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BRIDGING ANTHROPOMETRY, CARDIAC BIOMARKERS AND DIELECTRIC IMAGING: RETROSPECTIVE INSIGHTS IN RHEUMATIC HEART DISEASE PATIENTS

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Abstract
Rheumatic heart disease (RHD) continues to impose a substantial burden in low- and middle-income countries, yet objective tools for monitoring disease status remain underutilized. This study addressed the need to integrate multimodal assessment by examining the relationships between anthropometry, N-terminal pro-B-type natriuretic peptide (NT-ProBNP), and Remote Dielectric Sensing (ReDS) in relation to New York Heart Association (NYHA) functional class in RHD patients. In a retrospective cross-sectional analysis of 100 adults meeting standardized diagnostic criteria, BMI, NT-ProBNP, and ReDS were measured alongside echocardiographic and clinical data. The primary objective was to evaluate whether ReDS and NT-ProBNP varied across NYHA classes and correlated with BMI. Results showed no significant variation in NT-ProBNP values median 2,145 pg/mL (IQR 612–3,487) in Class I, 2,097 pg/mL (1,048–3,292) in Class II, and 2,502 pg/mL (890–4,015) in Class III or ReDS across functional classes, suggesting that symptom-based classification alone may miss subclinical congestion. Gender analysis revealed higher ReDS scores in males, while NT-ProBNP showed no sex difference, indicating these modalities assess distinct physiological domains. Correlation analyses demonstrated weak, non-significant associations between BMI, NT-ProBNP, and ReDS. These findings highlight the potential of combining biomarkers and dielectric imaging for comprehensive RHD evaluation and support prospective validation with sex-specific interpretation protocols to optimize patient care.

Keywords: Anthropometry, Cardiac Biomarkers, Dielectric Imaging, Rheumatic Heart Disease, Subclinical Congestion

Introduction
One preventable but persistent cause of cardiovascular disease and death, especially in countries with poor and middle incomes, is rheumatic heart disease (RHD).[1] It is the chronic sequela of acute rheumatic fever and causes progressive valvular damage over decades before culminating in heart failure or other serious complications.[2] The global burden of RHD is estimated to surpass 40 million people, with the greatest burden in South Asia and sub-Saharan Africa.[3] India is a major contributor to this burden, with RHD affecting.

The pathophysiology of RHD is characterized by chronic inflammation, fibrosis and calcification of the heart valves, mostly the mitral valve.[4] These processes cause volume and pressure load on the myocardium, which induces a compensatory remodeling.[5] Such adaptations might maintain the function in the short-term, but they can conceal the initial manifestations of decompensation, making it difficult to detect the development of heart failure in time.[6] Early intervention at this stage can postpone hospitalizations and improve outcomes, but it needs accurate, reproducible, and sensitive monitoring methods.[7]

Traditional assessment methods have notable limitations. Although the New York Heart Association (NYHA) functional classification is widely used, it is inherently subjective, relying on self-reported symptoms and interpretation by clinicians, and thus is subject to observer variability.[8] Additionally, early hemodynamic alterations are not reflected in NYHA class. B-type N-terminal pro A quantitative indicator of myocardial wall stress, natriuretic peptide (NT-ProBNP) has prognostic significance in heart failure.[9] In RHD, it can give an indication of the combined effects of valvular dysfunction and ventricular strain. Nevertheless, it is affected by age, renal function and body mass index (BMI) that can diminish specificity in chronic valvular disease.[10]

Remote Dielectric Sensing (ReDS) is a new, non-invasive technology to measure the fluid content of the lungs in real-time by using low-powered electromagnetic signals.[11] ReDS has been validated across populations with diverse heart failure and demonstrated strong correlations between ReDS and invasive measures (pulmonary capillary wedge pressure) and fewer readmissions with ReDS-guided therapy.[12] Use of ReDS to guide therapy has been associated with more effective diuretic use and improved outpatient management.[13] Nevertheless, the use of ReDS has its limitations, and, to date, ReDS has been tested almost exclusively within ischemic or mixed-etiology heart failure populations.[14] The application of ReDS in RHD, where lesions are chronic and valves are subject to distinct adaptive processes, has not been studied. RHD patients can also have stable symptoms with pulmonary congestion, and there is a potential that ReDS can identify abnormalities that are not identified by NYHA class or NT-ProBNP.[15]

The great burden of RHD and the low access to invasive hemodynamic assessment beyond tertiary facilities in India makes a practical, objective tool highly needed. Most patients reside too far away to receive treatment at specialized centers, so frequent advanced monitoring is not feasible.[16] Portable, non-invasive, real-time devices like ReDS have the potential to fill this gap, providing an objective metric of patient status in an outpatient or community setting.[17] A correlation of ReDS with known scales of assessment, such as BMI, NT-ProBNP, and NYHA class, would help to determine whether ReDS can be a useful adjunct to individualized care.

