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IMMUNOMETABOLIC CORRELATIONS OF AUTOANTIBODIES IN LATENT AUTOIMMUNE DIABETES IN ADULTS PATIENTS (LADA): A CROSS-SECTIONAL STUDY

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Abstract.

Background: As a form of diabetes mellitus, latent autoimmune diabetes in adults (LADA) shares the features of both type 1 diabetes mellitus and type 2 diabetes mellitus, which can result in misdiagnosis at the early stage of insulin-independence. However, we have limited knowledge about the relations between immunological, anthropometric and clinical parameters in LADA, mainly in Sudanese subjects. **Objective:** We aimed to assess the prevalence of LADA in patients with T2DM and to investigate associations between autoantibodies, C-peptide, anthropometry, and clinical characteristics. **Methods:** A cross-sectional comparative study was conducted from April 2020 to January 2024 in Osman Degna Hospital and Ahmed Hassan Diabetic Center. A total of 250 patients with type 2 diabetes were included in the study: 150 on insulin treatment several years after diagnosis (study group) and 100 patients not using insulin (control group). Structured interviews were used to obtain demographic, clinical and lifestyle information. C-peptide, GADA, and IA-2A autoantibodies in serum were detected by the MAGLUMI-800 chemiluminescence immunoassay. **Results:** The prevalence of LADA was 10.7%. The mean C-peptide level was significantly lower in patients with LADA as compared to non-LADA patients (0.50±0.18 vs. p0.7, $p<0.001$], whilst C-peptide levels negatively correlated with GADA concentrations [$r=-0.65$, $p<0.001$]. Inverted correlations were found for autoantibody titers and BMI, waist, weight ($p<0.01$), showing a link of autoimmune activity with leaner phenotypes and less preserved β cell function. **Conclusion:** LADA is under recognized with (10.7%), GADA as a significant early marker. Its close associations with C-peptide and anthropometric indices underline its autoimmune-metabolic profile.

Key words. GADA autoantibodies, LADA, β-cell function, autoimmune diabetes, biomarkers.

Introduction.

Diabetes mellitus is a complex metabolic disorder characterized by high blood sugar levels due to impaired insulin secretion, resistance to insulin's peripheral effects, or a combination of both. Persistent hyperglycemia can harm multiple organ systems, leading to potentially fatal health issues [1,2]. Diabetes is generally categorized into various types according to its fundamental mechanisms and onset features. Diabetes is categorized into Type 1, Type 2, Gestational, and Latent Autoimmune Diabetes in Adults (LADA). Type 1 is an autoimmune disorder, while Type 2 is insulin resistance. Gestational diabetes occurs during pregnancy and resolves postpartum, increasing the risk of Type 2 later.

Latent Autoimmune Diabetes in Adults (LADA) is an autoimmune disorder that shares immunological characteristics with Type 1 diabetes but progresses more gradually and typically presents in adulthood [3,4]. LADA is considered a polygenic disease, involving genetic susceptibility loci that contribute to the gradual destruction of pancreatic β-cells and progressive insulin deficiency, alongside autoimmune markers [5]. Although it overlaps clinically with both Type 1 and Type 2 diabetes, LADA has a distinct genetic and immunological profile. Compared to classical Type 1 diabetes, adult-onset LADA generally carries a lighter genetic burden, which may explain its slower progression and delayed insulin dependence.

A key feature of LADA is the presence of islet-specific autoantibodies, which are essential for diagnosis and help differentiate it from Type 2 diabetes. Among these, glutamic acid decarboxylase antibodies (GADA) are the most prevalent and are considered hallmark of LADA. Other important autoantibodies include insulinoma-associated protein-2 antibodies (IA-2A) and zinc transporter 8 antibodies (ZnT8A), which further support autoimmune involvement and may

influence disease severity and progression. Epidemiological studies show that approximately 2.6% to 14% of patients initially diagnosed with Type 2 diabetes are actually positive for islet autoantibodies, indicating misclassified cases of LADA. Prevalence varies by region, with rates ranging from 4% to 12% in European countries and 3.8% to 9% in Asian populations [6].

LADA is marked by the presence of autoimmune indicators, including autoantibodies, and features mild to moderate insulin deficiency, often appearing in adulthood, which complicates its diagnosis and treatment. Grasping the interaction between autoimmune reactions, beta-cell performance as reflected by C-peptide levels, along with anthropometric and clinical factors, is essential for enhancing diagnosis, prognosis, and tailored treatments for LADA patients. Autoantibodies such as GADA, IA-2, and Znt8 act as indicators of autoimmune processes and are crucial in distinguishing from type 2 diabetes [7]. C-peptide levels reflect endogenous insulin production, providing insight into beta-cell function. Meanwhile, anthropometric measures (such as BMI, waist circumference) and clinical parameters (like blood glucose levels, lipid profiles, blood pressure) are associated with disease progression and metabolic health [8].

