dGEMRIC Effectively Predicts Cartilage Damage Associated with Femoroacetabular Impingement

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Introduction

- Femoroacetabular impingement (FAI) is a dysfunction that causes labral tears and chondral delamination or erosion, through repetitive microtrauma between the proximal femur and the acetabular rim during extreme hip motions
  - Lesions progress over time and can result in osteoarthritis (OA) of the hip joint¹
  - Early detection is critical to the success of joint preserving surgical treatments²

- Recognition of FAI both clinically and radiographically may be difficult
  - MRI and MR arthrography are not effective in detecting cartilage damage
  - dGEMRIC allows to visualize the earliest biochemical changes in the cartilage using $T_1$ as an indirect measure of the concentration of glycosaminoglycans (GAGs)³
  - Following the development of fast $T_1$ mapping pulse sequences⁴,⁵, dGEMRIC in the hip has become clinically feasible and it has been proposed for early cartilage assessment in FAI⁶-⁸
  - It is still unclear how to best interpret dGEMRIC data in order to impact clinical decisions
  - A new method has been proposed to “standardized” dGEMRIC values for improved analysis⁸

- The goals of this study are:
  - Assess the performance of dGEMRIC on radial imaging planes⁹ at 3 Tesla for predicting cartilage abnormalities in FAI patients, using intra-operative findings as reference
  - Assess intra- and inter-observer repeatability for standardized dGEMRIC
  - Compare standardized dGEMRIC with morphologic MRI evaluation of the hip cartilage
Standardized dGEMRIC

- Clinical interpretation of dGEMRIC $T_1$ maps is still challenging
  - Affected by patient’s age and sex, diffusion and transport rates of gadolinium, etc.
- As cartilage lesions in FAI originate near the chondrolabral junction, the central portion of the femoral cartilage is healthy in early stages of FAI and can be used as an internal reference for standardization.

**Healthy Cartilage ROI**

Step 1: define an ROI over the central portion of the femoral cartilage

**Articular Cartilage ROI**

Step 3: define an ROI over the weight-bearing portion of the hip articular cartilage and use it to segment the parametric map

**Parametric Map**

Step 2: transform each pixel value $x$ of the dGEMRIC $T_1$ map into $z = (x - \mu)/\sigma$ “z-score”. $\mu$ and $\sigma$ are the average and standard deviation of the $T_1$ values within the healthy cartilage ROI

**Standardized dGEMRIC**

Step 4: adjust color scale to pinpoint regions of abnormal cartilage and superimpose the resulting standardized dGEMRIC map to the corresponding anatomic image

dGEMRIC effectively predicts cartilage damage associated with FAI. R. Lattanzi et al.
Materials and Methods

- Retrospective review of 20 hips (12 left) in 20 patients (11 females)
  - Preoperative morphologic and dGEMRIC 3T MRI exam at age 34 ± 11 years
  - Hip arthroscopy 52 ± 34 days after MRI
- A $B_1$-insensitive high-resolution 2D $T_1$ mapping pulse sequence was used to acquire dGEMRIC maps along radial imaging planes
  - 0.6 x 0.6 mm$^2$ in-plane spatial resolution, 4.0 mm slice thickness (1 m 40 s per slice)
  - 84 usable radial sections (ranging from 2 to 6 per patient because of motion and wrapping artifacts) covering the AS and PS regions of the acetabular cartilage
  - $z < -2$ was used as the threshold between normal and abnormal cartilage
  - Intra- and inter-observer variability were established
- Proton-density-weighted (PD) images were acquired at the same locations
  - TSE, 0.4 x 0.4 mm$^2$ in-plane, 4.0 mm slice thickness, TR/TE = 3110/25 ms (2 m 20 s total)
  - An experienced MSK radiologist evaluated the acetabular cartilage
- dGEMRIC and morphologic cartilage evaluations were validated against arthroscopic findings
Cartilage looking normal on morphologic evaluation (left) is clearly abnormal on the standardized dGEMRIC map (right).

dGEMRIC effectively predicts cartilage damage associated with FAI

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dGEMRIC vs. Morphologic

Standardized dGEMRIC Map  PD-Weighted MR Image

- Areas of abnormal cartilage (purple arrows) stand out with standardized dGEMRIC
- The central portion of the femoral cartilage (white arrows) can be assumed to be healthy and used as an internal reference
- Both lesions were confirmed by arthroscopy
- Posterior-superior cartilage was erroneously reported as normal on morphologic evaluation.

dGEMRIC effectively predicts cartilage damage associated with FAI  R. Lattanzi et al.
dGEMRIC vs. Morphologic Assessment