There is no published study that has systematically investigated the correlation between anthropometry, biomarkers, functional class, and dielectric imaging in an RHD specific cohort. This paper fills that gap by performing a retrospective assessment of patients with established RHD, including simultaneous BMI, NT-ProBNP, NYHA classification, and ReDS scores. The dataset offers the chance to evaluate whether ReDS is related to traditional measures, whether it detects differences indicating the possibility of subclinical congestion, and whether demographic variables like gender affect readings. This is the first and, as far as we know, the only dataset of an Indian and perhaps worldwide population of RHD patients that combines these four domains, which provides a rare opportunity to explore how dielectric imaging can be used to supplement conventional measures.

This study sought to compare ReDS measurements with traditional markers, BMI, NT-ProBNP and NYHA class, in patients with RHD. Our aim was to examine the relationship between BMI and ReDS scores, to investigate whether NT-ProBNP and ReDS significantly differ according to NYHA functional classes, to investigate gender-specific variations of ReDS and NT-ProBNP, and to determine whether dielectric imaging can provide incremental diagnostic value over established methods. Our hypothesis was that ReDS scores would be positively correlated with NT-ProBNP and NYHA class, and negatively correlated with BMI, since they are all related to pulmonary congestion. We also thought that ReDS would be able to identify congestion patterns unnoticed by traditional methods and so it would be appropriate to introduce it into the RHD monitoring procedures.

Methodology

Study Design and Setting

Between January 1, 2023, and December 31, 2023, the Department of Cardiology at Ravindra Nath Tagore (RNT) Medical College in Udaipur, Rajasthan, India, carried out this retrospective, cross-sectional observational study. Medical records of patients with Rheumatic Heart Disease (RHD) admitted to, or followed up in, the cardiology units during this period were reviewed. The study complied with the Declaration of Helsinki's ethical requirements and the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.

Study Population

Adults (18 years of age or older) having a verified diagnosis of RHD met the inclusion requirements which was diagnosed by the World Heart Federation echocardiographic criteria with a corresponding clinical picture. The requirements of inclusion were documented New York Heart Association (NYHA) functional classification, full anthropometric measurements of body mass index (BMI), serum NT-ProBNP, and Remote Dielectric Sensing (ReDS) measurement. During structured clinical evaluation, treating physicians assigned NYHA classification. Patients who had significant co-existing cardiac conditions, such as congenital heart disease or ischemic heart disease, were not included in case records, had incomplete information on all necessary variables, or were experiencing acute decompensated heart failure at the time of data collection. The 2021 European Society of Cardiology heart failure recommendations defined acute decompensated heart failure as pulmonary rales, increased jugular venous pressure, the need for IV diuretics in the hospital, and the development of new or increasing dyspnea.

Sample Size

The sampling technique was a total enumeration technique, in which all the patients who fit the inclusion criteria at the time of the study were used. This practice was able to provide maximum completeness of the dataset and reducing selection bias. The last sample included all the eligible patients in the 12-month review period.

Data Collection

A structured abstraction form was used to extract data with uniformity and reproducibility based on both electronic and paper-based patient records. Anthropometric data (height and weight) were obtained as well as demographic information (age and sex). BMI was computed by dividing height in meters squared by weight in kilos, and was taken during the same clinical visit as the measurements of the ReDS and NT-ProBNP to ensure temporal congruence.AQT90 FLEX ANALYZER, serum NT-ProBNP was quantified, and internal quality control material was tested every day. Variance coefficients within and between assays were less than three and five, respectively.

The ReDS scores were measured as percentage lung fluid content with the ReDS 101 (Sensible Medical Innovations, Netanya, Israel) system. The instrument was also calibrated as recommended by the manufacturer before every measurement session and the patients were measured in a sitting position and breathing normally. All of the measurements were automatically calculated and projected on the device monitor. Where more than one measurement on a given patient was present, the value acquired within 48 hours of the NT-ProBNP test was used.

