

Original Article

Dietary Adherence and Health-Related Quality of Life Among Algerian Children with Celiac Disease: A Prospective Cohort Study from a North African Tertiary Institution

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ABSTRACT

Background: Celiac disease is a chronic immune-mediated enteropathy caused by gluten exposure in genetically susceptible individuals, for which lifelong adherence to a gluten-free diet remains the only validated treatment. Data on dietary adherence and health-related quality of life in North African pediatric populations remain limited. This study aimed to assess GFD adherence, HRQoL, and factors associated with poor adherence among Algerian children with CD.

Methods: This prospective observational cohort study was conducted in the Pediatric Department B of the University Hospital Center of Oran, Algeria, between January 2022 and June 2024. Children aged 2–16 years with confirmed CD (2020 ESPGHAN diagnostic criteria) were consecutively enrolled and prospectively followed at approximately three-month intervals (mean follow-up 18 ± 6 months). GFD adherence was assessed through structured dietary interviews; nutritional status was evaluated clinically and by laboratory assays (hemoglobin, ferritin, vitamin D); HRQoL was measured using the PedsQL and PROMIS pediatric measures. Univariate and multivariable logistic regression were used to identify factors associated with poor adherence, with odds ratios and adjusted odds ratios (aORs) and their 95% confidence intervals.

Results: Of 130 children assessed, 100 were included (mean age, 8.7 ± 3.4 years); 38% were classified as adherent and 62% as non-adherent. Children subsequently classified as non-adherent had lower baseline global quality-of-life scores than adherent children (59.7 ± 12.8 versus 78.4 ± 9.6 ; $p < 0.001$). Anxiety scores were higher in the non-adherent group among 84 children with available scores (57.2 ± 9.3 versus 46.8 ± 7.8 ; $p < 0.001$). Limited access to gluten-free products (adjusted odds ratio, 4.34; 95% confidence interval, 2.00–9.40), economic difficulties (3.70; 1.80–7.60), and psychological stress (2.60; 1.20–5.40) were associated with non-adherence. Nutritional abnormalities were present at enrollment in 72% of children and were associated with lower baseline quality-of-life scores ($p < 0.001$).

Conclusions: GFD adherence is suboptimal among Algerian children with CD and is associated with socioeconomic and psychosocial barriers and reduced HRQoL. Multidisciplinary management addressing nutritional, socioeconomic, and psychological factors is warranted. Given the observational design, the associations identified should not be interpreted as causal; larger multicenter longitudinal studies are needed to confirm these findings.

Keywords: Celiac Disease; Dietary Adherence; Gluten-Free Diet; Nutritional Deficiencies; Quality of Life; Algeria

Introduction

Celiac disease (CD) is a chronic immune-mediated enteropathy triggered by dietary gluten exposure in genetically susceptible individuals, primarily carriers of the human leukocyte antigen (HLA)-DQ2 and HLA-DQ8 haplotypes, following the ingestion of gluten proteins contained in wheat, barley, and rye [1]. The resulting immune response leads to villous atrophy, crypt hyperplasia, and intraepithelial lymphocytosis, impairing nutrient absorption and causing a broad spectrum of intestinal and extraintestinal complications [2].

Historically considered a relatively rare pediatric malabsorption disorder, CD is now recognized as one of the most prevalent chronic immune-mediated gastrointestinal diseases worldwide [3]. A strict lifelong gluten-free diet (GFD) remains the only effective treatment. However, sustained dietary adherence can be challenging, particularly in children and adolescents, because it is influenced by individual, familial, social, and practical factors [4]. Current epidemiological evidence estimates the global prevalence of CD at approximately 0.7%–2.9%, with its reported incidence increasing across numerous geographic regions [5]. Improved serological screening, greater physician awareness, increased recognition of atypical and silent forms, and environmental influences may partly explain this increase [6,7].

The pathophysiology of CD involves a complex interaction among genetic predisposition, immune

dysregulation, impaired intestinal barrier function, and alterations in the gut microbiota [8]. Gluten-derived gliadin peptides cross the intestinal epithelium and undergo deamidation by tissue transglutaminase 2, increasing their affinity for HLA-DQ2/DQ8 molecules and triggering the activation of gluten-specific CD4⁺ T lymphocytes [9,10]. Alterations in the gut microbiota may further compromise intestinal barrier integrity and immune homeostasis, thereby contributing to the inflammatory response to gluten exposure [11,12].

The clinical presentation of pediatric CD is highly heterogeneous. Classical gastrointestinal manifestations include chronic diarrhea, abdominal distension, recurrent abdominal pain, vomiting, constipation, poor weight gain, and growth retardation [2,3,13]. Children may also present with non-classical or extraintestinal manifestations, including iron-deficiency anemia, chronic fatigue, delayed puberty, reduced bone mineral density, and behavioral disturbances [13,14]. Chronic intestinal malabsorption can result in micronutrient deficiencies involving iron, calcium, folate, vitamin B12, and vitamin D. Moreover, persistent symptoms and the social and practical burden of dietary restrictions may negatively affect emotional well-being, academic performance, and social integration [13–15]. The principal pathophysiological mechanisms and clinical manifestations of CD are summarized in Figure 1.

