# Precise Determination of Regions of Interest for Hepatic RFA Planning

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**Abstract.** Percutaneous radiofrequency ablation is a minimally invasive therapy for the treatment of liver tumors that consists in a destruction of tumors by heat. A correct insertion and placement of the needle inside the tumor is critical and conditions the success of the operation. We are developing a software that uses patients data to help the physician plan the operation. In this context, we propose a method that computes automatically, quickly and accurately the areas on the skin that provide a safe access to the tumor. The borders of the 3D mesh representing insertion areas are refined for a higher precision. Resulting zones are then used to restrict the research domain of the optimization process, and are visualized on the reconstructed patient as an indication for the physician.

**Keywords.** minimally invasive surgery, preoperative planning

## Introduction

At present, open surgery is still the main curative treatment for liver cancer. However liver resection is a painful operation that is not always possible due to the patient's condition, multiple tumor location or insufficient hepatic reserve. Several minimal invasive procedures has been recently developed in order to treat patients that are not good candidates for surgery. These techniques are based on the local destruction of tumors either by temperature (radiofrequency ablation, cryoablation, focused ultrasound) or by the effects of chemical agents (ethanol injection). In this work we focus on percutaneous radiofrequency ablation (RFA) that offers a low rate of local recurrence (*i.e.* no tumor is found at the original site during the follow-up) and complications [3].

RFA consists in inserting through the patient's skin a RF-needle that heats tissues until destruction. The radiologist places his needle in the tumor in order to kill cancerous cells and a surrounding 1cm safe margin. Because of the limited visibility during this kind of operation (needle placement is generally guided by CT or US images), preoperative planning takes an important place in the success of the therapy. The physician has to choose a needle path that allows a safe access to the tumor and a secure ablation relying on 2D-slices of the patient obtained by CT-scan. Planning from 2D slices is not really intuitive and requires a long learning process. As advances in medical image processing

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allow to rapidly reconstruct a virtual 3D model of the patient from CT-scan slices [8], we are developing a planning software based on the visualization of such 3D-reconstructed patients that would assist the physician in his decision. Our work is organized in 3 axis:

- Integration of constraints and rules governing RFA planning: strategies may vary from a specialist to another, however we have extracted recurrent information from their expertise and from medical literature [5,6] to define constraints included in the software.
- Resolution of the geometric problem corresponding to the previously specified constraints.
- Display facilities to browse the solution space: the physician may need to have access to various information concerning the different possible strategies.

We focus here on the second axis that is divided in two parts: firstly the determination of all solutions and secondly the choice of the optimal one. In this paper, we detail the method we developped for a fast computation of all needle trajectories that are technically feasible for each operation. The determination of an optimal trajectory among them is presented in [9]. Firstly, we briefly expose the approaches proposed in other studies concerning computer-aided planning of minimal invasive interventions. Then, we explain on which criteria we define a needle trajectory as being valid and we detail our method that computes with precision possible insertion zones on the skin, providing a safe access to the tumor. Finally we present and comment our results on several virtual patients.

## 1. Previous works

Various works have been recently published on computer assisted planning of different minimally invasive techniques, aiming at guiding the physician's decision. The problem of optimizing surgical tool placement has being addressed in a few studies. Optimizations have been performed regarding different criteria according to the therapy. In the case of thermal ablation, the different studies focus on minimizing damages to healthy tissues while killing the whole tumor [2,4]. Concerning robotically assisted heart intervention, the important criteria mainly concern distance between tools and angle between tools and patient [1,7]. In both cases, some trajectories could be immediately rejected for different reasons independent of the optimization criteria. For example the tools cannot cross bones in any case, the tools must be long enough to reach the surgical site or in case of the insertion of an endoscope, the surgical site must belong to the field of vision. These cases have to be taken into account otherwise there is no guarantee that the proposed optimized solution will be valid. In most of the studies this problem is avoided by the physician's intervention. The optimization is restricted within a limited number of solutions or an authorized access window that are provided by the surgeon and considered as valid. In one study [1], the set of insertion points proposed by the physician is controlled and insertion points that correspond to an intersection with an organ are eliminated.

While some studies propose an exhaustive examination of a limited number of possibilities preselected by the physician, our approach consist in an automatic selection of pertinent trajectories among the whole solution space. In a previous article [10] we presented a first approach that consisted in integrating the elimination of trajectories crossing vital organs in the optimization process. The optimization function was artificially modified by adding a huge penalty to these trajectories that were naturally avoided by the optimization process. However this method introduced artificial local minima in the optimization function, therefore we developed another approach consisting in computing an authorized insertion zone before the optimization step.

