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MRI

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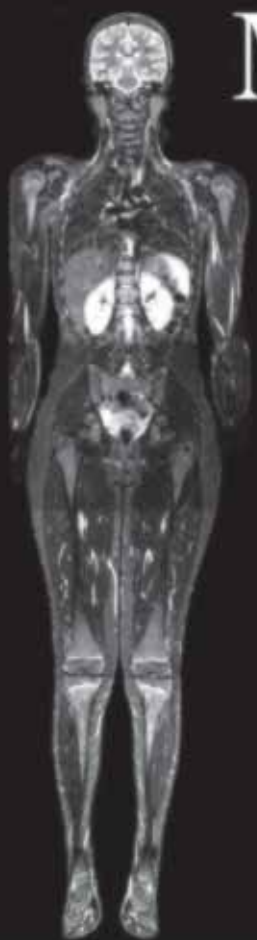
(for Beginners)



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THIRD EDITION

JAYPEE

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22 Cardiac Magnetic Resonance Imaging Techniques

Cardiac magnetic resonance imaging (MRI) provides virtually all of the information needed to assess the heart diseases. It provides anatomic and functional information in acquired and congenital heart diseases (CHDs). It has already become the modality of choice in many conditions like arrhythmogenic right ventricular dysplasia (ARVD), differentiation of constrictive pericarditis from restrictive cardiomyopathy and aortic dissection. It gives precise quantification of ventricular dimensions and function. Most exciting application of cardiac magnetic resonance (CMR) is assessment of myocardial viability and perfusion. The technique, imaging planes, and role of CMR in various cardiac conditions are discussed in this Chapter.

ELECTROCARDIOGRAPHIC GATING

Electrocardiographic (ECG/EKG) gating is essential for minimizing effect of cardiac pulsation on images of the heart. In prospective triggering, images are acquired in a particular phase of cardiac cycle in every cardiac cycle to avoid image blur and cardiac motion artifacts. The phase of the cardiac cycle during which images are acquired is decided by the ECG gating. Usually R-wave is used to trigger the acquisition after some trigger delay such that data is acquired in the diastolic phase (**Fig. 1**). Peripheral pulse can also

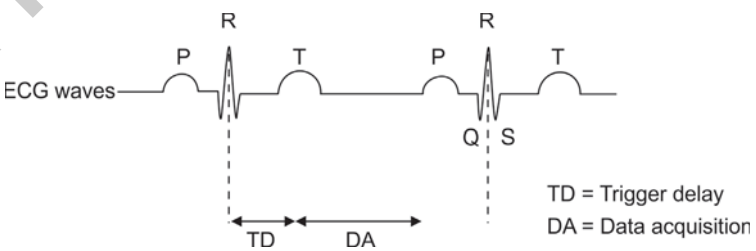


FIG. 1: Diagram of ECG gating.
(ECG: electrocardiographic)

be used for gating but it is less effective than ECG gating. In retrospective gating, imaging is continuously performed throughout the cardiac cycle and data segments are retrospectively gated.

CARDIAC IMAGING SEQUENCES

Pulse sequences used for CMR can be broadly divided into dark-blood and bright-blood techniques. These sequences are discussed in detail in Chapter 15 on MR angiography.

Dark-blood Technique

These are spin-echo sequences that show the flowing blood as flow void. These sequences include breath-hold turbo or fast spin-echo (TSE, FSE), single-shot FSE, and double inversion recovery FSE (double-IR-FSE) sequences.

Bright-blood Technique

These are gradient-echo (GRE) sequences that show the flowing blood bright. GRE sequences used for cardiac imaging include spoiled GRE [like turbofast low-angle shot/spoiled gradient-echo/T1-fast field echo (turboFLASH/SPGR/T1-FFE)] and balanced steady state free precession (bSSFP) [truefast imaging with steady precession/fast imaging employing steady state acquisition/balanced turbo-field-echo (TrueFISP/FIESTA/balanced TFE)] sequences. Balanced SSFP sequences are the mainstay sequences for cardiac MR and are used in every aspect of cardiac imaging. A motion picture loop through out the various phases of a cardiac cycle can be produced with GRE sequences like balanced SSFP to *get rapid cine imaging*. Cine imaging is useful for functional assessment of ventricles with calculation of ejection fraction and stroke volume as well as for valvular and cardiac wall motion evaluation.

