



ADVANCEMENTS IN PULMONARY DISEASE TREATMENT: THE IMPACT OF PRECISION MEDICINE ON ASTHMA MANAGEMENT

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Abstract

Asthma is a heterogeneous chronic inflammatory pulmonary disorder with variable clinical presentation and treatment response. Conventional step-wise management strategies often fail to address underlying biological diversity, prompting increased interest in precision medicine approaches that integrate biomarker-guided and targeted therapies to optimize asthma control in real-world clinical settings. This study aimed to evaluate clinical outcomes of asthma patients managed using precision medicine approaches in a retrospective cohort and to assess the association between biomarker-guided therapies and asthma control outcomes. A retrospective observational study was conducted involving 100 patients with a confirmed diagnosis of asthma managed using precision medicine-based strategies. Data were extracted from clinical records, including demographic characteristics, asthma severity, biomarker profiles, treatment modalities, and clinical outcomes. Statistical analysis included descriptive statistics, paired *t*-tests to compare pre- and post-management outcomes, Pearson correlation analysis, and multivariate linear regression to identify predictors of asthma control. Precision medicine-based management was associated with significant improvements in clinical outcomes. Mean exacerbation frequency decreased significantly, while pulmonary function, measured by forced expiratory volume in one second (FEV₁), showed notable improvement. Elevated inflammatory biomarkers were prevalent at baseline and were significantly associated with disease severity and asthma control. Regression analysis identified biomarker-guided biologic therapy as an independent predictor of improved asthma control. The findings provide real-world evidence supporting the effectiveness of precision medicine in asthma management. Biomarker-guided therapeutic strategies improve disease control, reduce exacerbation burden, and enhance pulmonary function, highlighting precision medicine as a valuable advancement in personalized pulmonary care.

Keywords: Asthma; Precision medicine; Biomarkers; Biologic therapy; Retrospective study

1. Introduction

Asthma is a chronic bronchial inflammation, airway hyper-responsive and variable airway obstruction, and intermittent respiratory symptoms with a colossal difference in the presentation and response to the treatment in the affected individuals (Appleton et al., 2024). Conventional treatment of asthma has been following a similarized stepwise treatment reduction model of therapeutic intervention relying on the inhaled corticosteroids and bronchodilators; however, the general treatment models do not react to biologic diversities influencing different treatment outcomes (Beitler et al., 2022). This weakness has resulted in a growing curiosity of precision medicine that supports patient-centred therapy based on molecular, genetic, and clinical characteristics (Benincasa et al., 2021). Recent discoveries in the field of pulmonology have confirmed that asthma has similar inflammatory and structural pathways to other chronic respiratory conditions, and that mechanism-targeted treatment approaches should be prioritized over symptom-based escalation models (Brandsma et al., 2020). The concept of precision medicine in asthma is to divide patients into specific phenotypes and endotypes, providing interventions that are specific to underlying immunological processes and drivers of disease (Canonica et al., 2023). This kind of stratification is a shift to non-uniform treatment paradigms into individualized disease management. The identification of pathways in severe and refractory asthma that can be treated has added to the importance of precision-based strategies, especially by finding immune-mediated pathways that can be specifically addressed (Chung and Adcock, 2019). Biomarker assessment has also been integrated into personalized respiratory care models to support the therapeutic decision-making process and to maximize patient outcomes (Franssen et al., 2019). The eosinophil cells in blood, serum immunoglobulin E, and fractional exhaled nitric oxide have become vital biomarkers according to the identification of inflammatory phenotypes in regard to being treatment responsive. Modern views focus on precision medicine as a paradigm shift approach in respiratory conditions, and asthma is used as an example of an ideal disease because of its immune heterogeneity, which is well characterized (Georgakopoulou et al., 2024). However, as a result of the classification of asthma in phenotypes according to clinical and molecular characteristics, there has been an improved understanding of the variability of the disease and its therapy with therapeutic targets (Gonzalez-Uribe et al., 2023). Simultaneously, technological solutions that include smart inhalers and digital tools have facilitated the use of personalized treatments and optimization of adherence in the management of asthma (Greene & Costello, 2019). All of these advances have led to the rise in the use of precision-guided treatments in real clinical environments.

