Cristina Oyarzun Laura*, Klaus Drechsler, Marius Erdt, Stefan Wesarg, and Reto Bale

Intervention assessment tool for primary tumors in the liver

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Abstract: After a liver tumor intervention the medical doctor has to compare both pre and postoperative CT acquisitions to ensure that all carcinogenic cells are destroyed. A correct assessment of the intervention is of vital importance, since it will reduce the probability of tumor recurrence. Some methods have been proposed to support the medical doctors during the assessment process, however, all of them focus on secondary tumors. In this paper a tool is presented that enables the outcome validation for both primary and secondary tumors. Therefore, a multiphase registration (preoperative arterial and portal phases) followed by a registration between the pre and postoperative CT images is carried out. The first registration is in charge of the primary tumors that are only visible in the arterial phase. The secondary tumors will be incorporated in the second registration step. Finally, the part of the tumor that was not covered by the necrosis is quantified and visualized. The method has been tested in 9 patients, with an average registration error of 1.41 mm.

Keywords: Outcome validation, intervention assessment, liver, tumor, registration, matching.

1 Introduction

Tumor recurrence is together with the difficulties for early diagnosis one of the main reasons for the high mortality rate of liver cancer. Thus, a proper outcome validation of the intervention is of vital importance. Medical doctors do not have proper tools to support them during assessment after intervention. Their only help to ensure the success of the intervention are the preoperative and postoperative CT images that are visualized side by side. Unfortunately, the livers in both images will differ due to deformations and it is hard to determine this way if the RF ablation covered the complete area of interest or not. Thus, it is difficult for them to determine whether the intervention was successful or if certain carcinogenic cells are still present. In up to 58% of the cases there exists an uncertainty to decide if the tumor was completely ablated or not [1].

The basis for an assessment tool that can support them during that process is the registration of the preoperative and postoperative images. Several methods have been proposed that deal with this problem. Some groups choose rigid registration for this purposes in a manual [2], semiautomatic [3], or automatic [4] manner. However, the liver is composed of soft tissue and will be subject to high deformations due to breathing and intervention. Thus, other groups have presented deformable registration methods to increase the registration accuracy using internal landmarks [5], surface [6] landmarks or a combination of both [1].

With the help of these registration methods assessment tools can be developed. Rieder et al. [7] base their tool in a manual registration technique and visualize the surface of the tumor using a traffic light color scheme according to its distance to the necrosis. Passera et al. [8] on the other side enhance their assessment tool with quantitative measures and deformable registration. In a previous paper we proposed to visualize the tumor, the necrosis and the safety margins with different colors [1].

The aforementioned methods permit the assessment of interventions for tumors that are visible in the portal phase (secondary tumors). Unfortunately, there exist tumors, namely, primary tumors and in concrete hepatocellular carcinomas, that are often only visible in the arterial phase. In this paper we propose an intervention assessment tool that can handle both types of tumors. Therefore, the tumors that are visible in the arterial phase will be segmented and registered to both the preoperative and the postoperative portal phases.

2 Methods

The workflow for the assessment of liver interventions presented in this paper is shown in Figure 1. In theory, one could directly register the preoperative arterial phase with the postoperative one. However, the goal is to be able to assess the intervention on both primary and secondary tumors. Therefore, a two-step registration method is needed. First, the primary tumors that are uniquely visible in the arterial phase, have to
be registered to the preoperative portal phase. To this end, the multiphase deformable registration proposed by Erdt et al. [9] has been used. Based on automatically segmented liver surfaces this method starts with a coarse landmark based registration followed by a Demons based registration. Once the registration is done, all visible primary tumors are segmented using belief propagation [10]. The next step, namely the registration of pre and postoperative portal phase images has two advantages. On the one side, this intermediate step allows the assessment of interventions on secondary tumors as well (tumors that are visible in the portal phase). Note that at this point all tumors are registered, as the primary tumors were previously transformed to fit the preoperative portal phase. From this point onward they can all be treated likewise and the transformation to register the preoperative and postoperative portal phases can be applied to all of them. On the other side, in the portal phase the liver vasculature is visible. This information can be used to carry out a more accurate registration which is the basis for a trustful assessment tool. In order to do this, the liver and its vasculature have to be previously segmented. The Pre/Post Registration (see Figure 1) is carried out as follows:

