Imaging needs for radiation therapy

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MRI for radiation therapy

As the delivery techniques in radiation therapy have reached unprecedented levels of accuracy, high-quality imaging to plan such treatments is essential. Anatomical and functional MRI techniques, used in a diagnostic setting for staging and patient selection, are increasingly used for tumor delineation. Many radiation therapy departments are either collaborating with radiology departments or investing themselves in dedicated equipment to facilitate MRI-based treatment planning.

The purpose of an MRI scan made for radiation therapy treatment planning differs from diagnosis. When a patient enters a radiation therapy department, the diagnosis usually has been established, and staging of the disease is done. The question at hand is to delineate the tumor and to identify its position relative to healthy normal tissue. To accommodate MR images into the workflow of radiation therapy treatment planning, specific demands have to be met with respect to patient position and geometrical accuracy. Thus, scanning protocols designed for diagnostic purposes may need to be adapted to meet the needs of radiation therapy [1, 2].

Radiation therapy workflow

External-beam radiation therapy is mostly delivered in a series of daily irradiation sessions that can last up to 2 months. This strategy exploits the fact that many tumors have a reduced capacity to repair DNA damage inflicted by radiation. Thus, normal tissue gets the time to recover between treatment fractions, while the damage accumulates in tumors. This practice requires great care to reproduce the patient position for each treatment session and to verify that the treatment fields are accurately aimed at the intended target volume. For this reason, a flat couch top is used as well as devices such as immobilization masks and arm supports. Based on a CT scan made in the same position, the target volumes and organs at risk are delineated and beam portals for irradiation are optimized to achieve an optimal distribution of the radiation dose. The same positioning requirements apply for a MRI examination made for radiation therapy planning. As the extent of the disease as seen on MRI defines the target volume, the geometrical fidelity of the MR images needs to be high.

Radiation therapy positioning in an MRI scanner

Scanning in treatment position may require alternative solutions to the standard diagnostic procedure for patient setup and choice of receive coils. A straightforward example is the use of a flat table top. This may somewhat increase the distance between posterior coils embedded in the table and the patient, but the impact on scan procedure and quality tends to be limited. With simple devices such as coil bridges that are positioned around the patient to support surface coils, distortion of the body contour can be avoided [1].

For head-neck and brain, reproducible positioning for RT requires the use of a fixation mask. The regular multi-channel head coils are not compatible with this. A suboptimal solution would be to refrain from using the fixation mask. The purpose of such a mask is not only to avoid patient motion, but also to force a flexing of the neck that minimizes exposure of the jaws during treatment. The more common solution is to use a set of flexible coils that are strapped around the mask. With such a solution a decent signal to noise can be achieved, although the limited number of channels pose constraints compared to diagnostic head coils

[1-3]. Development of a multi-channel head coil that is compatible with a fixation mask is therefore urgently needed.

Geometrical fidelity

Geometrical distortions are caused by nonlinearities in the gradient coils as well as by inhomogeneities in the static magnetic B_0 field. The latter are, to some extent, an intrinsic property of the scanner. However, air tissue transitions, in particular in cavities in the body, can cause substantial B_0 field distortions as well. Scanner-related distortions can be characterized with phantoms consisting of a grid of fluid-filled rods [4]. Both scanner-related B0 and gradient errors can be measured from combinations of images with opposite gradient directions [5-6]. Vendors provide 2D and 3D corrections that mitigate these distortions. However, residual distortions, larger than 2 mm can persist at larger distances from the isocenter [1].

Patient-induced B_0 field distortions can be visualized by comparing images with opposite readout gradient directions. Several approaches are feasible to minimize or correct such distortions. First, it is advantageous to increase read-out bandwidth, so as to diminish off-resonance effects. A water-fat shift of less than 1 pixel is usually feasible without unacceptable loss in signal-to-noise ratio. A second step is to optimize shimming in the images used for radiotherapy simulation. Higher order shimming or limitation of shim volumes to critical areas can be applied. If distortions are still too large, B_0-field mapping can be used to correct images afterwards [7]. Finally, a mutual information-based approach can be followed for mapping of the two images acquired with opposite readout gradients [8].

Imaging needs

The purpose of an MRI scan for radiation therapy is not diagnosis and staging, but delineation of the tumor and surrounding normal tissue. The trade-offs that are made in optimizing a scan protocol therefore can result in sequences that differ from those in a regular diagnostic exam. To minimize off-resonance effects a sequence for radiation therapy will have a limited water-fat shift at the expense of signal-to-noise [2]. For detailed contouring of tumors 3D sequences are attractive as they offer isotropic voxels in an acceptable scan time [1]. Furthermore, compared to 2D sequences, their geometrical fidelity tends to be better at larger distances from the center of the image when a 3D gradient correction is applied. However, contrasts differ from the conventional 2D sequences and it needs to be established if these differences are critical for tumor delineation. As increasingly automatic segmentation methods are used, the uniformity of image intensity and reproducibility of image contrast is an issue.

Particularly in the pelvis, internal organ motion makes registration of planning CT and MRI scans difficult, even if they are acquired directly after each other. Differences in rectum and bladder filling can be difficult to avoid, although detailed procedures have been implemented to this effect. If it is not practically feasible to achieve consistent CT and MRI images for the entire field of view, it can be considered to limit the field of view to the key area of interest. A local registration of the environment of the tumor may in some cases be sufficient for accurate delineation of the tumor.

An exciting development is to circumvent the use of a planning CT altogether. Several methods have been published to derive CT-like information from MRI images for attenuation correction in dose calculations [9-11].

Conclusion

In recent years, a considerable research effort has been dedicated to the integration of MRI into the external radiotherapy workflow. Specific scan procedures have been developed that allow reproducible patient positioning throughout the treatment. Diagnostic sequences have been adapted to afford a high geometrical fidelity. This allows the radiation therapy community to benefit from the superior soft-tissue contrast as compared to CT and from the versatility of anatomical and functional MRI techniques that are currently available.

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