Bone detection in MR Images and absorbed dose in a material behind bones in radiotherapy

This research examined two of the challenges related to the use of MR images only in radiotherapy treatment planning. The first investigated challenge was bone localization in MR images for accurate bone segmentation and pseudo-CT construction, which is inevitable since the lack of electron density information in MR images. The spatial errors are possible because of geometrical distortion, the susceptibility artifact and the dark appearance of the cortical bone. The second examined question was the influence of different bone parts on absorbed dose. This research is significant for use of the pseudo-CT images in treatment planning. Previously, the pseudo-CT images have been constructed for pelvic area dose calculations either by assuming the whole body as homogeneous matter or by setting an additional single electron density value for the bones [1-5]. However, the human bones include different types of bony tissues and, consequently, varying electron densities [6].

A phantom was constructed by positioning fresh deer bones (bag leg from pelvis to tibia) into a plastic box, so that the bones were couple of centimeters above the bottom, and the box was filled with gelatine (9 cm). The bone localization in MR images was evaluated by using five MR images with different sequence parameters (1.5 T imager GE Optima MR450w, GE Medical systems) and a CT image of the phantom. Using the images, the bone diameter and the distances from the bone edges to the phantom walls were determined at four predefined locations (bone within the radius of 12 cm from the isocenter). Full width at half maximum of the pixel values of the cortical bone was used as a criterion for the bone edge. The pixel-size of all the images was approximately 1 mm, and the measurement results were rounded to the nearest 0.5 mm. The distances measured from the images were compared to the actual physical measures. The absorbed doses in the material few centimetres behind the bone were quantified by averaging four irradiations of 100 MUs using linear accelerator Elekta Axesse by 9.6 · 10.4 cm open field at 6 and 15 MV. The dose distributions measured by a matrix detector (ionization chamber diameter and spacing: 0.5 cm) were compared with the reference distributions through the gelatine only. The percentage errors were calculated at four transverse profiles perpendicular to the bone (femur and hip). In addition, the calculated dose distributions were analysed as the measured ones using superposition and Monte Carlo algorithms (TPSs: Xio 4.60 and Monaco 3.00, Elekta CMS Software). Besides calculating dose distribution in the standard CT image, dose was also calculated in a pseudo-CT image, in which the electron density of the whole bone was set as 1.32 g/cm³.

The determined bone circumference by using the MR images was within 1 mm of the actual physical diameter in all of the measurements. In addition, the distances from the bone edges to the phantom walls were within the same error range. Moreover, by using the CT image the errors were of the same size. Figure 1 illustrates the transverse dose difference profiles behind bones (femur on left, hip bone on right) between investigations through bones and through gelatine only at 6 MV. The measured dose was decreased 1.3 percentage units more behind the edge of the femur than behind the middle part of it. The calculated dose distribution errors in the bulk density pseudo-CT image rose up to 2 % units compared to those in the standard CT image. These errors were most significant behind the middle part of the femur, and also, behind the femur edge, but on the opposite direction. Behind the hip bone the dose errors in the bulk density pseudo-CT image were consistently larger in magnitude than in the standard CT image.

The research ascertainst that the bones are represented accurately in MR images, and hence, the sole use of MR images is possible for the pseudo-CT construction and radiotherapy treatment planning. However, the study shows the strong effect of the cortical bone on the absorbed dose compared to other tissues. In addition, the work indicates that the use of a pseudo-CT image by assuming a single electron density for all types of bones can lead to significant errors in the calculated dose distribution. Especially behind bones with a lower density trabecular core surrounded by a thick shell of cortical bone, the use of a bulk density pseudo-CT image lead to misrepresentation of the dose distribution profile. Consequently, future research should investigate how to improve bony structure representation when the electron density is not directly accessible.
Figure 1: The measured and calculated transverse dose profiles behind bones (left: femur, right: hip bone) compared to dose through gelatine only. The 0.5 cm wide bars represent measurement results. The calculation results are represented as follows: The lines illustrate calculations by Xio superposition algorithm (solid line in the standard CT image, dashed line in the bulk density pseudo-CT image) and dots by Monaco Monte Carlo algorithm (solid dots in the standard CT image, open dots in the bulk density pseudo-CT image).


