CT-guided percutaneous transthoracic core biopsy (PTCB) of deep thoracic lesions using pure virtual navigation guidance (PVNG) with magnetic-tracking system: preliminary experiences

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Purpose

CT-guided PTCB is essential for the differential diagnosis between benign and malignant pulmonary and mediastinal tumors and for cellular characterization by somatic mutation and cellular differentiation analysis. Cellular characterization is becoming more and more important due to the development of oncologic targeted therapies and will be a field of growing interest in the near future[1-2].

For the same reasons, coaxial core biopsies are currently preferred to cytological specimens, as it allows multiple large samples to be obtained for molecular analysis[1]. Many experienced institutions report a low complication rate after a CT-guided transthoracic coaxial core biopsy. Nevertheless, national surveys still report a considerable incidence of major complication and death. Core biopsies is more demanding than fine needle aspiration and requires special technical considerations [1-3-4]. While many radiologists still need improved technical training, it is out of doubt that a widespread implementation of technological innovations will be effective in reducing procedure-related complications.

Usually PTCB is performed under cognitive-CT-guidance. On the basis of previous diagnostic modality (usually MDCT or PETCT) the patient is positioned on the CT table in the most convenient position (supine, prone etc.) for the safest approach to the lesion. A metal grid is attached to the patient's skin in an area planned for skin punctures. Finally, the skin entry point is marked and local anesthesia is performed.

Using the skin entry point, the biopsy needle is then advanced towards the target at the predetermined angle under cognitive guidance.

This technique is inexpensive but is susceptible to human error as it depends on a complex set of processes based on mental perception, learning and reasoning. Often the needle requires repositioning several times in order to reach the target satisfactorily. For these technical difficulties, usually a trajectory with a single or simple angle is preferred (i.e. vertical or horizontal).

In the last decade, two major technological innovations have been introduced: CT-fluoroscopy and C-Arm-CT. CT-fluoroscopy gives the unparalleled advantage of a real time visualization of the biopsy needle and lesion. Although accurate, both techniques have some drawbacks [5-6-7]:

a) They are expensive requiring specific hardware and software;

b) They increase the radiation exposure dose to patients and operators;

c) The geometrical characteristics of C-Am and CT-gantry restrict the operator independence.
In order to overcome the limitations of these techniques, we explored the application of pure virtual navigation guidance (PVNG) for the biopsy of deep mediastinal and pulmonary lesions.

Virtual navigation by images fusion techniques (also known as Interactive localizing techniques) has been proposed in the last two decades in order to spatially coregistrate a real time modality (i.e. US) with high resolution isotropic 3D CT and MRI or functional images (i.e. PET-CT) [6-8-9-10].

In this way, the operator can simultaneously use information from multiple image modalities to enhance diagnostic and localization capability. Virtual Navigator can also be used if the target organ in not visible under US examination. In this case, the CT or MR images can still be spatially coregistrated with the guiding device (simply, the US probe). So, target localization and percutaneous procedures will be performed only on the basis of virtual real-time multiplanar reconstructions of CT or MRI 3D acquisition (PVNG).

Image fusion can be achieved by Electro-Magnetic (EM), optical or mechanical devices. There are some advantages using EM devices over optical and mechanical devices:

a) The tracked device can reside out of generator sight;

b) The tracked device can be within the patient's body without signal attenuation;

c) There is no significant limitation to operator position and movement.

These advantages make EM tracking systems flexible as well as suited for multipurpose applications.

The main limitation of EM tracking systems is that a ferromagnetic environment can cause interference and distortion of magnetic coordinates. However, a new generation of EM tracking systems has a reduced susceptibility to the effects of the metal hardware [9].
Methods and materials

For the present study a MyLabTwice ultrasound scanner equipped with an EM tracking system and Virtual Navigation (VN) software (ESAOTE, Italy) and a 64 MDCT (Aquilion, Toshiba, Japan) were used. The procedure was performed with a convex transducer with single use multi-angle (15°-30°-45°) guiding system and reusable tracking bracket for magnetic sensor (CIVCO, USA) (Fig 1). Spatial coregistration was obtained with a reference device (omniTRAX) with a dedicated additional magnetic sensor (Fig 2).