1. **Secondary tumor/necrosis segmentation.** Liver segmentation is specially error prone when the tumor/necrosis is next to its surface. It has been shown in [11] that the liver segmentation results can improve if the tumor/necrosis is previously segmented and the intensities of the corresponding voxels in the CT image are internally exchanged with intensities that correspond to healthy tissue. Thus, secondary tumors/necrosis are segmented before the liver segmentation takes place. To this end, the same interactive belief propagation approach mentioned before is used.

2. **Liver segmentation.** The liver is segmented in both pre and postoperative portal phases using a model based approach [12].

3. **Vessel segmentation.** The vascular tree is segmented in both pre and postoperative datasets as well. The resulting vascular trees are further separated into their portal and hepatic veins [13].

4. **Tree matching.** After separation of both vascular trees correspondences (internal landmarks) between the preoperative and the postoperative vessel trees are detected using the learning-based tree matching and statistical outlier detection presented in [1].

5. **Registration.** The final registration is a simplified version of the one presented in [1]. Thin plate splines are used to register both CT images using the detected internal landmarks. Then, the already matched reference points (internal landmarks) are fixed and new landmarks are detected at the liver surfaces in a closest point manner. Then, a new thin plate spline iteration takes place to refine the results of the registration in areas closer to the surface where not so many internal landmarks are present.

The transformation that registers the preoperative and postoperative portal phases is calculated. This transformation is used to carry out the final transformation on the primary and secondary tumors, which are finally the input for the assessment tool. For the assessment the medical doctor is provided with a visualization and some quantitative measures. The contour of the primary tumor that was previously segmented from the preoperative arterial phase and registered to the postoperative portal phase is visualized over the postoperative CT as shown in Figure 2 (top left). This way the medical doctor has a way
to directly compare the tumor and the necrosis. Similarly to Rieder et al. [7], a traffic light color code is used to assess the outcome of the surgery. Note that the necrosis has already been segmented (step 1 of the Pre/Post registration) and distances between tumor and necrosis are therefore easy to calculate. The areas of the tumor that are not covered by the necrosis are visualized in red. The areas that are covered but do not respect the safety margin between tumor and necrosis are visualized in yellow. Those areas that are covered keeping a distance of at least the safety margin with the necrosis are visualized in green. To further allow clinical studies in the future the percentage of tumor surface that keeps a certain distance with the necrosis is calculated. Distances range from 0 mm to 10 mm (optimal safety margin in most of the cases) in 1 mm steps (lower graphic Figure 2).

3 Results

The method has been evaluated in sets of preoperative arterial and portal phases and their corresponding postoperative portal phase of 9 patients. Since the accuracy of the assessment tool is given by the accuracy of the registration the two registration steps have to be evaluated. The multiphase registration was previously evaluated on [9]. For the evaluation of the pre/postoperative portal phase registration a set of internal landmarks are manually selected. Therefore, the vascular tree of the registered image is segmented. Both preoperative registered and postoperative vascular trees are visualized (see Figure 3) and as many correspondences as possible are manually selected. The registration error for each patient is then given as the average Euclidean distance between corresponding points. An average distance of 1.41 mm has been detected following that evaluation method. The worst and best results were 2.3 mm and 0.99 mm respectively.

4 Conclusion

In this paper an assessment tool for liver tumor interventions is presented. The idea behind it is the ability to assess not only secondary tumors, but also primary tumors that are only visible in the arterial phase. Thus, a registration between preoperative arterial phase and postoperative portal phases is needed. We present a two-step registration method. With a Demons based multiphase registration we register both preoperative acquisitions, then we calculate the transformation that registers the pre and postoperative portal phases and use it to transform the primary (and also secondary) tumors. Finally, the medical doctor can visually and quantitatively assess the outcome of the intervention.

Author Statement

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