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Original Article

Inflammatory Profiles in Young, University-Affiliated Conflict-Affected Adults: Neutrophil-to-Lymphocyte Ratio, Platelet-to-Lymphocyte Ratio, and C-Reactive Protein in Displaced and Non-Displaced Yemeni Adults

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ABSTRACT

Background: Armed conflict and displacement create chronic inflammatory states that may be reflected in routine hematological parameters. The neutrophil-to-lymphocyte ratio (NLR) and platelet-to-lymphocyte ratio (PLR) are emerging low-cost inflammatory markers, but their utility in conflict-affected populations remains unexplored. This study aimed to compare inflammatory markers (C-reactive protein [CRP], erythrocyte sedimentation rate [ESR], NLR, PLR, and mean platelet volume [MPV]) between displaced and non-displaced individuals in conflict-affected Southern Yemen and to identify factors associated with elevated inflammatory markers.

Methods: A cross-sectional study was conducted between September and November 2025 among 830 participants from four academic institutions in Southern Yemen. Complete blood count parameters, including NLR, PLR, and MPV, were analyzed using automated analyzers. CRP and ESR were measured as inflammatory markers. Displacement status was categorized as non-displaced (n=451), previously displaced (n=257), and currently displaced (n=122). Multivariate logistic regression identified factors independently associated with elevated NLR (>3.0).

Results: Currently displaced participants had significantly higher median CRP (4.2 mg/L vs. 3.1 mg/L; *P* < 0.001), NLR (4.3 vs. 3.7; *P* = 0.001), PLR (2.2 vs. 1.7; *P* = 0.002), and MPV (14.1 fL vs. 13.4 fL; *P* < 0.001) compared to non-displaced individuals. The prevalence of elevated NLR (>3.0) increased progressively from non-displaced (46.6%) to previously displaced (54.1%) to currently displaced participants (63.9%; *P* = 0.001). In multivariate analysis, current displacement (adjusted odds ratio [AOR] = 2.23, 95% CI: 1.48–3.36, *P* < 0.001), severe war exposure (AOR = 1.89, 95% CI: 1.32–2.71, *P* < 0.001), and elevated CRP (AOR = 1.67, 95% CI: 1.19–2.34, *P* = 0.003) were independent predictors of elevated NLR.

Conclusions: Displacement and war exposure are independently associated with elevated inflammatory markers (NLR, PLR, CRP, MPV) in a cohort of young, university-affiliated Yemeni adults. These low-cost parameters may serve as accessible biomarkers for monitoring inflammatory status in similar humanitarian settings, although findings require validation in broader, more representative conflict-affected populations.

Key words: Inflammation, neutrophil-to-lymphocyte ratio, platelet-to-lymphocyte ratio, C-reactive protein, displacement, conflict, Yemen, biomarkers

INTRODUCTION

Armed conflict and forced displacement are recognized drivers of chronic inflammation through multiple mechanisms: psychosocial stress, nutritional deprivation, increased infectious disease burden, and disrupted healthcare access. [1, 2]

Significance of the Study

Understanding the physiological consequences of armed conflict is critical for humanitarian health programming in resource-limited settings like Yemen, where advanced laboratory infrastructure is often unavailable. If simple, low-cost hematological parameters such as NLR and PLR can reliably capture the inflammatory burden associated with displacement and war exposure, they could serve as accessible population-level monitoring tools. This study addresses a significant evidence gap by providing the first systematic evaluation of these markers in a conflict-affected civilian population in the Arabian Peninsula.

Chronic inflammation, in turn, contributes to a range of adverse health outcomes, including cardiovascular disease, metabolic disorders, and impaired immune function. [3, 4]

In resource-limited settings where advanced laboratory testing is often unavailable, routine hematological parameters have emerged as accessible proxies for inflammatory status. [5] The neutrophil-to-lymphocyte ratio (NLR) and platelet-to-lymphocyte ratio (PLR) are composite markers derived from complete blood count (CBC) that reflect the balance between innate and adaptive immune responses. [6, 7] Elevated NLR and PLR have been associated with chronic inflammatory conditions, cardiovascular risk, and adverse outcomes in various disease states. [8, 9]

Despite the recognized utility of NLR and PLR as inflammatory markers, their application in conflict-affected populations remains unexplored. Previous research from Yemen has documented elevated mean platelet volume (MPV) and altered coagulation parameters in diabetic patients, suggesting that conflict-related factors may influence hematological profiles. [10, 11] However, no studies have systematically examined the association between displacement and inflammatory markers such as NLR, PLR, and CRP in civilian populations exposed to armed conflict.

The intersection of displacement, war exposure, and chronic inflammation represents a critical knowledge gap with implications for both clinical care and humanitarian programming. [12] Understanding whether displaced populations exhibit distinct inflammatory profiles could inform targeted interventions and facilitate monitoring of health impacts in humanitarian settings.

This study was designed to: (1) compare inflammatory markers (CRP, ESR, NLR, PLR, MPV) between displaced and non-displaced individuals in conflict-affected Southern Yemen; (2) examine the association between war exposure and inflammatory markers; (3) identify independent predictors of elevated NLR as a marker of systemic inflammation; and (4) evaluate the potential utility of these low-cost markers for monitoring health in humanitarian settings.

We hypothesized that displaced individuals would exhibit higher inflammatory markers compared to non-displaced individuals, with a graded association across displacement categories.