<table>
<thead>
<tr>
<th></th>
<th>dGEMRIC* (z &lt; -2)</th>
<th>Morphologic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
<td>AS only</td>
</tr>
<tr>
<td>Accuracy</td>
<td>69% (60-77%)</td>
<td>73%</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>74% (61-83%)</td>
<td>71%</td>
</tr>
<tr>
<td>Specificity</td>
<td>61% (45-75%)</td>
<td>81%</td>
</tr>
<tr>
<td>PPV</td>
<td>77% (61-88%)</td>
<td>94%</td>
</tr>
<tr>
<td>NPV</td>
<td>56% (33-77%)</td>
<td>42%</td>
</tr>
</tbody>
</table>

* Combines the results of Observer 1 with those of the two sessions of Observer 2

95% confidence limits in parentheses
Substantial agreement based on kappa coefficient:

\[ k = 0.68 \text{ (inter-observer)} \]
\[ k = 0.76 \text{ (intra-observer)} \]

- **z < -2** used as threshold between normal and abnormal cartilage

<table>
<thead>
<tr>
<th></th>
<th>Observer 1</th>
<th>Observer 2 (I)</th>
<th>Observer 2 (II)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy</strong></td>
<td>75.0 %</td>
<td>69.0 %</td>
<td>63.1 %</td>
</tr>
<tr>
<td></td>
<td>(63/84)</td>
<td>(58/84)</td>
<td>(53/84)</td>
</tr>
<tr>
<td><strong>Sensitivity</strong></td>
<td>83.3 %*</td>
<td>68.5 %</td>
<td>68.5 %</td>
</tr>
<tr>
<td></td>
<td>(45/54)</td>
<td>(37/54)</td>
<td>(37/54)</td>
</tr>
<tr>
<td><strong>Specificity</strong></td>
<td>60.0 %</td>
<td>70.0 %</td>
<td>53.3 %</td>
</tr>
<tr>
<td></td>
<td>(18/30)</td>
<td>(21/30)</td>
<td>(16/30)</td>
</tr>
<tr>
<td><strong>PPV</strong></td>
<td>78.9 %</td>
<td>80.4 %</td>
<td>72.5 %</td>
</tr>
<tr>
<td></td>
<td>(45/57)</td>
<td>(37/46)</td>
<td>(37/51)</td>
</tr>
<tr>
<td><strong>NPV</strong></td>
<td>66.7 %</td>
<td>55.3 %</td>
<td>48.5 %</td>
</tr>
<tr>
<td></td>
<td>(18/27)</td>
<td>(21/38)</td>
<td>(16/33)</td>
</tr>
</tbody>
</table>

* \( p = 0.0064 \)
Discussion

• Standardized dGEMRIC improves cartilage evaluation compared to morphologic imaging.

• Diagnostic performance of standardized dGEMRIC was higher for the anterior-superior (AS) region where cartilage is directly visualized by the surgeon and so arthroscopic findings are more reliable.

• Diagnostic performance of standardized dGEMRIC was higher for the most experienced user (Observer 1), although repeatability analysis showed substantial agreement.

• Relatively low specificity of standardized dGEMRIC may be intrinsic to the dGEMRIC technique, as it can detect biochemical changes before macroscopic effects occur.
Comparison with Previous Studies

• Bittersohl et al. showed that the mean $T_1$ in the cartilage is lower in FAI patients than asymptomatic volunteers$^{10}$
  - Did not indicate a threshold to separate normal from abnormal cartilage

• Mamisch et al. showed that the mean $T_1$ in the cartilage is 488 ms for FAI patients and 643 ms for asymptomatic volunteers$^7$
  - Significant difference ($p < 0.001$) but no impact for clinical decisions because values overlapped considerably for individual cases

• Two studies at 1.5 T validated dGEMRIC predictions against intra-operative findings using $T_1 < 500$ ms as the threshold between normal and abnormal cartilage$^{11,8}$
  - Bittersohl et al. reported very weak correlation ($k = 0.114$)
  - Lattanzi et al. reported accuracy = 55 %, sensitivity = 47 %, specificity = 58 %
Conclusions

- This work validated dGEMRIC predictions against arthroscopic findings for FAI patients using radial sections of the hip at 3 T

- dGEMRIC standardization in FAI:
  - Removes the effects of intra- and inter-patient variability
  - Highlights regions of abnormal cartilage improving clinical interpretation
  - Can be applied at any field strength

- Standardized dGEMRIC is accurate in detecting pathologic articular cartilage in FAI patients
  - Used in combination with morphologic MRI it could considerably improve preoperative cartilage assessment
  - It could be used to guide surgical decisions for individual patients
References