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Needle deflection in thermal ablation procedures of liver tumors: A CT image analysis

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ABSTRACT

Introduction: Accurate needle placement is crucial in image-guided needle interventions. A targeting error may be introduced due to undesired needle deflection upon insertion through tissue, caused by e.g. patient breathing, tissue heterogeneity, or asymmetric needle tip geometries. This paper aims to quantify needle deflection in thermal ablation procedures of liver tumors by means of a CT image analysis.

Methods: Needle selection was done by using all clinical CT data that were made during thermal ablation procedures of the liver, ranging from 2008-2016, in the Erasmus MC, the Netherlands. The 3D needle shape was reconstructed for all selected insertions using manual segmentation. Subsequently, a straight line was computed between the entry point of the needle into the body and the needle tip. The maximal perpendicular distance between this straight line and the actual needle was used to calculate needle deflection.

Results: In total, 365 needles were included in the analysis ranging from 14G to 17G in diameter. Average needle insertion depth was 95mm (range: 32 mm – 182 mm). Needle deflection was on average 1.3 mm (range: 0.0 mm – 6.5 mm). 54% of the needles (n=196) had a needle deflection of more than one millimeter, whereas 7% of the needles (n=25) showed a large needle deflection of more than three millimeters.

Conclusions: Needle deflection in interventional radiology occurs in more than half of the needle insertions. Therefore, deflection should be taken into account when performing procedures and when defining design requirements for novel needles. Further, needle insertion models need to be developed that account for needle deflection.

Keywords: : bending, deflection, interventional radiology, MW, needles, RFA, thermal ablation

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1. INTRODUCTION

Liver cancer is the sixth most common cancer and the second most common cause of death from cancer worldwide [1]. Radiofrequency (RF) and microwave (MW) ablation of the liver are treatment options for liver tumors when resection cannot be performed [2]. During this radiologic intervention, an electrode needle is placed into the liver to destroy the tumor by means of thermal energy. Accurate placement of the needle is important during these procedures, as inaccurate needle placement can result in decreased treatment efficiency and/or a prolonged procedure time due to an increased number of needle insertions.

Inaccurate placement of the needle tip during medical procedures, also known as needle-targeting error, is defined as the difference between the end-position of the needle and its intended position inside the patient's body. Abolhassani [3] previously summarized, in an extensive review on needle insertions into soft tissue, that such a targeting error may be caused by imaging limitations, image misalignments, human errors, target movement and needle deflection.

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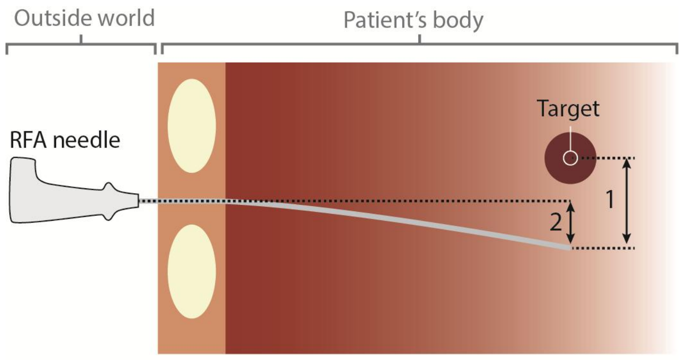

Fig. 1 Total needle targeting error and needle deflection. Needle deflection is the bending of the needle inside the patient's body and is one of the parameters that contributes to the total needle targeting error.

The focus of this study is on needle deflection, which is shown in *Fig. 1*. Needle deflection is the deviation of the needle from its suspected straight insertion path. In other words; it is the bending of the needle inside the patient's body. This can be caused by multiple parameters, such as: patient's breathing, tissue heterogeneity, and asymmetric needle tip geometries. These parameters may cause an unequal force distribution along the shaft and/or tip of the instrument upon, or, in the specific case of breathing motion, also after needle insertion. The magnitude of needle deflection in current clinical radiologic interventions is unknown. Therefore, in the current paper, we aim to quantify needle deflection in thermal ablation procedures of the liver, by means of a CT image analysis.

