

Right ventricular involvement in anterior myocardial infarction: a tissue Doppler-derived strain and strain rate study

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OBJECTIVE: Strain and strain rate imaging is currently the most popular echocardiographic technique that reveals subclinical myocardial damage. There are currently no available data on this imaging method with regard to assessing right ventricular involvement in anterior myocardial infarction. Therefore, we aimed to evaluate right ventricular regional functions using a derived strain and strain rate imaging tissue Doppler method in patients who were successfully treated for their first anterior myocardial infarction.

METHODS: The patient group was composed of 44 patients who had experienced their first anterior myocardial infarction and had undergone successful percutaneous coronary intervention. Twenty patients were selected for the control group. The right ventricular myocardial samplings were performed in three regions: the basal, mid, and apical segments of the lateral wall. The individual myocardial velocity, strain, and strain rate values of each basal, mid, and apical segment were obtained.

RESULTS: The right ventricular myocardial velocities of the patient group were significantly decreased with respect to all three velocities in the control group. The strain and strain rate values of the right mid and apical ventricular segments in the patient group were significantly lower than those of the control group (excluding the right ventricular basal strain and strain rate). In addition, changes in the right ventricular mean strain and strain rate values were significant.

CONCLUSION: Right ventricular involvement following anterior myocardial infarction can be assessed using tissue Doppler based strain and strain rate

KEYWORDS: Right Ventricle; Involvement; Strain/Strain Rate; Doppler; Anterior Myocardial Infarction.

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■ INTRODUCTION

Acute myocardial infarction (AMI) is characterized by a loss of contractile tissue and a change in ventricle geometry that causes substantial impairment of the right ventricle (RV) and left ventricle (LV) systolic and diastolic functions (1). Currently, strain and strain rate (S/SR) imaging is the most popular echocardiographic technique for use in AMI. Tissue Doppler imaging (TDi) and S/SR imaging are the most important modalities for revealing subclinical myocardial damage (2). RV involvement in inferior MI has been

demonstrated via electrocardiography (ECG), clinical findings, classical TDi findings, and S/SR imaging (3–7). Although both subclinical damage and myocardial injury have been thoroughly investigated using other imaging modalities, such as magnetic resonance imaging (MRI) for anterior MI (8–12), there is currently a lack of available data associated with the S/SR imaging method. Therefore, the aim of our study was to evaluate RV regional functions using TDi-derived S/SR imaging method in patients who experienced their first successfully treated anterior MI.

■ MATERIALS AND METHODS

Patient selection

Forty-four patients who had suffered their first anterior MI attack, had been hospitalized within 1–12 h of the onset of symptoms, and had undergone successful primary PCI were enrolled in the study. Bare metal stent was implanted to all patients and only TIMI-3 flow enrolled in the study,

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and the ethical implications regarding the study were approved by the local ethics committee. Informed consent was obtained from each patient. The patients who had a bundle branch block, a prior history of MI, percutaneous transluminal coronary angioplasty to the LAD, critical stenosis (>50%) in the right coronary artery (RCA) or circumflex coronary artery (Cx), moderate to severe valve regurgitation or stenosis, or undergone recurrent percutaneous intervention (acute stent thrombosis) were excluded from the study.

Control group selection

Twenty patients between the ages of 25 and 80 years who had undergone coronary angiography in any center and had a normal coronary artery or insignificant coronary stenosis (<50%) were enrolled in the control group. The age, gender, height, weight, and coronary artery disease risk factors were recorded for each patient. Heart rate and blood pressure were also recorded at admission.

Diagnostic protocol

Conventional tissue Doppler imaging. Echocardiography was performed within the first three days following AMI. The Philips Envisor-HD11XE and 2-4-MHz phase transducer (Philips Medical Systems) were used simultaneously with ECG recordings. Conventional parameters and TDi measurements were obtained using pulsed-wave tissue Doppler imaging (PW-TDi) from the apical four-chamber view, and RV measurements were obtained from the tricuspid lateral annulus in the left lateral decubitus position. The Sm value (myocardial systolic velocity) and the Em and Am values (diastolic velocities) were recorded. The TDi-derived MPI was calculated for both LV and RV using the “(IVRT+IVCT)/ET” formula:

$$\text{LV MPI (TDi)} = \text{LV (IVRT+IVCT) / ET, RV MPI (TDi)} = \text{RV (IVRT+IVCT) / ET}$$