This study aims to explore the correlations between these immunological, biochemical, anthropometric, and clinical parameters in LADA patients. The findings could shed light on the pathophysiological mechanisms underlying LADA, aid in early diagnosis, and guide targeted treatment strategies.

Materials and Methods.

This cross-sectional comparative study was carried out from April 2020 to January 2024 at Osman Degna Hospital and Ahmed Hassan Diabetic Center located in Port Sudan, Sudan. A total of 250 patients diagnosed with Type 2 diabetes were enrolled in the study. Out of these, 150 patients required insulin therapy after several years post-diagnosis and formed the study group, while the remaining 100 patients with Type 2 diabetes who did not need insulin therapy acted as the control group. Exclusion criteria encompassed patients younger than 35 years, those with Type 1 diabetes, renal or hepatic insufficiency, thyroid disorders, pancreatic carcinoma, Stiff Person Syndrome, and celiac disease. The study's sample size (250) was determined based on previous studies and a power analysis to ensure statistical significance. The target sample size was set at 80% power at a 5% significance level, assuming a moderate effect size, with an additional margin to accommodate potential dropouts or incomplete data.

Ethical approval was secured from the Committee of Postgraduate Studies and Scientific Research at Shendi University, in addition to the Ministry of Health Committee in Port Sudan. The objectives of the study were communicated to all participants, and written informed consent was acquired from everyone. Data collection was conducted through structured interviews to obtain demographic and clinical information, utilizing a standardized questionnaire. Fasting venous blood samples (3 mL) were drawn in plain tubes from all participants. Serum was separated after 30 minutes, aliquoted, and preserved at -20°C until analysis. Serum levels of C-peptide and autoantibodies, including GADA and IA-2A, were assessed using the fully automated MAGLUMI-800 Auto-Immunoassay Analyzer (Snibe), employing a sandwich chemiluminescence immunoassay (CLIA) technique.

Body Mass Index (BMI) was categorized according to WHO criteria. Cutoff values for other biomarkers were based on ADA guidelines, local laboratory reference ranges, or literature references.

The Shapiro-Wilk test was used to evaluate the normality of the data. With the proper post hoc analysis, the Kruskal-Wallis test was employed for nonparametric data and ANOVA for parametric data, depending on the distribution. Fixed and random factors were included in a linear mixed-effects model that addressed subject variability and repeated measurements. Residual analysis was used to confirm the model's assumptions. Multivariable models based on bivariate relationships and clinical relevance were used to account for confounders. A p-value of less than 0.05 was deemed statistically significant. Data were presented as mean ± standard deviation (SD), with analyses conducted using SPSS version 16.

Results.

The study identified that the prevalence of LADA among the T2DM patients studied was 10.7%. Out of 250 participants, 27 patients tested positive for autoantibodies consistent with LADA, with 16 patients (59.3%) positive for GADA alone, 4 patients (14.8%) positive for both GADA and IA-2A, and 7 patients (25.9%) positive for IA-2A alone (Tables 1 and 2). Patients diagnosed with LADA demonstrated significantly lower serum C-peptide levels (mean ± SD: 0.50 ± 0.18 ng/mL) compared to non-LADA patients (1.47 ± 0.04 ng/mL, $p<0.0001$), indicating impaired residual β-cell function in the LADA group. Autoantibody titters showed marked elevation in LADA patients, with GADA levels significantly higher (89.13 ± 50.37 IU/mL) compared to non-LADA patients (12.6 ± 0.46 IU/mL, $p<0.0001$). Similarly, IA-2A titers were higher in LADA patients (29.58 ± 33.62 IU/mL) versus non-LADA controls (6.14 ± 1.01 IU/mL, $p<0.0001$). Strong positive correlations were observed between GADA titers and IA-2A titers ($r > 0.7$, $p<0.001$), suggesting co-occurrence of autoantibody responses. In contrast, C-peptide levels exhibited a significant negative correlation with GADA titers ($r = -0.65$, $p<0.001$) and IA-2A titers ($r = -0.60$, $p<0.001$), indicating that higher autoimmune activity is associated with diminished β-cell reserve. Autoantibody titters (GADA and IA-2A) were inversely correlated with BMI, waist circumference, and weight ($p<0.01$), implying that higher autoimmune activity correlates with a leaner phenotype. Specifically, lower BMI was associated with higher GADA titers ($r = -0.39$, $p<0.01$) and IA-2A titers ($r = -0.34$, $p<0.01$). Conversely, serum C-peptide levels showed a positive correlation with BMI ($r= 0.32$, $p<0.01$).