2. METHODS

2.1 Needle selection

The needles used in the present study were retrieved from CT images made during radiofrequency ablation and microwave ablation procedures of the liver in the Erasmus MC of Rotterdam, the Netherlands, ranging from 2008 to 2016. All potentially relevant patient-IDs were identified from the Picture Archiving and Communication System (PACS) using the queries "RFA", "MW", "ablation", or "microwave" and were reviewed for the presence of CT images visualizing a needle. All CT data were anonymized upon extraction from the PACS system. The medical research ethics committee of the Erasmus University MC approved that the Medical Research Involving Human Subjects Act does not apply to this study and that no informed consent was required according to the local directives for retrospective studies (MEC-2015-414).

Computed tomography is frequently used when ultrasound appears to be insufficient in visualizing the tumor and surrounding structures. Often, multiple CT stacks are made during a thermal ablation procedure, depending on the need during the intervention. For example, CT scans can be made before the ablation starts and after the ablation to verify the needle tip position and ablation zone. One CT set of a procedure could involve multiple treated lesions, and thus multiple CT stacks that contain needles. Therefore, we systematically screened all patient scans for individual needles to be included in the analysis.

2.2 Needle shape reconstruction

Needle shape reconstruction was done with the axial plane CT images. The orientation of the needle with respect to these axial CT slices can either be parallel, perpendicular or oblique, as shown in *Fig 2*. In case of a parallel needle orientation, the needle is visible on one single axial CT slice. In case of a perpendicular oriented needle, the needle appears as a bright dot on multiple axial CT images.

