T1 Mapping Shows Increased Extracellular Matrix Size in the Myocardium Due to Amyloid Depositions

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Amyloidosis is a systemic infiltrative disorder in which insoluble protein fibrils are deposited in the extracellular matrix (ECM). The prognosis is predominantly determined by cardiac involvement because the amyloid depositions lead to a restrictive cardiomyopathy. Although endomyocardial biopsy is the gold standard for diagnosing cardiac amyloidosis, the associated risk for complications favors a noninvasive approach by using various cardiac imaging methods, whereas tissue diagnosis is made on a noncardiac biopsy. Accurate diagnosis of cardiac amyloidosis becomes difficult when a secondary cause of myocardial wall thickening (eg, hypertension) is present as well. Cardiac MRI is an excellent tool for assessment of systolic and diastolic function, myocardial thickness, and amyloid deposition with late gadolinium enhancement imaging. Late gadolinium enhancement imaging is a qualitative technique, which relies on the presence of normal myocardium to visualize infiltrated, enhanced tissue. Therefore, diffuse deposition of amyloid is difficult to highlight, because regional differences in signal intensities may be absent. T1-mapping is a cardiac MR technique, which allows absolute quantification of T1 values of the myocardium and enables assessment of ECM expansion present in cardiac amyloidosis.

A 71-year-old man with a medical history of hypertension presented with suspicion of congestive heart failure. A 12-lead electrocardiography showed atrial fibrillation and low voltages in the extremity leads, suggestive of cardiac amyloidosis.

Figure 1. Electrocardiography on admission showing low voltages in the extremity leads, suggestive of cardiac amyloidosis.

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low voltages in the extremity leads (Figure 1). Surprisingly, echocardiography demonstrated severe concentric hypertrophy with a preserved left ventricular systolic function (Figure 2). Due to the discrepancy between hypertrophy and low voltages, cardiac amyloid was suspected and cardiac MR imaging was performed using a clinical 1.5-T scanner (Avanto; Siemens, Erlangen, Germany). Despite atrial fibrillation, images were of diagnostic quality. Functional assessment showed a left ventricular ejection fraction of 53% and wall thickness of 16 mm. Both atria were dilated and small pericardial and pleural effusions were present (online-only Data Supplement movie). To differentiate between hypertension-induced hypertrophy and increased myocardial mass due to amyloid depositions with subsequent increase in ECM, T1 mapping was performed before and at 5 and 10 minutes after 0.2 mmol/kg Gd-DOTA (Dotarem; Guerbet, Villepinte, France) contrast administration. This gadolinium-based contrast agent does not cross intact cellular membranes and distributes only in the extracellular space. T1 mapping was performed with a single short axis slice modified...
look-locker inversion-recovery sequence obtained during breath-holding. After T1-mapping, late gadolinium enhancement imaging was performed using an inversion recovery gradient echo sequence. Signal suppression of normal myocardial tissue was difficult (Figures 3 and 4). To assess whether the increased mass was due to an increase in ECM size or due to cellular hypertrophy, ECM size was estimated by assessing the myocardial distribution volume of Gd-DOTA. This myocardial distribution volume consists of both the extracellular, extravascular space and the tissue plasma space. This tissue plasma space fraction is in the order of 0.045 but cannot be separately assessed by MRI. T1 relaxation times were calculated for the blood pool and 6 isoan- 
gular segments of myocardium at the midventricular level (Figure 5). With the T1 relaxation times of myocardium and blood pool before and after contrast administration and correcting for hematocrit value (viz 0.37 l/L), the myocardial distribution volume was calculated. Analysis revealed a sharply increased myocardial distribution volume of Gd-DOTA in all segments (49% ± 5% of the myocardium; range, 44%–58%; Table) compared with previously described values of 24% ± 3% in normal and 34% ± 3% in hypertensive patients. These findings reinforced the suspicion of amyloidosis and subcutaneous adipose tissue biopsy was performed, confirming the diagnosis (Figure 6).

Using T1 mapping, we were able to show that myocardial amyloid deposition was not only limited to the enhanced areas on late gadolinium enhancement, but that it was a generalized process resulting in a diffuse increase in myocardial volume. Figure 7 is an example of a different patient with cardiac amyloidosis. The cardiac tissue biopsy shows amyloid depositions giving rise to an increased ECM volume. T1 mapping has been used in patients with cardiac amyloidosis, although only for assessing T1 relaxation times. If cardiac amyloidosis is suspected and late gadolinium enhancement imaging is difficult due to diffuse infiltration, absolute quantification of myocardial distribution volume of an extracellular agent as an indication of ECM size may have additional value, especially if other causes for hypertrophy are present. Further analysis by comparison of T1 mapping and estimation of the ECM size in different pathophysiological processes causing myocardial wall thickening is necessary to assess the true applicability of this promising technique in clinical practice.

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<table>
<thead>
<tr>
<th>Location</th>
<th>T1 Relaxation Time Before Gd-DOTA</th>
<th>T1 Relaxation Time 5 Min After Gd-DOTA</th>
<th>T1 Relaxation Time 10 Min After Gd-DOTA</th>
<th>Calculated Volume of Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV blood pool</td>
<td>1558</td>
<td>237</td>
<td>350</td>
<td>N/A</td>
</tr>
<tr>
<td>IS</td>
<td>1121</td>
<td>273</td>
<td>400</td>
<td>48%</td>
</tr>
<tr>
<td>AS</td>
<td>1096</td>
<td>275</td>
<td>397</td>
<td>48%</td>
</tr>
<tr>
<td>AN</td>
<td>1105</td>
<td>274</td>
<td>399</td>
<td>48%</td>
</tr>
<tr>
<td>AL</td>
<td>1061</td>
<td>289</td>
<td>413</td>
<td>58%</td>
</tr>
<tr>
<td>IL</td>
<td>1078</td>
<td>281</td>
<td>399</td>
<td>46%</td>
</tr>
<tr>
<td>IN</td>
<td>1071</td>
<td>291</td>
<td>411</td>
<td>44%</td>
</tr>
</tbody>
</table>

By relating the T1 relaxation times of the blood pool and the myocardium, before and after contrast administration and after blood hematocrit correction using the formula $V_d = \frac{(1-hematocrit) \times (1/T1_{blood.post}) - (1/T1_{blood.pre})}{(1/T1_{myo.post}) - (1/T1_{myo.pre})}$, the myocardial volume of distribution of the extracellular agent (ie, extracellular matrix size) could be calculated, which was evidently increased.

LV indicates left ventricular; IS, inferoseptum; AS, anteroseptum; AN, anterior; AL, anterolateral; IL, inferolateral; IN, inferior; N/A, not applicable.

Figure 6. Congo red staining of abdominal subcutaneous adipose tissue biopsy showing red strands of amyloid fibrils among the extracellular matrix (magnification ×200).

Figure 7. Hematoxylin–eosin staining of cardiac tissue biopsy (different patient with cardiac amyloidosis) showing pinkish depositions (arrow) of amyloid fibrils (magnification ×100).
References


Key Words: amyloid — magnetic resonance imaging — pathology — T1 mapping — tissue characterization