Although there is increased evidence on the effectiveness of precision medicine in asthma, there still remain serious gaps in knowledge regarding its efficacy in uncontrolled, real-world settings. The existing understanding of asthma pathogenesis has developed to a higher level, but the translation of the accuracy of knowledge into everyday clinical achievements has not yet been sufficiently high (Hizawa, 2023). A lot of the current body of literature focuses on mechanistic or trial-based results, which might not be indicative of actual patient complexity and care delivery variability in the real world. The number of studies that have reviewed precision medicine in a retrospective clinical context is limited and prevents consideration of long-term outcomes and treatment sustainability (Karampitsakos et al., 2023). Moreover, the interstitial lung diseases and other chronic pulmonary conditions are often discussed as the subject of precision medicine research, and relatively less has been conducted in the area of asthma-specific real-world outcomes (Khor et al., 2023). This asymmetry restrains evidence-based asthma. Whereas immune modulation and targeted therapies have shown promise, systematic assessment of biomarker-directed asthma management not based on clinical trials has not been done (Lommatzsch and van Eeden, 2020). Also, the role of precision medicine in the daily clinical practice was not assessed thoroughly, especially in terms of outcome variability in the heterogeneous groups of patients with asthma (Maher et al., 2022). These gaps point to the need to conduct observational studies that would be able to capture routine care experiences.

Retrospective studies are also an effective methodological means of assessing the actual efficacy and safety of precision medicine-based strategies in asthma management, which are not easily reflected in randomized clinical trials (Moll and Silverman, 2024). These types of studies allow the

analysis of treatment results in different patient samples, as well as different clinical settings. The evaluation of biomarker-directed treatments based on available clinical data helps to comprehend their long-term effect on disease management and medical service usage (Proper et al., 2021). The retrospective designs enable one to assess the effectiveness of therapeutic use after a long period of time as it mirrors the true clinical judgement and adherence rates of the patients. The ability to learn the feasibility of the implementation of precision medicine in routine care of asthma is also a key factor in wider clinical adoption and integration of guidelines (Ramphul et al., 2021). In addition, the application of molecularly targeted biologic therapy needs to be assessed in practice to demonstrate its importance in managing asthma at the personal level outside the controlled environment (Salter et al., 2022).

Research Objectives

1. To evaluate clinical outcomes of asthma patients managed using precision medicine approaches in a retrospective cohort.
2. To assess the association between biomarker-guided therapies and asthma control outcomes.

2. Methodology

2.1 Study Design

The research design applied is the retrospective observational design to determine the impact of the precision medicine approach on asthma management using the available clinical records. This design allowed the evaluation of the effectiveness of the real-world treatments based on the documented patient outcomes without affecting the clinical decision-making. A retrospective framework was chosen due to the need to record regular patterns of clinical practice and enable the usage of comparative and inferential statistical tests depicting the observed shifts in clinical and biomarker-related outcomes.

2.2 Study Population

The sample size of the study consisted of 100

Inclusion criteria:

1. Patients who were diagnosed with asthma and treated by means of precision medicine-based treatment plans. Records which have complete demographic, clinical, biomarker and outcome information that were necessary to conduct statistical analysis were chosen as eligible. Only patients who had fully documented records.
2. Both male and female patients were included.

Exclusion criteria: those who had chronic pulmonary conditions that would have confounded the outcome were excluded to guarantee analysis consistency and validity of comparative studies.

2.3 Data Sources

Institutional medical records/ clinical databases, such as physician documentation, laboratory reports, pulmonary results, and treatment records, were evaluated to obtain data. Anonymization of all the data retrieved was done before analysis to ensure confidentiality. Only the variables that were pertinent in terms of baseline characterization, biomarker profiling, stratification of treatment and outcome measurement were extracted to facilitate correct interpretation of the statistic.