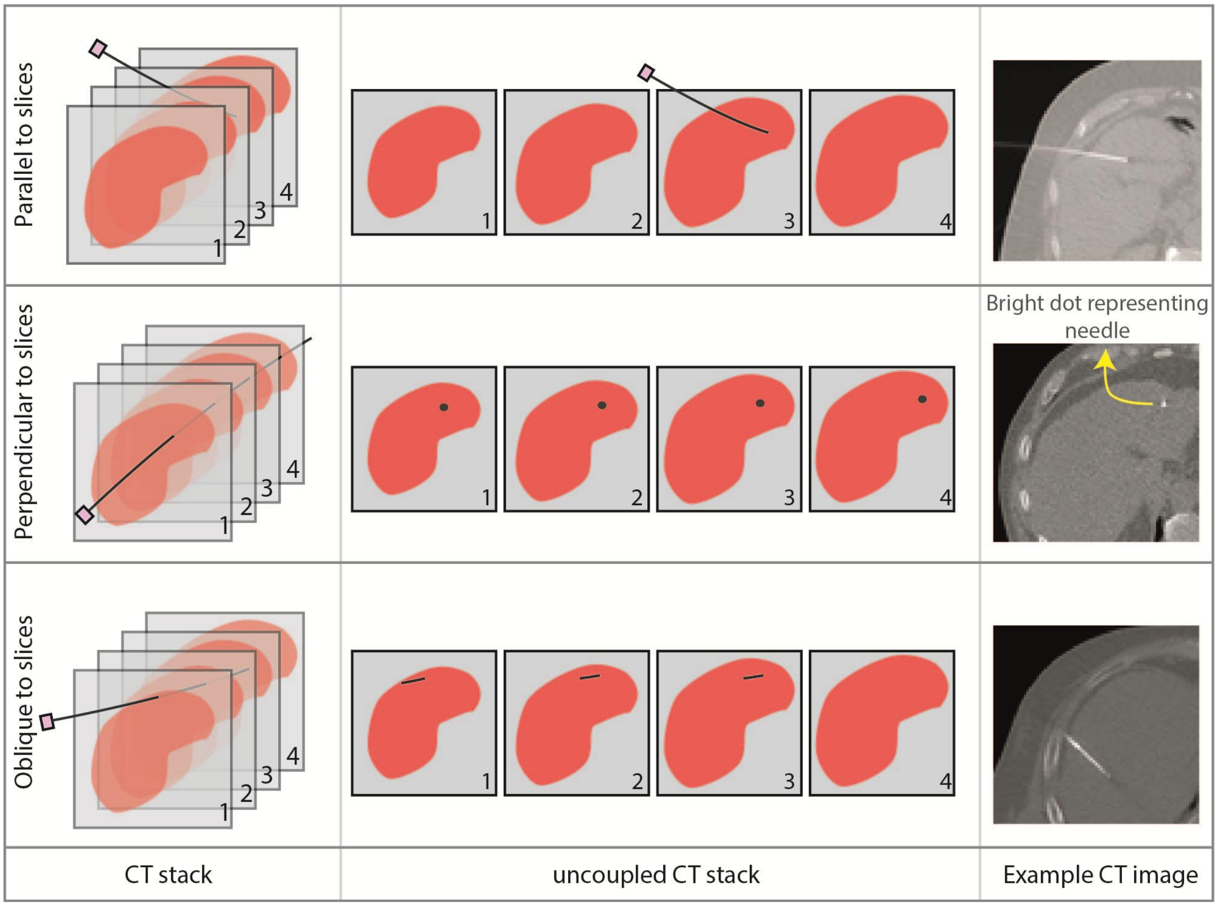

Fig. 2 Needle orientations with respect to the axial CT slices. The needle can either be projected parallel, perpendicular, or oblique.

Needle shape reconstruction was done using MeVisLab 2.7, a modular framework for image processing research and development, by making use of the Contour Segmentation Objects (CSO) library. Manual segmentation was chosen as it is still considered the gold standard in research and clinical practice over (semi)automatic segmentation [4]. The reconstruction method was dependent on the orientation of the needle with respect to the CT slices. In case of the parallel oriented needles, MeVisLab's CSOFreehandprocessor open spline module was used. Several seed points were manually placed following the needle shape. In case of the perpendicular and oblique needles, a point was placed in the middle of the bright shape visualizing that specific part of the needle. This was repeated for all slices that presented a bright shape. We started segmentation at the entry point of the needle inside the patient's body and ended at the needle tip.

The XYZ coordinates representing the needle shapes were stored in text files for further analysis, with X and Y being respectively the horizontal and vertical position on the CT slices, and Z being the depth of the CT slice with respect to the whole stack, all in millimeters.

2.3 Needle deflection quantification method

Quantification of needle deflection was done using MATLAB 2016b and shown in *Fig. 3*. All needle coordinates were loaded, after which smoothing and spline interpolation were applied, respectively. Ideally, the contribution of needle deflection to the total needle targeting error would be calculated, as illustrated in *Fig. 1*. However, extrapolation of a straight part of the needle was not always possible, due to the fact that there was not an existing straight part close to the needle entry point to extrapolate from. Therefore, a straight line was computed between the entry point of the needle into the body and needle tip. The maximal perpendicular distance in millimeters between this straight line and the actual needle was used as a measure to quantify needle deflection.

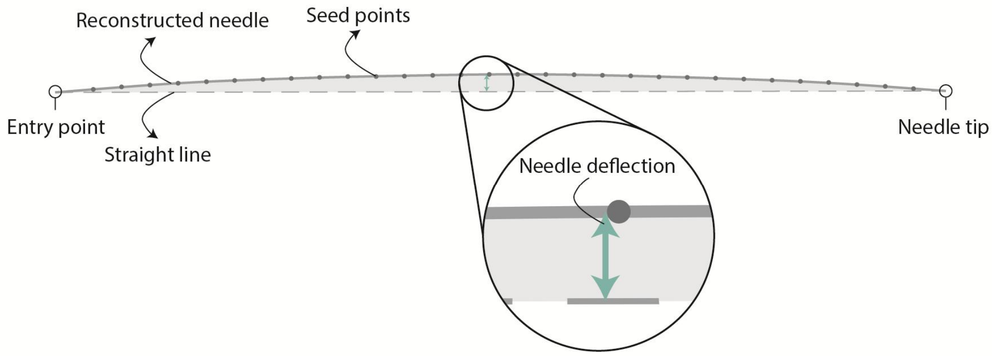

Fig. 3 Quantification of needle deflection. Needle deflection was defined as the maximal perpendicular distance between the reconstructed needle and a straight line interpolated between needle entry point and needle tip.

