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Computed Tomography Guided Percutaneous Liver Biopsy Using a Robotic Assistance Device—A Corpse Study

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Abstract

Purpose: To investigate a robot assistance device for CT-guided percutan liver biopsy. Materials and Methods: The liver of a corpse was equipped with target dummies. Four radiologists used a 16 G needle to perform biopsy of the target region in standard free hand technique and then used a robot system which allowed planning and aligning the trajectory path. Accuracy in terms of needle tip deviation, and time efficiency and radiation exposure in terms of effective dose for the radiologists were measured. Results: For in plane procedures, there was no significant benefit in accuracy when using the robot versus standard technique (4 mm vs. 5.6 mm, $p = 0.11$); timely effort was worse (443 sec vs. 405 sec, $p = 0.64$). For angulated punctures, a needle tip of 3.7 mm was measured by using the robotic device (vs. 10.8 mm, $p < 0.01$); mean biopsy duration was 490 sec (vs. 900 sec, $p < 0.01$). Mean radiation exposures in freehand technique were 2.4 µSv (in plane procedures) and 10.8 µSv (oblique procedures); the robotic assisted procedures were performed without additional image guidance. Conclusion: The proposed robotic assistance device may be superior for angulated interventions regarding accuracy and timely effort. Furthermore, the zero radiation exposure is a significant benefit for the interventional radiologist.

Keywords

Interventional Radiology, Robotic Assistance, Needle Biopsy, Radiation Dose

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1. Introduction

Percutaneous Computed Tomography (CT)-guided liver biopsies are highly efficient due to the high accuracy and minimally invasive character of the procedure [1]. Excellent differentiations of the target region and biopsy needle, independent of their location, are the most significant advantages that help keep a low risk profile when extracting a tissue sample. For intraprocedural needle guidance, however, only thin sliced images with a thickness of 5 mm or less are usually acquired in transverse direction. Therefore, radiologists favor in plane access routes which allow a simultaneous view of the biopsy instrument and the target tissue. However, if a vital or bony structure obstructs the direct access of the instrument, angulated and thus more difficult approaches in single- or even double-oblique techniques are essential for safe and successful needle placement.

Furthermore, repetitive monitoring of the correct trajectory of the biopsy instrument during the procedure causes the interventional radiologist to be exposed to a significant amount of scattered X-rays [2]. Obviously, the number of necessary images and therefore radiation dose increase with the complexity of the procedure and the length of the access path. Commonly used aprons only cover the body trunk and thyroid gland as these are radiosensitive anatomical areas. However, certain other anatomical areas such as the operator's hands and head are still exposed to the radiation regularly if not shielded in addition.

Recently, various robotic devices have been demonstrated to help to perform accurate CT-based percutaneous procedures, mainly by holding the needle device for the interventionalist [3]-[6]. In this corpse study, we tested a new and commercially available robotic device that allowed planning and guidance of in plane as well as angulated needle interventions using a CT dataset. Since the device integrates both planning and guidance of needle-based procedures, punctures can be performed without control scans, and thus without any additional radiation exposure for the patient and operator. This paper analyzes the accuracy, time efficiency, overall handling and limitations of the device when performing liver biopsy.

2. Materials and Methods

2.1. Robotic Assistance Device

The device used in this study (MAXIO, Perfint Healthcare Pvt. Ltd. Chennai, India) is a guidance robot for percutaneous needle interventions that aligns itself to trajectory paths that were previously planned by the physician.

Prior to performing interventional procedures, the robotic device has to be docked to a special floor-mounted plate besides the CT table for spatial orientation. After moving the robot on the floor manually, the device then registers and docks itself semi-automatically. The complete startup procedure takes about 8 minutes and has to be repeated if the robot is moved away in between interventional procedures.

Via a data cable, the robotic device imports the dataset of a previously conducted CT scan of the relevant anatomic area. With the use of an integrated planning computer targeting, a lesion is targeted in plane or in an angulated fashion on multiplanar reconstructed images. After planning the skin access point and target, the interventionalist can verify the needle path and modify if necessary. The software displays further relevant information such as the CT table position required and minimal length of the biopsy device. Then, the robot positions its needle-holding arm to the planned trajectory at the correct distance from the skin surface, considering the individual needle lengths up to 20 cm (**Figure 1** and **Figure 2**). With the combination of aligned access path and defined needle length, it will then be possible to reach the predefined target region without the need of any further image guidance.

