Quantitative volumetric assessment of percutaneous image-guided microwave ablations for colorectal liver metastases

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Abstract

Thermal ablations are becoming an increasingly common alternative treatment to surgery in patients with primary and secondary hepatic tumors. In image-guided percutaneous ablations of liver tumors, the technical post-interventional success of ablation treatment is defined by achieving complete tumor destruction and an ablation margin of at least 5 mm. Therefore, it is crucial that proper ablation verification is ensured intra-operatively or immediately post-operatively. In the current setting, the ablation-tumor coverage is visually evaluated by an interventional radiologist who compares the differences between the pre- and post-ablation images. To address this limitation, we have developed an image analysis pipeline consisting of a set of quantitative methods for evaluating the volumetric coverage of the ablation, which could be added to image-guidance systems. In this work, we present the quantitative ablation evaluation method and preliminary results after applying it to a retrospective cohort of 100 patients that were treated with image-guided percutaneous ablations for colorectal liver metastasis.

Keywords: Image-guidance, ablation, liver metastases, computer-assisted, image processing, quantification

1 Problem

Thermal ablation of colorectal liver metastases (CRLM) is a minimally invasive treatment alternative to surgical resection of which is the current gold standard for curative care. Not only is ablation considered for patients not amenable for surgical resection (< 20%), but also increasingly for resectable tumors even with a curative intent. Percutaneous ablation is a minimally invasive technique generally performed under image-guidance based on CT, MRI or ultrasound. Image based navigation leads to a simple, fast and accurate placement of the ablation probe into the liver tumor. The patients undergoing an ablation benefit from a drastically improved quality of life, as they go home the next day rather than staying in the hospital for a week. Despite the advantages provided by an ablation procedure, it has not yet taken over resection due to the local tumor progression (LTP) rates, which in these cases reach up to 48% [1]–[5]. LTP is generally associated with poor survival prognosis. One of the major limitations of this technique is achieving complete coverage of the tumor including a 5 mm margin, which has been shown to decrease the risk of LTP by 46% [1]–[5].

In hepatic resections it is straight-forward to evaluate the resection margin by simply cutting the specimen intra-operatively and even by histological assessment. In contrast to this, the ablated part remains in the liver and can only be visualized by non-invasive imaging like CT or MRI. In the clinical routine, the ablation is visually assessed by the expert eye of the radiologist, by displaying the pre- and post-ablation CT scans side-by-side or by overlaying them on top of each other. The ablation coverage and the margin between the tumor and the ablation is visually estimated and this presents several drawbacks. Firstly, visual assessment is a highly subjective technique which is limited by repeatability. Secondly, this is a 2D approach, where only the maximum and minimum diameter of the ablation zone are estimated. However, the ablation margin should be measured all around the tumor, but this is a challenging and time-consuming task in the 3D space of a CT or MRI image. All in all, these problems introduce large inaccuracies in measuring the ablation coverage and its margin, which might be a risk factor for LTP.

Currently there are very few software platforms available on the market for quantitatively assessing the ablation coverage post-operatively [1], [5], [6]. Unfortunately, the post-operative evaluation excludes the possibility of re-ablation during the same procedure and thus completely eradicating the tumor. More importantly, the sample size of these studies is rather small with a possible inhomogeneous study population [1], [5], [6].

To address the current limitations in the area of quantitative ablation assessment, we developed an image analysis pipeline to quantify the ablation margin with different metrics based on overlap of surface distances. We are currently evaluating these quantitative metrics on a retrospective multi-centric study of 100 patients with CRLM (clinicaltrials.gov: NCT02642185). In this work the image-analysis pipeline and some of the very early results from the multicentric study are presented.

2 Materials and Methods

A customized software for semi-automatic segmentation of tumors and ablations and subsequent quantification has been developed and integrated into a navigation system for percutaneous ablations [7]. The tumor and ablation volumes can be segmented manually or by employing "Fast-Marching" semi-automatic algorithm. The seeding point for the tumor and the ablation volumes are taken from the target point of the ablation probe. The binary masks are then saved as DICOM files along with the other CT scans. The entire analysis pipeline is shown in Figure 1, and based on these segmentations the following radiomics are computed:

a) Surface distance

The surface distance was calculated as the Euclidean distances between each surface voxel of the tumor and ablation volumes, also known as Maurer distance [8]. The calculated distances are displayed in a histogram marking the percentage of surface voxels covered by each range. A traffic light color scheme was applied to the histogram bins to mark the safety margin convention (green > 5mm, orange 0 – 5 mm, red <0 mm).

b) Volume coverage ratio and residual tumor

The volume coverage ratio (VCR) was computed as an adapted DICE coefficient between the tumor and the ablation volume. Additionally, the volume of the residual tumor is computed as the subtraction of the ablation from the tumor volume.