The analysis revealed significant differences between LADA and non-LADA groups in various correlations. In LADA patients, there was a strong positive correlation between the duration of insulin dependence and fasting serum C-peptide levels (Figure 1), with a correlation coefficient of $r = 0.723$ and $p = 0.000$. Conversely, this correlation was negatively significant in non-LADA patients. Regarding BMI and GADA titration, a strong negative correlation was observed in LADA patients (Figure 5; $r = -0.390$, $p = 0.000$), whereas a positive correlation was found in non-LADA individuals. The relationship between

Table 1. *Distribution and Prevalence of Autoantibody-Confirmed LADA in the Study Group of Type 2 Diabetic Patients.*

Antibodies	**R-values**	**Case group N=150**				**Control group N=100**	
		Negative		**Positive**		**Positive**	**Negative**
	1–17 IU/ml	N	%	N	%	Frequency	Frequency
GADA		139	92.7	11	7.3	0	100
IA-2A	1–28 U/ml	149	99.3	1	0.7	0	100
GADA **&** IA-2A		146	97.3	4	2.7	0	100
LADA		134	87.3	16	**10.7**	0	100

Table 2. *Serum C-Peptide Levels and Autoantibody Titers in LADA and Non-LADA Patients.*

Parameter	**LADA Patients (N=16)**	**Non-LADA Patients (N=134)**	**p-value**
Serum C-Peptide (ng/mL)	0.50 ± 0.18	1.47 ± 0.04	<0.0001
GADA (IU/mL)	89.13 ± 50.37	12.6 ± 0.46	<0.0001
IA-2A (IU/mL)	29.58 ± 33.62	6.14 ± 1.01	<0.0001

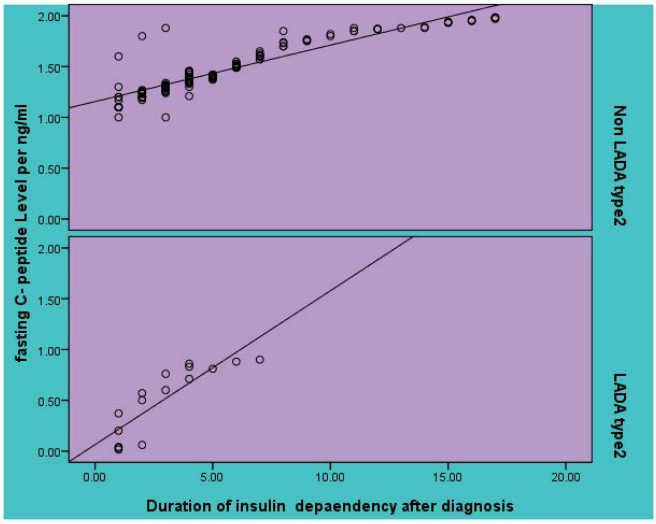

Figure 1. *Correlation between the period of Insulin dependency and the levels of fasting serum C-peptide in LADA and non- LADA groups. Shows strong significant positive correlation between the period of insulin dependency; and the levels of fasting serum C-peptide in LADA patients, (r =.723**, p = 0.000) and significant negative correlation in non- LADA patients.*

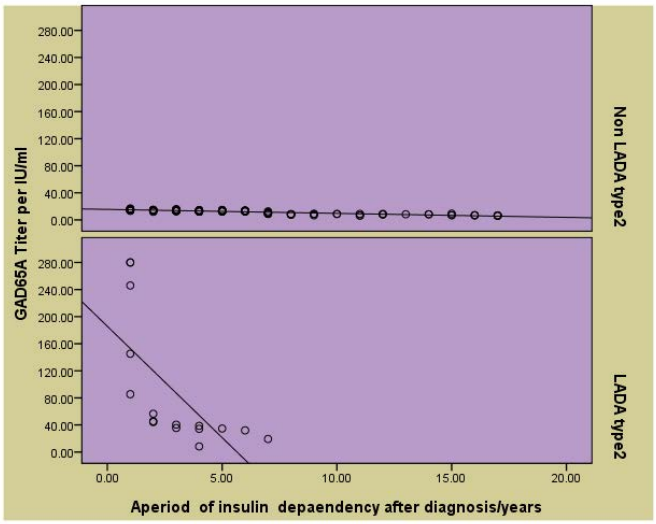

Figure 2. *Showed the Correlation between the period of Insulin dependency and serum GADA titration in LADA and non- LADA groups. Shows strong significant negative correlation between the period of insulin dependency and levels of serum GADA titration; in LADA patients, (r =-.269**, p = 0.001) and highly significant positive correlation in non- LADA patients.*

