Open Access Library Journal
2026, Volume 13, e15813
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Interleukin-10 and Interferon Gamma Levels in Long Term Antiretroviral Therapy in HIV Infected Children at the Bamenda Regional Hospital

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How to cite this paper: Ngwang, N.F., Ikomey, G.M., Shalanyuy, L.H. and Paul, I. (2026) Interleukin-10 and Interferon Gamma Levels in Long Term Antiretroviral Therapy in HIV Infected Children at the Bamenda Regional Hospital. *Open Access Library Journal*, **13**: e15813.
https://doi.org/10.4236/oalib.1115813

Received: July 27, 2026
Accepted: August 23, 2026
Published: August 26, 2026

Abstract

Background: Human immunodeficiency virus type 1 (HIV-1) infection induces persistent immune dysregulation characterized by alterations in cytokine production, even among children receiving effective antiretroviral therapy (ART). Interferon-gamma (IFN-γ), a key type-1 cytokine involved in antiviral immunity, and interleukin-10 (IL-10), a regulatory type-2 cytokine, play important roles in balancing immune activation and inflammation. However, the impact of HIV infection and long-term ART on these cytokine profiles among children remains incompletely understood. This study evaluated plasma concentrations of IFN-γ and IL-10 among HIV-infected children receiving ART compared with HIV-negative controls. **Methods:** A hospital-based analytical cross-sectional study was conducted among 78 children at Bamenda Regional Hospital, Cameroon, from July to December 2021. Participants included 40 HIV-positive children receiving ART and 38 HIV-negative controls. Plasma concentrations of IFN-γ and IL-10 were quantified using enzyme-linked immunosorbent assay (R&D Systems- Quantikine® ELISA). Demographic and clinical data was collected, and statistical analyses was performed using appropriate comparative and correlation tests, with statistical significance set at $p < 0.05$ in SPSS version 21. Ethical considerations were critically observed. **Results:** The study population was predominantly female (87.2%; n = 68), with children aged 3 - 4 years representing the majority (61.5%; n = 48). Plasma IL-10 concentrations ranged from 16.15 to 551.20 pg/mL and did not differ sig-

nificantly between HIV-positive children and controls (p = 0.08). IL-10 levels showed a very weak positive correlation with viral load (r = 0.044), which was not statistically significant (p = 0.69). Among HIV-positive children, IL-10 concentrations were higher in males (370.96 pg/mL) compared with females (289.38 pg/mL), although this difference was not significant (p = 0.10). Similarly, IL-10 concentrations did not differ significantly between children with viral loads ≤ 40 copies/mL and those with >40 copies/mL (p = 0.69). Plasma IFN-γ concentrations ranged from 2.74 to 432.00 pg/mL and were significantly different between HIV-positive children and controls (p = 0.019). IFN-γ levels were not significantly correlated with viral load (p = 0.34) and showed no significant association with gender (p = 0.49). Among HIV-infected children, IL-10 concentrations were significantly higher than IFN-γ concentrations (319.05 pg/mL vs 168.77 pg/mL; p = 0.001). **Conclusion:** HIV-infected children receiving ART demonstrated persistent alterations in cytokine profiles, characterized by significantly altered IFN-γ responses and a predominance of IL-10 over IFN-γ production. These findings suggest incomplete immune restoration despite ART-mediated viral suppression and highlight the potential role of cytokine monitoring in evaluating immune recovery among children living with HIV.

Subject Areas

Infectious Diseases, Internal Medicine

Keywords

HIV-1, Children, Antiretroviral Therapy, Interferon-Gamma, Interleukin-10, Cytokines, Immune Dysregulation, Cameroon

1. Introduction

Despite remarkable advances in the prevention of mother-to-child transmission (PMTCT) of human immunodeficiency virus type 1 (HIV-1), vertical transmission remains a significant public health challenge, particularly in sub-Saharan Africa where the burden of HIV infection among women of reproductive age remains high. Increasing access to antiretroviral therapy (ART) has substantially reduced the rate of maternal-infant transmission; however, a growing population of HIV-exposed and HIV-infected children continues to experience immunological abnormalities that may persist despite successful viral suppression [1] [2].