Other Techniques

Phase-contrast cine sequences are used for the measurement of velocity, blood flow, and assessment of flow direction in the vessels and across the cardiac valves. Phase-contrast technique is discussed in detail in Chapter 15 on MR angiography.

T1 mapping of myocardium can be performed using modified Look-Locker (MOLLI) or (SASHA, saturation recovery single-shot acquisition) sequences, discussed in Chapter 21.

As a general rule, imaging may begin with dark-blood sequences like single-shot FSE to obtain anatomic information and proceed with bright-blood techniques to assess functional abnormalities.

IMAGING PLANES

Orthogonal planes (axial, sagittal, and coronal) used for general chest imaging are not suitable for cardiac imaging because cardiac axes are not parallel to body axes.

Imaging starts with routine axial, sagittal, and coronal sections as localizers/scout images. Further imaging in the planes suitable for cardiac assessment is planned on these images as follows:

*Vertical long-axis plane (two-chamber view) (**Fig. 2**)*: This is prescribed from an axial image that shows the largest oblique diameter of the left ventricle (LV). The two chambers seen on this view are left atrium (LA) and LV. It is useful in assessing left heart structures and the mitral valve.

*Horizontal long-axis (four-chamber view) (**Fig. 3**)*: This is planned on the two-chamber view by drawing a line passing through LA, mitral valve, and LV. All four chambers, mitral, and tricuspid valves can be assessed together on this view.

Cine GRE images can be obtained in this plane to assess mitral, tricuspid, and aortic valve function, and right ventricle (RV) and LV wall motion.

Short-axis plane: Multiple cross-sections are obtained perpendicular to LV long-axis as seen on a two-chamber view (**Fig. 4**). These sections are taken from the base to apex of the heart.

Cine GRE images allow visualization and quantification of systolic myocardial wall thickening. Images in this plane can be postprocessed to calculate ventricular volume, mass, and ejection fraction.

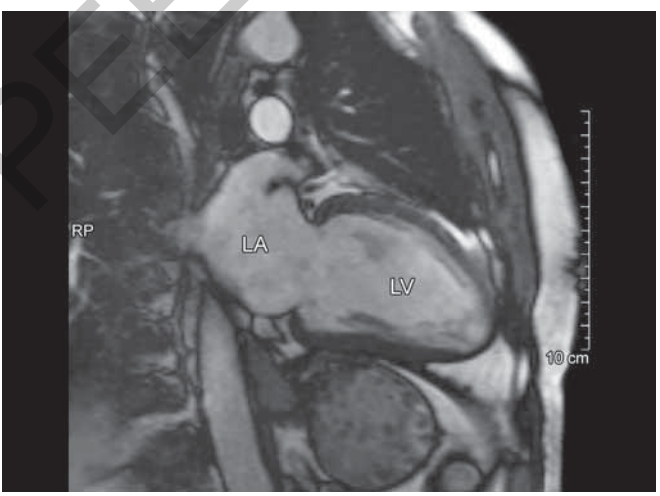


FIG. 2: Two-chamber view.
(LA: left atrium; LV: left ventricle)

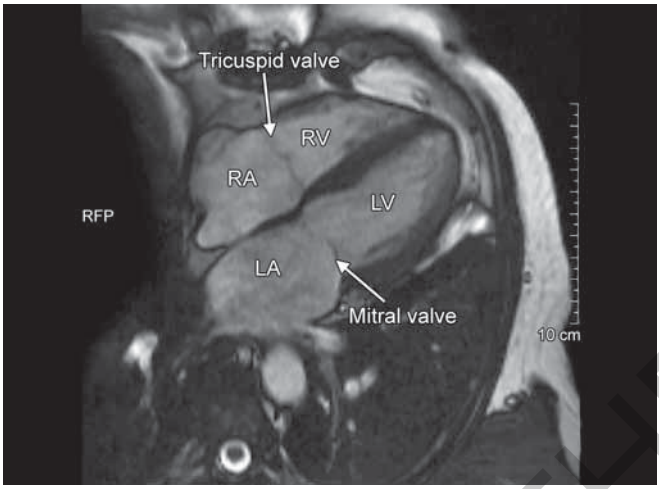


FIG. 3: Four-chamber view.
(LA: left atrium; LV: left ventricle; RA: right atrium; RV: right ventricle)

