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<table>
<thead>
<tr>
<th>Name (First, last)</th>
<th>Keith Wachowicz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mailing address</td>
<td>Medical Physics, Cross Cancer Institute, 11560 University Ave., Edmonton, AB, Canada, T6G 1Z2</td>
</tr>
<tr>
<td>Institution/organization</td>
<td>University of Alberta</td>
</tr>
<tr>
<td>Position</td>
<td>Assistant Professor</td>
</tr>
<tr>
<td>Telephone</td>
<td>1-780-989-4334</td>
</tr>
<tr>
<td>Email</td>
<td><a href="mailto:keith.wachowicz@ualberta.ca">keith.wachowicz@ualberta.ca</a></td>
</tr>
</tbody>
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PRESENTATION TITLE
Production of Beam's Eye View MR images for RT-MRI hybrids via specially-designed gradient hardware

AUTHOR(S)
Keith Wachowicz\textsuperscript{1,2}, Brad Murray\textsuperscript{1,2,3}, and B Gino Fallone\textsuperscript{1,2,3}\textsuperscript{*}
\textsuperscript{1} University of Alberta, Edmonton, Canada
\textsuperscript{2} Cross Cancer Institute, Edmonton, Canada
\textsuperscript{3} MagnetTx Oncology Solutions, Edmonton, Canada

ABSTRACT
Purpose:
One of the imaging tasks that hybridized RT-MRI units can ideally perform is real-time imaging of target and critical structures to guide or gate the treatment beam. In these circumstances, pixels within the guiding images should represent unique cross-sections of the treatment beam, which is inherently delivered in a coordinate system that diverges from a single source point. This work outlines a hardware solution that can allow an MRI to generate Beam's-Eye-View (BEV) images directly through the acquisition of k-space. This permits rapid BEV imaging suitable for real-time target tracking, an objective not possible given conventional MRI hardware.

Theory and Methods:
The encoding gradients must be altered in order to accommodate this new geometry. If the radiation source is fixed relative to the MR unit, only the two gradients perpendicular to the beam direction need be modified. The in-plane gradients will have to be changed to provide an increasing signal compression as one moves towards the beam source. This compression will correspond to an increasing in-plane gradient strength, allowing each non-cartesian voxel to be encoded with the same gradient field (Fig. 1A). As opposed to the conventional in-plane gradients which can be described as $G_i(x, y, z) \propto \hat{r}_i \cdot (x, y, z)$, the increasing gradient strength in the direction of the beam source can be described as $G_i(x, y, z) \propto \frac{\text{SID}}{\text{SID} + r_2(x, y, z)} \hat{r}_i \cdot (x, y, z)$, where $\hat{r}_i$ is the unit vector pointing in the direction of one of the in-plane gradients, and $\hat{r}_2$ is the unit vector pointing from the beam source toward isocentre.

This solution will only be achievable when the in-plane gradients are fixed relative to the beam-source. However, in some implementations of these MRI-radiotherapy hybrids, the source is made to rotate about a fixed MRI. In this circumstance there is no one gradient coil that can produce an in-plane BEV gradient for all source orientations. However, despite the fact that the ideal BEV gradient...
field does not vary linearly with distance to the source, a combination of a conventional linear gradient and a second-order field pattern can approximate the distribution well over small regions of space (Fig.1B). Two such gradients would be required for any one orientation, with a combination of four providing a basis set for all source positions.

To demonstrate the practical generation of fields necessary to provide this type of encoding, a boundary element method optimization\(^1\) was used to design current distributions for a set of BEV-encoding gradients in the simpler case where the radiation source and imaging magnet are fixed relative to each other.

**Results:**

The X BEV gradient is displayed in Fig.2, showing the current distribution on the left, and its corresponding divergent gradient field in cross-section on the right.

**Conclusions:**

For all implementations of MR-linac hybrids there is a practical means to implement encoding gradients that can directly image in the beam’s-eye-view, though in implementations where the linac rotates about the magnet, only an approximation to the theory is possible with the addition of 4 second-order gradient coils.

**References:**

\(^1\)Poole M, Bowtell R. *Concepts Magn Reson*. 2007;31B(3): 162–175

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**Figure 1.** BEV encoding field diagrams. A: Ideal B: Approximation utilizing 2\(^{nd}\)-order gradient fields.

**Figure 2.** A: BEV X gradient current pattern B: corresponding divergent encoding field