The placenta serves as a highly specialized immunological and anatomical barrier that protects the developing fetus against maternal pathogens, including HIV-1. This protection is mediated by its unique double-layered trophoblastic structure comprising cytotrophoblasts and syncytiotrophoblasts, which exhibit limited permissiveness to HIV-1 infection and restrict viral replication [3]. Nevertheless, in-

utero exposure to HIV-1, maternal immune activation, and placental inflammation can alter the fetal immune environment, potentially influencing neonatal immune development and susceptibility to infection [4]. The maternal-fetal interface is therefore recognized as a critical site where host immune responses and viral factors interact to determine the risk of HIV transmission.

Maintenance of a successful pregnancy requires a finely regulated balance between pro-inflammatory and anti-inflammatory immune responses. Cytokines play indispensable roles in establishing this balance, influencing placental development, fetal tolerance, and protection against infectious agents [5]. Among these cytokines, interferon-gamma (IFN-γ), a type-1 helper T-cell (Th1) cytokine, is a potent antiviral mediator that enhances macrophage activation, antigen presentation, and cellular immune responses. Conversely, interleukin-10 (IL-10), a type-2 helper T-cell (Th2) cytokine, exerts anti-inflammatory effects by suppressing excessive immune activation and maintaining immune homeostasis [6]. Alterations in the balance between these cytokines have been implicated in HIV disease progression, viral replication, and maternal-fetal transmission.

Evidence suggests that the placental cytokine milieu influences both susceptibility to HIV infection and pregnancy outcomes. Pro-inflammatory cytokines have been shown to activate HIV-1 proviral expression in trophoblast cells, whereas anti-inflammatory cytokines such as IL-10 may modulate viral replication and placental immune responses [3]. Studies have demonstrated that fetal exposure to HIV-1 may increase IL-10 production in cord blood, while a relatively stronger IFN-γ response has been associated with protection against perinatal HIV infection [7]. These findings indicate that cytokine profiles may serve as important biomarkers of immune competence and disease progression in HIV-exposed and HIV-infected children.

The widespread implementation of ART during pregnancy, labour, and the neonatal period has dramatically reduced perinatal HIV transmission. Landmark clinical trials demonstrated that zidovudine prophylaxis administered during pregnancy, delivery, and the neonatal period reduced vertical transmission by approximately two-thirds, while single-dose nevirapine administered to mothers during labour and to newborns shortly after birth reduced transmission by nearly half [8] [9]. In addition to suppressing maternal viral load, these antiretroviral agents readily cross the placenta, providing both pre- and post-exposure prophylactic effects in the fetus. Emerging evidence further suggests that ART may modify the placental cytokine environment, thereby contributing to immune protection independently of viral suppression [7].

Although ART has transformed HIV infection into a manageable chronic disease, HIV-infected children continue to experience persistent immune dysfunction even after prolonged treatment. Chronic immune activation, residual inflammation, and impaired cytokine production remain common despite sustained virological suppression [10]. The neonatal immune system is intrinsically immature, characterized by reduced production of B lymphocytes, immunoglobulins, com-

plement proteins, IFN-γ, and several interleukins, together with impaired neutrophil and cell-mediated immune functions [11]. HIV infection further exacerbates these deficiencies, increasing susceptibility to opportunistic infections and contributing to long-term immune dysregulation.

Several studies have reported altered circulating concentrations of IFN-γ and IL-10 among HIV-infected adults, pregnant women, and children receiving ART [12] [13]. Reduced production of these cytokines has been associated with impaired antiviral immunity, persistent inflammation, and increased risk of HIV-related complications. Beyond opportunistic infections, chronic immune activation in HIV has been linked to the development of cardiovascular disease, chronic kidney disease, liver disease, osteoporosis, metabolic disorders, non-AIDS-defining malignancies, frailty, and neurocognitive impairment, even among individuals receiving effective ART [14]. Despite these observations, the immunological consequences of long-term ART on cytokine regulation in young HIV-infected children remain insufficiently characterized, particularly in resource-limited settings where the burden of pediatric HIV is greatest.