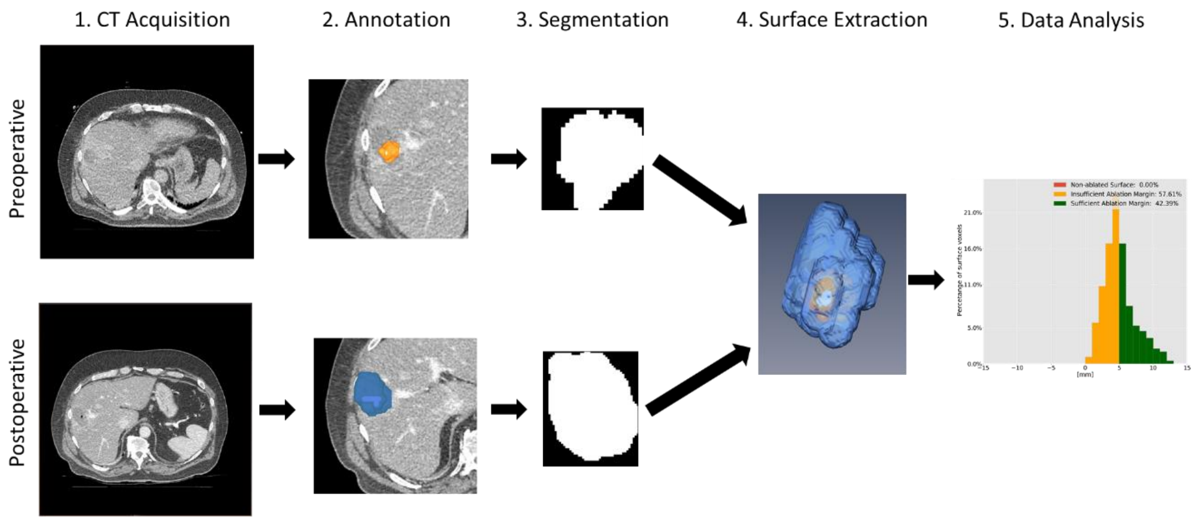

Figure 1 Quantitative ablation evaluation pipeline from acquisition of the pre-/post-operative images to the visualization of the results

2.1 Retrospective evaluation on CRLM cohort

This analysis is part of the MAVERRIC trial (Microwave Ablation Versus Resection for Resectable Colorectal Liver Metastasis) which includes the analysis of the ablation volumes. This trial aims to prove that a strategy of first line local ablation of colorectal liver metastases with microwaves is not inferior to liver resections in terms of survival rates at three years with secondary endpoints being survival at five and ten years. The study included a cohort of 100 patients with tumors < 31 mm in diameter and 1-5 metastases, treated with microwave ablation under CT-image guidance. In this cohort a total of 173 lesions were treated. From each patient, the tumor and the ablation from the interventional CT scans were extracted using a semi-automatic segmentation tool [7]. The segmentations were validated by an experienced radiologist. From these datasets, 65 lesions where excluded due to missing ablation validation scans, which is mainly due to the constraints in applicable contrast agent.

3 Results

Out of the 173 lesions in this study 108 can be included in this analysis pipeline. From 108 lesions eligible for analysis, we have currently analyzed 2 out of 173 (2 patients with a single lesion each). Figure 2 depicts these two examples, consisting of sufficiently (right) and insufficiently (left) volumetric ablation coverage. The histograms show the percentage of distances plotted with respect to the surface voxels covered. The tumor with insufficient margin (left) had an LTP whereas the tumor with sufficient margin (right) had no LTP at 6 months.

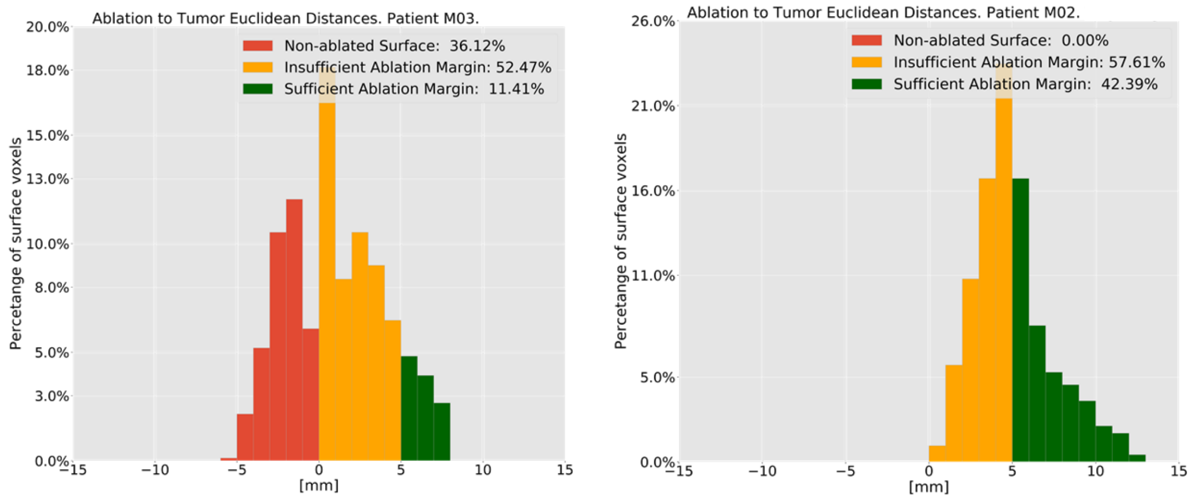

Figure 2: Histograms of the surface distances between the tumor and the ablation volumes

Figure 3 shows a 3D visualization of the volume overlap with the tumor (orange) and the ablation zone (blue). In the image on the left, one can see the residual tumor with a volume of 1.08 ml. That means that the volume coverage ratio [7] is only 31.68% , whereas in the right picture from Figure 3 there is no residual tumor visible.