In order to evaluate the possible influence of ferromagnetic environment (CT gantry and table) on the accuracy of the magnetic tracking system, we performed tests using a homemade phantom consisting of a styrofoam box with some targets inside (Fig 3).

Following this, we checked the accuracy of the system performing the biopsy in the patient with superficial lesions visible on both CT and US (Fig 4-5) comparing the planned and the actual position of the coaxial needle.

Biopsies were carried out using a coaxial technique with a 17G coaxial needle and a 18G trucut needle. 2-3 samples were obtained from each lesion. 15 patients with mediastinal or pulmonary lesions were enrolled. The patient was asked to lie down on the CT table in the most suitable decubitus position (supine or prone) with the thorax on the plastic support for the magnetic generator (Fig 6). The reference tool was attached to the patient’s skin in the appropriate area, and a preliminary CT scan was performed with a reduced Z-axis, including the target lesion and the reference tool (omniTRAX) in the FOV. Images (2-3 mm. axial scan) were loaded from PACS to the ultrasound scanner and coregistered with the probe position. VN modality was activated and a virtual scan (virtual ultrasound) was performed moving the probe through the scanned area looking for the target and the best approach (Fig 7). Once the target lesion was visualized and the approach for biopsy was planned, local anesthesia was performed. The coaxial needle was advanced using the probe-guiding system at the estimated depth in a technique similar to US guided biopsies. A small Z-axis CT scan was made to check the correct position of the coaxial needle, and then the biopsy was performed (Fig 8). Finally, a low-dose whole lung scan was performed in order to rule out any complications.
**Fig. 1:** Probe assembly for virtual navigation guided biopsy. Convex probe with bracket for the multi-angle guiding system (white arrow), bracket for magnetic sensor (dotted white arrow) and magnetic sensor (white arrowhead) are shown.

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Fig. 2: omniTRAX (white arrow) connected to an additional magnetic sensor (black arrow). This device has to be fastened to the skin in the area of interest during the localizing CT scan and doesn't produce any beam hardening artifact. The connection with the magnetic sensor is necessary only during the co-registration phase allowing free movements of the CT table.

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**Fig. 3:** During the preliminary phase of the study a home-made styrofoam phantom was used to check the accuracy of the system and experimentally evaluate the influence of the ferromagnetic environment on the EM tracking system. You can see the convex probe as used during the transthoracic virtual navigation guided biopsy. omniTRAX with an additional magnetic sensor is shown fastened to phantom (black arrow head). Furthermore, the phantom allowed the operator to increase his/her confidence with the system during the learning curve.

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**Fig. 4:** For the preliminary clinical experience patients with superficial targets were enrolled. In this case the coregistration was performed outside of the CT room and without the use of the omniTRAX. Coregistration, though good, was not perfect as demonstrated in the images in a patient with pleural-based lesion visible on both US (white arrow) and CT (dotted white arrow).

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**Fig. 5:** The coregistration appeared almost perfect when performed on the CT bed with omniTRAX. The image demonstrates an accurate coregistration in a patient with a lung hilum tumor and large atelectasis visible on both US (white arrow) and CT (black arrow). The mismatch is less than 5 mm (dotted white arrow).

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Fig. 6: Set-up of the CT room for transthoracic virtual navigation guided biopsy. The patient is positioned in the more convenient way for the chosen approach. The support for the magnetic generator (black arrow) is positioned under the thorax of the patient. The magnetic generator is not present in this phase in order to avoid beam hardening artifacts. omniTRAX (not visible) is fastened to the skin in the area of interest.

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Fig. 7: After a short Z axis CT scan was performed in the area of interest, co-registration was performed. Virtual sonography was started in order to chose the best trajectory for the biopsy and the coaxial needle was advanced to the estimated depth with a single step technique.