The imaging angle was adjusted to ensure a parallel alignment of the sampling window with the myocardial segment of interest and was below 20°. The gain settings, filters, pulse repetitive frequency, sector size, and depth were adjusted to optimize color saturation. The PW-TDi spectral signal filters were adjusted to obtain a Nyquist limit of ± 20 cm/s. The gain was minimized to obtain a clear signal from the tissue with the lowest possible level of background noise. The color scale was set to ≤ 20 , and harmonics scale 2 was chosen. By aligning the appropriate color gain, the right ventricular lateral wall measurements were obtained from a maximum of 1 cm above the tricuspid annulus with PW Doppler. The sample volume of the PW Doppler (gate) was set to 0.33 cm. The sweep speed for the tissue Doppler measurements was set to 100 mm/sec, and the color scale was set to the uncolored (gray) tone. The measurements were obtained from three consecutive beats, and the mean values were recorded. The measurements were recorded while the patient was holding his/her breath at expiration. The measurements were recorded to a CD in DICOM format for subsequent analysis. The conventional echocardiographic measurements were performed based on the recommendations of the American Society of Echocardiography (13,14).

Tissue doppler-derived strain and strain rate imaging

Tissue Doppler evaluation of the RV was initiated with imaging of the RV lateral wall from the apical four-chamber

view. The ratio of the PW axis to the RV longitudinal axis was set to $< 20^\circ$. The imaging view of the right ventricular lateral wall was narrowed to increase the gain and frame rate for S/SR imaging. Angle correction was applied to all images. At least three beats were recorded for each measurement. The frame rates were set to > 120 frames/sec for the colored recordings (15,16). All images were recorded with the following settings for strain/strain rate imaging. The RV myocardial samplings were divided between three regions, namely the RV basal, mid, and apical segments of the lateral wall. The M-mod width was set to a smaller degree than that of the right ventricular myocardium and the calculation line, with a maximum value of 1 cm (15,16). From these measurements, the individual myocardial velocity, strain, and strain rate values of each basal, mid, and apical segment were obtained (Figure 1). For off-line analyses, QLab (2009) (Philips Medical Systems, compatible with the Philips Envisor HD11XE device) was used, and the recordings were made based on the mean values of these measurements.

Statistical analysis

The statistical analyses were performed using SPSS (version 15.0, SPSS Inc., Chicago, IL, USA). The Kolmogorov–Smirnov test was used to evaluate whether the variables were normally distributed. The continuous variables are presented as the means \pm SD or as the median interquartile range. Student’s t test and the chi-square test were used for comparisons of the normally distributed continuous variables and categorical variables in two groups. The Mann-Whitney U test was used for non-normally distributed variables. A p -value < 0.05 was considered statistically significant.

■ RESULTS

A total of 64 patients, 44 in the patient group and 20 in the control group, were enrolled in the study. The demographic characteristics of the patients are listed in Table 1. The majority of the patients were middle-aged men (mean age: 55 years). The control group was formed by performing age matching with the patient group (Table 1). The baseline echocardiographic characteristics of the patients are listed in Table 1. With regard to conventional echocardiographic parameters, the E/E’ and RV MPi values were significantly higher in the patient group. In the analyses in which the basal, mid, and apical segments of the RV were evaluated, there was no significant difference in the conventional TDi findings between the two groups (Table 2). The RV myocardial velocities and means of these values were significantly decreased with respect to all three velocities compared with the control group (5.6 ± 1.7 and 7.1 ± 2.3 cm/sn, $p = 0.01$, for the basal segment; 3.2 ± 1.7 and 4.4 ± 1.8 cm/sn, $p = 0.03$, for the mid segment; 1.5 ± 1.2 and 2.1 ± 0.8 cm/sn, $p = 0.049$, for the apical segment; 3.4 ± 1.3 and 4.5 ± 1.4 cm/sn, $p = 0.008$, for the mean values). Decreases in the RV basal segment and changes in the mean RV velocities were especially prominent in the patient group compared with the control group (Table 2). The S/SR values of the RV are shown in Table 2. According to these results, the S/SR values of the mid and apical RV segments in the patient group were significantly lower than those in the control group, except for the RV basal S/SR values. In addition, changes in the RV mean S/