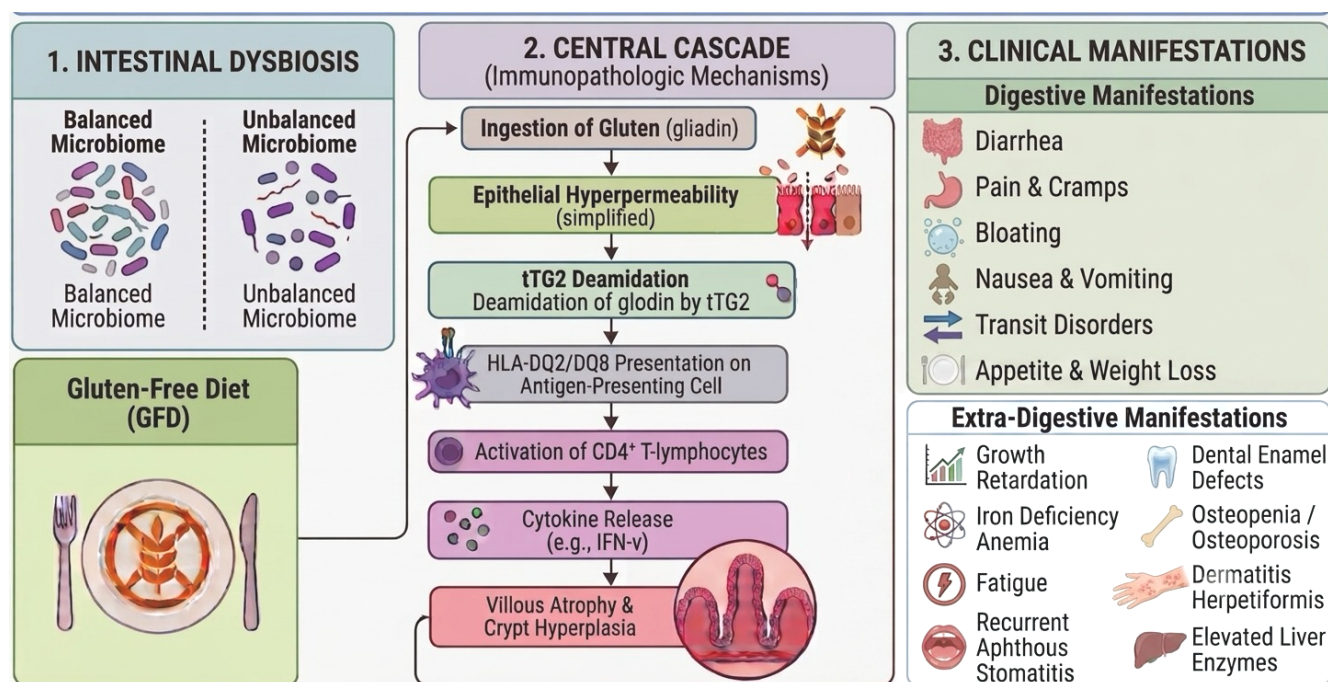


Figure 1. Pathophysiological mechanisms and clinical manifestations of celiac disease.

Schematic overview of the pathophysiological mechanisms and major clinical manifestations of pediatric celiac disease.

Lifelong adherence to a strict gluten-free diet remains the only validated therapeutic strategy capable of promoting mucosal healing, improving nutritional status, alleviating symptoms, and preventing long-term complications [15]. Nevertheless, maintaining strict long-term adherence is challenging, particularly during childhood and adolescence, owing to the high cost of gluten-free products, limited product availability, inadequate food-labeling practices, risk of accidental gluten contamination, and psychological fatigue associated with permanent dietary restrictions [16]. These restrictions may also generate frustration,

anxiety, embarrassment, social exclusion, and reduced health-related quality of life, imposing a substantial burden on affected children and their families [17].

In North African pediatric populations, evidence regarding dietary adherence and health-related quality of life in CD remains limited. The present study was therefore designed to evaluate adherence to the GFD, nutritional status, and health-related quality of life among Algerian children with CD, and to identify factors associated with poor dietary adherence in this setting.

Materials and Methods

Study Design and Setting

This prospective observational cohort study was conducted in the Pediatric Department B of the University Hospital Center of Oran, Algeria, a tertiary referral institution providing specialized pediatric gastroenterology and nutritional care. Patients were consecutively enrolled between January 2022 and June 2024 during routine clinical follow-up.

The cohort included children with confirmed celiac disease who had already been prescribed a gluten-free diet at the time of enrollment; enrollment therefore did not necessarily coincide with the initial diagnosis of celiac disease. Patients were prospectively followed at approximately three-month intervals, with a mean observation period of 18 ± 6 months. Clinical, nutritional, dietary, and psychosocial data were collected during these scheduled follow-up visits.

Dietary adherence was assessed throughout the follow-up period using structured dietary interviews and reported gluten exposure, whereas health-related quality of life was evaluated once at study enrollment using the PedsQL and PROMIS pediatric measures. The primary analyses compared clinical, nutritional, and quality-of-life characteristics between patients classified as adherent and non-adherent to the gluten-free diet, rather than assessing within-patient longitudinal changes over time.

Study Population

Children aged between 2 and 16 years with confirmed celiac disease were consecutively recruited during routine outpatient follow-up consultations and pediatric hospital admissions throughout the study period. Diagnosis of CD was established according to the 2020 European Society for Paediatric Gastroenterology, Hepatology and Nutrition guidelines [1] and was based on compatible clinical manifestations, positive serological markers including anti-tissue transglutaminase antibodies, and histopathological findings when indicated. Prior to enrollment, all participants and their caregivers received standardized medical and nutritional

counseling regarding strict adherence to a gluten-free diet. A consecutive sampling strategy was adopted to minimize selection bias and ensure systematic inclusion of all eligible patients presenting to the study center during the recruitment period. Given the relatively limited number of pediatric CD cases regularly followed at the institution, all patients fulfilling the inclusion criteria were enrolled. Consequently, no formal a priori sample size calculation was performed, and the final sample size corresponded to the total number of consecutively recruited eligible participants available during the study period.

Inclusion and Exclusion Criteria

Patients were eligible for inclusion if they had a confirmed diagnosis of celiac disease, were 2–16 years of age at enrollment, had been prescribed a gluten-free diet, and had regular clinical follow-up available at the study center. For the purposes of the regression analyses, adolescence was defined as an age ≥ 10 years at study enrollment. Age at celiac disease diagnosis was recorded separately and was not used to classify patients as adolescents.

Patients were excluded if they had incomplete medical records, severe chronic comorbidities likely to interfere with nutritional status or health-related quality-of-life assessment, or were lost to follow-up during the study period.

These criteria were applied to ensure adequate availability and consistency of the clinical, nutritional, dietary, and quality-of-life data required for the study analyses.

Diagnostic Criteria for Celiac Disease

The diagnosis of celiac disease was established according to pediatric diagnostic criteria based on clinical assessment, celiac-specific serology, and small-bowel histopathology when indicated. Serological evaluation included serum immunoglobulin A anti-tissue transglutaminase antibodies (tTG-IgA) together with total serum IgA. In patients with IgA deficiency, appropriate IgG-based celiac-specific serological testing was used.

Among the 100 patients included in the final analytical cohort, 17 patients (17%) underwent upper gastrointestinal endoscopy with duodenal biopsy and had histopathological findings consistent with CD. The remaining 83 patients (83%) were diagnosed through the no-biopsy pathway, based on tTG-IgA concentrations ≥ 10 times the upper limit of normal and positive endomysial antibodies confirmed in a second blood sample.

