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ORIGINAL PAPER

CLINICAL UTILITY OF FRACTIONAL EXHALED NITRIC OXIDE IN ACTIVE PULMONARY SARCOIDOSIS

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Abstract

Introduction. Fractional exhaled nitric oxide (FeNO) is an established biomarker of type 2 airway inflammation in asthma, but its clinical utility in sarcoidosis remains uncertain.
The objective of the study was (i) to describe FeNO levels in active disease; (ii) to analyse the association between FeNO and blood eosinophilia, spirometric and plethysmographic parameters and radiographic stage; and (iii) to explore the relationship between FeNO and markers of small airway involvement, particularly mid- and distal expiratory flows.
Material and methods. We conducted a prospective observational study at a national reference centre for pulmonary diseases in Albania. During 2020–2024, 422 adults with pulmonary sarcoidosis were hospitalized; FeNO, spirometry, body plethysmography and serum angiotensin converting enzyme (SACE) were assessed in an analytic cohort of 139 patients with clinically active disease. FeNO was measured with a NIOX MINO analyser according to American Thoracic Society/ European Respiratory Society (ATS/ERS). Associations between FeNO, blood eosinophils, radiographic stage (I–IV), lung function indices and small-airway flows were evaluated with correlation and subgroup analyses.

Résumé

Utilité clinique de la fraction d'oxyde nitrique exhalé dans la sarcoïdose pulmonaire active

Introduction. La fraction exhalée d'oxyde nitrique (FeNO) est un biomarqueur reconnu de l'inflammation des voies respiratoires de type 2 dans l'asthme, mais son utilité clinique dans la sarcoïdose reste incertaine.
L'objectif de cette étude était de : (i) décrire les taux de FeNO en phase active de la maladie; (ii) analyser l'association entre le FeNO et l'éosinophilie sanguine, les paramètres spirométriques et pléthysmographiques, ainsi que le stade radiographique; et (iii) explorer la relation entre le FeNO et les marqueurs d'atteinte des petites voies aériennes, notamment les débits expiratoires moyens et distaux.
Matériel et méthodes. Nous avons mené une étude observationnelle prospective dans un centre national de référence pour les maladies pulmonaires en Albanie. Entre 2020 et 2024, 422 adultes atteints de sarcoïdose pulmonaire ont été hospitalisés; le FeNO, la spirométrie, la pléthysmographie corporelle et l'enzyme de conversion de l'angiotensine sérique (ECA) ont été évalués dans une cohorte analytique de 139 patients

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Results. The mean FeNO was 11.1±4.7 ppb (median 11 ppb; range 4–25 ppb), indicating generally low to intermediate levels. FeNO showed a moderate positive correlation with peripheral blood eosinophil percentage (r = 0.39, p = 0.01). FeNO values did not differ significantly across radiographic stages (p = 0.10) and were not significantly associated with forced expiratory volume in one second (FEV1), forced vital capacity (FVC), total lung capacity (TLC), residual volume (RV), intrathoracic gas volume (ITGV), RV/TLC ratio, or SACE. In a subgroup of 54 patients with documented small airway obstruction, FeNO correlated moderately and negatively with maximal expiratory flow at 25% (MEF25)(%) (r = –0.40, p = 0.04), consistent with higher FeNO levels in patients with more pronounced distal airflow limitation.

Conclusions. FeNO values were generally low to intermediate and showed limited ability to reflect overall disease activity. FeNO may provide complementary information in patients with blood eosinophilia or small airway obstruction, but it should not be used as a stand-alone biomarker for assessing sarcoidosis activity.

Keywords: sarcoidosis, nitric oxide, respiratory function tests.

List of abbreviations:
ATS – American Thoracic Society
ERS – European Respiratory Society
FeNO – fractional exhaled nitric oxide
FEV1- forced expiratory volume in 1 second
FVC – forced vital capacity
ITGV – intrathoracic gas volume
MEF 25 – maximal expiratory flow at 25%
MEF 50 – maximal expiratory flow at 50%
MEF 75 – maximal expiratory flow at 75%
PEF – peak expiratory flow
Raw – airway resistance
RV – residual volume
SACE – serum angiotensin converting enzyme
TLC – total lung capacity
WASOG – World Association for Sarcoidosis and Other Granulomatous Disorders

présentant une maladie cliniquement active. Le FeNO a été mesuré à l'aide d'un analyseur NIOX MINO, conformément aux recommandations de l'American Thoracic Society/European Respiratory Society (ATS/ERS). Les associations entre le FeNO, l'éosinophilie sanguine, le stade radiographique (I à IV), les indices de fonction pulmonaire et les débits des petites voies aériennes ont été évaluées par des analyses de corrélation et de sous-groupes.

