Towards online surgical margin assessment using micro-CT in breast tumours

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Aims

Breast conserving surgery (BCS) is the cornerstone of breast cancer treatment. An essential quality indicator for BCS is the surgical resection margin, which unfortunately is positive in 10-30% of cases, and is not known until several days after surgery. If we could assess the margin in an online setting while the patient is still on the OR table, the resection could be extended when needed during the same procedure. Several technologies, e.g. frozen section and cytology were developed for intraoperative margin assessment (IMA). Unfortunately, all have failed to penetrate routine practice due to limitations, slow reporting times, low accuracy, and complex logistics [1]. An IMA technology gaining attention recently is micro-computed tomography (µCT) [2]. With µCT the entire lumpectomy specimen is scanned, allowing 3D analysis of the entire margin. State of the art systems take approximately 8 minutes to acquire the data and another 4 minutes for reconstruction. Image quality is highly influenced by metal implants in the tumour, which are often present as markers for biopsy locations, or as guides for the surgeon (wire-guides or radioactive seeds). In this study we aimed to reduce the reconstruction time by implementing inline-reconstruction, and to improve the image quality by removing the metal implants from the projection images before reconstruction.

Method

Images were acquired with a Bruker Skyscan® 1275 (Bruker, Kontich, Belgium). All specimens were scanned at 50 kV, 200 mA, using 1 mm Aluminium filter and step-and-shoot acquisition of 901 projection images at 0.4° spacing (470 seconds scan time). The detector has 1944x1536 pixels, with 75 µm pixels, a focus detector distance of 283 mm, and images are stored in 16-bit tiff format. The focus to object distance is variable, and was between 100 and 125 mm. The µCT system comes with standard back-projection reconstruction software [3] which utilizes the GPU (nRecon), and can only be used for offline reconstruction. We implemented inline reconstruction software, which can start with back-projection calculations as soon as the first projection image is available. Calculations were done multi-threaded on the CPU, implemented in C++. The main aim was to determine at which reconstruction resolution the software was fast enough to cover the acquisition speed. We started at an in-plane resolution of 512x512, increasing in steps of 64. Calculations were performed on a 64 bit Intel Xeon 3.4 GHz dual-core with 6 threads each with 128 GB RAM.

For metal artefact reduction the affected areas were removed from the projection images. The replacement method of the pixels was inspired on texture synthesis by non-parametric sampling [4]. The metal implant region was replaced pixel by pixel by comparing the neighbourhood of a pixel (a patch) to all possible patches in a sample region in the same image. The centre pixel of the patch in the sample region with the least squares difference with the target pixel was used to replace the pixel.

Segmentation of the implants was done using the following steps: absolute vertical and horizontal derivative filtering followed by a closing operation using a 12 voxel kernel (optimized for radioactive seeds) was added to the image to highlight the implants, followed by simple thresholding. The segmentation was expanded by 12 pixels, resulting in the target region which needed to be replaced. The sample region was determined by taking a 40 pixel expansion around the target region. The optimal patch size was empirically determined at 11x11 pixels. To assess image quality and segmentation accuracy, 3D µCT reconstructions were calculated with and without the artefact reduction, and were subsequently subtracted. The difference image was used to assess if only the metal artefacts were removed without changing the remainder of the scan. Calculations were done on a 64bit 2.4 GHz 4-core i7 with 16 GB RAM, and calculation speed per image was evaluated.

Reconstruction and metal artefact reduction was evaluated on a dataset of 16 breast lumpectomy scans. Cases were selected on the presence of one or multiple metal objects, and the presence of naturally occurring calcifications, which needed to be preserved.

Results

Fourteen of the samples contained one radioactive iodine seed, of which 5 had an additional biopsy marker. One sample contained 4 surgical clips, and one sample contained a twist marker. Up until a reconstruction cube of 832x832x704 with 70 µm resolution and down-sampling of the projection images by a factor 2 the inline reconstruction was capable of processing the images at the acquisition speed, making the reconstruction available to the user within seconds after acquisition. At 896x896x768 a 73 seconds delays started to appear. Besides the change in resolution, image quality of the inline reconstructions was comparable to the offline nRecon reconstructions.

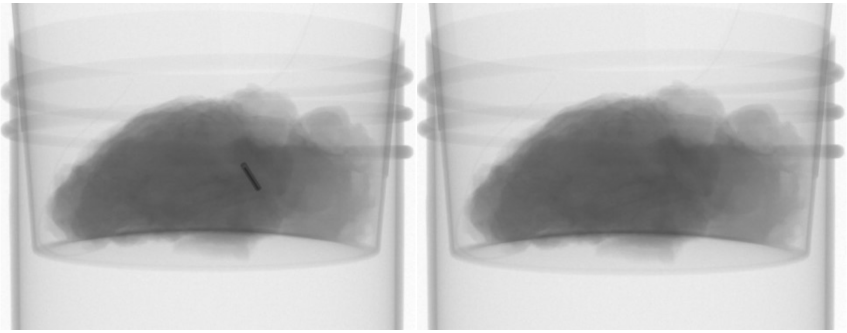

Figure 1: projection image of a sample (±4 cm diameter) containing a radioactive iodine marker (left). The same projection image after digital removal of the iodine seed (right).