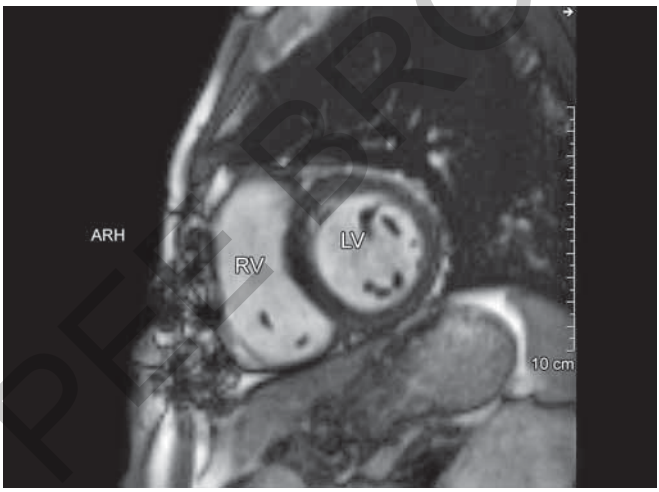


FIG. 4: Short-axis view.
(LV: left ventricle; RV: right ventricle)

Five-chamber view: This view is obtained parallel to the line passing through the LV apex and aortic outflow tract on the coronal images. Apart from all four chambers, this view also shows aortic root, the fifth chamber. This plane demonstrates both mitral and aortic valves.

Right ventricular outflow tract (RVOT): Plane passing through the RVOT.

CLINICAL APPLICATIONS OF CARDIAC MAGNETIC RESONANCE IMAGING

- *Congenital heart disease*: Cardiac MRI is useful in understanding complex anatomy in CHD and gives the information not obtained by echocardiography. CMR not only detects atrial septal defect (ASD), ventricular septal defect (VSD) with high sensitivity and specificity but also calculates shunt size with phase-velocity mapping. Using imaging planes aligned with cardiac chambers anatomic details of conditions such as transposition of great arteries (TGA), truncus arteriosus, double outlet LV, and other complex cardiac diseases can be obtained. Cardiac MRI is also useful for the diagnosis of anomalies of systemic venous and arterial systems (**Fig. 5**). Survival has significantly improved in patients with CHD due to availability of various treatment options. Cardiac MRI plays important role in evaluating complex surgical shunts and baffles including their size as well as function. The need for sedation/anesthesia in most children is a major limitation of cardiac MRI.
- *Valvular heart disease*: Cardiac MRI can demonstrate the presence and quantify the severity of valvular heart disease. Valvular stenosis or regurgitation results into a dark jet within the bright blood containing chambers (**Fig. 6**). The duration or extent of the signal void (jet) on MR images correlate with the severity of the aortic stenosis and total area of signal loss correlates with the severity of mitral regurgitation. Direct measurement of the jet velocity can be done using phase-contrast technique for assessment of severity and quantification. Cine GRE sequence is useful for the assessment of the valve leaflets.

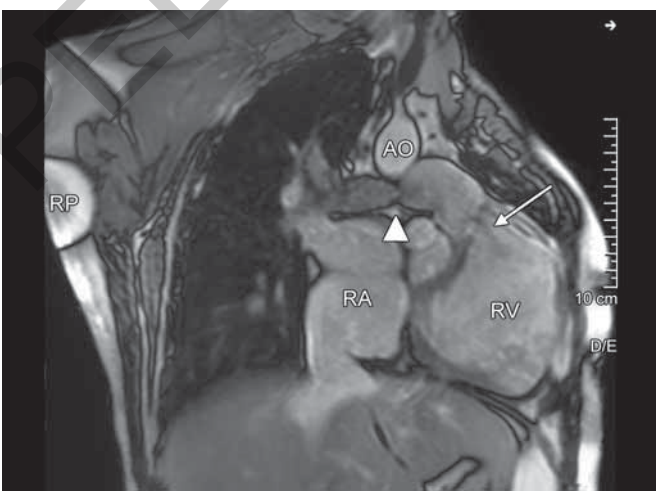


FIG. 5: Congenital heart disease, tetralogy of fallot. Coronal TrueFISP image shows right ventricular (RV) hypertrophy, a jet in the right ventricular outflow tract (arrow) indicating pulmonary regurgitation and right pulmonary artery stenosis (arrowhead).