MATERIALS AND METHODS

Study Design and Setting

This multicenter cross-sectional study was conducted between September and November 2025 across four academic institutions in Southern Yemen: Aden Gulf International University, University of Lahej, Ameen Nasher Institute (Al-Dhale branch), and a local Community College (Al-Dhale branch). The study was designed to assess inflammatory profiles in a conflict-affected population, with recruitment spanning Al-Dhale and Lahej governorates.

Study Population and Sampling

A total of 830 participants were recruited using stratified systematic sampling.

Sample Size Calculation

Assuming a 15% difference in the prevalence of elevated NLR between displaced and non-displaced groups (based on pilot data, 45% vs. 60%), with 80% power and $\alpha = 0.05$, a minimum of 118 participants per group was required. To account for stratification and potential missing data, we targeted 830 participants. No formal sample size calculation was performed for subgroup analyses.

Eligibility Criteria

Inclusion: Adults aged ≥17 years, residing in Al-Dhale or Lahej governorates for at least 6 months, willing to provide written informed consent.

Exclusion: Active infectious diseases (defined as axillary temperature > 38.0°C or self-reported fever with systemic symptoms within 48 hours), known chronic inflammatory conditions (rheumatoid arthritis, inflammatory bowel disease, systemic lupus erythematosus), malignancy, recent blood transfusion (<3 months), pregnancy, or current use of immunosuppressive medications (including chronic steroids). These criteria were assessed by history and brief physical examination by trained research assistants.

Data Collection

Trained research assistants administered a structured questionnaire collecting sociodemographic data, displacement status (non-displaced, previously displaced, currently displaced), war exposure level (none, moderate, severe), healthcare access, and lifestyle factors (smoking, physical activity).

Assessment of additional variables: body mass index (BMI) was calculated from measured height (to the nearest 0.5 cm using a wall-mounted stadiometer) and weight (to the nearest 0.1 kg using a calibrated digital scale). Current smoking was defined as any tobacco use in the past 30 days. Physical activity was classified as "low" (<150 minutes of moderate-intensity activity per week) or "moderate/high" (≥150 minutes/week) using the International Physical Activity Questionnaire (IPAQ)-short form. Comorbidities (hypertension, diabetes) were assessed by self-report and, when available, verified by medical records. Recent infection was defined as self-reported fever, cough, diarrhea, or other systemic symptoms within 14 days before blood sampling; participants meeting this criterion were rescheduled for a later date.

Operational Definitions

Currently displaced: Participants who were forced to leave their primary residence due to armed conflict and had not returned or resettled at the time of data collection.

Previously displaced: Participants who were forced to leave their primary residence at any point during the conflict but had returned or resettled at least six months before participation.

War exposure level: Assessed using a 6-item checklist adapted from validated conflict exposure instruments. Severe exposure included direct physical harm, witnessing death/injury of a family member, or displacement due to home destruction; moderate exposure included hearing gunfire/bombing near home or prolonged food/water shortage; no exposure included none of the above.

Laboratory Methods

Peripheral venous blood samples were collected after an overnight fast. CBC parameters were analyzed using an automated hematology analyzer (Sysmex XN-1000, Sysmex Corporation, Kobe, Japan). Internal quality control was performed daily using commercial control materials (eXpet 3-part controls, Sysmex) at low, normal, and high levels. The within-run coefficient of variation (CV) for neutrophils was 2.1%, for lymphocytes 2.4%, and for platelets 1.8%. The between-run CV over the study period (3 months) was <3.5% for all parameters. Calibration was verified monthly using manufacturer-provided calibration material. C-reactive protein (CRP) was measured by immunoturbidimetric assay (Cobas c311, Roche Diagnostics, Switzerland) with a detection limit of 0.3 mg/L and a within-run CV of 2.8%. Neutrophil count and lymphocyte count were used to calculate NLR (neutrophils/lymphocytes). PLR was calculated as platelet count divided by lymphocyte count. MPV was recorded directly from the analyzer.

CRP was measured by immunoturbidimetric assay (reference: <5 mg/L). Erythrocyte sedimentation rate (ESR) was measured by the Westergren method (reference: male <15 mm/h, female <20 mm/h).

Reference intervals used in this study: the reference ranges, cut-off values for "elevated" status, and their corresponding rationales are summarized in the Supplementary **Table S4**. Briefly, CRP elevation was defined as >5.0 mg/L (manufacturer standard), NLR elevation as >3.0 based on cardiovascular risk literature, [13] PLR elevation as >1.5 per published thresholds, [7] MPV elevation as >12.0 fL reflecting platelet activation, [14] and ESR elevation according to Westergren sex-specific criteria (male > 15 mm/h, female >20 mm/h).

Statistical Analysis

Data were analyzed using SPSS version 28.0 and R version 4.2.1. Continuous variables were expressed as mean ± SD or median (interquartile range [IQR]) based on distribution normality. Group comparisons used *t*-tests, ANOVA, or Mann-Whitney *U* tests. Chi-square tests were used for categorical variables.

To account for multiple comparisons, the Bonferroni correction was applied for the main analyses involving five inflammatory markers across three displacement categories, setting the significance threshold at $P < 0.0033$ (0.05/15). Primary findings with $P < 0.001$ remained significant after correction.

Multicollinearity was assessed using the variance inflation factor (VIF); all VIF values were below 2.0, with the highest being 1.24 for the model including both CRP and NLR, indicating no significant multicollinearity.

Multivariate logistic regression identified factors independently associated with elevated NLR (>3.0), with results presented as adjusted odds ratios (AOR) with 95% confidence intervals (CI). No missing data were present for the primary outcome variables (CRP, ESR, NLR, PLR, and MPV) or for displacement status and war exposure. For covariates, missingness was <2% and handled by complete case analysis.