Reports of echocardiography were obtained and analyzed by certified cardiologists based on standard transthoracic echocardiography. The following classifications were used to valve lesions: tricuspid valve disease, aortic valve disease, progressive mitral stenosis (Prog MS), Mitral regurgitation (MR) and mitral stenosis (MS) are assessed in compliance with the guidelines set forth by the American Society of Echocardiography. Valve lesion categories were not mutually exclusive.

Statistical Analysis

To complete the statistical analyses, SPSS Statistics for Windows, version 28.0 (IBM Corp., Armonk, NY, USA), was used. To check if continuous variables were normal, Shapiro-Wilk was used. Consistent with the available data, the NT-ProBNP values in the different NYHA classes and by sex were reported as mean + standard deviation (SD), not median (IQR), unless the raw data were recalculated. The mean standard deviation (SD) was used to represent regularly distributed variables, The interquartile range (IQR) and median were utilized to report variables that were not normally distributed. Frequencies and percentages were used to represent categorical variables.

If both of the continuous variables were regularly distributed, the Pearson correlation coefficient was used to evaluate the relationship between them; if not, the Spearman rank correlation coefficient was employed. Specifically, correlations were examined between BMI and ReDS scores. If computed using the raw dataset, the correlation between the NT-ProBNP and ReDS scores will be reported, otherwise it will not be reported. KruskalWallis H test was employed in the comparison of the values of NT-ProBNP and ReDS in different NYHA classes. In contrast to the independent samples t-test, which was used to compare the NT-ProBNP and ReDS levels of men and women because they were normally distributed, the Mann-Whitney U test was used to compare the levels of these variables between men and women because they were not. Where estimates were calculated using the dataset, effect sizes (e.g., Cohen d for group comparison) and 95 per cent confidence limits (95 per cent CI) were given. In cases where Bonferonni correction was applicable, it was used to correct multiple comparisons. According to the standards of clinical research, the statistical tests were two-tailed, and the threshold of statistical significance was $p < 0.05$. The Results section will report the number of cases omitted on the basis of missing data per analysis.

Results

Demographics and Baseline Characteristics

The inclusion criteria were that 100 patients with confirmed Rheumatic Heart Disease (RHD) during the study period (January 1, 2023-December 31, 2023) were included. Majority patients were within the middle-aged groups as the cohort was mostly female. The most frequent valvular lesion was severe mitral stenosis or mitral regurgitation; progressive mitral stenosis, tricuspid valve disease and aortic valve disease were also common. Table 1 provides comprehensive details about clinical and demographic characteristics.

Table 1. Baseline demographic and clinical characteristics of the study population (N = 100)

Characteristic	**Value**
Total patients, n	100
Age groups, n (%)	
<20 years	7 (7.0)
20–29 years	10 (10.0)
30–39 years	15 (15.0)
40–49 years	24 (24.0)
50–59 years	24 (24.0)
60–70 years	19 (19.0)
>70 years	1 (1.0)
Sex, n (%)	
Male	34 (34.0)
Female	66 (66.0)
******Valvular involvement, n (%)*	
Severe MS/MR	78 (78.0)
Progressive MS	17 (17.0)
Aortic valve disease	22 (22.0)
Tricuspid valve disease	34 (34.0)
NYHA class, n (%)	
Class I	50 (50.0)
Class II	39 (39.0)

Class III	11 (11.0)
Class IV	0 (0.0)

*Valve lesion categories are not mutually exclusive.

NYHA Functional Classification

During the assessment, fifty percent of the patients were categorized as NYHA Class I, with Class II and Class III being the next, and no cases of Class IV were observed. Figure 1 shows the distribution of NYHA functional classes.

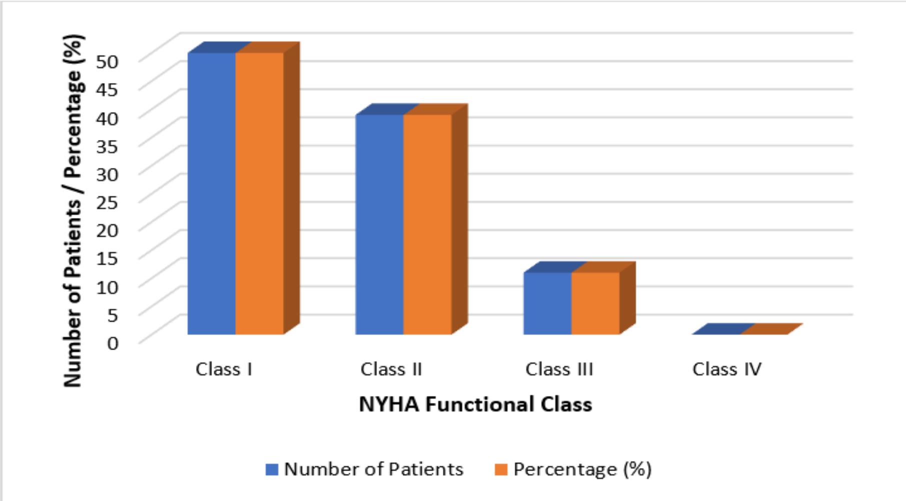

Figure 1. Distribution of NYHA functional classes among patients with rheumatic heart disease (N = 100)