## 2. Objective

This study aims at designing and implementing a method that automatically computes possible trajectories for each operation. We must then define what we consider as a possible trajectory. A trajectory can be regarded as a possible choice if it satisfies all the required conditions for an operation. At this time, several constraints governing RFA planning have been identified thanks to bibliography and interviews with specialists. Among these constraints, some are strict constraints that define the validity of a trajectory, others are soft constraints that have to be optimized and combined with an appropriate weighting. In this paper, we focus on the processing of stricts constraints, that are directly involved in the determination of the feasible trajectories, as soft constraints only provide information on their quality. Among these strict constraints, we selected the two most obvious ones. Firstly the insertion depth has to be below the needle size. Secondly a valid trajectory cannot cross neither bones, large vessels nor surrounding vital organs. Nevertheless, our method could easily be adapted to additional strict constraints. For example, the physician could consider that a trajectory approaching a vital organ with less than 1 cm is not a possibility.

In order to precisely define the possible trajectories, we chose to determine what are the possible insertion points on the skin. Then the possible strategies are materialized by a simple area on the skin's mesh that is easily visualized. To each trajectory corresponds one insertion point, if it belongs to the possible insertion zone then the trajectory is valid. To each insertion point corresponds a set of trajectories and among them a few are pertinent. A trajectory can be viewed as pertinent if the target point belongs the tumor for example. Then an insertion point is accepted in the possible insertion zone if all the corresponding pertinent trajectories verify the constraints.

## 3. Method

We want then to determine precisely all the points of the skin that correspond to valid trajectories. A needle trajectory is considered as a valid solution if the needle passes through the skin and does not cross any organ. The initial possible trajectories are materialized by the surface mesh of the patient's skin. Triangles are progressively eliminated as the corresponding trajectories are declared not satisfactory regarding the previously specified conditions. Our algorithm could be summarized in:

**Input :**
$L = list\ of\ skin's\ triangles,$
$O = center\ of\ the\ tumor's\ bounding\ box,$
$E = set\ of\ organs\ to\ avoid$
**Output :**
$L = list\ of\ eligible\ triangles$

```
// Elimination of insertion points that are too far from the tumor
For each triangle t in L
    If distAboveNeedleLength(O, t)
        eraseFrom(L, t)
    Else if distPartlyAboveNeedleLength(O, t)
        eraseFrom(L, t) and subdivide(t, L)

// Elimination of insertion points that don't provide an access to the tumor
For each voxel v in tumor's border
    s = renderScene(v, E)
    For each triangle t in L
        If hiddenFrom(s, t)
            eraseFrom(L, t)
        Else if partlyHiddenFrom(s, t)
            eraseFrom(L, t) and subdivide(t, L)
```

The two parts of the algorithm resolve respectively our two constraints and follow the same principle: a triangle that does not respect the constraint is definitely eliminated. A triangle that partly fulfills a constraint is subdivided in four subtriangles that replace it and will be evaluated separately. Other triangles are kept in the possible insertion zone and will be evaluated regarding the other constraints. Finally the possible insertion zone only contains triangles that satisfy all the constraints. Other constraints could be added easily in this algorithm, assuming that it is possible to determine quickly if a needle insertion in a triangle fulfill the constraint in all the cases, in some cases or in no case.

Concerning our first constraint, the validity of an insertion triangle is determined by computing the distance between the center of the tumor's bounding box and the three corners of the triangle. The determination of the validity according to the second constraint requires a more complete verification. We chose to check the constraint not only for trajectories targeting the tumor's center but for an access to the whole tumor. It is important for this constraint that a light displacement from the trajectory does not compromise the validity of the trajectory. The test is then executed while targeting each voxel of the tumor's border. Our accessibility problem can be considered as a visibility problem. If a triangle is completely visible from the target point that means that no obstacle is on the way between any point of the triangle and the target. From a position, the visibility (partial visibility, total visibility or invisibility) of all candidate triangles can be determined by observing six renderings of the scene, each corresponding to a face of a virtual cube placed around the target position. More details can be found in [9] where we presented a first version of our computation of insertion zones.