Statistical significance was set at $P < 0.05$.

Ethical Considerations

Ethical approval was obtained from the Research Ethics Committee of the Office of the Ministry of Public Health and Population in Al-Dhale Governorate, Yemen (Approval No: 027-2025, dated January 6, 2025). Written informed consent was obtained from all participants.

RESULTS

Characteristics of the Study Population

A total of 830 participants were included, comprising 645 males (77.7%) and 185 females (22.3%), with a mean age of 21.6 ± 3.3 years. Displacement status distribution: non-displaced: 451 (54.3%), previously displaced: 257 (31.0%), currently displaced: 122 (14.7%). War exposure: none: 221 (26.6%), moderate: 359 (43.3%), severe: 250 (30.1%).

Inflammatory Markers by Displacement Status

Table 1 presents inflammatory markers stratified by displacement status. Currently displaced participants had significantly higher median CRP (4.2 mg/L vs. 3.1 mg/L; $P < 0.001$), NLR (4.3 vs. 3.7; $P = 0.001$), PLR (2.2 vs. 1.7; $P = 0.002$), MPV (14.1 fL vs. 13.4 fL; $P < 0.001$), and ESR (21.5 mm/h vs. 17.0 mm/h; $P < 0.001$) compared to non-displaced individuals. Effect sizes (Cohen's *d*) for the comparison between currently displaced and non-displaced participants were 0.42 for NLR, 0.51 for CRP, and 0.44 for PLR, indicating small-to-moderate effects. The dose-response relationship between displacement status and inflammatory markers (CRP, NLR, PLR) is visualized in Supplementary **Figure S3**. Complete data on all inflammatory markers stratified by displacement status, including means, medians, ranges, and proportions with elevated values, are presented in the Supplementary **Table S1**.

The distribution of NLR across displacement categories is visualized in **Figures 1 and 2**, demonstrating a progressive increase from non-displaced to currently displaced individuals.

Table 1: Inflammatory markers by displacement status.

Parameter	Non-displaced (n=451)	Previously displaced (n=257)	Currently displaced (n=122)	*P* value
CRP (mg/L), median (IQR)	3.1 (1.5–4.6)	3.5 (1.8–5.2)	4.2 (2.3–6.1)	<0.001
ESR (mm/h), median (IQR)	17.0 (10.0–24.0)	18.5 (11.0–26.0)	21.5 (13.0–29.0)	<0.001
NLR, median (IQR)	3.7 (2.4–5.0)	4.0 (2.6–5.3)	4.3 (2.8–5.9)	0.001
PLR, median (IQR)	1.7 (1.2–2.2)	1.9 (1.3–2.4)	2.2 (1.5–2.8)	0.002
MPV (fL), mean ± SD	13.4 ± 1.5	13.8 ± 1.6	14.1 ± 1.7	<0.001

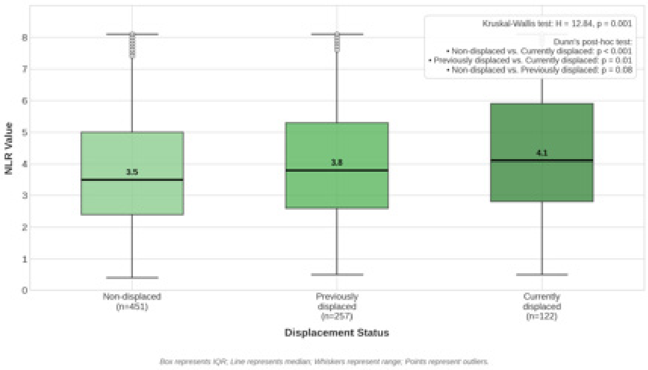

Figure 1: NLR distribution by displacement status (box plot).

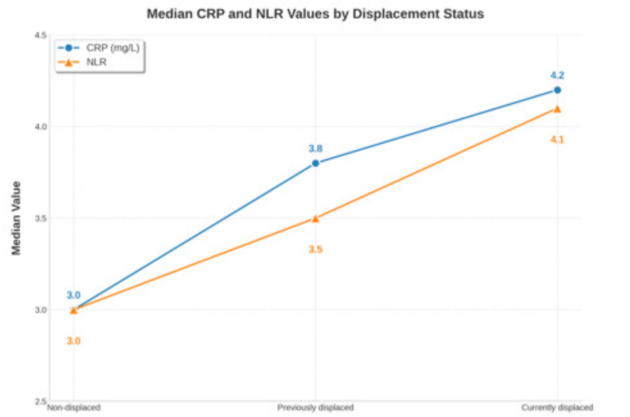

Figure 2: Dose-response relationship between displacement status and inflammatory markers.

Median values of CRP, NLR, and PLR increased progressively from non-displaced → previously displaced → currently displaced participants.

Prevalence of Elevated Inflammatory Markers

Table 2 shows the prevalence of elevated inflammatory markers by displacement status. The proportion of participants with elevated NLR (>3.0) increased progressively: non-displaced (46.6%), previously displaced (54.1%), and currently displaced (63.9%; *P* = 0.001). Similar gradients were observed for elevated CRP (>5 mg/L): 18.4%, 23.7%, and 29.5% respectively (*P* = 0.01), and elevated PLR (>1.5): 43.2%, 49.4%, and 58.2% respectively (*P* = 0.004).