Résultats. Le FeNO moyen était de 11,1±4,7 ppb (médiane 11 ppb; intervalle 4 à 25 ppb), indiquant des niveaux généralement faibles à intermédiaires. Le FeNO a montré une corrélation positive modérée avec le pourcentage d'éosinophiles dans le sang périphérique (r = 0,39, p = 0,01). Les valeurs de FeNO ne différaient pas significativement selon les stades radiographiques (p = 0,10) et n'étaient pas significativement associées au volume expiratoire maximal en une seconde (VEMS), à la capacité vitale forcée (CVF), à la capacité pulmonaire totale (CPT), au volume résiduel (VR), au volume gazeux intrathoracique (VGIT), au rapport VR/CPT ni à l'ACE. Dans un sous-groupe de 54 patients présentant une obstruction documentée des petites voies aériennes, le FeNO était modérément et négativement corrélé au débit expiratoire maximal à 25 % (DEM25) (r = –0,40, p = 0,04), ce qui concorde avec des taux de FeNO plus élevés chez les patients présentant une limitation du débit d'air distal plus marquée.

Conclusions. Les valeurs de FeNO étaient généralement faibles à intermédiaires et reflétaient peu l'activité globale de la maladie. Le FeNO peut fournir des informations complémentaires chez les patients présentant une éosinophilie sanguine ou une obstruction des petites voies aériennes, mais il ne doit pas être utilisé comme biomarqueur unique pour évaluer l'activité de la sarcoïdose.

Mots-clés: sarcoïdose, oxyde nitrique, explorations fonctionnelles respiratoires.

Introduction

Sarcoidosis is a systemic granulomatous disease of unknown cause, characterized by non-caseating granulomas that can affect virtually any organ, with a predilection for the intrathoracic lymph nodes and lung parenchyma. Clinical presentation and course are highly heterogeneous: many patients remain stable or remit spontaneously, whereas others develop chronic pulmonary impairment and progressive fibrosis despite treatment[1].

Granulomatous inflammation in sarcoidosis is characterized by accumulation of activated macrophages and T lymphocytes, with enhanced production of nitric oxide (NO) and reactive oxygen species in the lung, although experimental data also suggest increased scavenging and consumption of NO within different compartments of the respiratory tract [2].

Fractional exhaled nitric oxide (FeNO) is an established, non-invasive biomarker of type 2 airway inflammation and is widely used to support the diagnosis and management of asthma [3]. Several small

studies have evaluated FeNO in pulmonary sarcoidosis with conflicting results, reporting normal, increased or only modestly elevated FeNO levels compared with healthy controls or other interstitial lung diseases[4]. These discrepancies raise uncertainty about the clinical utility of FeNO as a global marker of sarcoidosis activity.

Several pathophysiological mechanisms may explain these discrepant findings, including heterogeneity in disease phenotype, concomitant atopic or eosinophilic airway inflammation, variable use of inhaled or systemic corticosteroids and differences in FeNO measurement protocols. Moreover, compartmentalization of NO production between central and peripheral airways and the alveolar space may limit the interpretability of single-flow FeNO measurements in sarcoidosis, especially in patients with predominant parenchymal or small-airway involvement[5].

Given these uncertainties, the clinical value of FeNO in pulmonary sarcoidosis remains unclear. In this prospective study, we evaluated FeNO in a cohort of patients with documented pulmonary sarcoidosis followed at a national reference centre.

The objectives of the study were: (i) to describe FeNO levels in active disease; (ii) to analyse the association between FeNO and blood eosinophilia, spirometric and plethysmographic parameters and radiographic stage; and (iii) to explore the relationship between FeNO and markers of small airway involvement, particularly mid- and distal expiratory flows.

Materials and method

This was a prospective observational study conducted at the University Hospital "Shefqet Ndroqi" in Tirana, Albania, a national reference centre for pulmonary diseases. During the study period 2020-2024, 422 adult patients with pulmonary sarcoidosis were hospitalized in the clinic. The diagnosis was based on compatible clinical and radiological findings together with histological confirmation of non-caseating granulomas obtained by fibreoptic bronchoscopy, in accordance with American Thoracic Society/ European Respiratory Society (ATS/ERS)/ World Association for Sarcoidosis and other Granulomatous Disorders (WASOG)[6,7].