The subdivision of border triangles results in the loss of neighbourhood information. However, in our context this kind of information is not necessary as we use the mesh of the insertion zone only to test if trajectories cross it. The subdivision of the triangles allows to compute precisely the insertion zone independently of the precision of the initial mesh of the skin. The maximum authorized subdivision level determines the precision of the borders of the insertion zone. Above this maximum subdivision level or below a significant size limit, triangles that do not completely fulfill a constraint are dismissed without subdivision. A reduced number of subdivisions enables to compute the insertion zone with a satisfying precision. We will detail our results in the next section.

## 4. Results

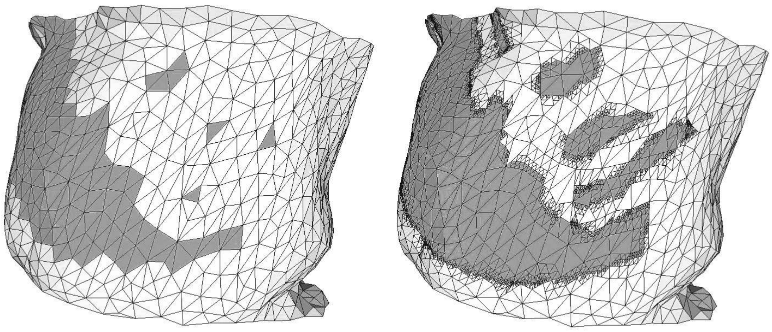

**Figure 1.** Insertion zones with 0 and 3 subdivision levels

Insertion zones have been computed for 15 tumors in 7 virtually reconstructed patients (represented in tab.1). The surfaces of zones are variable (10-300 $cm^2$) since tumors are more or less accessible. Although computing zones without triangles subdivisions provides a good idea of possible strategies, it discards many possible insertion points. The average surface loss between computations with 3 and no subdivision is 45% and often more important when the insertion zone is small. By observing fig. 1 we notice that the biggest zone is well represented in both cases while thin zones representing an insertion between ribs are almost occulted in the case of a computation without subdivisions. Computation with 3 subdivision levels provides insertion zones with a good precision in 4 seconds to 2 minutes (average: 30s) that represents 230% of the computation time without sudivision. With more subdivision levels, the resulting surface does not differ significantly from the zone computed with only 3 levels while taking much more time (140% of the time with 3 subdivisions). At a same subdivision level, the computation time can vary between tumors, that mainly depends on the number of tumor's voxels (150-13000) since it determines the number of time the visibility tests have to be done.

## 5. Conclusion

In this paper, we presented a method for computing automatically possible insertion zones on the skin for the planning of a radiofrequency ablation. Any needle insertion in this zone respects two constraints : it does not cross any vital organs, bone or large vessel and the needle can reach the tumor from the corresponding insertion point on the skin. Our method based on elimination and subdivision of triangles of the skin that do not respect the constraints quickly produces possible insertion zones on the skin with high precision. These zones are used in our patient-specific preoperative planning software to reduce the research domain for the optimization stage and provide valuable information to the physician who can easily see all possibilities for each operation.

**Table 1.** Surface of insertion zones and computation time for 15 tumors in 7 patients

| case | surf. of insert. zones ($cm^2$) | | | computation time (s) | | |
|---|---|---|---|---|---|---|
| | no subd. | 3 subd. | 4 subd. | no subd. | 3 subd. | 4 subd. |
| 1 | 3 | 18 | 18 | 50 | 115 | 150 |
| 2 | 174 | 219 | 219 | 13 | 41 | 54 |
| 3 | 97 | 122 | 122 | 12 | 27 | 31 |
| 4 | 51 | 87 | 87 | 8 | 20 | 25 |
| 5 | 79 | 126 | 126 | 9 | 27 | 35 |
| 6 | 39 | 106 | 106 | 5 | 22 | 32 |
| 7 | 224 | 301 | 301 | 31 | 75 | 119 |
| 8 | 43 | 85 | 85 | 25 | 55 | 88 |
| 9 | 74 | 148 | 148 | 9 | 21 | 36 |
| 10 | 238 | 258 | 258 | 4 | 7 | 10 |
| 11 | 156 | 205 | 205 | 16 | 15 | 20 |
| 12 | 71 | 154 | 155 | 3 | 8 | 17 |
| 13 | 47 | 129 | 129 | 3 | 6 | 12 |
| 14 | 266 | 360 | 360 | 3 | 6 | 7 |
| 15 | 0 | 11 | 11 | 2 | 4 | 7 |


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