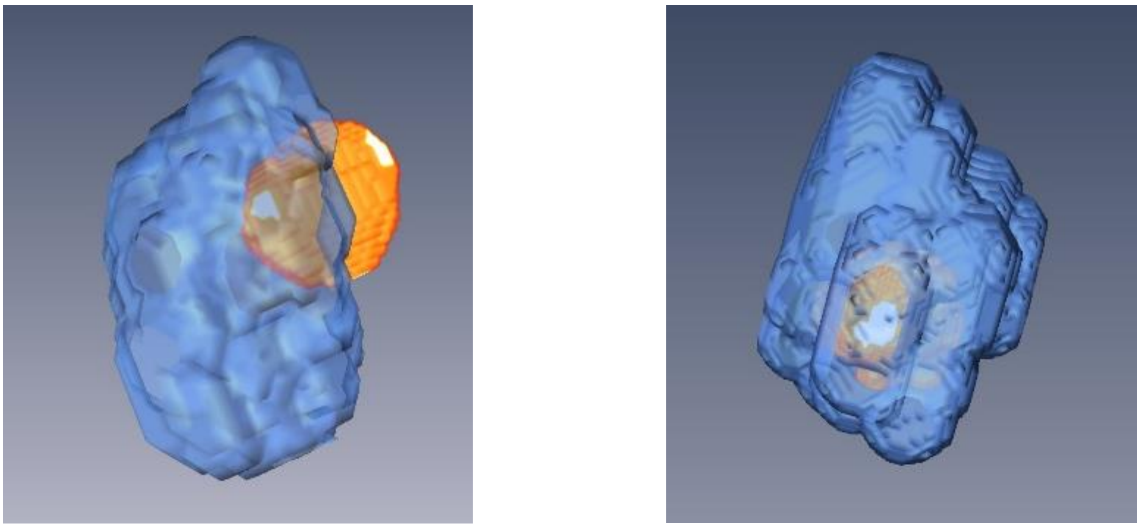

Figure 3: Volumetric representation of residual tumor (corresponding to Figure 2)

4 Discussion

The quantitative evaluation pipeline (Figure 1) for assessing ablation coverage might be a useful tool to provide a quantitative measurement over the entire 3D space. As shown by previous studies it is crucial to cover the tumor with a minimum of 5 mm margin [1]–[5]. Therefore, this tool will be especially useful when applied intra-operatively, so the radiologist can either re-ablate the residual tumor or call the patient for an earlier follow-up.

The ablation margin histograms (Figure 2) reflect the coverage depicted by their 3D model representation. We hypothesize that the percentage of tumor covered within a certain ablation margin could correlate with the local tumor progression rate. To test this hypothesis, we will correlate the results from the ablation metric with the local tumor progression at 6-months and 1-year follow-up for the whole study population once the rest of the follow-up data is available. However, this analysis needs to include more variables than just these radiomics to control for other confounding factors. It is important to note that the results presented here are preliminary and reflect just the first 2 cases that were fully analyzed.

So far, we have identified 108 out of 173 complete datasets that could be analyzed with this method. At this point, some special cases (52 out of 108) had to be excluded from the analysis because the distance metric does not account for them. One case for which we need an adjusted metric is subcapsular lesions, i.e. lesions that are within 5 mm of the border of the liver. These lesions need an adjusted ablation margin metric which considers that lesions close to the surface cannot have a margin larger than 5 mm. Another case where an adjusted metric is needed is when ablation zones from several ablations merge together. The exceptionally large ablation volume created in this instance might skew the ablation margin metrics towards a false positive trend.

Overall, the major advantages of this volumetric quantitative analysis pipeline are its speed, automated steps and most importantly the fact that it has already been integrated into an existing image-guided navigation system. The last point just makes it easier for the method to be deployed intra-operatively, becoming part of the clinical routine if the ablation margin metric is validated and ultimately decreasing the risk of local tumor progression. If we manage to achieve this, there will be a paradigm shift from resection towards ablation as a first line of treatment for liver tumors.

5 Conclusion

To conclude, this work proposes a quantitative ablation evaluation for measuring the coverage of the ablation volumes. The method could enable a precise measurement of ablation margins and volumes that could be utilized to identify patients with increased risk of local tumor progression. Eventually, this method might provide an important intra-operative feedback that would allow precise re-ablations in the same treatment session.

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