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Fig. 8: CT scan, performed soon after the procedure, demonstrates the correct position of the 17G coaxial needle allowing the core biopsy to be performed.

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Results

Preliminary tests with the Styrofoam phantom demonstrated no influence from the ferromagnetic environment if the volume of interest was at least 1 meter away from the CT gantry. In this setting the coregistration was accurate and immediate (Fig 9).

35 samples were obtained on the 15 lesions (maximum diameter ranging from 40 to 15 mm.; average 25) in 15 patients (age 45-85, with an average of 72). In all cases, a single step procedure was possible without the necessity of needle repositioning.

All biopsies were diagnostic (metastases 3, lung carcinomas 12). No major complications were encountered. 4 pneumothorax and 3 parenchymal hemorrhages resolved spontaneously. PVNG biopsies required an average time of 35 minutes (ranging from 25 to 45 minutes).

An analysis of MPR of the CT scan was obtained to assess the position of the coaxial needle; an accuracy of 5 mm or less was demonstrated in all reconstruction planes (when compared with the intended position) for all cases. (Fig 10-11). In the majority of patients, a complex path of the needle was demonstrated with angulations in all axes of the scanned volume (Fig 12).
Fig. 9: The preliminary experience with the styrofoam phantom demonstrated that the system was accurate and unaffected by the ferromagnetic environment in our CT room.

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Fig. 10: In this patient with a large lesion in the right lung, images demonstrate a good matching between the virtual and the real path of the needle

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Fig. 11: Another patient with a tumor of the anterior and superior mediastinum. Again images demonstrate a good matching between the virtual and the real trajectory of the needle.

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Fig. 12: MPR of the CT scan after the insertion of the coaxial needle demonstrates the unconventional but effective and safe trajectory chosen by the operator.

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Conclusion

Our preliminary study demonstrates that PVNG transthoracic lung biopsies are feasible as the ferromagnetic environment of the CT unit does not significantly affect the accuracy of the EM tracking device according to the experience of Wood et al [9]. A test with a phantom is however mandatory, as the results can be related to the specific CT unit used. The use of a small reference device (i.e. omniTRAX) allows a small Z-Axis CT scan to be performed during the planning phase, significantly reducing the radiation dose to the patient. As regards the cost, we have to consider that many commercial ultrasound units are currently equipped with EM tracking devices, as well as software, with a variety of diagnostic and interventional applications. A break-even point can be fairly rapidly reached in a standard radiology department. All these considerations overcome some of the concerns reported by Sarti et al in a previous paper [6]. The time necessary for the PVNG biopsies is comparable with the time for CT-Fluoroscopy procedures [11].

The evidence, that a single step procedure without needle repositioning and manipulation was possible in all cases, encourages further developments as the reduction in the number of complications can be reasonably expected. Excessive needle manipulation due to an incorrect initial position can result in pleural laceration, pneumothorax and hemorrhage [1].

The evidence that complex and large angulations were frequently used highlights another advantage of PVNG biopsy with respect to CT-fluoroscopy and C-Arm CT. In fact, PVNG biopsy overcomes all limitations and restraints due to gantry-tilting and the geometry of these imaging modalities.

With an increase in the current trend of using of PET to select patients for transthoracic biopsy, PVNG biopsies with PET-CT fusion can be aimed at the area of abnormal metabolic activity. This is particularly important in large necrotic tumors or smaller tumors producing large atelectasis. Larger clinical experiences are needed in order to evaluate the precise role of PVNG for transthoracic biopsy. However, as it is less operator dependent, PVNG technique can be considered a step ahead of the cognitive techniques and a valid alternative to C-Arm CT and CT fluoroscopy.

We should consider that further technological improvements are still possible in the field of virtual reality, allowing the production of inexpensive, more accurate and more user-friendly systems. Thanks to virtual reality, future thoracic biopsies can plausibly be performed outside the CT room, without the risk of additional radiation exposure to both patient and operator.
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