A better understanding of cytokine dynamics in HIV-infected children may provide valuable insights into immune recovery, disease progression, and treatment monitoring. IFN-γ and IL-10 represent key immunological markers that reflect the balance between antiviral immunity and immune regulation, making them attractive candidates for evaluating immune status in children receiving long-term ART [1] [12]. However, data describing their expression among children aged five years and below on prolonged antiretroviral therapy remain limited. This research is therefore aimed at evaluating the interleukin-10 and interferon gamma levels in long term antiretroviral therapy in HIV infected children at the Bamenda Regional Hospital.

2. Materials and Methods

This hospital-based analytical cross-sectional study was conducted over a six-month period (July-December 2021) at the Bamenda Regional Hospital, Northwest Region, Cameroon. The study population comprised HIV-infected children aged ≤ 5 years receiving long-term antiretroviral therapy (ART) at the hospital's HIV treatment centre and age-matched apparently healthy HIV-negative children recruited from the surrounding community as controls. A convenience sampling technique was employed to recruit eligible participants. The minimum sample size was estimated using the Lorenz formula for prevalence studies at a 95% confidence level and a 5% margin of error, yielding a required sample size of 78 participants. Children aged ≤ 5 years with confirmed HIV infection who had been receiving ART and whose parents or guardians provided informed consent were included. The control group consisted of apparently healthy HIV-negative children aged ≤ 5 years with no recent history of acute illness or antibiotic use. Children with severe concurrent illnesses, chronic inflammatory conditions, or whose parents declined participation were excluded. Approximately 3 - 5 mL of periph-

eral venous blood was collected aseptically into EDTA anticoagulated tubes from each participant. Blood samples were centrifuged to obtain plasma, which was aliquoted and stored at −20˚C until analysis. Plasma concentrations of interferon-gamma (IFN-γ) and interleukin-10 (IL-10) were quantitatively determined using commercially available sandwich enzyme-linked immunosorbent assay (ELISA) kits according to the manufacturer's instructions (R&D Systems- Quantikine® ELISA). Optical density was measured using a calibrated microplate reader, and cytokine concentrations were calculated from standard calibration curves and expressed in pg/mL. Demographic and clinical data, including age, sex, weight, HIV status, ART duration, and relevant clinical characteristics, were obtained from structured questionnaires and/or patients' medical records. Data was entered into Microsoft Excel and analyzed using Statistical Package for the Social Sciences (SPSS) version 21.0 (IBM Corp., Armonk, NY, USA). Continuous variables were summarized as mean ± standard deviation (SD) or median with interquartile range (IQR), depending on data distribution, while categorical variables were presented as frequencies and percentages. Normality of continuous variables was assessed using the Shapiro-Wilk test. Comparison between groups was performed using the independent-samples t-test or Mann-Whitney U test for continuous variables and the Chi-square or Fisher's exact test for categorical variables, as appropriate. Associations between cytokine concentrations and clinical variables were evaluated using Pearson's or Spearman's correlation analysis. Statistical significance was established at a two-sided p-value of <0.05. Ethical approval for the study was obtained from the appropriate Institutional Review Board and administrative authorization was granted by the Bamenda Regional Hospital. Written informed consent was obtained from the parents or legal guardians of all participating children prior to enrolment.

3. Results

3.1. Demographic Characteristics of the Study Population

A total of 78 children were enrolled in the study, comprising 40 (51.3%) HIV-positive children and 38 (48.7%) HIV-negative controls. Overall, the study population was predominantly female, with 87.2% (n = 68) being females compared to 12.8% (n = 10) males. Regarding age distribution, the majority of participants were aged 3 - 4 years (61.5%; n = 48), followed by children aged ≤ 2 years (20.5%; n = 16), while those aged 5 years accounted for 18.0% (n = 14). Among the HIV-positive children, females constituted the majority, representing 90.0% (n = 36), whereas males accounted for 10.0% (n = 4). Most HIV-positive children were 5 years old (60.0%; n = 24), followed by those aged 3 - 4 years (30.0%; n = 12), while children aged ≤ 2 years constituted 10.0% (n = 4). Similarly, the HIV-negative control group was predominantly female, comprising 84.2% (n = 32), while males represented 15.8% (n = 6). Half of the controls were aged 3 - 4 years (50.0%; n = 19), followed by 5-year-old children (31.6%; n = 12), whereas children aged ≤ 2 years accounted for 18.4% (n = 7) (**Table 1**).