2.4 Study Variables

The variables were extracted, including demographic variables (age and sex) and clinical variables (severe asthma, status of asthma control, and history of asthma exacerbation) and biomarker variables (blood eosinophil count, serum immunoglobulin E, and fractional exhaled nitric oxide). Variables linked to treatment comprised the application of biologic therapies and non-biologic precision. Outcome variables were on asthma control status, frequency of exacerbation and pulmonary capacity, namely forced expiratory volume in one second.

2.5 Outcome Assessment

Clinical outcomes were determined by comparing recorded data of asthma control, exacerbation rate, and pulmonary function prior to and subsequent to the introduction of management based on precision medicine. The evaluation of changes in clinical outcomes was assessed to examine the effectiveness of treatment, and the outcomes were based on the improvement of the disease control, the decrease of the exacerbation burden, and the improvement of the parameters of pulmonary functions measured during the routine clinical assessment.

2.6 Data Analysis

The baseline characteristics were summarized with descriptive statistics in the form of frequencies and percentages of categorical variables and mean $\pm$ standard deviation of continuous variables. Paired t-tests were used to compare clinical outcomes prior to and following the management using precision medicine. Pearson correlation was conducted to evaluate the relationships between the level of biomarkers or clinical outcomes. The multivariate linear regression analysis was carried out to determine independent predictors of asthma control after precision medicine interventions.

2.7 Ethical Considerations

All the procedures met the standards of institutional retrospective research. Ethical risk was minimized by removing patient identifiers in the process of data extraction, and no direct interaction with the patient or intervention was conducted, thus minimizing the risk of an ethical violation.

3. Results

3.1 Baseline Characteristics of the Study Population

The retrospective cohort study involved 100 asthma patients of which 58% and 42% of the study group was both female and male, respectively. The most common severity category was moderate (47%), then severe and mild asthma (35% and 18%). In patients with uncontrolled asthma at baseline, 62% reported uncontrolled asthma, and 68 percent reported having an exacerbation. The group of biomarker profiling showed that 54% of patients exhibited higher levels of blood eosinophils, 49 percent showed higher levels of serum IgE, 46% showed higher levels of FeNO, and therefore, the cohort is inflammatory in nature (Table 1).

Table 1. Baseline Characteristics of the Study Population (n = 100)

Category	Variable	Frequency (n)	Percentage (%)
Sex	Male	42	42.0
	Female	58	58.0
Asthma Severity	Mild	18	18.0
	Moderate	47	47.0
	Severe	35	35.0
Asthma Control Status	Controlled	38	38.0
	Uncontrolled	62	62.0
Exacerbation History	≥ 1 exacerbation	68	68.0

	No exacerbation	32	32.0
Biomarker Profile	Elevated eosinophils	54	54.0
	Elevated serum IgE	49	49.0
	Elevated FeNO	46	46.0

The visualization of the baseline demographic variables, the severity of asthma, the control status, exacerbation history, and biomarker profile of the study population provided an overview of the cohort characteristics. The frequency of more important clinical and inflammatory features was provided in percentage-based representation.