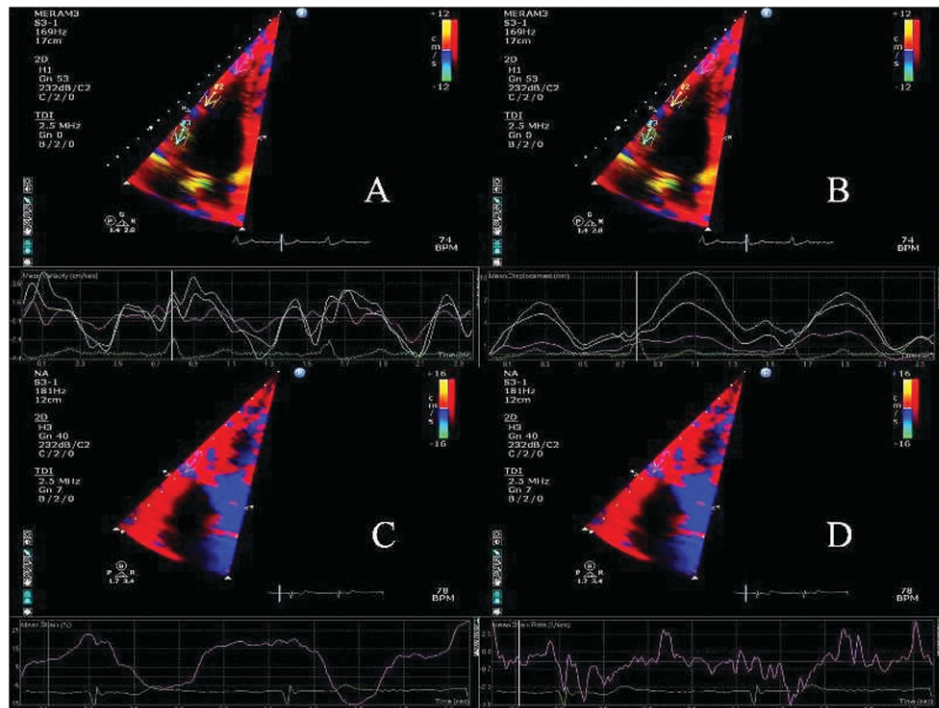


Figure 1 - A) Myocardial velocities associated with the basal, mid, and apical segments of the right ventricle. **B)** Myocardial deformation curves associated with the basal, mid, and apical segments of the right ventricle. **C)** Strain curve of the mid segment of the right ventricle. **D)** Strain rate curve of the mid segment of the right ventricle.

Table 1 - Baseline patient characteristics.

	Patient Group N = 44	Control Group N = 20	p-value
Patient characteristics			
Age (years) mean ± SD	55 ± 13	55 ± 12	NS
Female / Male	8/36	4/15	NS
Body mass index (BMI)(kg/m ²) mean ± SD	28.1 ± 4.6	27.1 ± 3.6	NS
Medical history n (%)			
Current smoker	15 (35%)	7 (43%)	NS
Hypertension	13(30%)	6(33%)	NS
Diabetes mellitus	10(21%)	4 (23%)	NS
Heredity for Coronary artery disease	6(14%)	2 (11%)	NS
Hemodynamics mean ± SD			
Blood Pressure (mmHg)			
Systolic	106 ± 10	105 ± 9	NS
Diastolic	69 ± 6	68 ± 5	NS
Heart rate (beats/min)	78 ± 11	76 ± 10	NS
Conventional echocardiography mean ± SD			
LVEF Mean (%)	42.8 ± 8.2	64 ± 4.5	0.001
LVEDD (cm)	4.7 ± 0.4	4.5 ± 0.4	NS
LVESD (cm)	3.0 ± 0.5	2.9 ± 0.5	NS
LV Mass (gr)			
Mitral E/A	1.05 ± 0.44	0.90 ± 0.27	0.130
Tricuspid E/A	1.00 ± 0.36	0.96 ± 0.32	0.740
E/E'	8.0 (7.1–9.9)	6.3 (5.0–7.3)	0.001*
MPI RV conventional	0.32 ± 0.12	0.24 ± 0.96	0.015
MPI RV TDi	0.55 ± 0.22	0.40 ± 0.10	0.007
PSAP (mmhg)	27 ± 6.3	26 ± 4.7	NS

LVEF: Left Ventricular Ejection Fraction, LVEDD: Left Ventricular End Diastolic Diameter, LVESD: Left Ventricular End Systolic Diameter, RV: Right Ventricle, MPI: Myocardial Performance Index, NS: Not Significant, PSAP: Pulmonary Systolic Arterial Pressure. The chi-square and Student's t tests were used.

