

Study to Evaluate Endocrine and Metabolic Disorders in HIV/Aids Patients Attending Art Centre of District Agra

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ABSTRACT

Introduction: Millions of individuals worldwide are impacted by HIV/AIDS, which continues to be a serious global health concern. While antiretroviral therapy (ART) has significantly improved the life expectancy and quality of life for individuals with HIV, its long-term use has given rise to new health challenges, particularly metabolic and endocrine abnormalities. These disorders, including thyroid dysfunction, insulin resistance, dyslipidaemia, and lipodystrophy, are often exacerbated by both the HIV infection and the side effects of ART. Despite significant progress in HIV treatment, limited research exists on the prevalence of these disorders in developing countries, particularly in rural and semi-urban areas of India. This study aims to bridge that gap by analysing various blood parameters, such as lipid profiles, glucose levels, and hormone levels, and examining their correlation with CD4 counts.

Objectives: To estimate the prevalence of endocrine and metabolic disorders in HIV/AIDS infected patients and correlate them with their CD4 count.

Methods: This cross-sectional observational study involved 250 HIV patients at the ART Centre, S.N. Medical College, Agra, from July 2023 to December 2024. Inclusion criteria included confirmed HIV patients above 18 years of age with written informed consent and Exclusion criteria included patients with prior endocrine disorders, comorbidities and those on medications affecting hormone metabolism. Participants were categorized into three groups based on their CD4 count. Laboratory tests were conducted to assess hormonal levels (Free T3, Free T4, TSH, cortisol, FSH, LH, and testosterone), CD4 counts, and metabolic parameters (lipid profile, fasting glucose, HbA1c, and serum electrolytes). Data were collected through laboratory tests and subsequently analysed using IBM SPSS version 26.

Results: A total of 250 HIV/AIDS patients attending the ART Centre of District Agra were included in the study to evaluate endocrine and metabolic disorders. The majority of patients were in the 31-50 years age group (48%) and males comprised of 69.2%. Thyroid dysfunction was observed in a small proportion of patients, with 4.4% exhibiting elevated S.TSH levels, and 7.2% having elevated fT4 levels and only 1.6 % had decreased fT3 levels. Hypogonadism was prevalent, as 75.58% of patients had low testosterone levels ($r = 0.824$, $p = <0.001$). Additionally, 45.2% of patients had low basal cortisol levels ($r = 0.513$, $p = <0.001$), suggesting adrenal insufficiency. Glycaemic abnormalities were notable, with 15.2% of patients showing prediabetes and 2.4% having diabetes.

Dyslipidaemia was widespread, with 53.2% exhibiting elevated triglyceride levels and 16.4% showing low HDL cholesterol. A significant proportion of patients had borderline cholesterol levels (35.6%) and 7.2% had hypercholesterolemia. These findings highlight the high burden of endocrine and metabolic complications in HIV/AIDS.

Conclusion: This study underscores the intricate relationship between immune function and metabolic and hormonal changes in HIV/AIDS patients. Significant associations were observed between CD4 count and testosterone, cortisol, and serum calcium levels, suggesting that immune recovery may positively influence gonadal and adrenal function, as well as calcium homeostasis.

However, no significant correlations were found between CD4 count and other biochemical markers, including FSH, LH, triglycerides, and electrolytes.

Additionally, the study revealed a high burden of metabolic complications, with notable prevalence glycemic abnormalities, and dyslipidemia.

Keywords: HIV, CD4 Count, Endocrinopathies, Metabolic Disorders, Antiretroviral Therapy

Introduction

HIV/AIDS Remains a Major Global Health Concern, Affecting Millions Worldwide

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While antiretroviral therapy (ART) has significantly improved life expectancy and quality of life for those living with HIV, it has also introduced new challenges, particularly the rise of endocrine and metabolic disorders.

The endocrine system, responsible for regulating metabolism, growth, and reproduction, is especially vulnerable in HIV-infected individuals. HIV can directly affect endocrine glands, leading to disorders such as thyroid dysfunction, adrenal insufficiency, and hypogonadism. ART compounds these effects, often exacerbating hormonal imbalances.

Metabolic complications-such as insulin resistance, glucose intolerance, dyslipidemia, and lipodystrophy-are also common. These issues increase the risk of metabolic syndrome, a condition marked by hypertension, central obesity, high blood sugar, and abnormal cholesterol levels, elevating cardiovascular risk.