(AO: arch of aorta; RA: right atrium; TrueFISP: true fast imaging with steady precession)

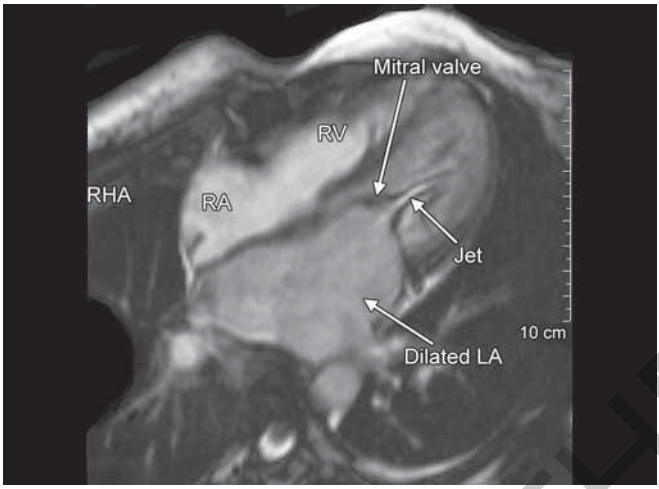


FIG. 6: *Mitral stenosis*. Four-chamber view shows stenosis of the mitral valve with a jet in the left ventricle and a dilated left atrium. The mitral valve stenosis was caused by rheumatic fever.

(LA: left atrium; RA: right atrium; RV: right ventricle)

- *Cardiomyopathies*:
  - *ARVD*: Arrhythmogenic right ventricular dysplasia is characterized by fatty or fibrous infiltration (**Fig. 7**) with thinning or thickening of the RV free wall associated with wall motion abnormality. These changes are responsible for ventricular arrhythmias and are one of the causes of sudden cardiac death in young patients. MRI with its ability to provide excellent soft tissue contrast is the modality of choice for the diagnosis of ARVD. Fat in the RV free wall is identified on T1-weighted images. Other findings include thinning of wall, enlargement and dilatation of RV, areas of dyskinesia, focal bulging of free wall during systole, decreased ejection fraction, and impaired ventricular filling during the diastole.
  - *Hypertrophic cardiomyopathy*: The diagnosis is usually made by echocardiography. Cardiac MRI is useful in the diagnosis of variant confined to the apex and assessment of RV involvement. Cine GRE sequences demonstrate the degree and extent of LV hypertrophy. The degree of associated LV outflow tract obstruction and mitral regurgitation can also be assessed by cardiac MRI.
  - *Restrictive cardiomyopathy versus constrictive pericarditis*: This is a clinical dilemma as both conditions have the same clinical presentation. Differentiation is important because constrictive pericarditis can be treated surgically by stripping the pericardium. Cardiac MRI can differentiate constrictive pericarditis (**Figs. 8A** and **B**) from restrictive cardiomyopathy by the presence of pericardial thickness >4 mm. Dark signal void can also be seen suggestive of calcifications in the pericardium. Restrictive cardiomyopathy will have normal