3. RESULTS

The initial search in the PACS system resulted in 1749 potential relevant patient IDs, of which 1435 were excluded because no thermal ablation of the liver was performed, the records did not contain medical images, or no needles were captured on any of the images. The remaining 314 patient records were screened for the presence of at least one needle on a CT image. Patients (n=15) were excluded as the needle was only captured on a 2D topogram, and not on CT images. Subsequently, the remaining 299 patients were screened for individual needles. The resulting 403 needles were checked for completeness of the needle visualization, i.e. from the entry point of the patient's body up to needle tip, due to which 34 needles were excluded from the analysis. Finally, four extra needles were excluded because of several

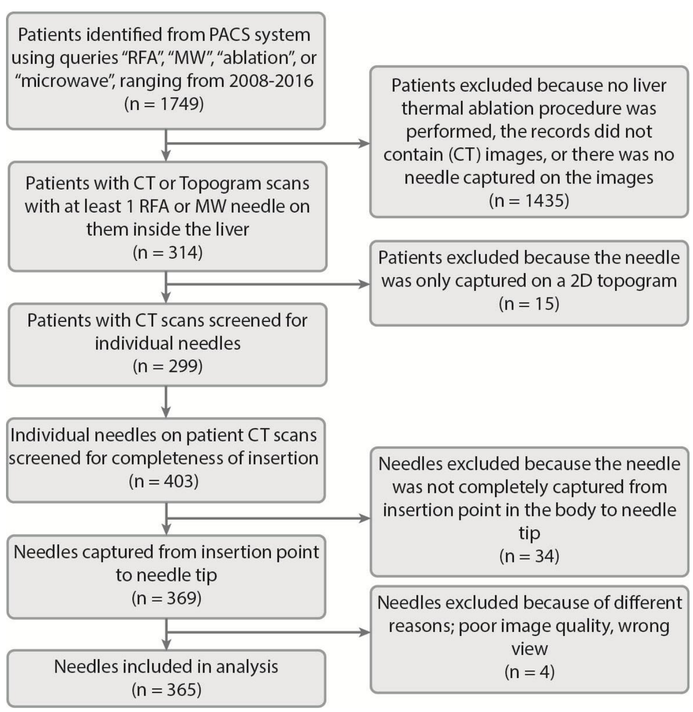

Fig. 4 Flow diagram of the systematic needle selection procedure for analysis

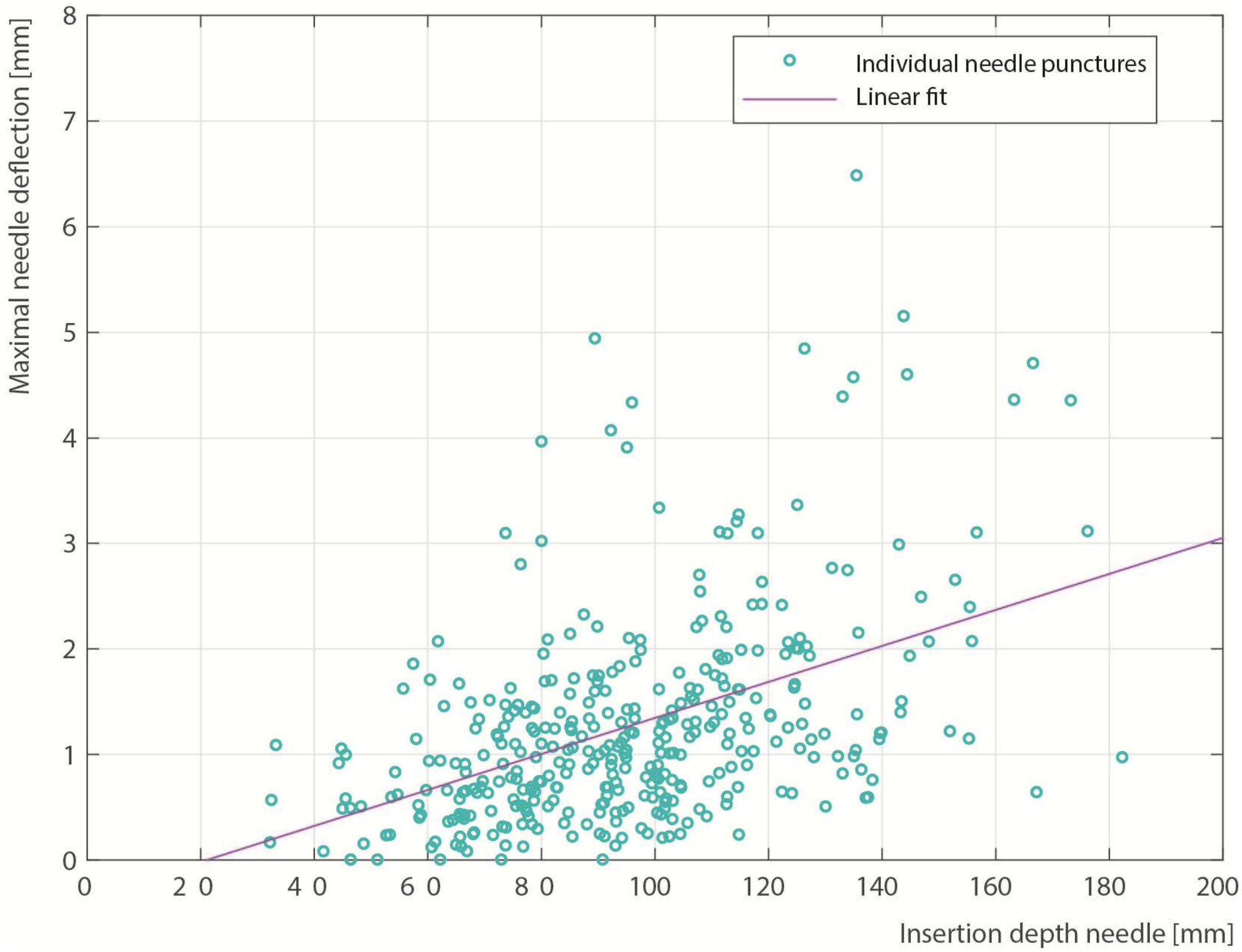

Fig. 5 Scatterplot of the maximal needle deflection of 365 needle insertions during thermal ablation procedures of liver tumors

reasons, such as poor image quality and sagittal capture instead of axial capture. This resulted in 365 individual needles that were included in the needle deflection analysis. *Fig. 4* summarizes the systematic needle selection procedure for analysis in a flow diagram.

The analysed needles were either 14G or 17G in diameter. The pixel resolution of the scans varied from 0.4mm to 1mm, whereas the slice thickness ranged from 0.8mm to 6mm. The kernel types that were used to scan ranged from B10f to B31f, i.e. body kernels with smooth images, good contrast detail and low noise level.

A scatterplot of the maximal needle deflection for all insertions with respect to needle insertion depth is shown in *Fig. 5* (n=365). Overall, needle deflection tends to increase with insertion depth, as indicated by the positive slope of the linear least squares fit on the figure. The variability in needle deflection increases with increased insertion depth (i.e. heteroscedasticity). On average, the insertion depth was 95mm, ranging from 32 mm to 182 mm. Needle deflection was on average 1.3 mm, ranging from 0.0 mm to 6.5 mm. In total, 54% of the needles (n=196) had a needle deflection of more than 1mm, whereas 7% of the needles (n=25) showed a needle deflection of more than 3 mm.

