Computer Assisted Planning And Image-guided Robotics In CT-guided Interventional Procedures

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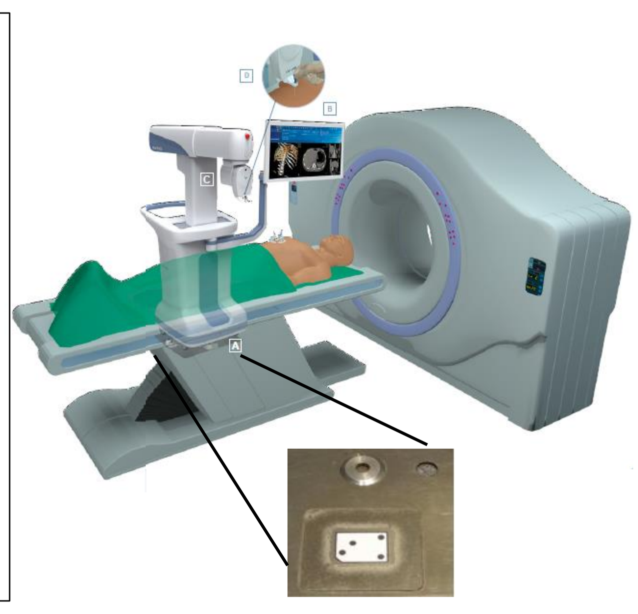
Introduction

MAXIO™ is a user controlled, stereotactic accessory intended to assist in the planning and manual advancement of one or more instruments during CT-guided percutaneous procedures such such as ablation, biopsy, drainage, FNAC and pain management. MAXIO's workflow can be divided into the following four steps: 1) See 2) Plan 3) Treat 4) Verify. Figure 1a shows a MAXIO system with its various components and Figure 1b highlights the different steps in a typical workflow.

Figure 1a. MAXIO docked on patient's left side. A: Docking plate and mechanism B: Planning system C: Robotic positioner D: End effector and needle guide used to hold the needle in place. Zoomed inlet shows the docking plate fixed to the floor of the CT suite and the unique asymmetrical pattern used to register the device to the CT scanner. MAXIO uses an optical camera and a proprietary optical registration algorithm for this registration. In addition there is a tilt sensor affixed to the bottom of the device which ensures that the device is always in its calibrated state.