*: Mann Whitney U test.



Table 2 - Tissue Doppler and Strain/Strain Rate Findings.

	Patient Group	Control Group	p-value
	N = 44	N = 19	
Tissue Doppler-derived S/SR mean ± SD			
RV velocity basal systolic V (cm/sm)	5.6 ± 1.7	7.1 ± 2.3	0.002
RV velocity mid	3.2 ± 1.7	4.4 ± 1.8	0.030
RV velocity apical	1.5 ± 1.2	2.1 ± 0.8	0.010
RV velocity mean	3.4 ± 1.3	4.5 ± 1.4	0.002
RV E mean diastolic	2.9 ± 1.3	2.9 ± 1.2	0.234
RV A mean	2.4 ± 1.4	3.0 ± 1.3	0.116
RV strain basal ε (%)	-21.4 ± 6.8	-24.6 ± 5.5	0.101
RV strain mid	-15.8 ± 6.8	-22.0 ± 5.6	0.003
RV strain apical	-8.6 ± 5.4	-19.5 ± 5.2	0.0001
RV strain mean	-15.2 ± 4.6	-22.0 ± 4.6	0.0001
RV strain rate basal (s ⁻¹)	-1.9 ± 0.9	-2.02 ± 0.6	0.622
RV strain rate mid	-1.4 ± 0.7	-2.3 ± 0.5	0.0001
RV strain rate apical	-0.8 ± 0.52	-1.8 ± 0.55	0.0001
RV strain rate mean	-1.4 ± 0.6	-2.04 ± 0.4	0.0001
Conventional TDi Findings mean ± SD			
RV Sm TDi Systolic V (cm/sm)	12.3 ± 2.2	13.1 ± 2.0	0.35
RV Em TDi diastolic	10.1 ± 2.15	10.4 ± 2.3	0.360
RV Am TDi diastolic	7.24 ± 2.1	7.78 ± .15	0.880

RV: Right Ventricle, MPI: Myocardial Performance Index, TDi: Tissue Doppler Imaging, Sm: Systolic Motion, Em: Early Motion, Am: Atrial Motion.

SR values were significant ($-15.2 \pm 4.6 \epsilon (\%)$ and $-22.0 \pm 4.6 \epsilon (\%)$, $p=0.0001$, for the RV mean strain and $-1.4 \pm 0.6 s^{-1}$ and $-2.04 \pm 0.4 s^{-1}$, $p=0.0001$, for the RV mean strain rate).

While the RV basal segment S/SR values in the patient group were lower than those in the control group, this difference was not statistically significant.