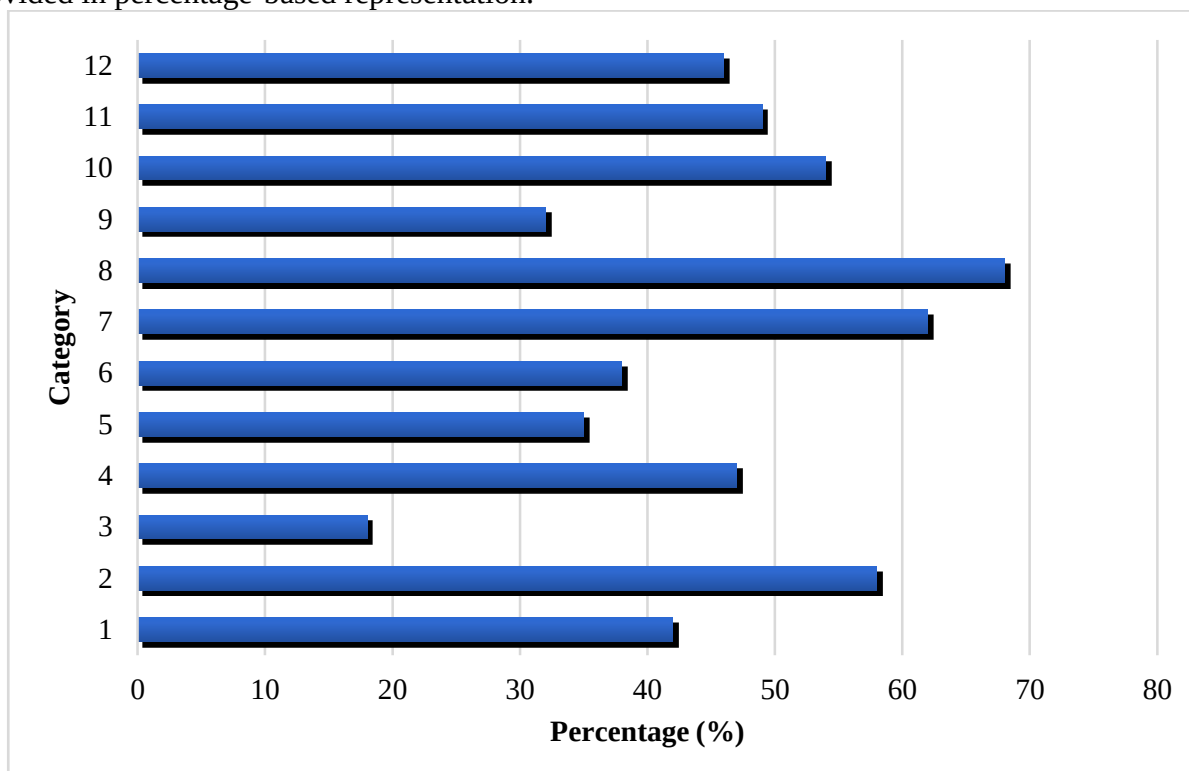


Figure 1. Distribution of Baseline Demographic, Clinical, and Biomarker Characteristics of the Study Population

The findings of Figure 1 demonstrate a higher prevalence of moderate to severe asthma, a greater percentage of uncontrolled disease and a significant amount of prior exacerbation in the cohort. A significant percentage of the patients showed high levels of biomarkers, which served as evidence of the non-uniformity of the inflammatory patterns and the importance of precision medicine-based stratification.

3.2 Precision Medicine Interventions

The mean levels of biomarkers varied significantly depending on the nature of precision medicine strategy. The mean blood eosinophil count (412.6 ± 96.4 cells/ μ L), serum IgE levels (326.8 ± 110.2 IU/mL) of patients treated with biomarker-directed biologic therapy were higher than the same measurements of patients treated with non-biologic precision strategies. On the same note, biologics patients had higher mean levels of FeNO, which indicates stratified treatment allocation by inflammatory burden (Table 2).

Table 2. Biomarker Levels According to Precision Medicine Strategy (Mean $\pm$ SD)

Biomarker	Biologic Therapy	Non-Biologic Precision
Eosinophils (cells/ μ L)	412.6 $\pm$ 96.4	248.3 $\pm$ 72.1
Serum IgE (IU/mL)	326.8 $\pm$ 110.2	182.5 $\pm$ 65.4
FeNO (ppb)	38.9 $\pm$ 12.6	24.1 $\pm$ 8.3

The mean levels of biomarkers were compared in patients who received biologic therapy and the marketed with non-biologic precision treatment methods to show the differences in inflammatory profiles of the treatment strategies. The comparison was based on blood eosinophil level, serum immunoglobulin E and fractional exhaled nitric oxide.

