Clinical Utility of Cardiac T1- and Extracellular Volume (ECV) Mapping. A Brief Review

Magnus Lundin, M.D.; Martin Ugander, M.D., Ph.D.
Department of Clinical Physiology, Karolinska Institutet and Karolinska University Hospital, Stockholm, Sweden

The clinical utility of cardiovascular magnetic resonance (CMR) is rooted in the ability to provide important clinical information on myocardial tissue characterization. Late gadolinium enhancement (LGE) sequences are established routine for detecting myocardial infarction and focal myocardial scarring of non-ischemic origin [1]. However, LGE is based on T1-weighted inversion recovery imaging and entails visual interpretation of relative signal intensities in relation to healthy myocardium. CMR has been experimentally shown to be able to quantify the distribution of gadolinium-based extracellular contrast agents [2], also known as the extracellular volume fraction (ECV). The basis for measuring ECV is the measurement of T1 before and after the administration of a clinical gadolinium-based extracellular contrast agent at a clinical dose. The inverse of T1 (1/T1) is referred to as R1, and the change in R1 that occurs following contrast administration is proportional to contrast agent concentration. Importantly, blood has a known extracellular space which can be measured by venous blood sampling as 1-hematocrit. Consequently, since extracellular contrast agents distribute into the extracellular space, T1-mapping can be used to quantify relative contrast agents concentrations calibrated to the blood, thus yielding ECV.

ECV is a physiologically intuitive measure insofar as it measures the proportion of tissue comprised of the space between cells. It has recently become possible to generate ECV-maps in clinical routine through automated processing [3]. Myocardial ECV has a normal range of 20-30% [4], but is altered in various myocardial pathologies. These conditions include diffuse fibrosis, acute and chronic myocardial infarction, myocarditis, hypertrophic cardiomyopathy, dilated cardiomyopathy, and amyloidosis [4–6]. A benefit of ECV mapping is that it is measured in absolute units, which allows for a more accurate diagnosis in disease that homogeneously affect the myocardium. Furthermore, this allows for quantitative comparisons both over time in the same patient as well as comparisons between different patients. Importantly, use of mapping allows for visualization of the extent of changes in myocardial ECV.

Native T1-maps alone provide important clinical information, since native T1 is increased in conditions including inflammation [7] and edema in myocardial infarction [8]. T1 is also measured in absolute units as opposed to other sequences that can detect edema, including T2-weighted imaging. Furthermore, T1 is decreased in myocardial iron overload [9] as well as in myocardial glycolipid overload, as seen in Anderson-Fabry disease [10].
The combination of ECV-mapping and T1-mapping can provide quantitative characterization of a number of myocardial pathologies. Figure 1 is a schematic illustration that can be used to interpret the clinical results of T1 and ECV. Figures 2-5 show four clinical cases showing: T1-map (left), LGE (middle) and ECV-map (right). T1 is shown using a color scale from black (0 ms) to white (2000 ms), normal range is purple. LGE shows focal lesions as white and remote myocardium as black. ECV is shown using a color scale where blue is normal range (20-30%); turquoise and light green, indicates increased ECV; and red and white is very high ECV.

LGE: Late gadolinium enhancement
ECV: extracellular volume

Notably, ECV imaging has been proven to provide important prognostic information [11], and a first consensus statement on the use of T1 and ECV in CMR has been published [12]. Continued work is underway to enable implementation for optimized clinical workflow, and there is an expanding number of publications in the field.

Taken together, the combination of ECV-mapping and T1-mapping represent a powerful diagnostic tool in CMR. Not only can otherwise undetectable abnormalities be visualized, but findings can also be characterized in absolute units. This feature both improves the diagnostic accuracy and makes it possible to objectively determine the severity of disease.

2 A 47-year-old woman with amyloidosis (A) with increased ECV (42%) and slightly increased T1 (1100 ms) but normal appearing LGE.

3 A 21-year-old man with acute presentation of myocarditis (M) midmurally in all segments except the inferolateral segment where the myocardium appears normal (N). The affected regions are shown clearly on both ECV (80%) and LGE, in stark contrast to the normal segment (T1 1075 ms, ECV 34%).

4 A 70-year-old woman with a chronic infarction (CI) that is shown clearly on both LGE and ECV (70%) and less clear on T1-maps (1140 ms). This patient also had diffuse fibrosis (DF) in the septum (T1 1075 ms, ECV 34%).

5 A 40-year-old woman presenting with chest pain and ST-elevation, but a normal invasive coronary angiogram. CMR shows segmental edema (E) based on increased T1 (1300 ms) and ECV (40%) compared to normal (N) myocardium (T1 1040 ms, ECV 29%). Note that the edematous segment appears normal on LGE. The case was interpreted as likely segmental stress cardiomyopathy or coronary spasm, and no infarction.

6 A 2-year-old child with acute presentation of myocarditis (M) midmurally in all segments except the inferolateral segment where the myocardium appears normal (N). The affected regions are shown clearly on both ECV (80%) and LGE, in stark contrast to the normal segment (T1 1075 ms, ECV 34%).
References


Contact

Martin Ugander, M.D., Ph.D.
Department of Clinical Physiology N2:01
Karolinska Institutet and Karolinska University Hospital
SE-171 76 Stockholm
Sweden
Phone: +46709850088
martin.ugander@ki.se