the duration of insulin dependence and serum GADA titration was also examined, showing a significant negative correlation in LADA patients (Figure 2), with r = -0.269 and p = 0.001, and a positive, highly significant correlation in non-LADA patients. Furthermore, the correlation between insulin dependence and serum IA-2A titration was insignificant in LADA patients (Figure 3; r = -0.123, p = 0.134), but highly significant and positive in non-LADA patients. The analysis of BMI and IA-2A titration revealed a strong negative correlation in LADA patients (Figure 6; r = -0.321, p = 0.000), and a highly significant positive correlation in non-LADA subjects. Lastly, BMI showed a weak positive correlation with fasting serum C-peptide levels in LADA patients (Figure 4; r = 0.317, p = 0.000) and a significant negative correlation in non-LADA patients. These findings underscore the differing immunometabolic profiles between the two groups, highlighting the importance of specific autoimmune markers and metabolic parameters in the disease characterization.

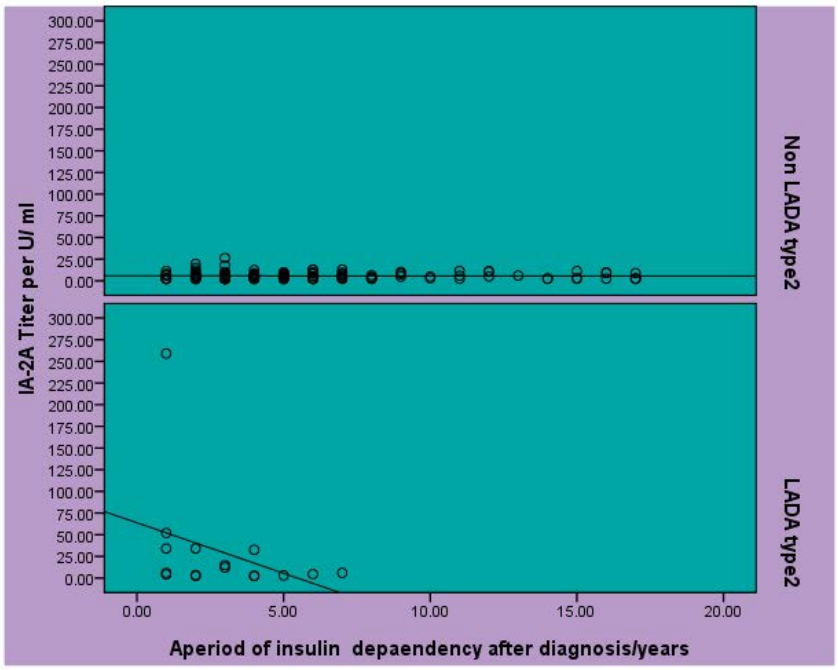

Figure 3. *Correlation between the period of Insulin dependency and serum IA-2A titration in LADA and non- LADA groups. Showed there was insignificant negative correlation in LADA patients, (123-, p = .134).*