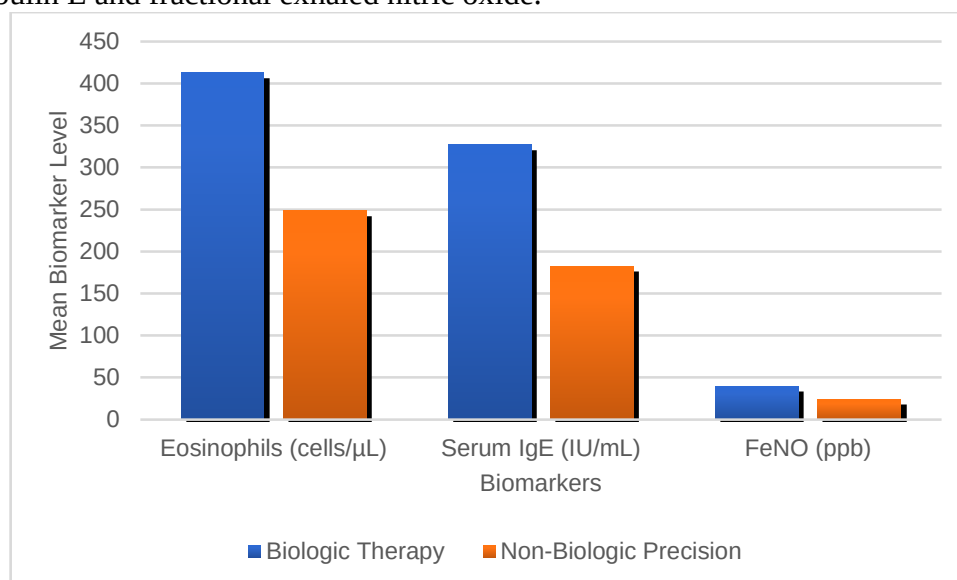


Figure 2. Comparison of Biomarker Levels Between Biologic and Non-Biologic Precision Therapy Groups

As shown in Figure 2, there is an increase in the mean level of eosinophils, serum IgE, and FeNO among patients who are treated with biologic therapy as compared to those who are treated with non-biologic precision strategies; this is an indication of stratified treatment selection based on the burden of inflammation.

3.3 Comparison of Clinical Outcomes

Paired *t*-test analysis demonstrated statistically significant improvements in clinical outcomes following precision medicine-based management. Mean exacerbation frequency decreased from 2.6 $\pm$ 1.1 to 1.1 $\pm$ 0.7 episodes per patient, while mean FEV₁ increased from 68.4 $\pm$ 12.9 to 78.6 $\pm$ 11.3. Both changes were statistically significant, indicating improved asthma control and pulmonary function following individualized treatment strategies (Table 3).

Table 3. Comparison of Clinical Outcomes Before and After Precision Medicine-Based Management

Outcome	Baseline (Mean $\pm$ SD)	Post-Management (Mean $\pm$ SD)	t-value	p-value
Exacerbations	2.6 $\pm$ 1.1	1.1 $\pm$ 0.7	12.84	<0.001
FEV ₁	68.4 $\pm$ 12.9	78.6 $\pm$ 11.3	-9.76	<0.001

The frequency of exacerbations and pulmonary functions were also changed to provide a visual comparison of the results of baseline and post-precision medicine. To indicate the extent and direction of clinical improvements after the administration of individualized asthma management, the mean exacerbations and forced expiratory volume in one second (FEV₁) were plotted.