Thus, all patients included in the study had a confirmed diagnosis of CD through either a serology-based no-biopsy pathway or histopathological confirmation, according to the pediatric diagnostic criteria applicable at the time of diagnosis.

Data Collection

Clinical, demographic, nutritional, laboratory, and dietary data were prospectively collected at approximately 3-month intervals during routine follow-up visits using standardized case-report forms specifically designed for the study. Baseline information included age at diagnosis, sex, gastrointestinal and extraintestinal manifestations, anthropometric parameters, nutritional deficiencies, and available serological findings.

During follow-up, clinical evolution, anthropometric parameters, nutritional status, dietary adherence, reported gluten exposure, and psychosocial factors potentially affecting adherence were systematically assessed. Dietary adherence was evaluated throughout the observation period on the basis of information collected during the scheduled follow-up visits.

Anthropometric evaluation included measurements of body weight, height, and body mass index adjusted for age and sex. Nutritional status and growth parameters were interpreted according to World Health Organization child growth standards and age- and sex-specific growth reference charts. Detailed dietary histories were also obtained during follow-up to identify potential barriers to maintaining a gluten-free diet, including socioeconomic and psychosocial factors.

Assessment of Nutritional Status

Nutritional status was evaluated through clinical examination and laboratory investigations performed at study enrollment and during follow-up. The baseline evaluation identified nutritional deficiencies associated with celiac disease. Follow-up evaluations monitored whether these deficiencies resolved or persisted over time.

Laboratory assessment included hemoglobin concentration, serum ferritin, serum 25-hydroxyvitamin D, calcium, and other routine biochemical parameters relevant to pediatric nutritional

evaluation. Nutritional deficiencies were defined using age- and sex-specific pediatric reference standards. Particular attention was given to iron-deficiency anemia and vitamin D deficiency.

At study enrollment, patients were classified into four mutually exclusive categories: no nutritional deficiency, isolated vitamin D deficiency, isolated iron-deficiency anemia, or combined iron-deficiency anemia and vitamin D deficiency. These categories were used to examine the association between baseline nutritional status and the PedsQL score measured at the same time point.

Persistent nutritional deficiency was analyzed separately and defined as the continued presence of iron-deficiency anemia and/or vitamin D deficiency during repeated follow-up assessments despite a prescribed gluten-free diet and nutritional management. Because persistent deficiency and dietary adherence were both assessed during follow-up, their temporal order could not be established. Persistent deficiency was included as a candidate variable in the initial multivariable model but was removed during backward selection and was not retained in the final model. Its univariate association with non-adherence should therefore not be interpreted as predictive or causal.

Evaluation of Gluten-Free Diet Adherence

Adherence to the gluten-free diet was prospectively assessed at approximately three-month intervals during scheduled follow-up visits using structured dietary interviews, patient and caregiver reports, and detailed dietary histories. The assessment addressed intentional and accidental gluten exposure, the frequency and circumstances of dietary lapses, patients' and caregivers' knowledge of gluten-containing foods, awareness of cross-contamination, and difficulties encountered in maintaining a strict gluten-free diet. This approach followed the principles of standardized dietary assessment described in pediatric patients with celiac disease [18].

For the purposes of the present study, strict adherence was operationally defined as complete avoidance of gluten-containing foods, with no intentional or accidental gluten ingestion reported during follow-up. Patients were classified as adherent when repeated dietary assessments consistently documented no reported gluten consumption. Any reported intentional or accidental ingestion of gluten-containing food was considered a dietary lapse. Patients with one or more documented dietary lapses or inconsistent maintenance of the gluten-free diet during follow-up were classified as non-adherent.

Clinical symptoms, anthropometric findings, and nutritional deficiencies were assessed separately and were not used to determine adherence status.

Potential barriers to adherence were recorded during the same follow-up interviews and coded separately from reported gluten ingestion. Economic difficulties referred to patient- or caregiver-reported difficulty affording foods needed to maintain a gluten-free diet. Limited access to gluten-free products referred to reported difficulty obtaining these products locally or regularly, irrespective of their cost. Psychological stress referred to patient- or caregiver-reported emotional strain associated with maintaining the diet; it was assessed during the interview rather than defined by a PROMIS score. For each barrier, a participant was classified as exposed if it was reported at least once during follow-up and unexposed if it was not reported at any follow-up visit. Difficulties interpreting food labels were also recorded but were not included among these three principal predictors.

Quality-of-Life Assessment

Health-related quality of life was assessed once at study enrollment using age-appropriate English-language forms of the PedsQL 4.0 Generic Core Scales. Anxiety, depressive symptoms, fatigue, and peer relationships were assessed using four English-language PROMIS Pediatric Self-Report Short Forms: Anxiety 8a, Depressive Symptoms 8a, Fatigue 10a, and Peer Relationships 8a. The English-language questionnaires were administered under physician supervision. When needed, healthcare professionals provided oral explanations in Arabic or French to facilitate comprehension. No Arabic- or French-language questionnaire forms were administered; the printed items, response options, questionnaire structure, and scoring procedures were not changed.

The PedsQL 4.0 Generic Core Scales assessed physical, emotional, social, and school functioning. Parents or legal guardians completed the age-appropriate PedsQL Parent Report for children aged 2–4 years. Children aged 5–16 years completed the corresponding PedsQL self-report forms. PROMIS analyses were restricted to the 84 children aged 8–16 years who completed the Pediatric Self-Report forms. Children aged 2–7 years did not contribute to the reported PROMIS scores.

The PedsQL total score was analyzed as a continuous variable, with higher scores indicating better health-related quality of life. A cutoff of <70 was not used because no validated threshold was available for the present population. PROMIS raw scores were converted to standardized T-scores according to the corresponding scoring guidelines. Higher T-scores indicate greater anxiety, depressive symptoms, and

fatigue, whereas higher peer-relationship T-scores indicate better social functioning. Because PROMIS T-scores are based primarily on United States reference calibration samples, their interpretation in this Algerian pediatric cohort requires caution.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean $\pm$ standard deviation, and categorical variables as frequencies and percentages. Between-group comparisons were performed using Student's t-test or the Mann–Whitney U test for continuous variables, and the chi-square test or Fisher's exact test for categorical variables, as appropriate.