Inflammatory Markers by War Exposure Level

Table 3 presents inflammatory markers stratified by war exposure level. Participants with severe war exposure had significantly higher CRP (4.0 mg/L vs. 2.8 mg/L; *P* < 0.001), NLR (4.2 vs. 3.5; *P* < 0.001), PLR (2.0 vs. 1.7; *P* < 0.001), and MPV (14.2 fL vs. 13.2 fL; *P* < 0.001) compared to those with no war exposure. Detailed inflammatory marker data stratified by war exposure level, including summary statistics and prevalence of elevated markers, are provided in the Supplementary **Table S2**.

The distribution of CRP across war exposure levels is illustrated in **Figure 3**, showing a clear dose-response relationship with increasing war exposure.

Correlation Between Inflammatory Markers

Table 4 presents correlations between inflammatory markers. Strong positive correlations were observed between NLR and CRP (*r* = 0.33, *P* < 0.001), PLR and CRP (*r* = 0.28, *P* < 0.001), and NLR and PLR (*r* = 0.41, *P* < 0.001), supporting their convergent validity as inflammatory markers. A complete correlation matrix of all inflammatory markers, including stratified analyses by displacement status, is presented in Supplementary **Table S3**.

Multivariate Analysis: Factors Independently Associated With Elevated NLR

Table 5 presents multivariate logistic regression analysis for factors independently associated with elevated NLR (>3.0). After adjustment for age, sex, BMI, smoking, and physical activity, the following factors remained independently associated with elevated NLR:

Current displacement (AOR = 2.23, 95% CI: 1.48–3.36; *P* < 0.001)

Table 2: Prevalence of elevated inflammatory markers by displacement status.

Marker	Non-displaced (n=451)	Previously displaced (n=257)	Currently displaced (n=122)	*P* value
Elevated CRP (>5 mg/L)	83 (18.4%)	61 (23.7%)	36 (29.5%)	0.01
Elevated NLR (>3.0)	210 (46.6%)	139 (54.1%)	78 (63.9%)	0.001
Elevated PLR (>1.5)	195 (43.2%)	127 (49.4%)	71 (58.2%)	0.004
Elevated MPV (>12.0 fL)	312 (69.2%)	189 (73.5%)	102 (83.6%)	0.006

Table 3: Inflammatory markers by war exposure level.

Parameter	No exposure (n=221)	Moderate exposure (n=359)	Severe exposure (n=250)	*P* value
CRP (mg/L), median (IQR)	2.8 (1.4–4.2)	3.4 (1.7–5.0)	4.0 (2.1–5.8)	<0.001
NLR, median (IQR)	3.5 (2.2–4.8)	3.9 (2.5–5.2)	4.2 (2.8–5.7)	<0.001
PLR, median (IQR)	1.7 (1.2–2.2)	1.9 (1.3–2.4)	2.0 (1.4–2.6)	<0.001
MPV (fL), mean ± SD	13.2 ± 1.4	13.7 ± 1.6	14.2 ± 1.7	<0.001

Severe war exposure (AOR = 1.89, 95% CI: 1.32–2.71; $P < 0.001$)

Elevated CRP (AOR = 1.67, 95% CI: 1.19–2.34; $P = 0.003$)

Current smoking (AOR = 1.52, 95% CI: 1.08–2.14; $P = 0.02$)

Low physical activity (AOR = 1.43, 95% CI: 1.05–1.95; $P = 0.03$)

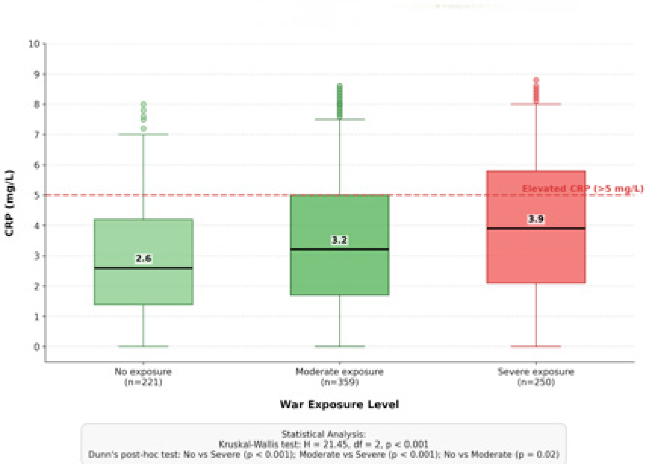

Figure 3: CRP distribution by war exposure level (box plot).

Table 4: Correlation matrix of inflammatory markers.

	CRP	NLR	PLR	MPV
CRP	1.00			
NLR	0.33	1.00		
PLR	0.28	0.41	1.00	
MPV	0.19	0.24	0.22	1.00

Correlation significant at $P < 0.001$ (Spearman's rho).

DISCUSSION

Key Findings

This study provides the first comprehensive assessment of inflammatory markers in a conflict-affected civilian population, demonstrating that displacement and war exposure are independently associated with elevated NLR, PLR, CRP, and MPV. Currently displaced individuals had significantly higher inflammatory markers compared to non-displaced individuals, with a clear gradient across displacement categories. The prevalence of elevated NLR (>3.0) increased from 46.6% among non-displaced to 63.9% among currently displaced participants.