In 13 of the 16 samples, the metal implants were adequately segmented. In the remaining samples (with multiple implants) there was some oversampling at regions outside of the implants. After digital removal of the metal implants it was impossible to recognize the original location of the metal implant (Fig. 1 & 3). With metal artefact reduction the implants were almost entirely removed from the reconstruction images (Fig. 2). Depending on the implant type, sometimes only the border of the implant was still visible (Fig. 3), but the main streak artefacts were gone. The implementation was notably slow, ranging from 1.6 seconds per projection image for the smaller implants to 16 seconds for removal of the four surgical clips at the full 1944x1536 resolution.

For one case with one implanted iodine seed the inline reconstruction and metal artefact reduction was combined. The artefact reduction was performed after downsizing the projection images. At a reconstruction cube of 512x512x448 isotropic voxels of 110 µm and a projection image downsize factor 4 it was possible to keep up with image acquisition.

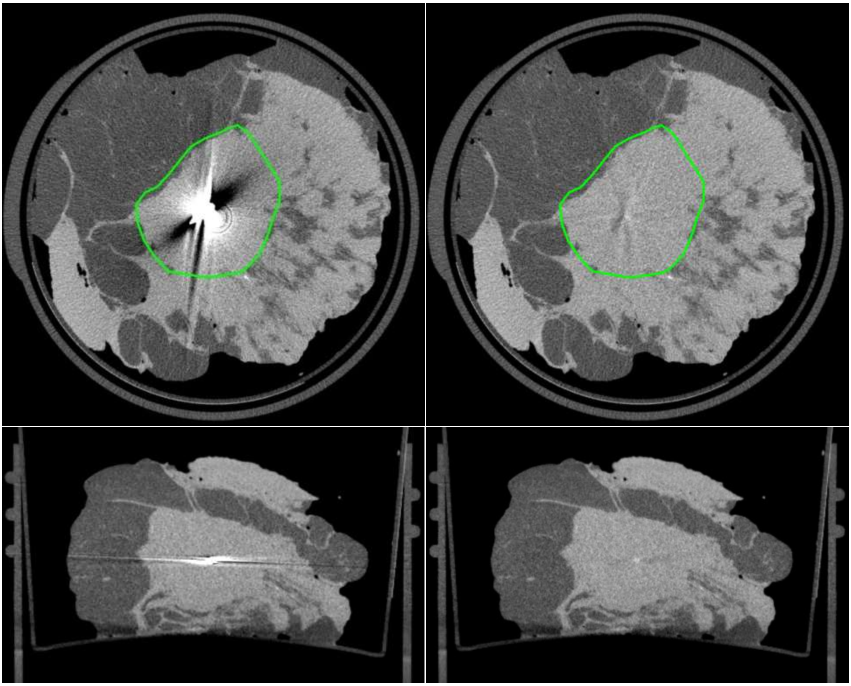

Figure 2: Reconstruction of a lumpectomy specimen scan (same as figure 1) containing a radioactive iodine seed (left), axial view (top) and side view (bottom). The tumour is manually outlined in green. On the right the same reconstruction is provided after digital removal of the iodine seed from the projection images for metal artefact reduction.

Conclusion

With our inline reconstruction it is possible to provide the users with a scan with sufficient resolution several seconds after scan acquisition. The metal artefact reduction fully removes the streak artefacts from the scans, but needs further speed up to perform fast enough at a sufficient resolution. It is now possible to assess the surgical margins on a µCT within 10 minutes, which is clinically acceptable.

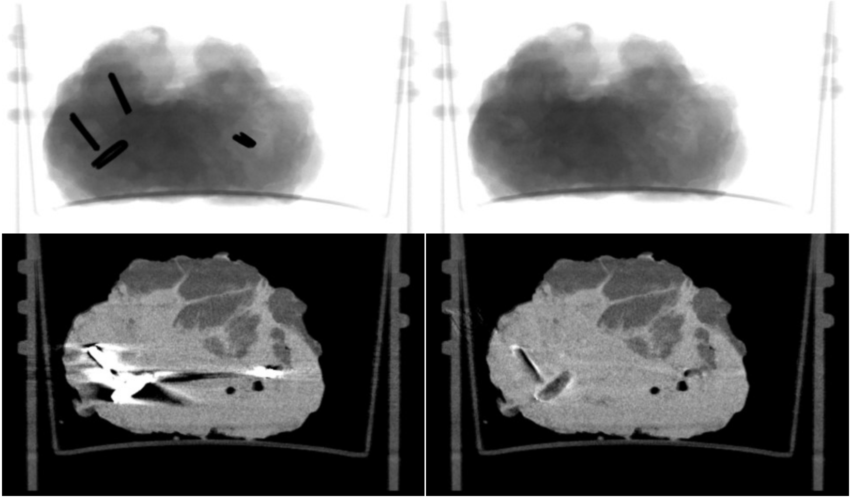

Figure 3: Toprow: projection images of a lumpectomy specimen containing four surgical clips (left) and after digital removal of the metal implants (right). Bottomrow shows a sideview of the corresponding reconstructions. Note that the edges of the surgical clips stay visible, but streak artefacts disappear.

References:

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