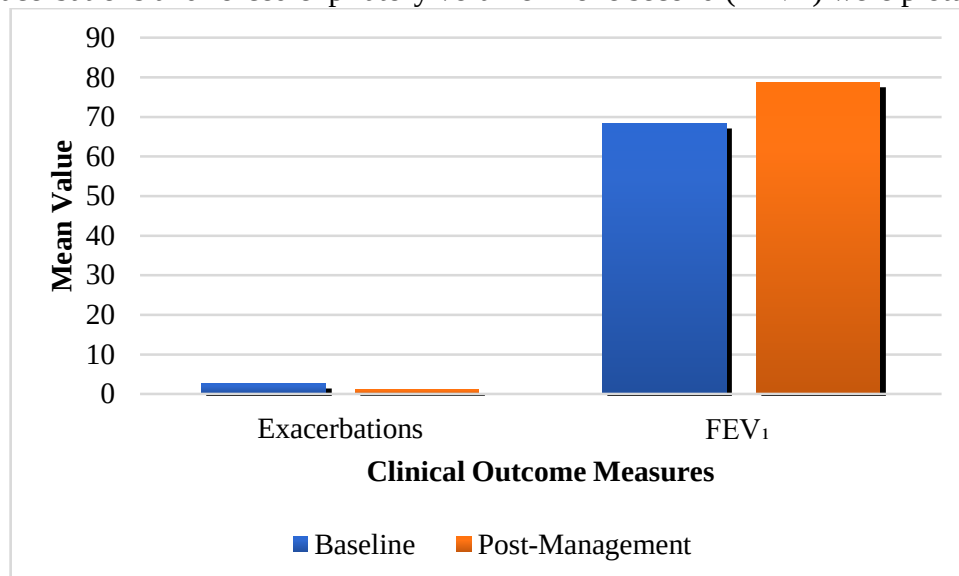


Figure 3. Exacerbation Frequency and FEV₁ Before and After Precision Medicine–Based Asthma Management

As shown in Figure 3, there is a significant decrease in exacerbation rate and a significant improvement in FEV₁ after precision medicine-based management. Such visual trends are in agreement with the statistical data and emphasize the positive effect of biomarker-driven therapeutic approaches on asthma management.

3.4 Associations Between Biomarkers and Clinical Outcomes

Pearson correlation analysis showed a strong positive relationship between the eosinophil level in the blood and the severity of asthma ($r = 0.48$, $p < 0.001$), as well as a moderate negative relationship between the eosinophil level in the blood and the post-treatment asthma control ($r = -0.42$, $p < 0.001$). The level of serum IgE was also significantly positively correlated with the frequency of exacerbations ($r = 0.39$, $p = 0.002$) which means that an increase in the level of biomarkers was related to the worsening of baseline disease control.

Table 4. Correlation Between Biomarkers and Clinical Outcomes

Variables Compared	r-value	p-value
Eosinophils vs. asthma severity	0.48	<0.001
Eosinophils vs. asthma control	-0.42	<0.001
IgE vs. exacerbation frequency	0.39	0.002

3.5 Predictors of Asthma Control Following Precision Medicine–Based Management

Multivariate linear regression analysis showed that biomarker-guided biologic therapy is a meaningful independent variable predictive of better asthma control after precision medicine-based management ($\beta = -0.46$, $p < 0.001$). The predictive value of blood eosinophil levels and baseline severity of asthma was also found to have significant predictive value as compared to both age and sex, which was not found to have a significant predictive value when it came to asthma control

outcomes. The regression model captured 41% of the variance in post-treatment asthma control, which was good in terms of explanatory power (Table 5).

Table 5. Multivariate Regression Analysis Predicting Asthma Control Outcome

Predictor Variable	β Coefficient	Standard Error	p-value
Biologic therapy	-0.46	0.09	<0.001
Blood eosinophils	0.31	0.08	0.001
Baseline severity	0.28	0.07	0.003
Age	0.06	0.05	0.214
Sex	0.04	0.04	0.331

4. Discussion

The study provides evidence that the management of asthma using precision medicine can be tied to the significant change of clinical outcomes. The decreases in the frequency of exacerbations, the promotion of the pulmonary functions, the better asthma management after the individualized treatment plans are observed, which demonstrates the clinical importance of making therapeutic decisions based on biomarkers. The abundance of high level of inflammatory biomarkers at baseline highlights the non-homogeneity of asthma and supports the use of stratified treatment strategies instead of homogeneous treatment patterns. The baseline levels of biomarkers were also elevated in patients undergoing biologic therapy, indicating the suitable adjustment of treatment intensity to the level of inflammatory activity. The statistically significant changes of individualized therapy were made due to the use of paired comparisons showing the contribution of individualized therapy to better disease stability and functional outcome. Correlation and regression analyses also demonstrated that biomarkers and treatment modality had an independent impact on the control of asthma, which further corroborated the idea of precision medicine as another method of targeting a disease mechanism rather than a symptom.