Certain ART drugs, notably protease inhibitors (PIs) and nucleoside reverse transcriptase inhibitors (NRTIs), are linked to these complications, affecting insulin sensitivity and fat distribution. Consequently, the focus in HIV care is shifting to include the management of non-communicable diseases (NCDs) like diabetes and cardiovascular disease.

Although extensively studied in developed countries, data on the prevalence of endocrine and metabolic disorders in HIV-positive individuals in low- and middle-income countries like India remain limited. Rural and semi-urban regions, in particular, lack targeted research.

District Agra in Uttar Pradesh, with a substantial HIV-positive population attending its ART centre, represents one such region. However, the extent of endocrine and metabolic disorders in this group remains underexplored. There is a pressing need to evaluate these disorders and their correlation with immune markers such as CD4 count.

This Study Aims to Assess the Prevalence of Metabolic and Endocrine Abnormalities Among HIV/Aids Patients at the Agra Art Centre. It will analyse blood parameters including lipid profiles, glucose, thyroid function, and hormone levels, and examine their correlation with CD4 counts. The findings will help inform more comprehensive and region-specific treatment strategies, addressing both HIV management and associated chronic health conditions.

Material and method

Study Design

This was a cross-sectional observational study conducted to assess the prevalence and mechanisms of endocrine and metabolic disorders in HIV/AIDS patients attending the ART Centre at S.N. Medical College, Agra. Data were collected at a single time point, focusing on clinical and laboratory parameters, particularly the correlation between CD4 counts and endocrine/metabolic abnormalities.

Study Setting

The study took place at the outpatient clinic of the Department of Medicine, in collaboration with the ART Centre, S.N. Medical

College, Agra. The centre, equipped with facilities for CD4 count, hormone assays, and metabolic tests, served a diverse cohort of HIV-positive patients, making it ideal for the study.

Study Duration

The study was conducted over 1.5 years, encompassing patient recruitment, sample collection, testing, and data analysis. This duration allowed for comprehensive data acquisition and identification of relevant trends.

Participants-Inclusion and Exclusion Criteria

Inclusion Criteria

- HIV-positive patients (≥ 18 years) per NACO guidelines.
- Newly diagnosed or on ART.
- Provided informed consent.

Exclusion Criteria

- Known endocrine disorders or on hormone therapy.
- Medications affecting hormone metabolism.
- Abnormal liver/renal function.
- Diabetes, alcoholism, active infections, or pregnancy.

Study Sampling

A non-randomized sampling approach was used. Eligible HIV-positive patients visiting the ART Centre during the study period were screened and enrolled upon consent. The aim was to include 250 patients representing a diverse clinical spectrum.

Sample Size

Based on standard cross-sectional sample size calculation methods (considering estimated prevalence, 95% confidence level, and margin of error), a target of 250 participants was established to ensure adequate statistical power.

Study Groups

Participants were categorized based on CD4 count:

- Group A: $<200/\text{mm}^3$ (severe immunosuppression)
- Group B: $200\text{--}350/\text{mm}^3$ (moderate)
- Group C: $>350/\text{mm}^3$ (mild/no immunosuppression)

This stratification enabled assessment of disorder prevalence relative to immune status.

Study Parameters

Key parameters included:

- **Hormonal assays:** Free T3, T4, TSH, cortisol, FSH, LH, testosterone (via Chemiluminescence).
- **CD4 count:** Flow cytometry.
- **Metabolic profile:** Lipid profile, fasting glucose, HbA1c, serum electrolytes.

Study Procedure

After informed consent, patients underwent clinical evaluation and were grouped by CD4 count. Blood samples were collected between 8–9 AM after fasting, processed, and stored at -20°C for testing. Standardized lab methods ensured consistency.

Data Collection

Clinical and laboratory data were recorded on a case report form and entered into Microsoft Excel. All patient information was

anonymized and securely stored to ensure confidentiality.

Data Analysis

Data were analysed using SPSS v26. Descriptive statistics summarized baseline characteristics. Chi-square tests assessed categorical associations, while logistic regression evaluated relationships between hormone/metabolic levels and CD4 count. P-values < 0.05 were considered statistically significant.