Differences in baseline global PedsQL scores across the four nutritional-status categories were assessed using one-way analysis of variance. When the overall test was statistically significant, Tukey's honestly significant difference test was used for pairwise comparisons. For comparisons between adherence groups across the five PedsQL outcomes and four PROMIS measures, a Bonferroni-corrected significance threshold of $p < 0.0056$ ($0.05/9$) was applied. All other tests were two-sided, with $p < 0.05$ considered statistically significant.

Adolescence was defined as age ≥ 10 years at study enrollment. Univariate logistic regression analyses were used to examine factors associated with non-adherence to the gluten-free diet; crude odds ratios and 95% confidence intervals were reported. The initial multivariable logistic regression model included six candidate variables: adolescence, economic difficulties, limited access to gluten-free products, psychological stress, low parental educational level, and persistent nutritional deficiency. Backward stepwise selection using the likelihood-ratio method was applied, with variables removed when $p > 0.10$. Low parental educational level and persistent nutritional deficiency were removed during this procedure. The final model retained adolescence, economic difficulties, limited access to gluten-free products, and psychological stress. Adjusted odds ratios and 95% confidence intervals were reported.

Analyses used available data for each variable, without imputation.

Ethical Considerations

The study protocol was reviewed and approved by the Ethics Committee of the University Hospital Center of Oran, Algeria. Written informed consent was obtained from parents or legal guardians prior to inclusion in the study. All procedures were conducted in accordance with the ethical principles

outlined in the Declaration of Helsinki concerning research involving human participants.

Results

Patient Flow and Follow-up

A total of 130 children with celiac disease were initially assessed for eligibility during the study period. Of these, 30 patients were excluded because they did not meet the predefined eligibility and follow-up requirements, including incomplete medical records,

insufficient longitudinal assessments, or loss to follow-up. The final analytical cohort therefore comprised 100 patients with adequate clinical and follow-up data. Participant selection and reasons for exclusion are summarized in Figure 2.

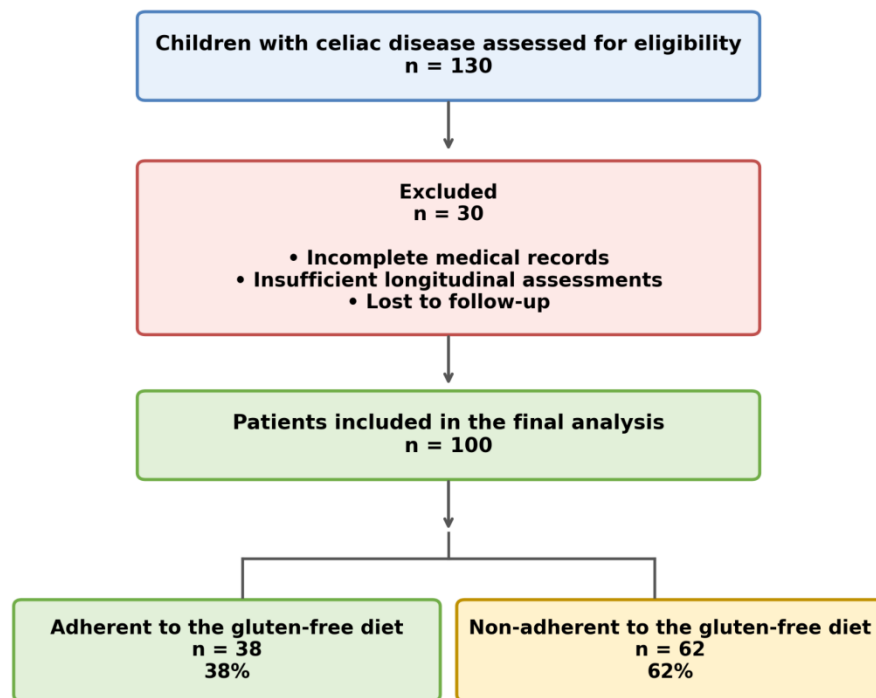


Figure 2. Patient flow and classification according to gluten-free diet adherence.

Flow diagram showing patient enrollment, exclusions, and the final analytical cohort.

Baseline Characteristics of the Study Population

A total of 100 pediatric patients with confirmed celiac disease were included in the final analytical cohort. The study population comprised 63 males and 37 females, corresponding to a male-to-female ratio of 1.7:1. The mean age at enrollment was 8.7 ± 3.4 years, with the largest age group comprising children aged 6–12 years at study enrollment (51%). The mean duration of clinical follow-up was 18 ± 6 months.

Among the 100 patients included in the final analytical cohort, 17 (17%) had histological confirmation by duodenal biopsy, while 83 (83%) were diagnosed through the serology-based no-biopsy pathway.

Gastrointestinal manifestations were the most common presenting features and were observed in 74% of patients. Extraintestinal manifestations were

identified in 58% of cases, highlighting the heterogeneous clinical spectrum of pediatric CD. Growth retardation was documented in 31% of children.

At study enrollment, nutritional abnormalities were identified in 72% of the study population. Vitamin D deficiency was the most frequently identified abnormality (34%), followed by iron-deficiency anemia (27%) and combined iron-deficiency anemia and vitamin D deficiency (11%); the remaining 28% had no identified nutritional deficiency. Patients with combined iron-deficiency anemia and vitamin D deficiency had the lowest mean health-related quality-of-life score. A one-way analysis of variance demonstrated a significant overall difference in mean PedsQL scores across the four baseline nutritional-status categories ($F(3, 96) = 17.21, p < 0.001$).

Table 1. Demographic and Clinical Characteristics of the Pediatric Celiac Disease Cohort (n = 100)

Variables	Values
Male sex	63 (63%)
Female sex	37 (37%)
Age at enrollment (years)	8.7 ± 3.4
Most frequent age group	6–12 years (51%)
Mean follow-up duration	18 ± 6 months
Gastrointestinal symptoms	74 (74%)
Extraintestinal manifestations	58 (58%)
Growth retardation	31 (31%)
Vitamin D deficiency	34 (34%)
Iron-deficiency anemia	27 (27%)
Combined iron and vitamin D deficiency	11 (11%)

Clinical Presentation and Nutritional Status

The clinical presentation of CD in the study cohort demonstrated substantial variability. Gastrointestinal manifestations included chronic diarrhea, recurrent abdominal pain, abdominal distension, vomiting, constipation, and altered bowel habits. In addition to digestive symptoms, numerous patients exhibited extraintestinal manifestations such as chronic fatigue, weight loss, delayed growth, behavioral disturbances, and reduced physical performance. Biological investigations revealed a high burden of micronutrient deficiencies, indicating persistent nutritional impairment among affected children. Combined iron-deficiency anemia and vitamin D deficiency were associated with the lowest mean health-related quality-of-life scores, whereas patients without nutritional deficiencies demonstrated better physical and psychosocial outcomes ($p < 0.001$).