The inclusion criteria were age ≥18 years and radiologically documented pulmonary involvement. Patients with alternative explanations for their radiological abnormalities or with significant coexistent chronic respiratory disease were excluded.

Fractional exhaled nitric oxide (FeNO) was measured using an electrochemical analyser (NIOX MINO; Aerocrine AB, Solna, Sweden) following ATS/ERS technical standards[8]. All measurements were performed at a flow of 0.05 L/s. The patients were instructed to avoid food, beverages, smoking and strenuous physical activity for at least four hours before the examination and to avoid nitrate-rich foods on the day of testing. Because corticosteroids are known to reduce FeNO and β2-agonists may increase it, all subjects refrained from inhaled or systemic corticosteroids and bronchodilators for at least 12 hours prior to FeNO measurement. At least two acceptable manoeuvres were obtained in each patient, and the mean value was used for analysis.

Pulmonary function testing was performed after FeNO measurement using a JAEGER body plethysmograph (Jaeger, Germany) according to ATS/ERS guidelines[7]. Spirometric indices included FEV1, FVC, the FEV1/FVC ratio and peak expiratory flow (PEF). Static lung volumes and airway resistance were also recorded, including TLC, RV, ITGV), RV/TLC ratio and airway resistance (Raw). Small airway involvement was assessed by mid and distal expiratory flows (MEF75, MEF50, MEF25). All values were expressed as percentages of the predicted values for healthy, non smoking adults.

Laboratory evaluation included a complete blood count with differential, with blood eosinophilia defined as eosinophils >4% of total leukocytes, and serum angiotensin converting enzyme (SACE) measurement. Imaging assessment consisted of chest radiography and computed tomography (CT) to characterize the pattern and extent of parenchymal involvement and hilar or mediastinal lymphadenopathy[9]. Radiographic stage was classified according to the conventional staging system (stages I–IV). Sociodemographic data (age, sex, place of residence), anthropometric variables (height, weight, body mass index) and smoking status were also recorded. Of the 422 hospitalized patients, FeNO measurements and complete lung function data were available in 139 individuals with clinically active pulmonary sarcoidosis, who constituted the analytic cohort for the present study.

Statistical analysis

Data were analysed using MedCalc® Statistical Software version 23.3.7 (MedCalc Software Ltd, Ostend, Belgium; https://www.medcalc.org; 2025). Continuous variables are presented as mean ± standard deviation (SD) and, when appropriate, as median and interquartile range (IQR), whereas categorical variables are expressed as absolute numbers and percentages. Normality of distribution was assessed using the Kolmogorov–Smirnov test. Group comparisons for categorical variables were performed with the chi square test. Comparisons of continuous variables

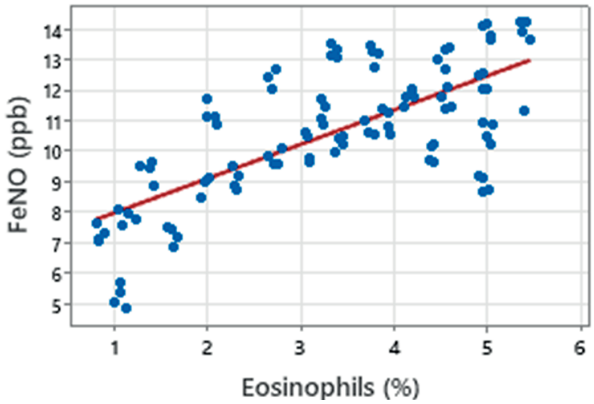


Figure 1. Correlation between FeNO values and eosinophils (%) in blood

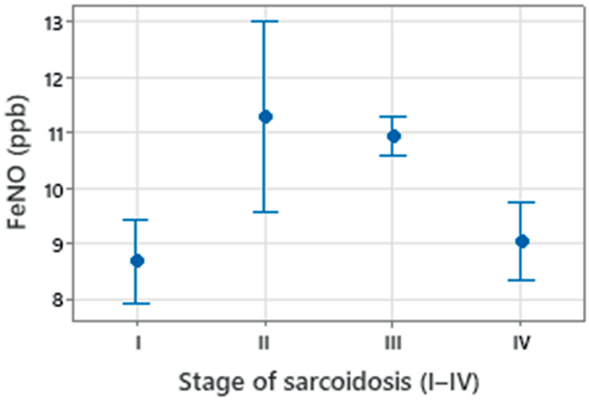


Figure 2. FeNO values according to radiographic stage (I–IV) of pulmonary sarcoidosis.