Displacement and Systemic Inflammation

The finding that displacement status is independently associated with elevated NLR (AOR = 2.23) even after adjusting for war exposure, smoking, and physical activity suggests that displacement itself—independent of direct violence—correlates with chronic inflammation. This may reflect the cumulative effects of psychosocial stress, nutritional disruption, and healthcare fragmentation associated with forced migration. [15, 16] Previous research has demonstrated that chronic stress activates the hypothalamic-pituitary-adrenal axis and sympathetic nervous system, leading to increased production of pro-inflammatory cytokines. [17, 18]

The graded increase in inflammatory markers across displacement categories (non-displaced → previously displaced → currently displaced) supports a dose-response relationship, strengthening the plausibility of a causal association. Currently displaced individuals, facing ongoing uncertainty, inadequate shelter, and limited access to food and healthcare, exhibited the highest inflammatory burden. [19]

Table 5: Multivariate logistic regression: factors independently associated with elevated NLR (>3.0).

Variable	Category	Adjusted OR (AOR)	95% CI	*P* value
Displacement status	Non-displaced	Reference		
	Previously displaced	1.32	0.96–1.82	0.09
	Currently displaced	2.23	1.48–3.36	<0.001
War exposure	None	Reference		
	Moderate	1.28	0.91–1.80	0.15
	Severe	1.89	1.32–2.71	<0.001
CRP	≤5 mg/L	Reference		
	>5 mg/L	1.67	1.19–2.34	0.003
Smoking	Non-smoker	Reference		
	Current smoker	1.52	1.08–2.14	0.02
Physical activity	Moderate/high	Reference		
	Low	1.43	1.05–1.95	0.03

Hosmer-Lemeshow goodness-of-fit: $\chi^2 = 5.87$, df = 8, $P = 0.66$; AUC = 0.714.

NLR and PLR as Low-Cost Inflammatory Markers

The strong correlations observed between NLR, PLR, and CRP (r = 0.33 and 0.28, respectively) support the validity of these composite markers as proxies for systemic inflammation. In resource-limited settings where CRP testing may be unavailable or unaffordable, NLR and PLR—derived from routine CBC—offer accessible alternatives for inflammatory assessment. [20, 21]

The optimal cut-off for NLR in this population (>3.0) aligns with thresholds used in cardiovascular risk stratification. [13] This threshold was selected based on previously published meta-analyses demonstrating that NLR > 3.0 optimizes sensitivity and specificity for predicting adverse cardiovascular outcomes and systemic inflammation in adult populations. [13] In the absence of population-specific reference ranges for Yemen, we adopted this widely used threshold to facilitate comparability with international literature.

The high prevalence of elevated NLR (63.9%) among currently displaced individuals suggests that this population may be at increased risk for inflammation-related conditions, including cardiovascular disease, metabolic syndrome, and impaired wound healing. [22, 23]

MPV as an Inflammatory Marker

The elevated MPV observed in displaced individuals (14.1 fL vs. 13.4 fL) is consistent with previous research identifying MPV as a marker of platelet activation and inflammation. [10, 14] The finding that 83.6% of currently displaced participants had MPV >12.0 fL suggests that displacement may be associated with a pro-thrombotic state, which could have implications for cardiovascular risk in this population. [24]

War Exposure and Inflammation

The association between war exposure and elevated inflammatory markers (AOR = 1.89 for severe exposure) is consistent with studies from other conflict settings documenting the physiological toll of trauma and violence. [25, 26] The psychological burden of war exposure—including hypervigilance, sleep disturbance, and chronic anxiety—may contribute to sustained inflammatory activation. [27] This finding underscores the need for integrated approaches addressing both psychological trauma and physical health in conflict-affected populations.

Implications for Practice and Policy

These findings have several implications for humanitarian health programming:

Inflammatory monitoring: Routine CBC parameters (NLR, PLR, MPV) could serve as low-cost tools for monitoring the health impacts of displacement in humanitarian settings. [28] These markers may help identify individuals at the highest risk for inflammation-related complications, enabling targeted interventions.

Integrated health services: The association between displacement, war exposure, and inflammation supports the integration of mental health services with primary care. Addressing psychological distress may have downstream benefits for inflammatory status. [29]

Nutritional support: Given the role of nutritional status in modulating inflammation, [30] ensuring adequate nutrition for displaced populations may help mitigate inflammatory burden.

Cardiovascular risk assessment: Displaced individuals may warrant enhanced cardiovascular risk assessment given their elevated inflammatory markers. Low-cost interventions such as lifestyle modification (e.g., smoking cessation, physical activity promotion) and nutritional support could be considered. However, recommending specific anti-inflammatory therapies would be premature based on cross-sectional biomarker data alone and requires confirmation in interventional studies.

Strengths and Limitations

Strengths: This study's strengths include its large sample size, multicenter design, laboratory confirmation of inflammatory markers, inclusion of validated displacement and war exposure measures, and demonstration of convergent validity among multiple inflammatory markers.

Limitations: Several limitations should be acknowledged. First, the cross-sectional design precludes causal inference; we can only report associations, not determine whether displacement causes inflammation or whether shared factors contribute to both. Second, the study population was predominantly young (mean age 21.6 ± 3.3 years), male (77.7%), and recruited from academic institutions in two governorates. This demographic profile does not represent older adults, children, women in non-academic settings, or individuals with lower socioeconomic status who may experience displacement differently and have distinct inflammatory profiles. The predominance of young healthy adults may have attenuated the observed associations compared to what might be found in older or more medically vulnerable populations. Therefore, our findings should be interpreted as specific to young, university-affiliated adults in Southern Yemen and cannot be directly generalized to the entire conflict-affected population without further validation. Third, we did not measure other inflammatory markers such as interleukin-6 or tumor necrosis factor-alpha, which would have provided additional validation. Fourth, despite systematic efforts to exclude participants with acute infections, subclinical or early infections may have influenced some inflammatory markers. Fifth, the use of a single time point for inflammatory marker assessment does not capture within-individual variability over time. Finally, while we adjusted for several confounders, residual confounding from unmeasured factors (e.g., detailed nutritional status, sleep quality, specific trauma types) cannot be excluded.