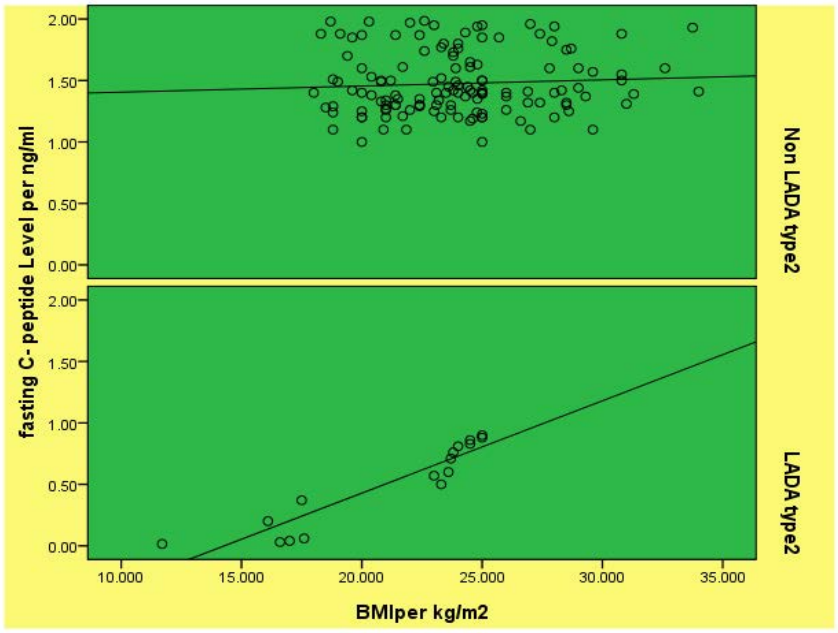

Figure 4. *Correlation between BMI in study group and the levels of fasting serum C-peptide.*
*Shows weak significant positive correlation between the BMI and the levels of fasting serum C-peptide; (r =.317**, p = 0.000), in LADA patients, and highly significant negative correlation in non- LADA patients.*

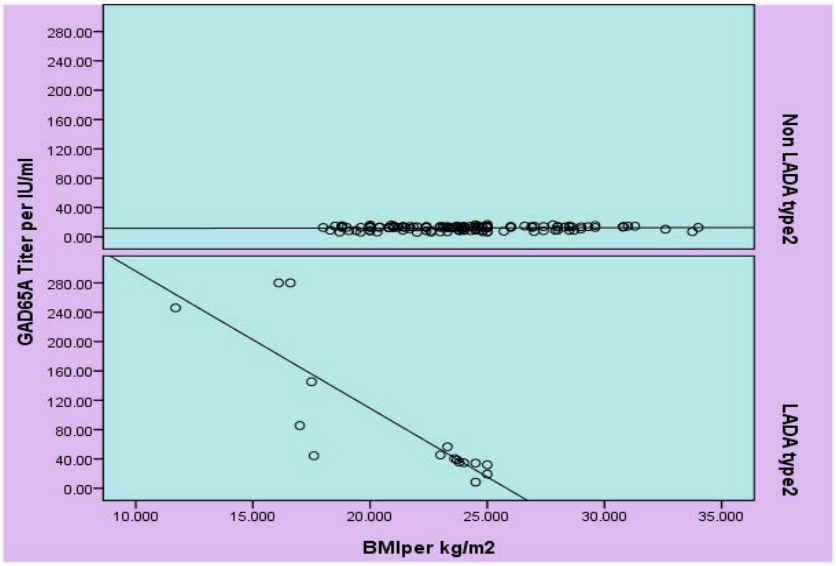

Figure 5. *Correlation between BMI in study group and the GADA titration.*
*Showed strong significant negative correlation between the BMI and the GADA titration (r = -.390**, p = 0.000), in LADA patients, and significant positive correlation in non- LADA patients.*

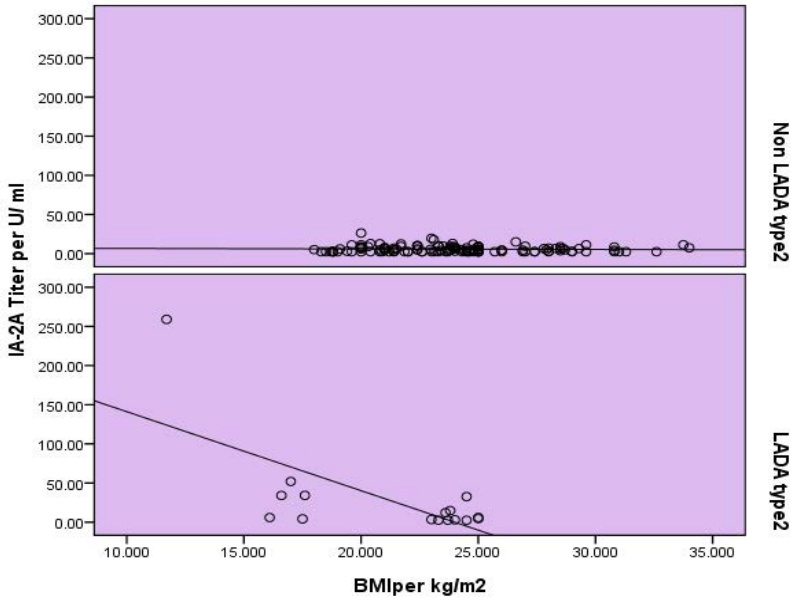

Figure 6. *Correlation between BMI in study group and the IA-2A titration.*
*Showed strong significant negative correlation between the BMI and the IA-2A titration (r = -.321**, p = 0.000) in LADA patients, and highly significant positive correlation in non- LADA patients.*

Discussion.