Table 1. Correlation of FeNO values with the following variables in pulmonary sarcoidosis

Variables	r	95%CI	p
FEV1 (%)	-0.004	-0.3199 - 0.3112	0.9
FVC (%)	-0.10	-0.4081 - 0.2253	0.5
FEV1/FVC (%)	0.08	-0.2410 - 0.3864	0.6
PEF (%)	-0.01	-0.3330 - 0.2978	0.9
TLC (%)	-0.21	-0.5424 - 0.1747	0.2
RV (%)	-0.08	-0.4449 - 0.2965	0.6
ITGV (%)	-0.16	-0.5050 - 0.2242	0.4
RV/TLC (%)	0.08	-0.2985 - 0.4432	0.6
SACE	0.28	-0.4157 - 0.7775	0.4

between two groups used the unpaired Student t test, and comparisons among more than two groups used one way analysis of variance (ANOVA) with post hoc tests when indicated. Correlations between FeNO and continuous variables (e.g. blood eosinophil percentage, SACE, lung function indices) were assessed by Pearson correlation coefficients. A p value ≤0.05 was considered statistically significant.

Results

FeNO measurements were available for 139 patients with active pulmonary sarcoidosis from the cohort of 422 followed patients. The mean FeNO value was 11.1±4.7 ppb, with a median of 11 ppb (range 4–25 ppb), indicating generally low to intermediate levels.

A statistically significant moderate positive correlation was observed between FeNO levels and the percentage of eosinophils in peripheral blood (r = 0.39, p = 0.01), suggesting that higher FeNO values clustered in patients with relative eosinophilia. This relationship is illustrated in Figure 1.

FeNO values across radiographic stages were 8.6±2.6 ppb in stage I, 12.5±5.5 ppb in stage II, 9.7±1.5 ppb in stage III and 9.0±3.0 ppb in stage IV. Although FeNO tended to be higher in stage II, differences among stages were not statistically significant (ANOVA F-ratio = 1.9, p = 0.1; Figure 2).

Similarly, no significant associations were found between FeNO and standard lung function indices (FEV1, FVC, FEV1/FVC, TLC, RV, RV/TLC, ITGV) or between FeNO and SACE levels, indicating that FeNO does not parallel conventional markers of disease activity in this cohort (Table 1).

In a subgroup of 54 patients with pulmonary sarcoidosis and documented small airway obstruction, the mean FeNO value was 11.4±5.1 ppb (median 11.5 ppb; range 4–25 ppb). Within this subgroup, FeNO showed no relevant correlation with MEF75(%) or MEF50(%), but a statistically significant moderate negative correlation was observed with MEF25(%) (r = –0.40, p = 0.04), consistent with higher FeNO levels in patients with more pronounced distal airflow limitation.

Discussion

In this study, FeNO values were generally in the low to intermediate range and showed limited value as a global marker of disease activity. The principal

findings were: (i) a statistically significant moderate positive correlation between FeNO and peripheral blood eosinophils; (ii) no meaningful association between FeNO and radiographic stage, global spirometric or plethysmographic indices or SACE; and (iii) a moderate negative correlation between FeNO and MEF25(%) in the subgroup with small airway obstruction.

The average FeNO level of approximately 11 ppb in active sarcoidosis observed in our cohort is substantially lower than values typically reported in eosinophilic asthma, in which FeNO is usually elevated and strongly related to type 2 airway inflammation and response to corticosteroids[10]. Our findings are broadly in line with earlier studies suggesting that FeNO may be increased compared with healthy controls but does not consistently differentiate between active and inactive sarcoidosis or between different radiographic stages[11].

The observed correlation between FeNO and peripheral blood eosinophils suggests that a subset of sarcoidosis patients may exhibit overlapping type 2 inflammatory features. Although eosinophilia is not a classical hallmark of sarcoidosis, interactions between Th1- and Th2-mediated pathways and co-existing atopic disease may modulate NO production[12]. Similar associations between FeNO and blood eosinophils have been described in asthma cohorts[13], and our data indicate that this relationship may also be present, albeit more modestly, in sarcoidosis.