Ethical consideration

The study was approved by the Institutional Ethics Committee of S.N. Medical College, Agra. Written informed consent was obtained from all participants after explaining the study's purpose, procedures, and confidentiality measures. Data were anonymized and securely stored. Participation was voluntary, with the option to withdraw at any time without penalty. The study adhered to ethical standards for human research, ensuring respect for patient rights and well-being.

Results

Age Distribution

Among HIV/AIDS patients at the ART Centre in District Agra, the majority (48%) were aged 31–50 years (120 patients), followed by 18–30 years (43.2%, 108 patients), and 51–70 years (8.8%, 22 patients). This indicates that HIV/AIDS primarily affects individuals in early to middle adulthood, necessitating focused interventions for these age groups.

Table: Age Distribution

| Age Group | Frequency | Percent |
|-----------|-----------|---------|
| 18–30 | 108 | 43.2% |
| 31–50 | 120 | 48.0% |
| 51–70 | 22 | 8.8% |

Figure 3: Age Distribution of HIV/AIDS Patients

Gender Distribution

Out of 250 patients, 69.2% were male (173) and 30.8% female (77), showing a higher prevalence of HIV among males. This highlights the need for gender-specific awareness and treatment programs.

Table: Gender Distribution

| Gender | Frequency | Percent |
|--------|-----------|---------|
| Female | 77 | 30.8% |
| Male | 173 | 69.2% |

Figure 4: Gender Distribution of HIV/AIDS Patients

CD4 Count Distribution

A significant portion of patients had CD4 counts <200/mm³ (39.2%, 98 patients), indicating severe immunosuppression. Moderate immunosuppression (CD4 200–350/mm³) was seen in 33.6% (84), while 27.2% (68) had CD4 counts >350/mm³, reflecting relatively preserved immunity.

Table: CD4 Count Distribution

| CD4 Count | Frequency | Percent |
|-----------|-----------|---------|
| <200 | 98 | 39.2% |
| 200–350 | 84 | 33.6% |
| >350 | 68 | 27.2% |

Figure 5: CD4 Count Distribution

S.TSH Distribution

Most patients (95.6%, 239) had normal thyroid function (S.TSH 0.35–4.94 µIU/mL). Only 4.4% (11) had elevated TSH, indicating possible hypothyroidism. While thyroid dysfunction is uncommon, regular monitoring remains important.

Table: S.TSH Distribution

| S.TSH (µIU/mL) | Frequency | Percent |
|----------------|-----------|---------|
| 0.35–4.94 | 239 | 95.6% |
| >4.94 | 11 | 4.4% |

Figure 6: S.TSH Distribution

Ft3 Distribution

Most patients (98.4%, 246) had normal fT3 levels (1.71–3.23 pg/mL), while 1.6% (4) showed low fT3 (<1.71), suggesting rare thyroid dysfunction or non-thyroidal illness. Regular monitoring is still advised.

Table: fT3 Distribution

| fT3 (pg/mL) | Frequency | Percent |
|-------------|-----------|---------|
| <1.71 | 4 | 1.6% |
| 1.71–3.23 | 246 | 98.4% |

Figure 7: fT3 Distribution

Ft4 Distribution

91.6% (229) had normal fT4 (0.7–1.48 ng/dL), 7.2% (18) had elevated fT4 (>1.48), suggesting possible hyperthyroidism, and 1.2% (3) had low fT4 (<0.7), indicating potential hypothyroidism. Thyroid dysfunction was uncommon but present.

Table: fT4 Distribution

| fT4 (ng/dL) | Frequency | Percent |
|-------------|-----------|---------|
| <0.7 | 3 | 1.2% |
| 0.7–1.48 | 229 | 91.6% |
| >1.48 | 18 | 7.2% |

Figure 8: fT4 Distribution

HbA1C Distribution

82% (205) had normal HbA1C (<5.7%), 15.2% (38) were prediabetic (5.7–6.4%), and 2.4% (6) had diabetes (>6.4%). Although most had normal glycemic levels, early intervention is essential for those with impaired glucose regulation.

Table: HbA1C Distribution

| HbA1C (%) | Frequency | Percent |
|-----------|-----------|---------|
| <5.7 | 205 | 82.0% |
| 5.7–6.4 | 38 | 15.2% |
| >6.4 | 6 | 2.4% |

Figure 9: HbA1C Distribution**Total Cholesterol (TC) Distribution**

57.2% (143) had TC <150 mg/dL, 35.6% (89) were in the 150–200 mg/dL range, and 7.2% (18) had TC >200, indicating hypercholesterolemia. Lipid monitoring is vital due to cardiovascular risk.