Table 1. Demographic characteristics of the study population.

Variable	Characteristic	Frequency (n)	Percentage (%)
Overall gender (n = 78)	Male	10	12.8
	Female	68	87.2
Overall age (n = 78)	≤2 years	16	20.5
	3 - 4 years	48	61.5
	5 years	14	18.0
HIV status (n = 78)	HIV-positive	40	51.3
	HIV-negative (controls)	38	48.7
Gender of HIV-positive children (n = 40)	Male	4	10.0
	Female	36	90.0
Gender of HIV-negative controls (n = 38)	Male	6	15.8
	Female	32	84.2
Age of HIV-positive children (n = 40)	≤2 years	4	10.0
	3 - 4 years	12	30.0
	5 years	24	60.0
Age of HIV-negative controls (n = 38)	≤2 years	7	18.4
	3 - 4 years	19	50.0
	5 years	12	31.6

3.2. Clinical Data

Interleukin-10 Levels in Children

The plasma interleukin-10 (IL-10) concentrations among HIV-positive children aged less than 10 years receiving antiretroviral therapy and the HIV-negative control group ranged from 16.15 pg/mL to 551.20 pg/mL. Although IL-10 levels varied between the two groups, the difference was not statistically significant ($p = 0.08$), indicating that IL-10 concentrations were comparable between HIV-infected children on ART and healthy controls (Figure 1).

Interleukin-10 Levels and Viral Loads

The correlation analysis demonstrated a very weak positive relationship between plasma interleukin-10 (IL-10) concentrations and HIV viral load among HIV-infected children, with viral loads ranging from <40 to 317 copies/mL ($r = 0.044$). However, this association was not statistically significant ($p = 0.69$), indicating that IL-10 concentrations were not significantly correlated with viral load in this study population (Figure 2).

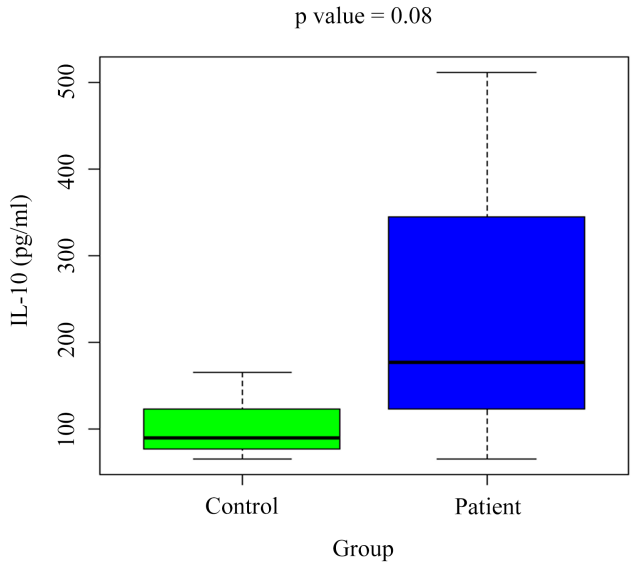

Figure 1. Box plot of interleukin-10 among HIV children and the control group.

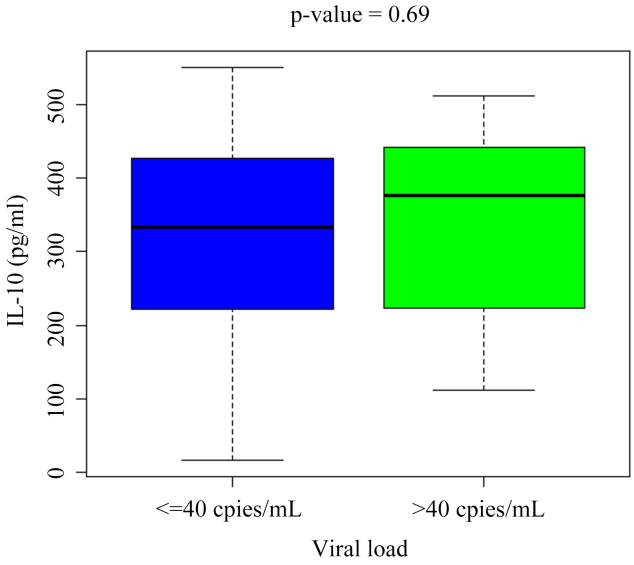

Figure 2. Box plot of interleukin-10 and viral load in HIV positive children.