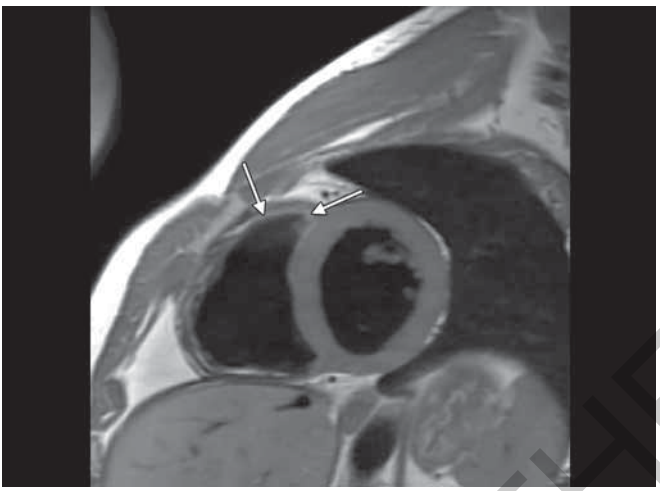
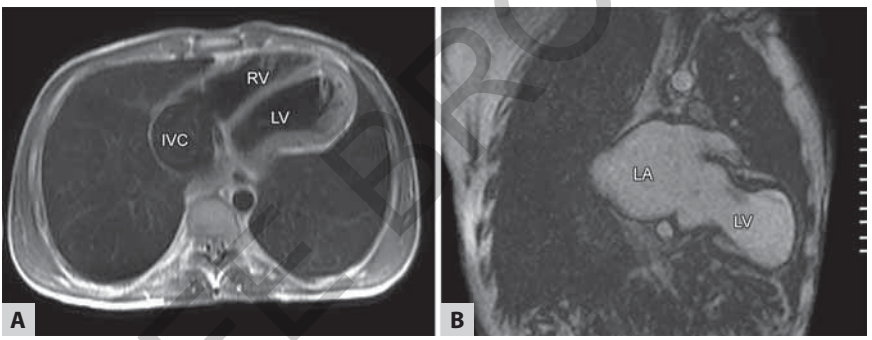


FIG. 7: Arrhythmogenic right ventricular dysplasia (ARVD). Short-axis view T1-weighted image shows a linear high intensity fat in the right ventricular wall (arrows).



FIGS. 8A AND B: *Constrictive pericarditis*. HASTE axial image (A) and T1-weighted GRE two-chamber view (B) show small ventricular cavities (LV and RV), dilated inferior vena cava (IVC), and the left atrium (LA). The pericardium was thickened (not appreciated on these images).

(GRE: gradient-echo; LA: left atrium; LV: left ventricle; RV: right ventricle)

pericardium with thickened ventricular walls. Cardiac MRI also shows associated complications like mitral regurgitation. Other associated findings seen in both conditions include dilated inferior vena cava/superior vena cava (IVC/SVC), hepatic veins, and right atrium (RA). Causes of the restrictive cardiomyopathy include sarcoidosis, amyloidosis, hemochromatosis, scleroderma, storage disorder, and idiopathic. Causes of the constrictive pericarditis include infective, connective tissue disorders, neoplasm, renal failure, postcardiac surgery, and radiotherapy.

  - *Hemochromatosis*: Myocardial iron deposition in hemochromatosis or transfusion-dependent conditions like thalassemia and sickle cell disease, can be quantified by T2*-weighted sequence. Cardiac MR is used to monitor iron overload in these patients and to assess response to the chelating agents.
- *Ventricular function*: Cardiac MRI is reported to be more accurate than 2D echocardiography in the functional assessment of the heart. Cardiac MRI can accurately measure ventricular ejection fraction, end-diastolic, and end-systolic volumes. Usually these measurements are done on short-axis images using software. The sequence used is balanced SSFP that has good contrast between the blood pool and the myocardium.
- *Coronary artery assessment*: Cardiac MRI is still not good enough for the visualization of distal coronary arteries and its branches. The present role of MRI in coronary imaging include assessment of anomalous coronary arteries, aneurysm, and bypass graft patency. Sequences used are standard GRE sequences like balanced SSFP with or without contrast injection.
- *Myocardial perfusion and viability*:
  - *Myocardial perfusion study*: Gadolinium is injected intravenously as a tight bolus during pharmacologic stress. The pharmacologic stress for the myocardium is achieved by slow intravenous (IV) injection of adenosine 140 μg/kg body weight. The sequence used is T1-weighted GRE sequence with high temporal resolution. Low signal areas of under-perfusion on these images correspond with regions of ischemia or infarct.
  - *Myocardial viability*: The imaging sequence for assessment of viability is run 10–15 minutes after gadolinium-based contrast agent (GBCA) injection. The sequences used are either inversion recovery T1-weighted GRE or inversion recovery balanced SSFP sequence. Inversion pulse is used to suppress the myocardium so that any enhancement within the myocardium will be appreciated against the background of the black myocardium. Selection of proper inversion time (TI) is important to suppress signals from the normal myocardium. An infarcted area shows enhancement or bright signal on viability imaging. *"Bright is dead"* on the viability imaging (**Fig. 9**). MR viability study shows the extent and severity of the nonviable myocardium. It helps to assess whether the patient will benefit from revascularization procedure like angioplasty and bypass or not.
- *Cardiac and pericardial masses*: Cardiac MRI is an excellent method to evaluate cardiac and pericardial masses (**Figs. 10A** and **B**). A thrombus is the most common filling defect in a cardiac chamber. Enhancement after GBCA injection differentiates the thrombus from a mass. Most of the cardiac neoplasms are secondary or metastatic. Primary cardiac tumors are rare and 80% are benign.