Table: Total Cholesterol Distribution

| TC (mg/dL) | Frequency | Percent |
|------------|-----------|---------|
| <150 | 143 | 57.2% |
| 150–200 | 89 | 35.6% |
| >200 | 18 | 7.2% |

Figure 10: Total Cholesterol Distribution**LDL Distribution**

42% (105) had LDL <65 mg/dL, 57.6% (144) had LDL 65–170 mg/dL, and only 0.4% (1) had LDL >170, indicating elevated LDL is rare but monitoring remains crucial.

Table: LDL Distribution

| LDL (mg/dL) | Frequency | Percent |
|-------------|-----------|---------|
| <65 | 105 | 42.0% |
| 65–170 | 144 | 57.6% |
| >170 | 1 | 0.4% |

Figure 11: LDL Distribution**HDL Distribution**

Among HIV/AIDS patients, 83.6% had normal HDL levels (35–69 mg/dL), while 16.4% had low HDL (<35 mg/dL), posing increased cardiovascular risk. Regular lipid monitoring and lifestyle changes are essential.

Table: HDL Distribution of HIV/AIDS Patients

| HDL | Percent |
|-------|---------|
| <35 | 16.40% |
| 35–69 | 83.60% |

Figure 12: HDL Distribution**Triglycerides (TG) Distribution**

Hypertriglyceridemia (>140 mg/dL) was found in 53.2% of patients, while 46.8% had normal levels (40–140 mg/dL), indicating a high metabolic risk in this population.

Table: TG Distribution of HIV/AIDS Patients

| TG | Percent |
|--------|---------|
| 40–140 | 46.80% |
| >140 | 53.20% |

Figure 13: TG Distribution**FSH Distribution**

FSH levels were normal (3–12 mIU/mL) in 20.4% of patients. Low FSH (<3) was seen in 7.2%, and high FSH (>12) in 3.6%, suggesting possible gonadal or pituitary dysfunction.

Table: FSH Distribution

| FSH | Percent |
|------|---------|
| <3 | 7.20% |
| 3–12 | 20.40% |
| >12 | 3.60% |

Figure 14: FSH Distribution**LH Distribution**

Normal LH (1–10 mIU/mL) was observed in 24.4% of patients. Low LH (<1) and high LH (>10) were seen in 3.6% and 3.2%, respectively, indicating potential endocrine disturbances.

Table: LH Distribution

| LH | Percent |
|------|---------|
| <1 | 3.60% |
| 1–10 | 24.40% |
| >10 | 3.20% |

Figure 15: LH Distribution**Testosterone Distribution**

Low testosterone (<1.93 ng/mL) was found in 75.6% of patients, indicating a high prevalence of hypogonadism. Normal levels (1.93–7.40) were seen in 23.3%, and high levels (>7.40) in 1.2%.

Table: Testosterone Distribution

| Testosterone | Percent |
|--------------|---------|
| <1.93 | 75.58% |
| 1.93–7.40 | 23.26% |
| >7.40 | 1.16% |

Figure 16: Testosterone Distribution**Basal Cortisol Distribution**

54.8% had normal basal cortisol (5–20 µg/dL), while 45.2% had low levels (<5), indicating a high prevalence of adrenal insufficiency among HIV patients. Regular adrenal function monitoring is recommended.

Table: Basal Cortisol Distribution

<5: 113 (45.2%)
5–20: 137 (54.8%)

Serum Calcium (S. Ca) Distribution

73.2% had normal calcium levels (1.13–1.25 mmol/L), while 26.8% had low levels (<1.13), suggesting risk for hypocalcemia. Routine calcium monitoring is essential.

Table: S. Ca Distribution

<1.13: 67 (26.8%)
1.13–1.25: 183 (73.2%)

Serum Sodium (S. Na) Distribution

Hyponatremia (<135 mmol/L) was found in 57.6% of patients, while 42.4% had normal sodium (135–145). This high rate of electrolyte imbalance warrants regular monitoring.

Table: S. Na Distribution

<135: 144 (57.6%)
135–145: 106 (42.4%)

Serum Potassium (S. K) Distribution

Most patients (92%) had normal potassium (3.5–5.3 mmol/L), while 8% had hypokalemia (<3.5), indicating relatively low prevalence but needing periodic assessment.