Adherence to the Gluten-Free Diet

Long-term adherence to the gluten-free diet remained suboptimal in the study population, with an adherence rate of 38%. During follow-up, 38 patients (38%) were classified as adherent, whereas 62 patients (62%) were classified as non-adherent.

Several barriers to dietary adherence were identified during follow-up assessments and dietary interviews. The most frequently reported challenges included the high cost of gluten-free products, limited market availability, difficulties related to food labeling, risk of accidental gluten exposure, and the psychological burden associated with maintaining lifelong dietary restrictions.

Adolescents demonstrated significantly poorer adherence to the gluten-free diet than younger children (Pearson's $\chi^2(1) = 5.89$, $p = 0.015$). Persistent nutritional deficiencies were significantly more frequent among

non-adherent patients than among adherent patients (67.7% vs. 28.9%, $p < 0.001$).

The distribution of gluten-free diet adherence in the study cohort is illustrated in Figure 3.

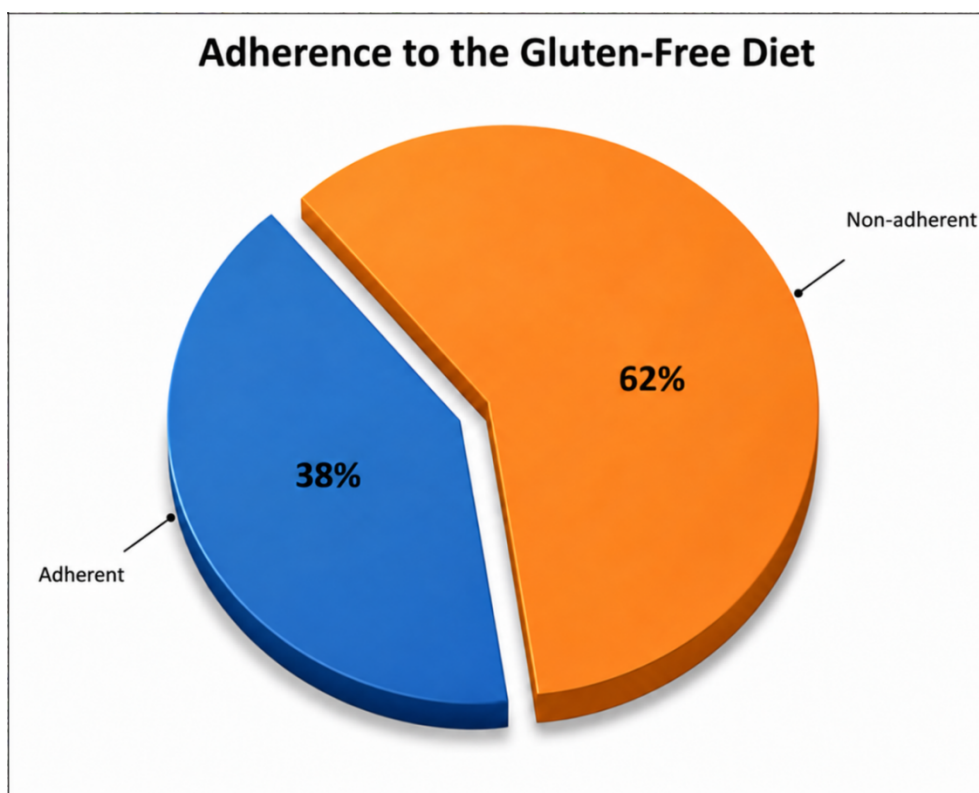


Figure 3. Adherence to the gluten-free diet among the study participants.

Distribution of participants classified as adherent (38%) or non-adherent (62%) according to the predefined dietary-adherence criteria.

Table 2. Comparison Between Adherent and Non-Adherent Patients to the Gluten-Free Diet

Variables	Adherent Patients (n=38)	Non-Adherent Patients (n = 62)	p-value
Mean age (years)	7.9 ± 2.8	9.3 ± 3.6	0.041
Adolescents, n (%)	7 (18.4%)	26 (41.9%)	0.015
Persistent nutritional deficiencies, n (%)	11 (28.9%)	42 (67.7%)	<0.001
Global PedsQL score	78.4 ± 9.6	59.7 ± 12.8	<0.001
Economic difficulties, n (%)	13 (34.2%)	47 (75.8%)	<0.001
Limited access to gluten-free products, n (%)	15 (39.5%)	51 (82.3%)	<0.001
Psychological stress, n (%)	10 (26.3%)	42 (67.7%)	<0.001

Persistent nutritional deficiencies refer to iron-deficiency anemia and/or vitamin D deficiency that remained present during follow-up despite dietary and nutritional management.

Continuous variables are presented as mean ± standard deviation. Categorical variables are presented as number (percentage). PedsQL, Pediatric Quality of Life Inventory.

Health-Related Quality of Life

Health-related quality of life was evaluated using the Pediatric Quality of Life Inventory (PedsQL) and PROMIS pediatric measures. Age-appropriate English-language questionnaires were administered once at study enrollment under physician supervision. When needed, healthcare professionals provided oral explanations in Arabic or French to facilitate comprehension. The reported PedsQL and PROMIS scores therefore correspond to the baseline assessment and were subsequently compared according to the

adherence status documented during prospective follow-up.

Children with poor dietary adherence demonstrated significantly less favorable health-related quality-of-life outcomes than adherent children. As shown in Table 3, the global PedsQL score was significantly lower in the non-adherent group (59.7 ± 12.8) than in the adherent group (78.4 ± 9.6 ; $p < 0.001$). Non-adherent patients also had significantly lower emotional, social, school, and physical functioning scores (Table 3).

PROMIS pediatric measures showed a consistent pattern. Compared with adherent patients, non-adherent patients reported higher anxiety, depressive-symptom, and fatigue T-scores, together with lower peer-relationship T-scores (all $p < 0.001$; Figure 4).