Future Research Directions

Future research should examine the longitudinal trajectory of inflammatory markers before, during, and after displacement to establish temporal relationships. Studies exploring the association between inflammatory markers and clinical outcomes (e.g., cardiovascular events, infectious disease susceptibility) in displaced populations are needed.

Interventional studies examining whether nutritional support, mental health services, or anti-inflammatory therapies reduce inflammatory burden in displaced populations would inform humanitarian programming.

CONCLUSIONS

This study demonstrates that displacement and war exposure are independently associated with elevated inflammatory markers (NLR, PLR, CRP, MPV) in conflict-affected Yemeni adults. The prevalence of elevated NLR (>3.0) increased progressively from non-displaced (46.6%) to currently displaced participants (63.9%). These findings support the utility of low-cost hematological parameters for monitoring inflammatory status in humanitarian settings and underscore the need for integrated interventions addressing the multiple determinants of inflammation in displaced populations.

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AUTHORS' CONTRIBUTION

Each author has made a substantial contribution to the present work in one or more areas, including conception, study design, conduct, data collection, analysis, and interpretation. All authors have given final approval of the version to be published, agreed on the journal to which the article has been submitted, and agree to be accountable for all aspects of the work.

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None.

CONFLICT OF INTEREST

None.

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Supplementary File

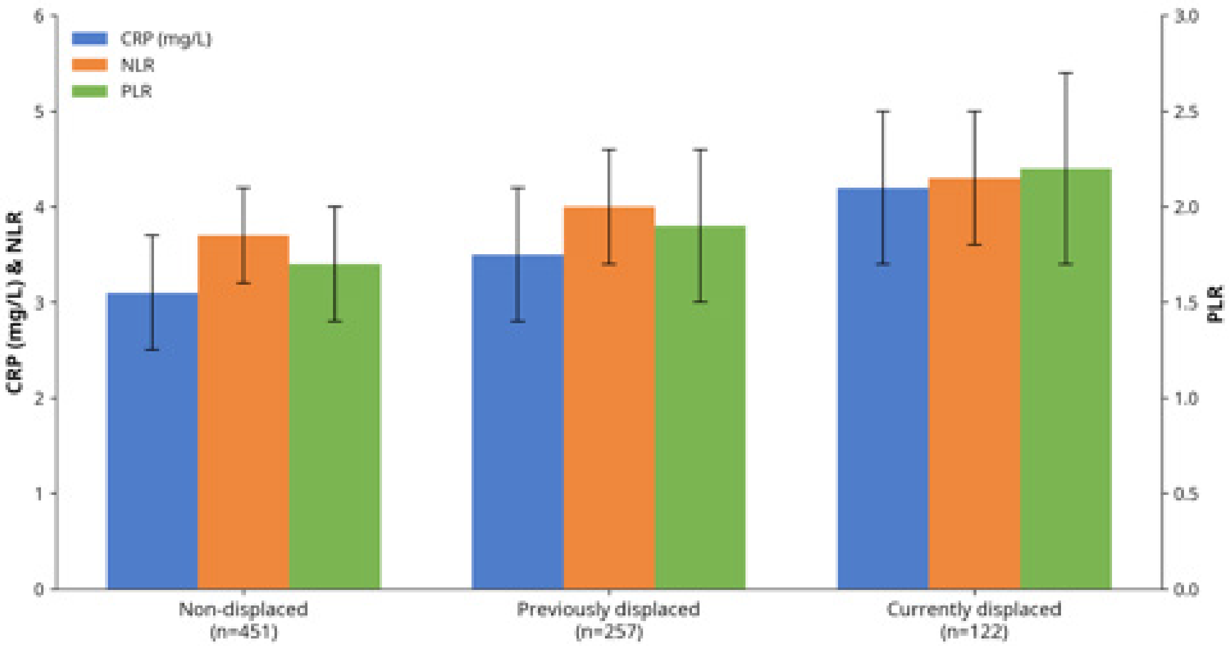

Figure S3: Dose-response relationship between displacement status and inflammatory markers (CRP, NLR, PLR)