Table: S. K Distribution

<3.5: 20 (8.0%)
3.5–5.3: 230 (92.0%)

Correlation Between CD4 Count and S.TSH

A significant negative correlation was observed ($r = -0.212$, $p = 0.001$), indicating that lower CD4 counts are associated with higher S.TSH levels. Thyroid function should be monitored in immunocompromised patients.

Conclusion: Statistically significant ($p < 0.05$)

Correlation Between CD4 Count and fT3

A weak positive correlation ($r = 0.094$) was found, but it was not statistically significant ($p = 0.137$), suggesting no meaningful link between CD4 count and fT3 levels.

Conclusion: Not statistically significant ($p > 0.05$)

CD4 Count and fT4

A weak positive correlation ($r = 0.204$, $p = 0.001$) indicates a statistically significant association between higher CD4 counts and increased fT4 levels.

CD4 Count and HbA1C

A very weak negative correlation ($r = -0.040$, $p = 0.530$) is not statistically significant, suggesting no link between immune status and glycaemic control.

CD4 Count and Total Cholesterol (TC)

A weak positive correlation ($r = 0.288$, $p < 0.001$) shows a significant association between higher CD4 counts and elevated TC levels, possibly due to ART effects.

CD4 Count and LDL

A weak positive correlation ($r = 0.203$, $p = 0.001$) indicates a significant association between CD4 count and LDL levels.

CD4 Count and HDL

A moderate positive correlation ($r = 0.353$, $p < 0.001$) is statistically significant, suggesting improved lipid profile with better immune function.

CD4 Count and Triglycerides (TG)

A weak positive correlation ($r = 0.069$, $p = 0.278$) is not statistically significant, showing no meaningful link between CD4 and TG.

CD4 Count and FSH

A weak negative correlation ($r = -0.046$, $p = 0.688$) is not significant, suggesting no association between CD4 count and FSH levels.

CD4 Count and LH

A weak negative correlation ($r = -0.070$, $p = 0.542$) is not significant, indicating no link between immune status and LH levels.

CD4 Count and Testosterone

A strong positive correlation ($r = 0.824$, $p < 0.001$) is statistically significant, showing a strong association between higher CD4 counts and increased testosterone levels.

CD4 Count and Basal Cortisol

A moderate positive correlation ($r = 0.513$, $p < 0.001$) suggests a significant association between improved immune function and adrenal activity.

CD4 Count and Serum Calcium (S. Ca)

A weak positive correlation ($r = 0.181$, $p = 0.004$) is statistically significant, indicating a potential link between higher CD4 counts and increased serum calcium levels, suggesting improved immune function may enhance calcium homeostasis.

CD4 Count and Serum Sodium (S. Na)

A weak positive correlation ($r = 0.073$, $p = 0.249$) is not statistically significant, showing no meaningful relationship between immune status and sodium levels.

CD4 Count and Serum Potassium (S. K)

A weak positive correlation ($r = 0.071$, $p = 0.263$) is not statistically significant, suggesting no association between CD4 count and potassium levels.

Discussion

This study investigates the relationship between immune function and metabolic/endocrine abnormalities in HIV/AIDS patients at the ART Centre of District Agra. It highlights the impact of HIV and antiretroviral therapy (ART) on calcium metabolism, electrolyte balance, hormonal regulation, and lipid/glucose profiles.

Key Findings

- Immune & Metabolic Correlations
 - o Serum Calcium:
 - o Weak but significant positive correlation with CD4 count ($r = 0.181$, $p = 0.004$), suggesting improved immune function supports calcium regulation.

- o Sodium & Potassium
- o Weak, non-significant correlations with CD4 count ($p > 0.05$), implying no direct immune influence.

• Demographics

- o Age: Most patients are aged 31–50 (48%) and 18–30 (43.2%), highlighting early to mid-adulthood vulnerability.
- o Gender: Males dominate (69.2%), likely due to higher risk behaviours.

• CD4 Count Distribution

- o 39.2% had $CD4 < 200$, indicating severe immunosuppression.

• Thyroid Function

- o 4.4% had elevated S.TSH; 1.6% low fT3; 7.2% high fT4—suggesting occasional dysfunction.

• Glycemic Status:

- o 15.2% prediabetic; 2.4% diabetic. ART and metabolic syndrome may contribute.