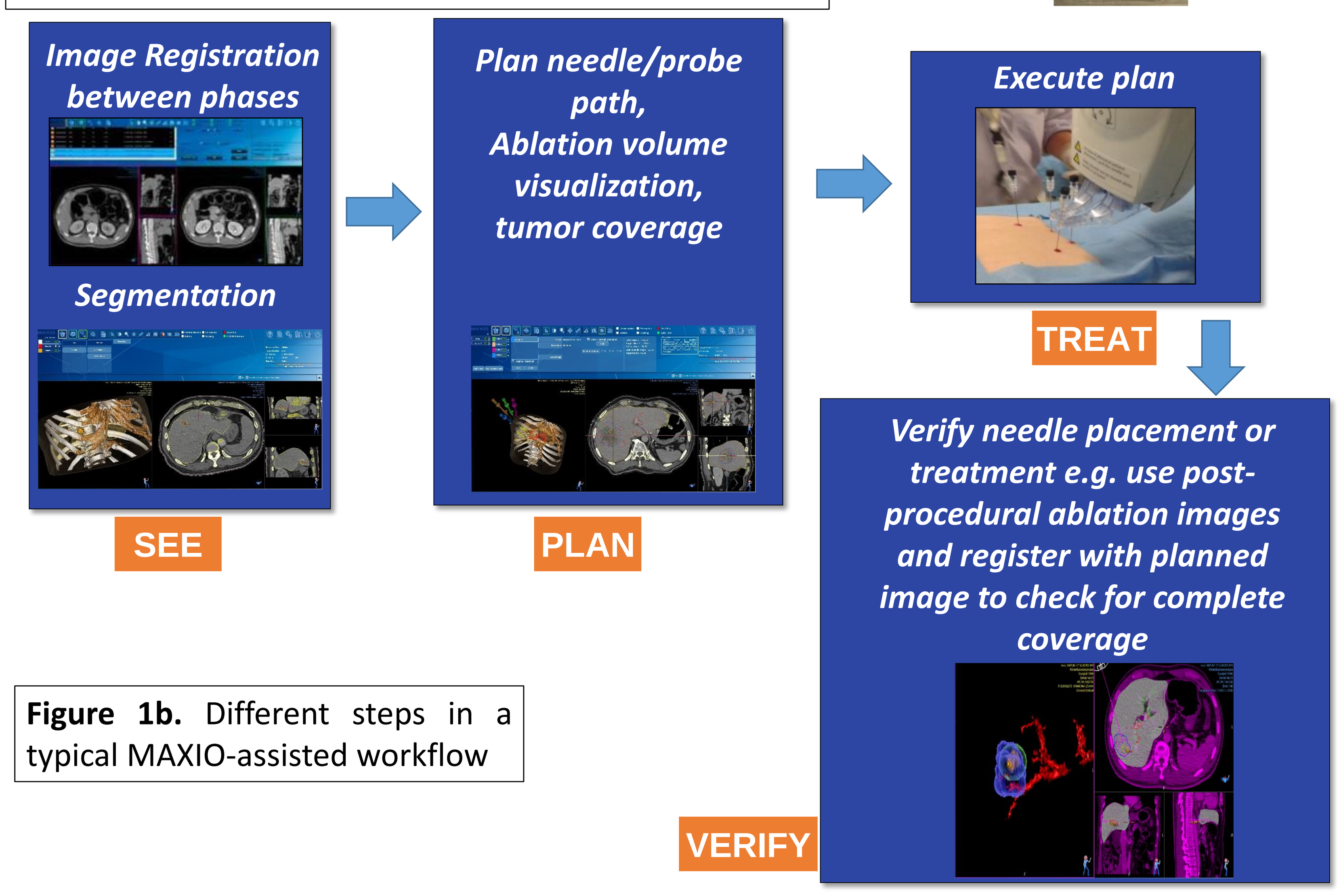


Figure 1b. Different steps in a typical MAXIO-assisted workflow

Planning – Methods and Results

MAXIO uses a semi-automatic atlas-based segmentation for liver segmentation and an interactive intensity based segmentation algorithm for tumors, vessels and other organs such as gall bladder, kidneys and pancreas. Once the organs and tumor have been segmented, clinicians can plan interventional procedures in 2D or 3D by selecting the target and entry points for the needles/probes. MAXIO facilitates ablation planning by superimposing the ablation zone (obtained from ablation probe manufacturers) over the 3D surface of tumor (obtained from segmentation).

In order to asses the value of computer-assisted planning in liver ablations, Crocetti et al[2]. conducted a retrospective study of 16 patients with metastatic colorectal cancer in the liver (18 lesions in total). For all 18 lesions, they planned ablation procedures manually and using MAXIO and studied all deviations in MAXIO-assisted plans from manual plans (deviation being described as change in ablation strategy or a change in ablation protocol or a change in the planned needle path). Table 1 shows the results of their study and as seen in the table Crocetti et al[2]. observed that 3D planning using MAXIO changed their ablation strategy in 61% of the cases (for example in 39% of the cases they had to change the entry point for the ablation needle and in 50% of the cases they had to change either the ablation technology or use additional ablation probes.

Deviations in MAXIO-assisted planning compared to manual planning (16 patients, 18 lesions)		
Change in ablation protocol	Change in planned needle trajectory	Any change
9/18 (50%)	7/18(39%)	11/18 (61%)

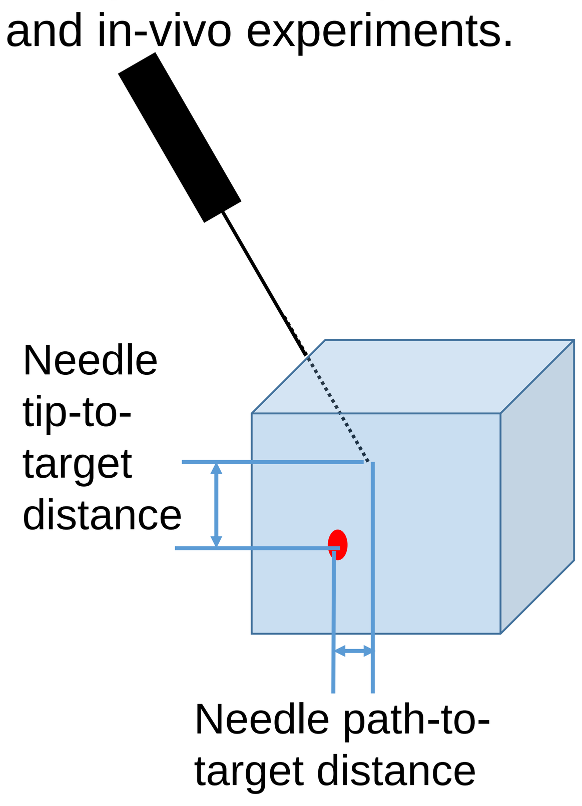
Table 1. Results of the 16 patient (18 lesions total) retrospective study conducted at University of Pisa, Italy to assess the need for computer assisted planning in liver ablation procedures.