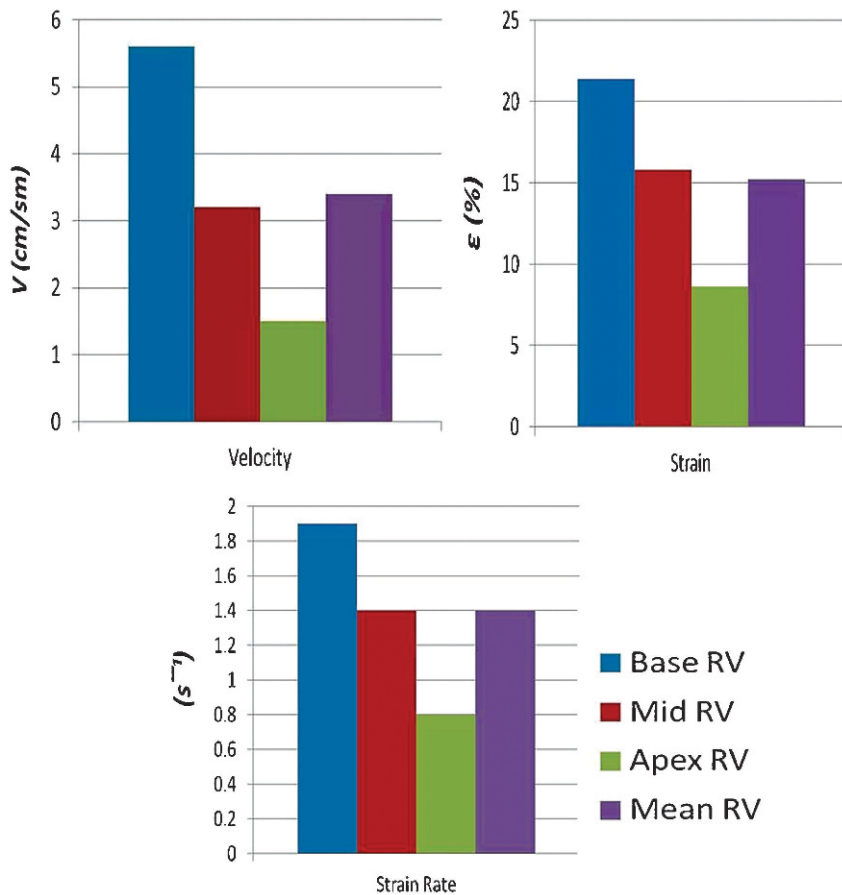


Figure 2 - Myocardial velocity, strain, and strain rate values of the basal, mid, and apical segments of the right ventricle showing RV involvement from the base to the apex in Ami patients.



DISCUSSION

The main finding of the present study was that a significant decrease in TDi-based myocardial velocities and S/SR values of the RV has a global effect following AMi. We can conclude that, following AMi, the mid and apical RV segments are affected by LV ischemia and infarction, whereas there is no change in classical TDi findings. S/SR imaging is currently the most popular echocardiographic modality for revealing subclinical myocardial damage (2,15,16). In the literature, postmortem studies mention RV involvement after left ventricular infarction (19). Abbate et al. found RV cardiomyocyte apoptosis in patients with anteroseptal myocardial infarction and RV-free wall involvement upon histopathological examination (20). Bodi et al. showed RV involvement after AMi in an animal model via MRI (8). Jensen et al. revealed RV involvement after anterior STEMI in a patient via MRI, and they found that delayed RV enhancement in anterior ST-segment elevation MI is associated with a worse prognosis (10).

This is the first study to assess RV function after anterior STEMI using TDi-based myocardial velocity and S/SR imaging, and it adds crucial information to the literature. Although there is an abundance of classical TDi data on RV involvement after inferior Mi, few studies in the literature have obtained TDi-based S/SR measurements (6–10). Interestingly, in these studies, the degree of RV involvement was found to increase from the apex to the base (9). In AMI, we found that RV involvement increases from the base to the apex; thus, our findings are the inverse of those for RV involvement in inferior MI (Figures 2 and 3). Additionally, due to the current lack of available studies, it would be

reasonable to wait for larger studies conducted with a greater number of patients.

In this study, we observed that both systolic and diastolic functions were affected after anterior STEMI. Although an increase in the LV myocardial performance index (MPI) (21) and E/E' values (22) is a natural consequence of an anterior MI, a significant increase in the RV MPI after anterior MI can be an important factor affecting prognosis. Symptoms and signs of RV failure after acute MI are associated with a poor prognosis and a survey of shorter than 2 years (23). While investigating TDi-based increases in RV MPI after anterior STEMI, Ozturk et al. found similar increases in RV MPI (21).

In classical TDi studies, the RV annular velocities were lower in the patient group compared with the control group; however, this difference was not statistically significant. Alam et al. evaluated 33 patients who had experienced their first attack of anterior MI and 24 patients in a control group and reported similar findings (3).

One of the findings of our study involved the primary limitation of conventional TDi imaging, which has already been demonstrated in other investigations of myocardial velocities. A nonfunctional segment joined to a normally functioning segment could have normal velocities upon sampling, which complicates data interpretation (17). Myocardial strains are independent of translational motion and other through-plane motion effects and are less influenced by tethering effects and overall cardiac function (18). Therefore, myocardial strain data should be preferred over velocity information and could overcome this problem (2,15,16).