• Lipid Profile

- o Total Cholesterol: 35.6% borderline; 7.2% elevated.
- o LDL: 57.6% in normal range; 0.4% elevated.
- o HDL: 16.4% had low HDL (< 35 mg/dL).
- o Triglycerides: 53.2% had elevated levels (> 140 mg/dL).

• Hormonal Profile

- o FSH: 7.2% low, 3.6% high—possible gonadal dysfunction.
- o LH: 3.6% low, 3.2% high—possible pituitary or gonadal issues.
- o Testosterone: 75.58% had low levels, indicating high hypogonadism prevalence.
- o Cortisol: 45.2% had low basal levels, suggesting adrenal insufficiency.

• Electrolytes

- o Calcium: 26.8% low.
- o Sodium: 57.6% had hyponatremia.
- o Potassium: 8% had hypokalemia.

CD4 Count Correlations with Other Markers

- S.TSH: Negative, significant correlation ($r = -0.212$, $p = 0.001$)
- fT4: Weak positive, significant correlation ($r = 0.204$, $p = 0.001$)
- fT3 & HbA1C: Weak, non-significant correlations.

• Lipids

- o Total Cholesterol: Positive correlation ($r = 0.288$, $p < 0.001$)
- o LDL: Positive ($r = 0.203$, $p = 0.001$)
- o HDL: Strongest correlation ($r = 0.353$, $p < 0.001$)
- o Triglycerides: Weak, non-significant

• Hormones

- o FSH & LH: Weak, non-significant negative correlations
- o Testosterone: Strong positive correlation ($r = 0.824$, $p < 0.001$)
- o Cortisol: Moderate positive correlation ($r = 0.513$, $p < 0.001$)

• Electrolytes

- o Calcium: Weak but significant positive ($r = 0.181$, $p = 0.004$)
- o Sodium & Potassium: Weak, non-significant correlations

Strengths

This study provides valuable insights into the correlation between CD4 counts and various biochemical parameters in HIV/AIDS patients attending the ART Centre in Agra. Key strengths include

- Robust Sample Size: With 250 patients, the study has adequate statistical power to detect meaningful associations.
- Comprehensive Biochemical Assessment: Inclusion of diverse parameters (e.g., triglycerides, FSH, LH, testosterone, cortisol, calcium, sodium, and potassium) offers a broad view of metabolic and endocrine alterations.
- Standardized Analysis: Pearson correlation analysis ensures valid, interpretable statistical associations.
- Significant Findings: Strong positive correlations were identified between CD4 count and testosterone ($r = 0.824$, $p < 0.001$), cortisol ($r = 0.513$, $p < 0.001$), and calcium ($r = 0.181$, $p = 0.004$), supporting the role of immune function in hormonal and metabolic regulation.
- Clinical Relevance: The findings help clarify which parameters are likely to reflect immune status, refining clinical focus and guiding future research.
- Methodological Rigor: Well-defined inclusion/exclusion criteria and two-tailed significance testing enhance data reliability and result interpretation.

Limitations

- Single-Center Design: Conducted at a single ART centre in Agra, which may limit generalizability.
- Cross-Sectional Nature: Limits the ability to establish causality between CD4 count and biochemical markers.
- Lack of Confounding Factors: Variables such as diet, renal function, medications, and hydration status were not controlled, which may affect results.
- Moderate Sample Size: While adequate, a larger, more diverse cohort would improve statistical strength.
- Potential Measurement Bias: Laboratory variability and non-standardized sample conditions (e.g., hydration) may impact accuracy.

Conclusion

This study highlights significant associations between immune status and selects biochemical parameters in HIV/AIDS patients. Notably:

- Hormonal Correlates: Strong positive relationships were observed between CD4 count and testosterone and cortisol, indicating improved gonadal and adrenal function with better immune health.
- Calcium Regulation: A weak but significant correlation with serum calcium suggests potential benefits for bone and mineral balance.
- Non-significant Parameters: No meaningful associations were found for FSH, LH, triglycerides, sodium, or potassium, indicating these may be less directly affected by immune function.

These findings emphasize the need for integrated HIV care that includes monitoring of endocrine and metabolic health. Future longitudinal and interventional studies are warranted to explore the effects of ART duration, drug regimens, and the potential benefit of hormone or metabolic therapies. Personalized approaches targeting both immune restoration and biochemical balance could ultimately enhance quality of life and long-term outcomes in HIV/AIDS patients.