The plasma interleukin-10 (IL-10) concentrations varied considerably among the study participants. Male participants had a higher mean IL-10 concentration (370.96 pg/mL; 95% CI: 289.04 - 452.87) than females (289.38 pg/mL; 95% CI: 235.68 - 343.07). The median IL-10 concentrations were 416.65 pg/mL in males and 332.10 pg/mL in females, while the maximum concentration observed in both groups was 459.03 pg/mL. However, the difference in IL-10 concentrations between males and females was not statistically significant ($p = 0.10$), indicating that gender was not significantly associated with plasma IL-10 levels. When participants were stratified according to viral load, children with viral loads ≤ 40 copies/mL had a mean IL-10 concentration of 333.20 pg/mL (95% CI: 281.89 - 384.50) and a median of 221.92 pg/mL, with values ranging from 16.15 pg/mL to 551.20

pg/mL. Those with viral loads > 40 copies/mL had a slightly higher mean IL-10 concentration of 376.70 pg/mL (95% CI: 256.78 - 496.61) and a median of 250.65 pg/mL, with concentrations ranging from 112.10 pg/mL to 512.30 pg/mL. Nevertheless, this difference was not statistically significant (p = 0.69), suggesting that plasma IL-10 concentrations were not associated with viral load among HIV-infected children receiving antiretroviral therapy (Table 2).

Table 2. Plasma interleukin-10 (IL-10) concentrations according to gender and viral load among HIV-infected children receiving antiretroviral therapy.

Variable	Category	n (%)	Mean IL-10 concentration (pg/mL)	Median IL-10 concentration (pg/mL)	Range (Min - Max)	p-value
Gender	Male	4 (10.0)	370.96	416.65	123.90 - 459.03	0.10
	Female	36 (90.0)	289.38	332.10	16.15 - 459.03	
Viral load	≤40 copies/mL	-	333.20	221.92	16.15 - 551.20	0.69
	>40 copies/mL	-	376.70	250.65	112.10 - 512.30	

Interferon-Gamma Levels in Children

The plasma interferon-gamma (IFN-γ) concentrations among HIV-positive children aged less than 5 years receiving antiretroviral therapy and the HIV-negative control group ranged from 2.74 pg/mL to 432.00 pg/mL. The difference in IFN-γ levels between the two groups was statistically significant (p = 0.019), indicating that HIV infection and/or long-term antiretroviral therapy was associated with altered IFN-γ production among the study participants (Figure 3).

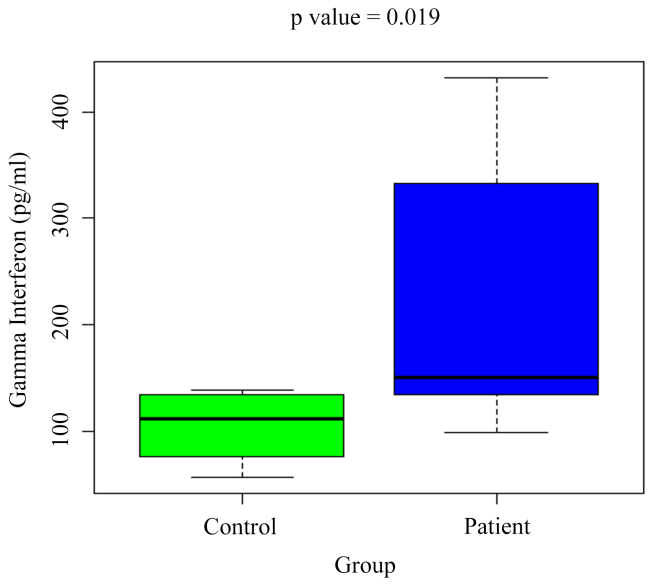

Figure 3. Box plot of Interferon-gamma among HIV children and the control group.