Targeting – Methods and Results

Once the planning is complete, clinicians execute their planned needle path with the help of stereotactic needle positioner in MAXIO. It should be noted that clinicians can plan and advance up to six needles using MAXIO in either a sequential or a simultaneous fashion. Upon executing the plan, clinicians can obtain CT scans and using image fusion (non-rigid registration for liver ablation procedures and an intensity based rigid registration for other organs and procedures), clinicians can compare the planned needle trajectories to the actual needle path. In order to evaluate the accuracy of needle placements using MAXIO, we conducted a series of phantom and in-vivo experiments.

Phantom Experiments

Using an abdominal phantom (3D abdominal phantom model 057, CIRS, Norfolk, VA, USA) Koethe et al[1]. compared the accuracy of freehand single-pass needle insertions to insertions facilitated using MAXIO. Twenty virtual targets were selected and targeted at complex angles (average angulation of 65deg) using 18-gauge, 15cm needles. With the needles still in place, CT scans were obtained and used to measure the needle tip-to-target distance and needle path-to-target distance.



Therefore for a given target, two sets of distances were obtained (one for freehand insertion and the other for robotic targeting). Koethe et al[1]. showed that when compared to the freehand insertion, MAXIO reduced both the mean needle tip-to-target error and the mean needle path-to-target error by 59%.

Clinical Experiences

In a series of 147 interventional procedures completed at 9 different clinical sites between December 2012 and November 2013, we measured the 3D distance between the planned and actual needle tip and results have been presented in Table 2. It should be noted that needle insertions and targeting were done by expert clinicians in all 9 sites and clinical conditions during the interventional procedures were not altered in any fashion. Averaging over all the sites, the mean targeting error was found to be 2.6mm ± 2.1mm. It is worth noting that the stereotactic accuracy was either comparable or slightly better even in cases where (a) multiple needles were used (34/170 needle insertions were multiple needle procedures and accuracy was found to be 2.5mm±1.5mm) and, (b) complex angulations and needle trajectories were required because the tumors were located close to sensitive structures like major blood vessels, bowels and lungs (37/170 needle insertions required complex needle trajectories and accuracy was found to be 2.3mm ± 1.6mm).

Table 2. Stereotactic Accuracy of MAXIO measured at 9 different clinical sites over a total of 147 procedures. Clinical conditions have been reported as observed during the procedures and they were not altered or modified in any fashion because of MAXIO.

Clinical Conditions		Number of needle placements	Mean ± Std. dev. (both in mm)
Respiratory motion management	With Breath hold	63	2.3 ± 1.9
	Without Breath hold	107	2.8 ± 2.2
Patient movement management	With patient immobilizer	103	2.3 ± 1.7
	Without patient immobilizer	67	3.0 ± 2.5
Type of procedure	Ablation/IRE	33	2.7 ± 1.8
	Biopsy	107	2.6 ± 2.4
	Drainage	5	1.7 ± 1.0
	FNAC	2	1.0 ± 0.0
	Pain management	21	2.4 ± 1.2
Anatomical Region	Abdomen	49	2.3 ± 1.6
	Pelvic	107	2.2 ± 1.2
	Thorax	5	3.0 ± 2.7
# of needles	Single needle procedure	136	2.6 ± 2.2
	Multiple needle procedure	34	2.5 ± 1.5
Target depth	< 3cm	9	1.9 ± 1.8
	3cm – 5cm	33	2.4 ± 1.9
	5.1cm – 7.5cm	15	2.3 ± 1.5
	7.6cm – 10cm	66	2.8 ± 2.5
	> 10cm	47	2.3 ± 1.6
Angulation in needle trajectories	Combination of cranio-caudal and orbital angles	37	2.3 ± 1.6
	Trajectories with no deviation about the orbital axis	6	3.0 ± 3.7
	Trajectories with no deviation about the cranio-caudal axis	133	2.6 ± 2.2

Conclusions

Comparing the plans generated using MAXIO to manual planning, Crocetti et al[2]. demonstrated the need for computer-assisted planning during ablation procedures. In phantom experiments we demonstrated that MAXIO improved the needle placement accuracy. Based on our anecdotal observations during interventional procedures it could be said that MAXIO is accurate and its accuracy can be repeated across most clinical scenarios encountered during interventional procedures.

Several studies[3,4,5] have shown that customized ablation planning and improved needle placement accuracy during interventional procedures may (a) clinically translate to decreased complication rates (b) lead to greater sampling success during biopsies (c) decrease recurrence rates during ablations and, (d) reduce radiation exposure during pain management procedures. While more studies are needed, we are optimistic about the promising role for MAXIO in percutaneous CT-guided interventional procedures.

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References

1. Koethe Y. et al. Eur Radiol, 2014, 24(3):723-730
2. Crocetti L. et al. WCIO 2013 (presented as a talk)
3. Tiong L. et al., Br J Surg, 2011, 98:1210-1224
4. Kobayashi K et al. Radiographics, 2012, 32:1483-1501
5. Best SL et al., JURO, 2012, 187:1183-1189