women [47]. A study in the USA included 22 women living with HIV and 14 non-HIV infected women. All women were virally suppressed and the majority was using an INSTI/NRTI based ART regimen. Women living with HIV had more myocardial fibrosis and reduced diastolic function compared to the HIV-negative women [48].

Taken together, in the current ART era the prevalence of heart failure and prestages of heart failure are still higher in PLWH compared to HIV negative people. However, there is no specific ART class or drug that seems to be responsible, but rather HIV related characteristics like (nadir) CD4 count and viral load.

**CONCLUSION**

For newly diagnosed PLWH who are initiated on a contemporary ART regimen early in the course of HIV infection, cardiovascular toxicity might become negligible, unless the weight gain signal related to INSTIs remains an issue. For PLWH who initiated ART when there was already significant immune derailing and/or who were exposed to older ART regimens, there should be awareness of the increased risk of CVD including heart failure. To attenuate this risk strict monitoring and treatment of modifiable CVD risk factors, like dyslipidemia and hypertension, is recommended.

Ongoing monitoring of PWLH, preferably in nationwide registries, is needed to inform CVD risk in the era of contemporary ART and the contribution of weight gain on INSTIs to CVD risk.
HIV infection and coronary heart disease: mechanisms and dyslipidemia, is higher than in the general population. This indicates that temporary ART the prevalence of CVD risk factors, particularly smoking, hypertension and dyslipidemia, is higher than in the general population. This is important as it indicates on macro level that ART becomes more efficient, and that benefits clearly outweigh side effects

This review summarizes the latest evidence around HIV and CVD and the role of ART on the development of metabolic syndrome and cardiovascular disease in people living with HIV. Circulation 2018; 138: 290–299.

This randomized controlled trial shows that upon initiation of dolutegravir PLWH had substantial weight gain, most pronounced in the group that used it in combination with tenofovir alafenamide, and more in women than in men. This urges the need for further research on the clinical consequences of weight gain as dolutegravir is part of first line ART worldwide.

In a pooled analysis of 4 randomized controlled trials INSPIRE was found to result in more weight gain than PIs or NNRTIs. Dolutegravir and bictegravir were associated with more weight gain than elvitegravir/cobicistat, and tenofovir alafenamide resulted in more weight gain than tenofovir disoproxil fumarate. Other factors related to weight gain were black race and female sex. This is important information as the clinical consequences of excessive weight need to be established in future research.

In a Vietnamese population of PLWH 53% of the participants had dyslipidemia. In total 10.5% of the participants were on ritonavir boosted lopinavir, and this drug increased the risk of dyslipidemia more than 3 times. This indicates that PIs are still frequently used and metabolic side effects still an issue of concern in the current ART era.


33. Nonterah EA, Boua PR, Klipstein-Grobusch K, Putcharoen O, Pleumkanitkul S, Chutinet A, alternative in case of excessive weight gain, but more research is needed provides an overview of what is known and research gaps. Doravirine might be an INSTI based regimen and in a cohort of 1208 patients the use of a PI based regimen increased the odds of metabolic syndrome with factor 2. This indicates that metabolic side effects of PI use are still an issue of concern in the current ART era.

Up to the introduction of dolutegravir in 2019 the use of PIs in India was increasing, and in a cohort of 1208 patients the use of a PI based regimen increased the odds of metabolic syndrome with factor 2. This indicates that metabolic side effects of PI use are still an issue of concern in the current ART era.


PLWH in South Africa, virally suppressed on ART (almost all on a NNRTI/NRTI combination) had greater myocardial fibrosis compared to healthy controls, and this effect was most pronounced in women. This is an important finding as the largest part of the HIV positive population resides in sub Saharan Africa. In indicated the need for further research into drivers of myocardial fibrosis, the role of contemporary ART in promoting or reducing cardiac fibrosis and ways to prevent it.


Women with HIV on ART (the majority on INSTI/NRTI based ART) had increased myocardial fibrosis and reduced diastolic function compared to healthy women. In women with HIV and CD4 T cell counts below 400 cells/mm<sup>3</sup> and CD4% below 14%, IL-10 expression was related to cardiac parameters. This prompt further research to understand the increased risk of heart failure and directs research towards immunomodulatory strategies aiming to prevent heart failure in PLWH.