Biomarker and Dielectric Imaging Data Across NYHA Classes

The average values of NT-ProBNP with SD were 2,145.3 +/- 4,888.4 pg/mL in Class I, 2,096.7 +/- 2,070.9 pg/mL in Class II and 2,501.7 +/- 5,913.4 pg/mL in Class III. The NYHA classes did not differ statistically (KruskalWallis H = 1.72, p = 0.424).

Mean ReDS scores +/- SD was 34.4 +/- 12.5 percent in NYHA Class I, 30.3 +/- 11.6 percent in Class II, and 33.9 +/- 6.4 percent in Class III. Also, differences were not significant (KruskalWallis H = 1.41, p = 0.494). These distributions are illustrated in Table 2.

Table 2. NT-ProBNP and ReDS measurements across NYHA functional classes

NYHA Class	NT-ProBNP Mean (pg/mL) ± SD	ReDS Mean (%) ± SD
Class I	2,145.3 ± 4,888.4	34.4 ± 12.5
Class II	2,096.7 ± 2,070.9	30.3 ± 11.6
Class III	2,501.7 ± 5,913.4	33.9 ± 6.4

Note: *The values are reported as median (interquartile range) of NT-ProBNP and mean +/- standard deviation of ReDS. There were no significant differences between classes in either parameter (KruskalWallis test, p > 0.05), so functional class alone does not appear to be a determinant of biomarker or dielectric imaging values in stable RHD.*

Correlation Analyses

There was an insignificant positive correlation between BMI and ReDS score (Pearson r = 0.094, 95% CI -0.209 to 0.380 and p = 0.544). ReDS scores and the amount of NT-ProBNP did not substantially correlate (Spearman 0.071, 95% CI -0.232 to 0.359, p = 0.622). In patients with rheumatic heart disease, Table 3 shows that the ReDS scores and BMI and NT-ProBNP have extremely weak, non-significant relationships.

Table 3. Correlation matrix of BMI, NT-ProBNP, and ReDS scores in patients with rheumatic heart disease

Variable Pair	Correlation Coefficient	95% CI	p-value	Statistical Test
BMI vs ReDS	r = 0.094	–0.209 to 0.380	0.544	Pearson
NT-ProBNP vs ReDS	ρ = 0.071	–0.232 to 0.359	0.622	Spearman

Gender-Based Comparisons

There was no significant difference in the level of NT-ProBNP between men (2,476.8 5,757.6 pg/mL) and women (1,808.0 2,343.3 pg/mL) (independent samples t-test, $p = 0.339$, Cohen $d = 0.14$).

Male patients had significantly higher ReDS scores than female patients (36.9 12.0 vs 30.4 10.9, mean difference 6.5 1.0 12.0, $p = 0.024$) representing a higher measured lung fluid content in the male subgroup.

Missing Data

No variables had missing data in the final dataset; all analyses included the complete sample of 100 patients.

Discussion

One major cause of cardiovascular morbidity is still rheumatic heart disease (RHD). in nations with low and moderate incomes but clinical diagnosis is frequently based on subjective functional classification.[17] Objective measures of myocardial stress and pulmonary fluid volume can be achieved using biomarkers, such as NT-ProBNP, and imaging, such as Remote Dielectric Sensing (ReDS), and may be able to replace the more subjective symptom-based assessment.[18] This study examined how body mass index (BMI), NT-ProBNP, and ReDS are correlated and how these vary by gender and New York Heart Association (NYHA) functional class.