According to this study, the prevalence of Latent Autoimmune Diabetes in Adults (LADA) among those who were first diagnosed with type 2 diabetes was 10.7%. This is consistent with other investigations that found prevalences ranging from 4.4% to 14.8% in a variety of groups [9]. 59.3% of LADA patients tested positive for GADA alone, making it the most often found autoantibody profile among GAD autoantibodies. Its acknowledged sensitivity as a diagnostic sign for LADA is thus reinforced [10,11].

Although external validity is limited by the small sample size of 16 LADA patients (6.4% of the total cohort), we have overcome this limitation by using strong statistical techniques, such as nonparametric testing and linear mixed-effects models, to maximize interpretive reliability in spite of the small sample.

Significantly lower blood C-peptide levels in LADA patients (mean ± SD: 0.50 ± 0.18 ng/mL) than in non-LADA diabetics (1.47 ± 0.04 ng/mL) were a crucial finding, indicating decreased residual β-cell activity. This observation confirms previous observations that β-cell reserve decreases as autoimmune damage progresses [1,12].

Furthermore, correlational analysis showed that lower C-peptide levels were linked to higher GADA and IA-2A titers, suggesting that more advanced β-cell impairment is associated with increased autoimmune activity. In order to avoid causal overreach and acknowledge the observational nature of the data, we interpret these relationships cautiously [13,14].

With previous evidence of co-expression in autoimmune diabetes [15,16], the found positive association between GADA and IA-2A titers ($r > 0.7$, $p < 0.001$) points to a shared autoimmune mechanism.

From an Immunometabolic standpoint, our findings indicate that higher autoantibody titers were associated with a leaner phenotype, including lower BMI, waist circumference, and body weight ($p < 0.01$). These trends reflect known distinctions between autoimmune diabetes and typical type 2 diabetes phenotypes, wherein the latter often coexists with obesity and metabolic syndrome [17,18]. Furthermore, serum C-peptide levels positively correlated with BMI ($r = 0.32$, $p < 0.01$), indicating that preserved β-cell function may contribute to more stable metabolic profiles.

Regarding insulin dependency, LADA patients exhibited a positive correlation between serum C-peptide and duration without insulin ($r = 0.723$, $p = 0.000$), implying that greater residual β-cell function may delay insulin necessity. In contrast, non-LADA patients showed a negative correlation, suggesting differing disease trajectories. Additionally, an inverse relationship between GADA titers and insulin dependency duration ($r = -0.269$, $p = 0.001$) highlights the potential prognostic value of GADA in tracking β-cell deterioration, as also noted in previous studies [19].

While IA-2A titers did not significantly correlate with insulin dependence in LADA ($p = 0.134$), the negative correlation between IA-2A and BMI ($r = -0.321$, $p = 0.000$) supports its association with greater β-cell damage and leaner phenotype. These patterns emphasize the importance of both autoantibody profiles and metabolic indicators in understanding LADA progression [20,21].

This study's limitations include a small number of LADA cases (n=16), which limit generalizability, and its cross-sectional design, preventing causal inferences. The findings are based on specific hospitals in Sudan, possibly limiting applicability elsewhere. Potential selection bias and the focus on only GADA and IA-2A autoantibodies may underestimate autoimmune prevalence. Lack of genetic data and single-time measurements of autoantibodies and C-peptide restrict insights into disease progression. Future studies should explore specific biomarkers such as CD105 and CD34 for evaluation of angiogenesis and consider how immune responses relate to vascular and metabolic pathways to enhance diagnostic and prognostic accuracy.

Conclusion.

The current study showed that LADA is underdiagnosed with 10.7% prevalence. GADA autoantibodies are important early markers that correlate with decreased β-cell function and leaner body weight. The variant immunometabolic profiles between LADA and non-LADA also suggest the heterogeneous pattern of autoimmune and metabolic interaction in diabetes. The routine use of GADA testing should be evaluated against variables like cost, accessibility, and clinical value, even if it can help identify latent autoimmune diabetes in adults (LADA), especially in individuals with unusual type 2 diabetes presentations. Thus, in the majority of healthcare settings, targeted testing in certain circumstances might be a more practical and successful strategy.

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Conflict of interest.

The authors declare that there is no conflict of interest.

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