Introduction: Pulmonary artery (PA) hypertension (PAH) is characterized by elevated PA pressure (PAP), which increases the right ventricular (RV) afterload. Although PAP measurement is the gold standard for evaluating PAH, it is actually the RV condition that predicts patient survival. Despite the fact that both RV and PA are affected in PAH, there is insufficient data in literature regarding the RV interventions. The goal of this study is to investigate the relationships between different RV-related and PA-related MRI-derived parameters in an attempt to better understand the nature of RV-PA coupling in PAH.

Methods: 25 PAH patients, confirmed by catheterization, were scanned on a 3.0-Tesla Siemens scanner. A comprehensive MRI exam was developed that lasted for 30 minutes and included: 1) Cine images covering the heart; 2) Strainencoding (SENC) images; 3) Flow images across the main PA (MPA); 4) Flow images through the tricuspid valve. The cine images were processed to calculate: RV ejection fraction (RVEF), LVEF, ventricular volume index (VVI), ventricular mass index (VMI), RA size (RA area on a 4-CH slice at end systole), MPA diameter (at diastole), and the newly-introduced lunar index (LI). Peak RV longitudinal myoccardial strain and early-diastolic strain rate were calculated from SENC images. The following parameters were calculated from PA flow images: PA pulse wave velocity (PWV) using the flow-area method [2], PA distensibility, acceleration-to-ejection (a/e) time, flow rate (during acceleration phase), and mean velocity. Furthermore, the following standard measurements in PAH were obtained: mean mPAP (mPAP), pulmonary vascular resistance (PVR), tricuspid jet velocity (Tri JV), 6 minute walk (6MW), and brain natriuretic peptide (BNP). The parameters were divided into 3 groups: MRI RV parameters (RVEF, VFI, VMI, LI, RV E/A, strain, strain rate, LVEF, RA size); MRI PA parameters (MPA diameter, PWV, distensibility, a/e time, flow rate, mean velocity, PA diameter); and non-MRI measurements (mPAP, PVR, Tri JV, 6MW, BNP). Three types of statistical analysis were conducted: 1) Correlation analysis between all parameters to measure within- and across-group correlations; 2) Regression analysis to identify significant parameters, investigate within-group parameter redundancy, and study the relationship between MRI parameters and PAP; 3) Principal component analysis (PCA) to investigate data reduction in different parameter groups and identify insignificant parameters. Linear multiple regression analysis was conducted on RV and PA parameters using backward deletion modeling (mPAP is dependent variable). Regression’s collinearity statistic ‘tolerance’ (proportion of variable’s variance not accounted for by others), the model’s adjusted multiple correlation coefficient squared (R²), and ANOVA F statistic (ratio of regression to residual) were measured. Parameters’ communalities were measured in PCA.

Results: Fig.1 shows color-coded-correlation map between all parameters. In regression analysis in RV group, the following parameters were eliminated in this order: RV E/A, RA size, LVEF, RVEF, strain rate, VFI. The resulting model consisted of: lunar index (p (significance) = 0.001, β (standardized regression coefficient) = 0.41, tolerance = 0.48), VMI (p = 0.012, β = 0.32, tolerance = 0.37), strain (p = 0.012, β = 0.32, tolerance = 0.36). The model’s R² = 0.88, ANOVA F = 59.6, model significance < 0.005. In regression analysis on PA group, the following parameters were eliminated in this order: distensibility, a/e time, MPA diameter. The resulting model consisted of: PWV (p = 0.003, β = 0.45, tolerance = 0.42), mean velocity (p = 0.007, β = 0.36, tolerance = 0.34), flow rate (p = 0.06, β = 0.23, tolerance = 0.37). The model’s R² = 0.88, ANOVA F = 60.4, model significance < 0.005. Finally, regression analysis was conducted on both PA and RV parameters using backward deletion modeling (mPAP is dependent variable). The following parameters were eliminated in this order: PV (p = 0.003, β = 0.25, tolerance = 0.25), mean velocity (p = 0.003, β = 0.25, tolerance = 0.25), strain rate (p = 0.015, β = 0.24, tolerance = 0.33), strain (p = 0.04, β = 0.16, tolerance = 0.31). The model’s R² = 0.96, ANOVA F = 115, model significance < 0.005. PCA analysis was conducted on RV group. It resulted in two components (variances = 56.88% and 14.88%). Parameters’ communalities were: RVEF = 0.799, VFI = 0.77, VMI = 0.804, LI = 0.852, RV E/A = 0.723, strain = 0.679, strain rate = 0.638, LVEF = 0.485, RA size = 0.521. Components were: c1 = [0.888, -0.813, -0.897, 0.919, 0.039, 0.805, 0.796, -0.19, -0.074] and c2 = [0.002, 0.034, -0.011, 0.091, 0.85, -0.179, -0.064, 0.67, -0.98] (factors in same order as communalities). PCA factor analysis was conducted on parameters in PA group. It resulted in one component (variance = 76.83%). Parameters’ communalities were: PWV = 0.811, distensibility = 0.777, a/e time = 0.736, flow rate = 0.75, mean velocity = 0.849, PA diameter = 0.749. Component was: c1 = [0.9, -0.881, -0.858, 0.866, 0.921, 0.865]. Finally, PCA analysis was conducted on the non-MRI measurements group. It resulted in two components (variances = 61.77% and 20.21%). Parameters’ communalities were: mPAP = 0.954, PVR = 0.926, Tri JV = 0.823, 6MW = 0.668, BNP = 0.722. Components were: c1 = [0.975, 0.962, 0.754, -0.326, 0.267] and c2 = [-0.056, 0.011, 0.31, 0.75, 0.807].

Discussion: The results showed different degrees of correlations between analyzed parameters (Fig.2). Results from correlation analysis are in agreement with regression and PCA analyses. Strongly correlated within-group parameters reflected data redundancy, which can be excluded from analysis without much affecting the results. Data redundancy comes in agreement with basic understanding of the nature of these parameters and PAH development process. Weakly correlated parameters reflected the parameters’ non-specificity or insignificance within its group. These results come in agreement with our understanding about the parameters’ roles in PAH. For example, although E/A=1 reflects diastolic dysfunction, E/A=1 does not necessarily mean normal function; it occurs also in pseudonormal and restrictive cases, which necessitates its interpretation with other parameters. VMI LI, strain rate, and mean velocity showed strong correlations with all PA parameters; RVEF showed moderate correlation with all PA parameters; and RV E/A, LVEF, and RA size showed weak correlations with PA parameters. The strongest correlation occurred between VMI and flow rate. From redundancy analysis, the significant parameters could be reduced to: RV group (LI, VMI, strain) and PA group (PWV, mean velocity, flow rate). In conclusion, RV and PA are coupled and their functions are negatively affected in PAH. Both entities should be evaluated and interpreted together in PAH for more understanding of the disease pathophysiology and better diagnosis and treatment.


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