Interferon Gamma Levels and Viral Loads

The correlation analysis between plasma interferon-gamma (IFN-γ) concentrations and HIV viral load among HIV-infected children receiving antiretroviral therapy, with viral loads ranging from <40 copies/mL to 317 copies/mL, showed no statistically significant association (p = 0.34) (Figure 4).

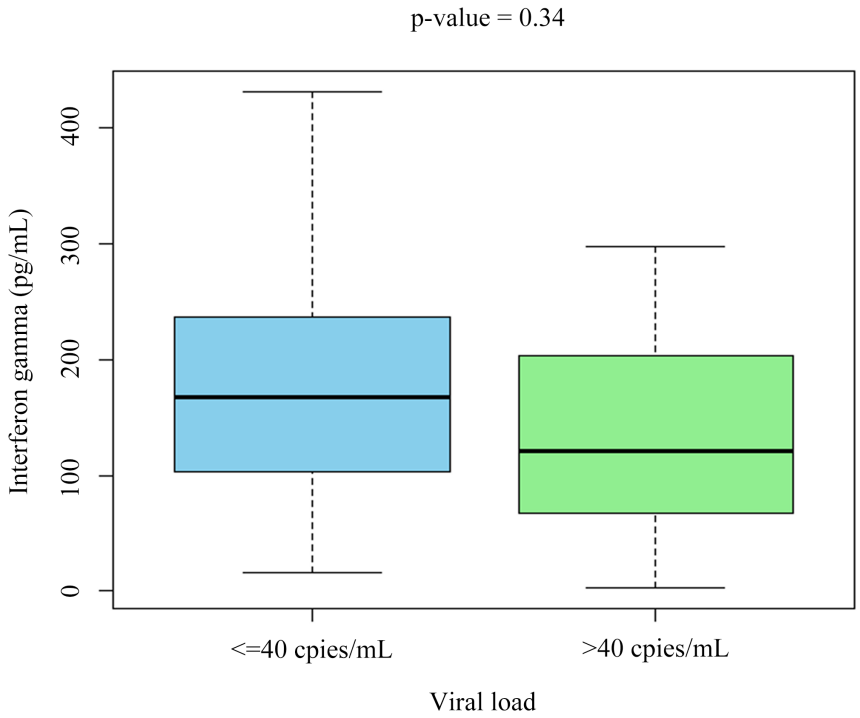

Figure 4. Box plot of Interferon gamma and viral load in HIV patients.

The plasma interferon-gamma (IFN-γ) concentrations varied according to gender among HIV-infected children receiving antiretroviral therapy. Male participants had a higher mean IFN-γ concentration (184.74 pg/mL) compared with females (159.64 pg/mL). The median IFN-γ concentration was 189.60 pg/mL among males and 133.20 pg/mL among females, with observed concentrations ranging from 67.50 - 321.90 pg/mL in males and 2.74 - 432.00 pg/mL in females. However, the difference in IFN-γ levels between males and females was not statistically significant (p = 0.49), suggesting that gender was not associated with variations in IFN-γ production. When stratified according to viral load, children with viral loads ≤ 40 copies/mL had a higher mean IFN-γ concentration (176.11 pg/mL; range: 15.74 - 432.00 pg/mL) compared with those with viral loads > 40 copies/mL (135.72 pg/mL; range: 2.74 - 297.60 pg/mL). The median IFN-γ concentrations were 167.50 pg/mL and 121.55 pg/mL among children with viral loads ≤ 40 copies/mL and >40 copies/mL, respectively. However, this difference was not statistically significant (p = 0.34), indicating that IFN-γ concentrations were not significantly influenced by viral load status among HIV-infected children receiving antiretroviral therapy (Table 3).

Table 3. Plasma interferon-gamma (IFN-γ) concentrations according to gender and viral load among HIV-infected children receiving antiretroviral therapy.