4. NEW OR BREAKTHROUGH WORK TO BE PRESENTED

Despite technological improvements in novel needle design, such as miniaturized steering mechanisms [5] and MRI compatibility [6], a number of clinical questions have remained regarding improved needles for interventional radiology. As a consequence, setting up relevant clinical design requirements for these needles is a challenge. The current work aimed to address one of the clinical questions: is undesired needle deflection an important factor in needle placement in interventional radiology, and what is its magnitude? This is the first time to the authors' knowledge, that needle deflection has been quantified using a large number of needle insertions in a clinical procedure.

5. DISCUSSION AND CONCLUSIONS

Improving needle placement in interventional radiology can be achieved by different means. Examples are: better imaging equipment, improved training, and innovations in needle design. Currently, innovative needle designs focus on the steerability of needles, either manually or robotically inserted, aiming to steer towards a hard-to-reach target and possibly to avoid anatomical obstacles (e.g. [7-9]).

The present study however, found that needle deflection occurs in over half of the insertions (i.e. needle deflection > 1mm) during thermal ablation procedures of the liver, and is therefore an important parameter that contributes to the total placement error. Whereas a focus exists on actively steering around anatomical obstacles in current needle steering and modeling developments, the findings of the present study suggest that compensating for undesired needle deflection during straight insertion is also of importance. In other words: undesired needle deflection upon insertion should be taken into account, both when designing novel needles, as well as when developing steering algorithms for needle insertion systems and/or path planners, with the ultimate goal to improve needle placement accuracy and precision in interventional radiology.

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The current work has not been submitted for publication or presentation elsewhere.