The current results have been in line with previous studies that have stressed the role of molecular and biomarker-based strategies in managing asthma. It is possible to note that the observed relationship between inflammatory biomarkers and the severity of the disease is consistent with previous data indicating that omics technologies are used to describe asthma heterogeneity and make individual interventions (Scelfo et al., 2018). Likewise, additional clinical outcomes that result after precision-guided therapy are comparable to the results found in studies that concentrate on phenotype- and endotype-based asthma management (Schoettler&Strek, 2020). The stratification of biomarkers identified in the context of the given study is in line with the bigger mechanism of precision medicine articulated in the context of chronic disease management, whereby integration of biological information makes treatment responsiveness and outcome prediction more effective (Subramanian et al., 2020). Furthermore, the practical enhancements that have been observed in this paper complement the recent reviews in the literature that highlight the growing role of precision medicine in chronic respiratory disease detection and therapy (Wesnawa, 2024).

The decrease in the number of exacerbations and the enhancement of lung capacity in this group are aligned with the current developments of asthma management practices that emphasize a personalized algorithm of care instead of the classic step-based escalation approaches (Witt et al.,

2022). It is also possible to make comparisons with the work of precision medicine in other related respiratory diseases, in which the biomarker-based approaches were proven to be effective with regards to treatment strategy optimization and better outcomes (Xie et al., 2025).

The findings of this study have immense clinical, research and healthcare system implications. The clinical implications consist of the clinical incorporation of the biomarker assessment in the normal asthma care to optimize its application in the treatment selection process and disease management. Precision medicine models can potentially decrease the healthcare utilization caused by exacerbations and improve the quality of life of a patient using a specific intervention.

As a research perspective, the proven links between the biomarkers, treatment strategy, and results indicate the necessity to explore further the personalized asthma management model. These results have been added to the accumulating real-world experience of precision medicine and could be used in future guideline development. At the healthcare system level the potential implication of initiating precision based strategies is that cost-effectiveness benefits may be achieved through unnecessary escalation of treatment and giving resources to patients who are most likely to respond well to advanced therapies. Notwithstanding its strengths, this research study has limitations associated with the retrospective nature of the research study. Using the available clinical records can create a bias in information as a result of incomplete or inconsistent reporting. This is due to the fixed sample size which inhibits generalizability and the lack of randomization inhibits causal inference. Also, the biomarker measurements and outcome measures were reliant on standard clinical practice and not standard research protocols, which could bring about variability.

Subsequent studies are needed in larger, multicenter, retrospective and prospective studies that would support these findings in different categories of population. Combination of multi-omics data and digital health solutions can also help optimize precision medicine in asthma. The evidence base would be enhanced with longitudinal studies that would determine how sustainable treatment benefits and health-economic outcomes can be over the long run. Moreover, integration of predictive models based on artificial intelligence can improve the interpretation of biomarkers and personalization of treatment during the routine asthma care.

5. Conclusion

The retrospective study has shown that the application of methods based on precision medicine has significant potential advantages in asthma treatment due to the ability to break down the disease in relation to its biological heterogeneity. The results suggest that biomarker-based treatment plans play a major role in asthma management, decreasing the number of exacerbations, and pulmonary dysfunction improvement. There was widespread high-level inflammatory biomarkers at baseline that support the argument of no standardized management of the situation, but personalized treatment choices. Precision-guided interventions, especially those directed by the inflammatory biomarkers profile, reported a good clinical response in patients, which indicated the efficacy of precision therapy in the routine clinical environment. Significant tendencies between levels of biomarkers, treatment modality, and outcomes of asthma control were identified in statistical analysis, which justifies the importance of precision medicine in terms of addressing the disease process, but not only symptoms. The individualized asthma management plans are clinically meaningful as expressed by the results of the forced expiratory volume and the reduction of the exacerbation burden. Overall, the study provides an applicable proof that the precision medicine perhaps can be used to make asthmatics more responsive to treatment and disease remission. The findings imply more interventions of biomarker assessment and therapy to the mainstream management of asthma. Precision medicine based on the alignment between the peculiarities of inflammatory phenotype and treatment option offers a valuable advancement in the pulmonary disease treatment and a potentially bright future of improved patient outcomes and improved healthcare delivery.

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