The main results failed to confirm the hypothesis that NT-ProBNP and ReDS would progressively increase with the increase in the NYHA class or have substantial correlation with the BMI. Both NT-ProBNP and ReDS did not differ significantly with NYHA I–III, though there was a tendency towards higher NT-ProBNP in Class III (Table 2, Figure 2). This implies that functional class does not adequately reflect hemodynamic or subclinical congestion in stable RHD.[19] Chronic valvular disease may facilitate physiologic compensation, preventing the increase in biomarkers in the presence of continuing structural disease.[20] Moreover, the NYHA classification is founded on the symptom that the patient reports, and it may be influenced by comorbidities, physical training, and the perception of exertion.[21]

The analysis based on the gender showed a significant difference in ReDS—males had a higher mean ReDS score than females—and NT-ProBNP levels had no significant sex difference. The discrepancy indicates that ReDS and NT-ProBNP measure different physiological events: ReDS is probably more responsive to anatomical or lung volume changes, whereas NT-ProBNP is mostly responsive to cardiac stretch.[22] The difference in ReDS readings has also been observed previously in heart failure populations where men have recorded higher rates than women,[23] but the impact of ReDS on RHD is still inadequately explored. Provided that they are verified in future research, sex-specific ReDS reference ranges may enhance the accuracy of interpretation.[24]

In the correlation analysis (Table 3) there were weak, non-significant relationships only between BMI and ReDS, and between NT-ProBNP and ReDS. These results suggest that body habitus, myocardial stress, and pulmonary fluid content are at least mostly independent parameters in RHD. This further supports the possible advantage of combining all three areas—anthropometry, biomarkers, and dielectric imaging—as a more thorough evaluation as compared to any single measure.[25] Comparison with existing literature reveals partial alignment. NT-ProBNP is often raised in severe valvular disease, but has not been consistently associated with the degree of symptoms in RHD,[26] perhaps because of preserved ventricular function in most patients. Although ReDS has been

validated in heart failure as a subclinical pulmonary congestion detection tool,[27] it has not been well tested in RHD. The feasibility of its application demonstrated in the current research, as well as the gender distinctions, determine its potential and limitations of its application in this population.[28]
Clinically, the lack of any meaningful gradients in NT-ProBNP or ReDS across NYHA classes indicates that the functional class is not enough to monitor the disease in stable RHD.[29] Objective measures would enable the earlier detection of hemodynamic changes and more aggressive management. The moderate gender impact on ReDS readings also indicates the necessity of individual interpretation, which can possibly avoid an under- or overestimation of the risk of congestion.[30]
Several limitations warrant consideration. The research is single-centered and retrospective, which makes it less generalizable and does not allow causal inference. Statistical power was restricted by the sample size, especially in NYHA Class III, and thus the potential to identify smaller but possibly clinically meaningful changes was diminished. ReDS has never been validated specifically in RHD and thoracic anatomy, body composition, and comorbid pulmonary disease can affect the readings. Medications and other confounders were not fully adjusted, although the measurement procedures are standardized, increasing the reliability of data. Multicentric prospective studies should be undertaken in future to substantiate these results and establish their prognostic potential. The longitudinal designs might reveal whether the changes in NT-ProBNP or ReDS might be a predictor of critical outcomes including hospitalization, valvular lesions, or surgical intervention. Comparing ReDS with gold-standard indices of pulmonary fluid content, and exploration of sex-specific calibration algorithms, would help to fine-tune its use in RHD care.

Conclusion

The first hypothesis assumed that Remote Dielectric Sensing (ReDS) and NT-ProBNP would have positive correlations, and they would be higher with progressive NYHA functional class and have relationships with body mass index (BMI) among patients with rheumatic heart disease (RHD). These hypotheses were not confirmed in this retrospective cross-sectional study. Both NT-ProBNP and ReDS were not significantly different across NYHA classes, and this indicates that classification based on symptoms alone cannot be used to detect hemodynamic status or subclinical congestion in stable RHD. The difference between ReDS scores was significant in males, but NT-ProBNP did not demonstrate any gender-related difference; thus, these measures reflect different physiological domains. Correlation analysis showed that there were insignificant, weak relationships between BMI, NT-ProBNP, and ReDS, which justified the conclusion that myocardial stress, pulmonary fluid content, and body habitus are relatively distinct dimensions of disease evaluation.
These results demonstrate the importance of multimodal monitoring approaches that combine biomarkers and non-invasive imaging to assess more thoroughly. The gender differences that were observed in ReDS also suggest that sex-specific interpretation thresholds should be used to improve diagnostic accuracy. The single-center, retrospective design, and somewhat small sample size of the study are its limitations; however, the findings can give new insights into the relationships between anthropometry, cardiac biomarkers and dielectric imaging in RHD, and also lead to further research on longitudinal validation, sex-specific calibration, and prognostic combination of these modalities in clinical practice.

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