Detailed PedsQL results are presented in Table 3, whereas Figure 4 presents the PROMIS pediatric measures exclusively, thereby avoiding duplication between the two outcome instruments.

Table 3. Association Between Gluten-Free Diet Adherence and Quality of Life

QoL Parameters (PedsQL)	Adherent Patients	Non-Adherent Patients	p-value
Global PedsQL score	78.4 ± 9.6	59.7 ± 12.8	<0.001
Emotional domain	80.2 ± 10.1	56.3 ± 13.2	<0.001
Social domain	82.1 ± 8.9	61.8 ± 11.7	<0.001
School functioning domain	75.3 ± 11.4	58.6 ± 14.5	<0.001
Physical functioning domain	79.8 ± 10.2	63.5 ± 12.9	<0.001

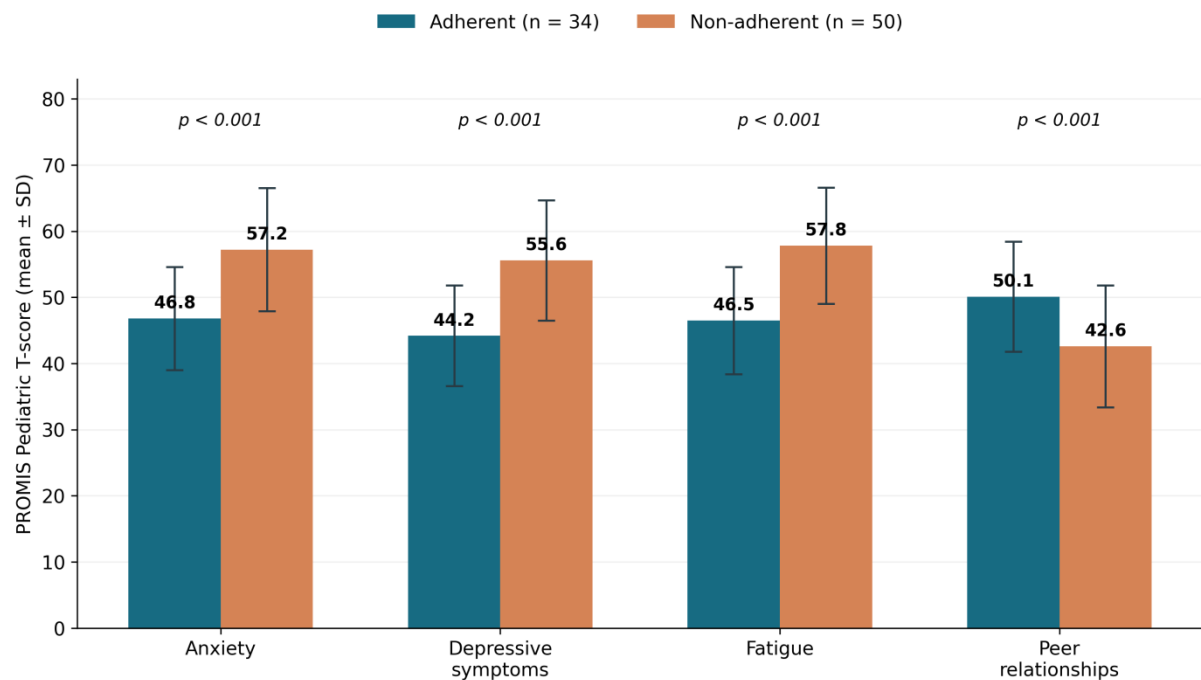


Figure 4. Comparison of PROMIS scores according to gluten-free diet adherence.

Mean PROMIS pediatric T-scores are compared between adherent and non-adherent patients. Error bars represent standard deviations. Higher scores indicate greater symptom severity for anxiety, depressive symptoms, and fatigue, whereas higher peer-relationship scores indicate better social functioning. All between-group differences were statistically significant ($p < 0.001$). PROMIS, Patient-Reported Outcomes Measurement Information System.

Association Between Nutritional Deficiencies and Quality of Life

Nutritional status and health-related quality of life were assessed at study enrollment. Baseline nutritional abnormalities were significantly associated with poorer health-related quality of life among children with celiac disease. Patients without nutritional deficiencies had the highest mean PedsQL score (78.9 ± 8.7), whereas those with combined iron-

deficiency anemia and vitamin D deficiency had the lowest mean score (54.2 ± 13.6).

A one-way analysis of variance demonstrated a significant overall difference in mean PedsQL scores across the four nutritional-status categories assessed at study enrollment ($F(3, 96) = 17.21$, $p < 0.001$). Following the significant omnibus ANOVA, Tukey's honestly significant difference post hoc test showed that patients with isolated vitamin D deficiency, isolated iron-

deficiency anemia, or combined iron-deficiency anemia and vitamin D deficiency had significantly lower mean PedsQL scores than patients without nutritional deficiencies (all $p < 0.001$). The corresponding pairwise comparisons are presented in Table 4.

These findings indicate that nutritional deficiencies identified at study enrollment were associated with poorer health-related quality of life at the same assessment time point in this pediatric cohort.

Table 4. Association Between Baseline Nutritional Status and Health-Related Quality of Life at Study Enrollment

Nutritional Status	Mean PedsQL Score $\pm$ SD	Post-hoc p-value vs. No Nutritional Deficiency
No nutritional deficiency	78.4 $\pm$ 8.7	Reference
Vitamin D deficiency	65.9 $\pm$ 11.2	<0.001
Iron-deficiency anemia	61.4 $\pm$ 12.4	<0.001
Combined iron-deficiency anemia and vitamin D deficiency	53.7 $\pm$ 13.6	<0.001

Values are presented as mean $\pm$ standard deviation (SD). Differences in mean PedsQL scores across nutritional-status groups were assessed using one-way analysis of variance (ANOVA) ($F(3, 96) = 17.21, p < 0.001$). Following the significant omnibus ANOVA, pairwise comparisons were performed using Tukey's honestly significant difference post-hoc test. P-values represent comparisons with the no-nutritional-deficiency reference group. PedsQL, Pediatric Quality of Life Inventory.

Factors Associated With Poor Gluten-Free Diet Adherence

Univariate logistic regression analysis identified several factors significantly associated with poor adherence to the gluten-free diet. In univariate logistic regression, adolescence was significantly associated with poor dietary adherence (OR = 3.20, 95% CI: 1.22–8.38, Wald $\chi^2 = 5.62, p = 0.018$).