Variable	Category	n (%)	Mean IFN-γ concentration (pg/mL)	Median IFN-γ concentration (pg/mL)	Range (Min - Max)	p-value
Gender	Male	4 (10.0)	184.74	189.60	67.50 - 321.90	0.49
	Female	36 (90.0)	159.64	133.20	2.74 - 432.00	
Viral load	≤40 copies/mL	-	176.11	167.50	15.74 - 432.00	0.34
	>40 copies/mL	-	135.72	121.55	2.74 - 297.60	

The plasma concentrations of interferon-gamma (IFN-γ) and interleukin-10 (IL-10) among HIV-infected children receiving antiretroviral therapy showed considerable variation. The mean IFN-γ concentration was 168.77 pg/mL (median: 145.70 pg/mL; range: 2.74 - 432.00 pg/mL), whereas IL-10 concentrations were comparatively higher, with a mean value of 319.05 pg/mL (median: 333.20 pg/mL; range: 16.15 - 551.20 pg/mL). The difference in plasma concentrations between the two cytokines was statistically significant ($p = 0.001$), indicating that IL-10 levels were significantly higher than IFN-γ levels among HIV-infected children on antiretroviral therapy. This predominance of IL-10 suggests a shift toward an anti-inflammatory cytokine profile, which may reflect persistent immune regulation or suppression of type-1 immune responses despite ongoing antiretroviral treatment (Table 4).

Table 4. Comparison of plasma interferon-gamma (IFN-γ) and interleukin-10 (IL-10) concentrations among HIV-infected children receiving antiretroviral therapy.

Variable	n	Mean concentration (pg/mL)	Median concentration (pg/mL)	Range (Min - Max)	p-value
Interferon-gamma (IFN-γ)	40	168.77	145.70	2.74 - 432.00	0.001
Interleukin-10 (IL-10)	40	319.05	333.20	16.15 - 551.20	

4. Discussion

This study evaluated plasma concentrations of the immunoregulatory cytokines interleukin-10 (IL-10) and interferon-gamma (IFN-γ) among HIV-infected children receiving antiretroviral therapy (ART) compared with HIV-negative controls. The study population consisted predominantly of females (87.2%; n = 68), with HIV-positive children accounting for 51.3% (n = 40) of participants. The predominance of females observed in this study may reflect differences in healthcare-seeking patterns, demographic characteristics of clinic attendees, or chance variation in recruitment. Similar observations of female predominance among pedi-

atric HIV cohorts have been reported in several African settings, although sex distribution may vary depending on study location and recruitment strategies [15]. The majority of participants were aged 3 - 4 years (61.5%; n = 48), with HIV-positive children predominantly aged 5 years (60.0%; n = 24). This age distribution is clinically relevant because early childhood represents a critical period of immune development, during which HIV infection may significantly affect maturation of both innate and adaptive immune responses [16].

The present study demonstrated that plasma IL-10 concentrations among HIV-positive children receiving ART and HIV-negative controls ranged from 16.15 pg/mL to 551.20 pg/mL, with no statistically significant difference between the groups ($p = 0.08$). IL-10 is an important anti-inflammatory cytokine that regulates immune activation by limiting excessive inflammatory responses and maintaining immune homeostasis [6]. Previous studies have demonstrated altered IL-10 production in HIV infection, with increased IL-10 responses proposed as a mechanism that suppresses effective antiviral immunity by reducing T-cell activation and macrophage function [12] [13]. The lack of significant difference in IL-10 concentrations between HIV-infected children on ART and controls in the present study may indicate partial restoration of immune regulation following ART initiation. Effective ART suppresses HIV replication, reduces chronic immune activation, and may contribute to normalization of cytokine profiles over time [10].

The correlation analysis between IL-10 concentrations and HIV viral load demonstrated a very weak positive relationship ($r = 0.044$) that was not statistically significant ($p = 0.69$). This finding suggests that circulating IL-10 levels were not directly influenced by viral burden among children receiving ART. Similar observations have shown that although HIV infection is associated with cytokine dysregulation, cytokine concentrations may not always correlate directly with plasma viral load, particularly among individuals receiving effective ART [12]. The absence of association may be explained by the low viral loads observed in this population, with most children likely achieving virological suppression. ART-mediated reduction in viral replication may decrease the direct stimulatory effect of HIV antigens on cytokine-producing immune cells, thereby weakening the relationship between viral load and IL-10 production [10].