Supplementary Table S1: Complete Inflammatory Marker Data by Displacement Status

Parameter	Non-displaced (n = 451)	Previously Displaced (n = 257)	Currently Displaced (n = 122)	Total (N = 830)	p-value
CRP (mg/L)					
Mean ± SD	3.1 ± 1.9	3.5 ± 2.1	4.2 ± 2.4	3.4 ± 2.1	<0.001
Median (IQR)	3.0 (1.5–4.6)	3.5 (1.8–5.2)	4.2 (2.3–6.1)	3.0 (1.6–4.8)	<0.001
Range (min–max)	0.0–8.8	0.0–8.6	0.0–8.5	0.0–8.8	
Elevated CRP (>5 mg/L)	83 (18.4%)	61 (23.7%)	36 (29.5%)	180 (21.7%)	0.01
ESR (mm/hr)					
Mean ± SD	17.0 ± 9.2	18.5 ± 9.4	21.5 ± 10.1	18.7 ± 9.6	<0.001
Median (IQR)	16.0 (10.0–24.0)	18.0 (11.0–26.0)	21.0 (13.0–29.0)	17.5 (11.0–25.0)	<0.001
Range (min–max)	0.1–48.0	0.2–51.8	0.1–49.2	0.1–51.8	
Elevated ESR	171 (37.9%)	111 (43.2%)	64 (52.5%)	346 (41.7%)	0.008
NLR					
Mean ± SD	3.7 ± 1.8	4.0 ± 2.0	4.3 ± 2.1	3.9 ± 1.9	0.001
Median (IQR)	3.5 (2.4–5.0)	3.8 (2.6–5.3)	4.1 (2.8–5.9)	3.6 (2.5–5.0)	0.001
Range (min–max)	0.4–8.1	0.5–8.1	0.5–8.1	0.4–8.1	
Elevated NLR (>3.0)	210 (46.6%)	139 (54.1%)	78 (63.9%)	427 (51.4%)	0.001
PLR					
Mean ± SD	1.7 ± 0.8	1.9 ± 0.9	2.2 ± 1.0	1.9 ± 0.9	0.002
Median (IQR)	1.6 (1.2–2.2)	1.8 (1.3–2.4)	2.1 (1.5–2.8)	1.7 (1.3–2.3)	0.002
Range (min–max)	0.5–5.8	0.5–5.8	0.5–5.6	0.5–5.8	
Elevated PLR (>1.5)	195 (43.2%)	127 (49.4%)	71 (58.2%)	393 (47.3%)	0.004
MPV (fL)					
Mean ± SD	13.4 ± 1.5	13.8 ± 1.6	14.1 ± 1.7	13.6 ± 1.6	<0.001
Median (IQR)	13.4 (12.4–14.4)	13.7 (12.7–14.9)	14.1 (13.0–15.2)	13.6 (12.6–14.6)	<0.001
Range (min–max)	9.7–18.2	9.9–18.2	10.1–17.9	9.7–18.2	
Elevated MPV (>12.0 fL)	312 (69.2%)	189 (73.5%)	102 (83.6%)	603 (72.7%)	0.006
WBC Count ($\times 10^9$/L)					
Mean ± SD	6.5 ± 2.0	6.7 ± 2.1	7.0 ± 2.2	6.7 ± 2.1	0.02
Median (IQR)	6.3 (5.1–8.0)	6.6 (5.2–8.1)	6.8 (5.3–8.4)	6.5 (5.2–8.0)	0.02
Neutrophils ($\times 10^9$/L)					
Mean ± SD	3.8 ± 1.4	4.0 ± 1.5	4.2 ± 1.6	3.9 ± 1.5	0.01
Lymphocytes ($\times 10^9$/L)					
Mean ± SD	2.2 ± 0.8	2.3 ± 0.9	2.4 ± 0.9	2.3 ± 0.9	0.04

Note: p-values from one-way ANOVA for continuous variables and chi-square test for categorical variables. Elevated ESR defined as >15 mm/hr for males and >20 mm/hr for females.

Supplementary Table S2: Inflammatory Markers by War Exposure Level (Detailed)

Parameter	No War Exposure (n = 221)	Moderate War Exposure (n = 359)	Severe War Exposure (n = 250)	Total (N = 830)	p-value
CRP (mg/L)					
Mean ± SD	2.8 ± 1.8	3.4 ± 2.1	4.0 ± 2.3	3.4 ± 2.1	<0.001
Median (IQR)	2.6 (1.4–4.2)	3.2 (1.7–5.0)	3.9 (2.1–5.8)	3.0 (1.6–4.8)	<0.001
Range (min–max)	0.0–8.0	0.0–8.6	0.0–8.8	0.0–8.8	
Elevated CRP (>5 mg/L)	34 (15.4%)	79 (22.0%)	74 (29.6%)	187 (22.5%)	<0.001
ESR (mm/hr)					
Mean ± SD	16.8 ± 8.9	18.5 ± 9.4	20.7 ± 10.1	18.7 ± 9.6	<0.001
Median (IQR)	16.0 (9.5–24.0)	18.0 (11.0–26.0)	20.0 (13.0–28.0)	17.5 (11.0–25.0)	<0.001
Range (min–max)	0.2–48.0	0.1–51.8	0.2–49.2	0.1–51.8	
Elevated ESR	76 (34.4%)	154 (42.9%)	116 (46.4%)	346 (41.7%)	0.02
NLR					
Mean ± SD	3.5 ± 1.7	3.9 ± 1.9	4.2 ± 2.0	3.9 ± 1.9	<0.001
Median (IQR)	3.3 (2.2–4.8)	3.7 (2.5–5.2)	4.0 (2.8–5.7)	3.6 (2.5–5.0)	<0.001
Range (min–max)	0.4–8.1	0.5–8.1	0.5–8.1	0.4–8.1	
Elevated NLR (>3.0)	102 (46.2%)	195 (54.3%)	154 (61.6%)	451 (54.3%)	<0.001
PLR					
Mean ± SD	1.7 ± 0.8	1.9 ± 0.9	2.0 ± 0.9	1.9 ± 0.9	<0.001
Median (IQR)	1.6 (1.2–2.2)	1.8 (1.3–2.4)	1.9 (1.4–2.6)	1.7 (1.3–2.3)	<0.001
Range (min–max)	0.5–5.8	0.5–5.6	0.5–5.8	0.5–5.8	
Elevated PLR (>1.5)	89 (40.3%)	172 (47.9%)	137 (54.8%)	398 (48.0%)	0.006
MPV (fL)					
Mean ± SD	13.2 ± 1.4	13.7 ± 1.6	14.2 ± 1.7	13.6 ± 1.6	<0.001
Median (IQR)	13.1 (12.2–14.2)	13.6 (12.6–14.7)	14.1 (13.0–15.2)	13.6 (12.6–14.6)	<0.001
Range (min–max)	9.7–17.9	9.9–18.2	10.1–18.0	9.7–18.2	
Elevated MPV (>12.0 fL)	142 (64.3%)	264 (73.5%)	197 (78.8%)	603 (72.7%)	<0.001
WBC Count ($\times10^9$/L)					
Mean ± SD	6.4 ± 2.0	6.7 ± 2.1	7.0 ± 2.2	6.7 ± 2.1	0.005
Median (IQR)	6.2 (5.0–7.9)	6.6 (5.2–8.1)	6.9 (5.3–8.4)	6.5 (5.2–8.0)	0.005
Neutrophils ($\times10^9$/L)					
Mean ± SD	3.7 ± 1.4	4.0 ± 1.5	4.2 ± 1.6	4.0 ± 1.5	0.002
Lymphocytes ($\times10^9$/L)					
Mean ± SD	2.2 ± 0.8	2.3 ± 0.9	2.4 ± 0.9	2.3 ± 0.9	0.03