Economic difficulties were reported in 13 of 38 adherent patients (34.2%) and 47 of 62 non-adherent patients (75.8%) and were significantly associated with poor dietary adherence (OR = 6.03, 95% CI: 2.48–14.63, $p < 0.001$).

Limited access to gluten-free products was reported in 15 of 38 adherent patients (39.5%) and 51 of

62 non-adherent patients (82.3%) and showed the strongest univariate association with poor dietary adherence (OR = 7.11, 95% CI: 2.83–17.85, $p < 0.001$).

Psychological stress was reported in 10 of 38 adherent patients (26.3%) and 42 of 62 non-adherent patients (67.7%) and was also significantly associated with poor dietary adherence (OR = 5.88, 95% CI: 2.40–14.42, $p < 0.001$).

Low parental educational level was also significantly associated with poor dietary adherence in the univariate analysis (OR = 2.10, 95% CI: 1.00–4.50, $p = 0.047$).

Table 5. Univariate Analysis of Factors Associated With Poor Adherence to the Gluten-Free Diet

Factors	OR	95% CI	p-value
Adolescence	3.20	1.22–8.38	0.018
Economic difficulties	6.03	2.48–14.63	<0.001
Limited access to gluten-free products	7.11	2.83–17.85	<0.001
Psychological stress	5.88	2.40–14.42	<0.001
Low parental educational level	2.10	1.00–4.50	0.047
Persistent nutritional deficiencies	5.15	2.18–12.19	<0.001

OR, odds ratio; CI, confidence interval. The outcome modeled was poor adherence to the gluten-free diet.

Multivariable Analysis of Independent Predictors of Poor Dietary Adherence

Variables associated with poor dietary adherence in the univariate analyses were considered as candidates for multivariable logistic regression. The

final model included adolescence, economic difficulties, limited access to gluten-free products, and psychological stress.

After adjustment, limited access to gluten-free products remained the factor most strongly associated

with poor dietary adherence (adjusted odds ratio [aOR] = 4.34, 95% CI: 2.00–9.40, $p < 0.001$). Economic difficulties (aOR = 3.70, 95% CI: 1.80–7.60, $p < 0.001$) and psychological stress (aOR = 2.60, 95% CI: 1.20–5.40, $p = 0.013$) also remained independently associated with poor dietary adherence.

Although adolescence was significantly associated with poor adherence in the univariate analysis (OR = 3.20, 95% CI: 1.22–8.38, $p = 0.018$), this

association was attenuated and was no longer statistically significant after multivariable adjustment (aOR = 1.90, 95% CI: 0.90–4.10, $p = 0.097$).

These findings indicate that socioeconomic and psychosocial factors, particularly limited access to gluten-free products, economic difficulties, and psychological stress, were independently associated with poor gluten-free diet adherence in this cohort.

Table 6. Multivariable Logistic Regression Analysis of Factors Associated With Poor Gluten-Free Diet Adherence.

Variables	Adjusted OR (aOR)	95% CI	p-value
Economic difficulties	3.70	1.80–7.60	<0.001
Limited access to gluten-free products	4.34	2.00–9.40	<0.001
Psychological stress	2.60	1.20–5.40	0.013
Adolescence	1.90	0.90–4.10	0.097

aOR, adjusted odds ratio; CI, confidence interval. The dependent variable was poor adherence to the gluten-free diet.

Discussion

The findings of this study are consistent with the current understanding of pediatric celiac disease (CD) as a chronic systemic immune-mediated disorder extending beyond isolated intestinal pathology. The increasing prevalence of CD worldwide highlights the importance of timely diagnosis, appropriate nutritional surveillance, and comprehensive multidisciplinary management.

The high frequency of iron-deficiency anemia and vitamin D deficiency observed in our Algerian cohort is consistent with findings reported in contemporary pediatric literature [19,20]. These deficiencies are clinically relevant during childhood because they may adversely affect skeletal development, immune function, neurocognitive maturation, and overall growth. Previous studies have also shown that nutritional imbalances may persist despite the implementation of a gluten-free diet (GFD) [16]. Furthermore, some processed gluten-free foods may have an unfavorable nutritional composition, including higher levels of refined carbohydrates and saturated fats and lower levels of fiber and selected micronutrients. Therefore, long-term dietary management of pediatric CD should address not only gluten exclusion but also overall nutritional adequacy and a balanced dietary intake.

Although the GFD remains the cornerstone of treatment for CD and the only established intervention for promoting intestinal mucosal recovery, maintaining strict lifelong adherence remains a major challenge. This challenge may be particularly pronounced in low- and middle-income settings, where the high cost and

limited availability of gluten-free products represent substantial barriers [4]. In our cohort, economic difficulties and limited access to gluten-free products were significantly associated with GFD non-adherence, emphasizing the importance of socioeconomic factors in the long-term management of pediatric CD.

The proportion of patients classified as non-adherent in our cohort was relatively high (62%). However, adherence rates reported in pediatric studies vary substantially according to the population studied, follow-up duration, adherence definition, and assessment method. In a multinational prospective cohort, Mehta et al. reported strict adherence rates of 73% at two years and 67% at five years after CD diagnosis, corresponding to non-adherence rates of approximately 27% and 33%, respectively [21]. In contrast, Wessels et al. identified dietary adherence problems in 52% of pediatric patients when a detailed standardized dietary interview was used, compared with only 14% when a short questionnaire was applied [18]. More broadly, reported pediatric adherence rates range from approximately 23% to 98%, illustrating the considerable methodological heterogeneity across studies [18,21].

The comparatively high non-adherence rate observed in our cohort may partly reflect the particularly strict operational definition used in this study. A daily gluten intake threshold of zero was applied: strict adherence required zero reported intentional or accidental gluten ingestion throughout follow-up, and any reported gluten consumption was considered a dietary lapse. Because classification was

based on repeated follow-up assessments, patients had multiple opportunities to report a dietary lapse. Moreover, follow-up duration varied among participants; those observed for longer had more opportunities to report at least one lapse and be classified as non-adherent. Nevertheless, the frequent economic constraints and limited availability of gluten-free products observed in our cohort suggest that this high rate may also reflect genuine contextual barriers in Algeria. Direct comparisons with other pediatric cohorts should therefore be interpreted cautiously because of differences in adherence definitions, assessment methods, follow-up duration, healthcare settings, and socioeconomic context.