Evaluation of IL-10 concentrations according to gender revealed higher mean levels among males (370.96 pg/mL) compared with females (289.38 pg/mL), although the difference was not statistically significant ($p = 0.10$). Similarly, children with viral loads above 40 copies/mL demonstrated slightly higher IL-10 concentrations (376.70 pg/mL) compared with those with suppressed viral loads ≤ 40 copies/mL (333.20 pg/mL), but this difference was not significant ($p = 0.69$). These findings suggest that neither gender nor virological suppression status significantly influenced IL-10 production in this cohort. Although sex-related differences in immune responses have been described, including variations in cytokine production due to hormonal and genetic factors, such differences may not be detectable in small pediatric populations [17].

In contrast to IL-10, plasma IFN-γ concentrations differed significantly between HIV-positive children receiving ART and HIV-negative controls, ranging from 2.74 pg/mL to 432.00 pg/mL ($p = 0.019$). IFN-γ is a key type-1 immune cytokine responsible for antiviral defense through activation of macrophages, enhancement of antigen presentation, and promotion of cellular immune responses [6]. The observed alteration in IFN-γ levels among HIV-infected children supports previous findings that HIV infection can disrupt Th1 immune responses, even among individuals receiving ART [12] [13]. Persistent immune activation and incomplete immune restoration despite viral suppression may contribute to abnormal IFN-γ production in treated HIV infection [10].

The significant difference in IFN-γ concentrations between HIV-positive children and controls contrasts with the IL-10 findings and may reflect differential effects of HIV infection on type-1 and type-2 immune pathways. Previous studies have suggested that HIV infection may induce a shift from protective Th1-mediated responses toward regulatory or anti-inflammatory immune profiles, characterized by impaired IFN-γ activity and increased regulatory cytokine responses [7]. Since IFN-γ plays an essential role in controlling intracellular pathogens, reduced or dysregulated production may contribute to increased susceptibility to opportunistic infections among HIV-infected children despite ART-mediated viral suppression [11].

Analysis of IFN-γ concentrations according to viral load showed no significant correlation between IFN-γ levels and HIV viral load ($p = 0.34$). Children with suppressed viral loads (≤40 copies/mL) had higher mean IFN-γ concentrations (176.11 pg/mL) compared with those with viral loads > 40 copies/mL (135.72 pg/mL), although the difference was not statistically significant. This observation suggests that immune recovery, rather than viral replication alone, may determine IFN-γ production during ART. Previous studies have reported persistent abnormalities in immune activation markers and cytokine responses despite successful virological suppression, indicating that ART does not completely restore immune function in all individuals [10] [14].

Similarly, gender was not significantly associated with IFN-γ concentrations, despite males demonstrating slightly higher mean levels (184.74 pg/mL) compared with females (159.64 pg/mL) ($p = 0.49$). The lack of statistical significance may be related to the small number of male participants (10.0%; $n = 4$) in the HIV-positive group, limiting the ability to detect subtle sex-related immune differences.

Comparison of the two cytokines among HIV-infected children demonstrated significantly higher IL-10 concentrations (mean: 319.05 pg/mL) compared with IFN-γ (mean: 168.77 pg/mL) ($p = 0.001$). This finding suggests a predominance of anti-inflammatory cytokine activity over type-1 antiviral immune responses in HIV-infected children receiving ART. A relatively increased IL-10/IFN-γ balance may indicate persistent immune regulation and suppression of effective cellular immune responses, which has been described as a characteristic feature of chronic HIV infection [7] [12]. Although ART effectively suppresses viral replication, im-

mune abnormalities, including altered cytokine production, may persist for prolonged periods and contribute to long-term complications associated with treated HIV infection [14].

5. Conclusion

This study demonstrated altered cytokine profiles among HIV-infected children receiving ART, characterized by significantly different IFN-γ levels and a predominance of IL-10 over IFN-γ concentrations. These findings suggest persistent immune dysregulation despite viral suppression and highlight the potential value of cytokine monitoring in assessing immune recovery.

6. Limitations

This study was limited by its relatively small sample size and cross-sectional design, which restricted the ability to establish temporal changes in cytokine levels during ART. Additionally, limited clinical information such as duration of ART, CD4 cell count, nutritional status, and history of opportunistic infections was not evaluated, which may have influenced cytokine concentrations.

Conflicts of Interest

The authors declare no conflicts of interest.

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