Note: p-values from one-way ANOVA for continuous variables and chi-square test for categorical variables. Elevated ESR defined as >15 mm/hr for males and >20 mm/hr for females.

Supplementary Table S3: Correlation Matrix of All Inflammatory Markers

Variable	CRP	ESR	NLR	PLR	MPV	WBC	Neutrophils	Lymphocytes
CRP	1.00							
ESR	0.42*	1.00						
NLR	0.33*	0.28*	1.00					
PLR	0.28*	0.24*	0.41*	1.00				
MPV	0.19*	0.16*	0.24*	0.22*	1.00			
WBC	0.22*	0.18*	0.35*	0.19*	0.12*	1.00		
Neutrophils	0.31*	0.26*	0.72*	0.18*	0.20*	0.78*	1.00	
Lymphocytes	-0.08	-0.04	-0.38*	-0.31*	-0.06	0.24*	-0.02	1.00
Platelets	0.15*	0.12*	0.09	0.45*	0.14*	0.06	0.05	0.08

Stratified Correlation Matrix by Displacement Status

Non-displaced (n = 451)

Variable	CRP	NLR	PLR	MPV
CRP	1.00			
NLR	0.31*	1.00		
PLR	0.26*	0.39*	1.00	
MPV	0.18*	0.22*	0.20*	1.00

Previously Displaced (n = 257)

Variable	CRP	NLR	PLR	MPV
CRP	1.00			
NLR	0.34*	1.00		
PLR	0.29*	0.42*	1.00	
MPV	0.20*	0.25*	0.23*	1.00

Currently Displaced (n = 122)

Variable	CRP	NLR	PLR	MPV
CRP	1.00			
NLR	0.36*	1.00		
PLR	0.31*	0.44*	1.00	
MPV	0.22*	0.27*	0.25*	1.00

Supplementary Table S4: Reference ranges, cut-off values, and rationales for inflammatory markers

Marker	Reference Range	Cut-off for "Elevated"	Rationale / Source
CRP	< 5.0 mg/L	5.0 mg/L	Manufacturer standard (immunoturbidimetric assay, Roche Diagnostics). Values >5.0 mg/L indicate clinically significant systemic inflammation.
ESR (Male)	< 15 mm/hr	15 mm/hr	Westergren method standard reference. Sex-specific criteria per International Council for Standardization in Haematology (ICSH).
ESR (Female)	< 20 mm/hr	20 mm/hr	Westergren method standard reference. Sex-specific criteria per ICSH.
NLR	0.78–3.0	3.0	Based on systematic review and meta-analysis by Angkananard et al. (2018) for cardiovascular risk stratification and systemic inflammation prediction. Optimizes sensitivity/specificity in adult populations.
PLR	0.8–1.5	1.5	Per published thresholds by Balta & Ozturk (2015) for cardiovascular events and inflammatory conditions.
MPV	7.2–12.0 fL	12.0 fL	Reflects platelet activation. Threshold per Korniluk et al. (2019) for inflammatory conditions. Values >12.0 fL indicate increased platelet reactivity.
WBC Count	4.0–11.0 × 10^9/L	11.0 × 10^9/L	Standard laboratory reference range. Elevation suggests leukocytosis, may indicate infection or inflammation.
Neutrophils	1.5–7.0 × 10^9/L	7.0 × 10^9/L	Standard laboratory reference range. Elevation indicates innate immune activation.
Lymphocytes	1.0–4.0 × 10^9/L	< 1.0 × 10^9/L	Standard laboratory reference range. Lymphopenia may indicate stress response or chronic inflammation.

Note: All cut-off values were established prior to data analysis based on published literature and manufacturer specifications. NLR = neutrophil-to-lymphocyte ratio; PLR = platelet-to-lymphocyte ratio; MPV = mean platelet volume; CRP = C-reactive protein; ESR = erythrocyte sedimentation rate; WBC = white blood cell.

Progressive increase in median CRP, NLR, and PLR values across displacement categories (non-displaced → previously displaced → currently displaced). Error bars represent interquartile ranges (IQR). All pairwise comparisons between currently displaced and non-displaced participants were statistically significant ($P < 0.001$ for CRP; $P = 0.001$ for NLR; $P = 0.002$ for PLR). Abbreviations: CRP, C-reactive protein; NLR, neutrophil-to-lymphocyte ratio; PLR, platelet-to-lymphocyte ratio; IQR, interquartile range."