Beyond its physical manifestations, pediatric CD may also be associated with a substantial emotional and social burden. Children and adolescents may experience anxiety, embarrassment, frustration, or social isolation related to dietary restrictions and concerns about accidental gluten exposure [17]. School meals, social events, and recreational activities may consequently represent challenging situations because of concerns regarding food safety, dietary restrictions, and social participation. Patients subsequently classified as non-adherent had lower PedsQL scores and less favorable PROMIS scores at study enrollment. Baseline nutritional-status groups also differed in their PedsQL scores. These comparisons were unadjusted; differences in age, sex, and respondent type may have contributed to the observed associations. Adherence status may also influence the association between nutritional status and health-related quality of life. These findings should therefore be interpreted as associations rather than independent effects

Parents and caregivers may likewise experience emotional burden and financial strain related to the continuous supervision required to maintain a strict GFD. In our cohort, psychological stress was significantly associated with GFD non-adherence, suggesting that psychosocial factors should be considered alongside nutritional and socioeconomic barriers in the long-term management of pediatric CD [17]. These findings support the potential value of incorporating psychological assessment and counseling into multidisciplinary care, particularly during adolescence. However, because of the observational study design, these associations should not be interpreted as demonstrating causality.

Recent advances in translational research have stimulated interest in therapeutic strategies that may eventually complement the GFD. Investigational approaches include oral gluten-degrading enzymes, modulation of intestinal permeability, cytokine-targeted therapies, induction of immune tolerance, and

vaccine-based interventions [22]. Although some preliminary findings are promising, these approaches remain experimental, and evidence concerning their long-term efficacy and safety in pediatric populations remains limited.

Comprehensive multidisciplinary care remains essential in pediatric CD and may involve collaboration among pediatricians, gastroenterologists, dietitians, psychologists, and educational professionals [23]. Nutritional counseling should address gluten avoidance, balanced dietary intake, and the prevention and correction of nutritional deficiencies. Greater awareness among healthcare professionals, schools, and families may facilitate timely recognition of CD and support the social inclusion of affected children. At a broader level, clearer food labeling and greater availability of affordable and nutritionally adequate gluten-free products may help address the practical barriers encountered by patients and families, particularly in resource-limited settings.

Finally, evidence from North African pediatric populations remains limited. Further multicenter longitudinal studies are needed to characterize regional epidemiological patterns and investigate the genetic, environmental, nutritional, psychosocial, and socioeconomic factors associated with dietary adherence and clinical outcomes. Such studies could also clarify the relationships among GFD adherence, nutritional status, and health-related quality of life while accounting for potential confounding factors and variations in adherence assessment.

Study Limitations

Several limitations should be considered when interpreting these findings. First, this single-center study was conducted in a tertiary referral hospital, which may limit its generalizability to the broader pediatric population in Algeria and other North African settings. Recruitment from a specialized center may also have introduced selection bias.

Second, the relatively small sample size may have limited the statistical power to detect weaker associations. The final multivariable logistic regression model included four covariates, with 38 patients in the smaller outcome category, corresponding to approximately 9.5 patients per covariate in that category. The model may therefore be susceptible to overfitting and imprecise coefficient estimates. The adjusted associations require confirmation in larger cohorts.

Third, dietary adherence was assessed through repeated structured dietary interviews and patient and caregiver reports rather than a validated celiac-specific pediatric adherence questionnaire or objective biomarkers of recent gluten exposure. Recall and social

desirability biases, unrecognized cross-contamination, and underreporting of dietary lapses may have resulted in adherence misclassification. Follow-up duration varied among participants (mean: 18 ± 6 months); participants observed for longer had more opportunities to report at least one dietary lapse and be classified as non-adherent.

Persistent nutritional deficiencies and dietary adherence were both assessed during follow-up. Their temporal order cannot be established, and reverse causation is possible. Their association should therefore not be interpreted as evidence that persistent deficiencies predicted non-adherence. Persistent deficiency was not included in the final multivariable model.

The comparisons of PedsQL and PROMIS outcomes between adherence groups, and of PedsQL scores across baseline nutritional-status groups, were unadjusted. Differences in age, sex, and other patient characteristics may have contributed to these findings. For children aged 2–4 years, PedsQL assessment relied on parent reports rather than the child's own

perspective. Parent reports may differ from children's experiences, and the use of parent-report and self-report forms across age groups may have affected the comparability of PedsQL scores. PROMIS analyses were limited to self-reports from 84 participants aged 8–16 years; their findings may not apply to younger children. Residual confounding by socioeconomic, familial, psychosocial, and disease-related factors cannot be excluded from the regression analyses.

In addition, 30 of the 130 initially assessed patients were excluded because of incomplete records, insufficient longitudinal assessments, loss to follow-up, or failure to meet other eligibility criteria. This may have introduced selection or attrition bias if excluded patients differed systematically from those retained in the final cohort.

Finally, because of the observational design, the identified relationships among gluten-free diet adherence, nutritional status, socioeconomic and psychosocial factors, and health-related quality of life should be interpreted as associations rather than causal effects.

Conclusion

Pediatric celiac disease is a chronic systemic disorder associated with important nutritional, developmental, psychological, and social challenges. The present study highlights the high frequency of micronutrient deficiencies, less favorable health-related quality-of-life outcomes, and suboptimal long-term adherence to the gluten-free diet among Algerian children with CD. Socioeconomic difficulties, limited access to gluten-free products, and psychological stress were significantly associated with poor dietary adherence, while non-adherent patients had significantly lower health-related quality-of-life scores. Baseline nutritional deficiencies were also significantly associated with poorer PedsQL outcomes at study enrollment.

These findings emphasize the importance of considering nutritional, socioeconomic, and psychosocial factors together in the long-term multidisciplinary management of pediatric CD. However, given the observational nature of the study, the associations identified should not be interpreted as evidence of causal relationships. Larger multicenter longitudinal studies are warranted to confirm these findings and further investigate the determinants of dietary adherence and their relationships with nutritional status and health-related quality of life in children with CD.

Supplementary Materials

Supplementary file available via:

https://www.aubiomed.org/suppfiler/777/UA_special_terms_Ameur_Auda_PedsQLT_139744.pdf

https://www.aubiomed.org/suppfiler/779/PROMIS-Gastrointestinal-Symptoms-Scoring-Manual_10Nov2025.pdf

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