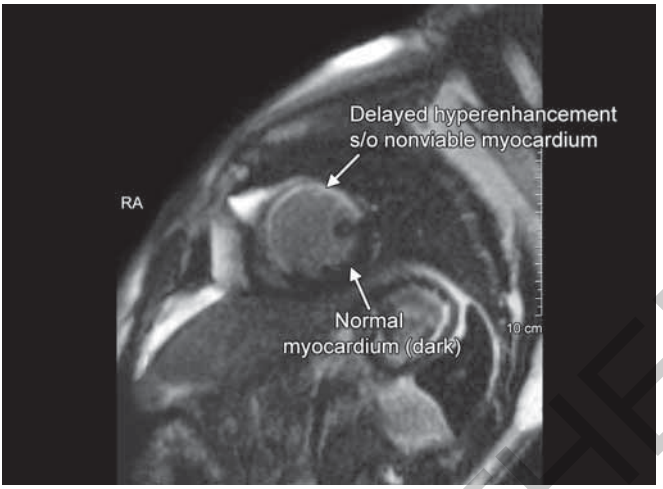
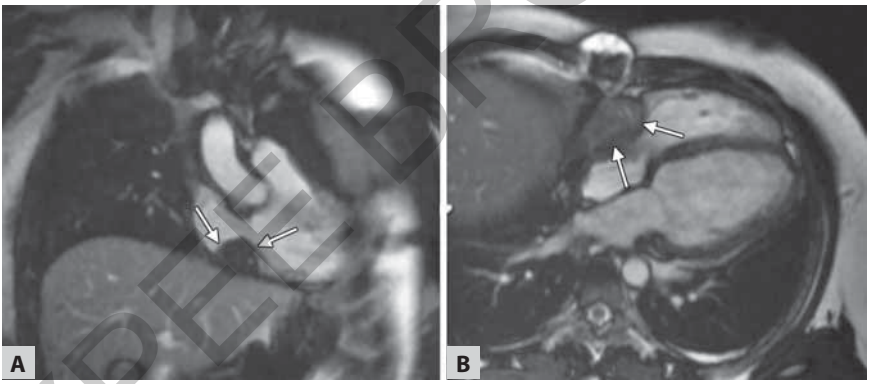


FIG. 9: *Myocardial viability*. Short-axis view obtained at 15 minutes after GBCA injection shows dark normal myocardium (suppressed by inversion recovery pulse) and enhancing nonviable myocardium.

(GBCA: gadolinium-based contrast agent)



FIGS. 10A AND B: *Cardiac mass*. Coronal (A) and four-chamber view (B) images show a hypointense mass (arrows) in the right atrium likely representing a myxoma (not pathologically proven).

- *Pericardial disease*: Pericardium can be visualized with spin-echo or GRE images. Normal pericardium is seen on the spin-echo images as a line of low signal intensity located between the high signals of pericardial and epicardial fat. Normal thickness is 1–2 mm; >4 mm is considered thickening.

MRI Made Easy®
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The first edition of this introductory book was written when the author felt the need for a book on the complex subject of MRI, that will be in simple words and that will give knowledge and confidence for day to day working. The third edition retains its easiness and the perspective for a beginner. Principles of MRI, sequences, interpretation, principles and basic physics behind special applications of MR such as diffusion, perfusion and spectroscopy are discussed in simple words. This edition has additions of many new MRI techniques including quantitative methods. It will enhance the confidence of the reader while monitoring the scans in console and during interpretations of images. This short book is enriched with more than 300 images and diagrams for easy understanding of the subject.

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