In contrast, FeNO did not correlate with SACE or global spirometric indices, including FEV1 and FVC. SACE primarily reflects granulomatous burden and activity within the interstitium and lymph nodes, whereas FeNO is influenced by NO production in the conducting airways and, to a lesser extent, in the distal acinar regions[14]. The lack of correlation between these markers, also reported by other authors[15], supports the concept that they capture distinct biological compartments of the disease rather than redundant information.

The moderate negative correlation between FeNO and MEF25(%) in the subgroup with small airway obstruction is of particular interest. Granulomatous involvement of small airways is well documented in sarcoidosis and may contribute to airflow limitation and gas-exchange abnormalities[16]. Our results suggest that, when small airways are predominantly affected, higher FeNO levels may accompany more severe distal obstruction, consistent with theoretical models of NO production and transport in the peripheral airways[17]. However, this finding should be interpreted cautiously because of the relatively small sample size of this subgroup and the cross-sectional nature of the study.

From a clinical perspective, these data indicate that FeNO alone is unlikely to serve as a reliable biomarker for routine assessment of sarcoidosis activity or treatment response. Nevertheless, FeNO measurement may contribute additional information in selected patients, particularly where blood eosinophilia or clinical features suggest overlapping type 2 airway inflammation. In such cases, FeNO could help to identify a subgroup in which inhaled corticosteroid therapy might have a more pronounced effect on symptoms, even if its impact on granulomatous disease per se remains limited[18,19].

To our knowledge, this is one of the larger single-centre cohorts to evaluate FeNO in pulmonary sarcoidosis in combination with comprehensive body plethysmography and detailed small-airway indices. By showing that FeNO is largely independent of global spirometric and radiographic measures, yet relates to peripheral eosinophilia and distal flow limitation in a specific subgroup, our findings support the concept that FeNO captures a distinct inflammatory phenotype rather than overall granulomatous burden.

This study has several limitations. First, FeNO measurements were available only in a subset of the total sarcoidosis cohort, reducing statistical power and potentially introducing selection bias. Second, the study was conducted at a single tertiary centre, which may limit generalizability to milder cases managed in primary or secondary care. Third, we did not include a healthy control group or patients with inactive sarcoidosis, which limits our ability to position FeNO values relative to background levels and to derive robust diagnostic cut-off values. Fourth, we did not perform longitudinal FeNO measurements or systematically relate FeNO changes to treatment or long-term outcomes. Finally, potential confounding by atopy and environmental exposures could not be fully excluded. Future multicentre studies with larger samples and serial FeNO assessments are needed to clarify whether FeNO can help to define clinically meaningful phenotypes or to monitor specific subsets of sarcoidosis patients.

Conclusions

In this cohort of patients with pulmonary sarcoidosis, FeNO values were generally low to intermediate and showed limited value as a global marker of disease activity. FeNO correlated moderately with peripheral blood eosinophils but not with radiographic stage, SACE or global spirometric indices, indicating that it reflects a component of airway inflammation that is largely independent of conventional markers of sarcoidosis activity. In patients with small airway obstruction, higher FeNO values were associated with

more pronounced distal airflow limitation as reflected by lower MEF25(%). These findings suggest that FeNO should not be used as a stand-alone marker of disease activity in sarcoidosis, but may provide complementary information in selected phenotypes, particularly those with co-existing eosinophilic airway inflammation.

Author Contributions:

Conceptualization, E.D. and P.K.; methodology, E.D. and P.K.; software, A.S.; validation, E.D. and P.K.; formal analysis, A.S.; investigation, E.D.; resources, E.D. and A. M.; data curation, A.S.; writing–original draft preparation, E.D.; writing–review and editing, E.D. and E. M.; visualization, E.D. and E. M.; supervision, P.K.; project administration, E.D., P.K.. All the authors have read and agreed with the final version of the article.

Compliance with Ethics Requirements:

The protocol of this study was reviewed and approved by the Medical University of Tirana Ethics Committee on 20th December, 2019, with Protocol number 412/3.

"The authors declare no conflict of interest regarding this article"

"The authors declare that all the procedures and experiments of this study respect the ethical standards in the Helsinki Declaration of 1975, as revised in 2008(5), as well as the national law. Informed consent was obtained from all the patients (or their parent/legal guardian/next of kin) included in the study"

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Data availability statement

Data sharing is applicable upon request.

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