Finally, the findings of Abbate et al. (20) may be helpful in explaining the mechanism of RV involvement. Abbate et al.

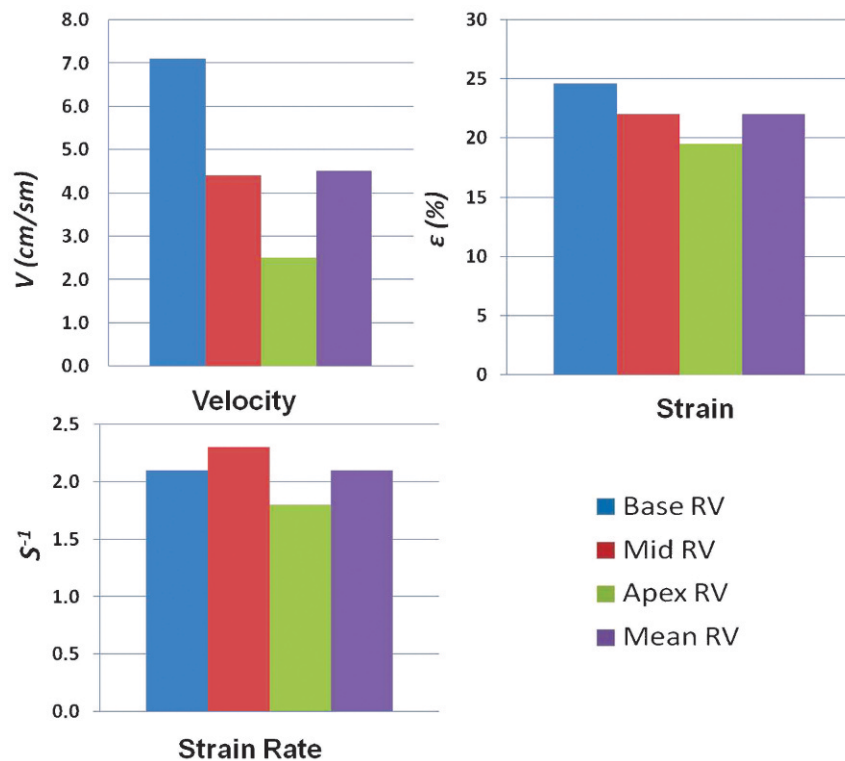


Figure 3 - Myocardial velocity, strain, and strain rate values of the basal, mid, and apical segments of the right ventricle in the control group.



showed remarkable RV cardiomyocyte apoptosis in the setting of acute myocardial infarction of the left ventricular wall. This apoptosis could be due to myocardial edema. Grothoff and Jensen et al. (10,12) revealed considerable edema in the RV of patients with anterior myocardial infarction in their MRI studies.

The most important limitation of the study was the frame rate of TDi-based S/SR and this data was not obtained with a greater frame rate. Another limitation was the presence of an angle dependency for assessing the RV. Newer two-dimensional calculations of myocardial motion and deformation speckle tracking velocity vector imaging could overcome the angle dependency of tissue Doppler-based techniques. As long as RV geometry is non-uniform, 3D echocardiographic data are undoubtedly valuable for obtaining RV volumes and performing EF analysis. It would be valuable to obtain laboratory information, such as troponin levels, in future studies; these data could be correlated with RV dysfunction, TDi, and strain information.

RV involvement following AMi was established using TDi-based S/SR imaging. According to our study results, S/SR echocardiographic evaluation of the RV may provide valuable information to aid the understanding of the pervasive nature and prognosis of the disease. RV dysfunction has also been related to poor prognosis; therefore, the function of both ventricles after AMi should be considered. RV assessment with these imaging modalities will have an increased value. However, larger studies are required to generalize the information and identify RV involvement.

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■ AUTHOR CONTRIBUTIONS

Sonmez O conceived and designed the study and had a large role in data analysis/interpretation, as well as in writing and editing the manuscript. Kayrak M, Altunbas G, and Abdulhalikov T performed the statistical analyses. Alihanoglu Y and Bacaksız A wrote and edited the manuscript. Ozdemir K served as a consultant and interpreted the data. Gok H served as a consultant and participated in the data interpretation and study design.

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