2.2. Experimental Set-Up

For this interventional study, a cadaver was placed onto the examination table of a modern CT device (Definition AS, Siemens Healthcare, Germany) in supine position. The institutional review board approved for this study. Prior to the experimental procedures, the liver was percutaneous equipped with 4 metal clips, serving as target dummies. The clips, about 1 mm in diameter, were located in liver segments 6, 5 and 4 and subcapsular in segment 8. For planning the subsequent procedures, a diagnostic CT scan of the liver was performed at 120 kV and 180 mAs; images were then reconstructed at 1 mm slice thickness (1 mm increment) in a medium soft kernel (D30) in soft tissue window (Center: 50 HU, width: 400). To evaluate performance of the robotic device, four radiologists with 1, 2, 5 and 10 years of experience first punctured the 4 clips manually using the standard freehand technique with a biopsy needle of 15 cm in length and 16 gauge diameter (Somatex Medical Technologies,

Figure 1. The experimental setup. The robotic device is mounted onto a docking plate (*) next to the CT table for spatial orientation. With the integrated planning computer access paths can be visualized by using a graphical user interface that supports multiplanar view angles. The white arrow marks the needle holding arm, which is then aligned to the planned trajectory. At the tip instruments from 11 to 24 gauge can be inserted through dedicated clamped adapters. The data cable, which is linked to the CT workstation and the power cord can be seen at the bottom of the image.

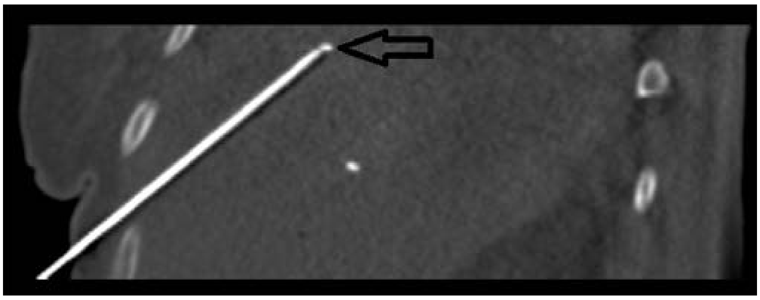

Figure 2. The final result of the needle tip next to the target dummy (arrow). Needle tip is at the level of the clip, the measured deviation to the center of the clip was 2 mm in this case.

Germany) and then repeated the procedure with the help of the robotic device. The radiologists were free to choose the approach path to the target, whether in or off plane view.

The target path was planned individually on a CT workstation (Syngo, 3D tool, Siemens Healthcare, Germany) for the freehand procedures. During the intervention, the radiologist controlled the position of the needle by using single sliced images (120 kV, 70 mA, 5 mm collimation). To measure the scattered radiation caused by image guidance, the radiologists were equipped with an electronic dosemeter (Raysafe i2, RaySafe, Sweden) that was placed at chest level onto the protective clothing. This dosemeter measured the environmental equivalent dose (Hp10) in ranges from 40 mSv to 150 mSv with a deviation of plus/minus 10%. After reaching the target, the achieved dosage and number of images taken for guidance were noted for each procedure and interventionalist. Furthermore, the time taken for planning (planning time) and executing the procedure (intervention time) was documented for each case. A post-procedural scan was performed to measure the total length of the access path and the needle point to the target distance.

In a second approach, the radiologists used the robotic device to plan and perform the needle interventions. For this approach, no image guidance was used during the needle advance, as the robotic arm was expected to position itself correctly regarding the target's position and needle length. Again, the length of access path, accuracy and timely effort were documented for each procedure.

2.3. Data Analysis

Average time taken for planning and performing the procedures, total access path length and accuracy (needle tip to target distance) were compared between manual and robot assistance interventions. Radiation exposure of the radiologists and the number of images required for the freehand technique was assessed, as was the patient radiation dosage for both techniques. Where applicable, Student's t-Test was used to analyze significant differences while assuming a confidence interval of 95% ($\alpha \leq 0.05$).

3. Results

A total of 32 percutaneous punctures were conducted upon the four liver targets. The radiologist used the in plane technique 22 times, and the subcapsular lesion located in segment 8 was punctured in single oblique technique all 8 times. The lesion in S5 was also targeted by two of the radiologists with an angulated trajectory. The average total procedure time for freehand technique was 443 seconds while robot-assisted needle interventions took 405 seconds ($p = 0.64$). Detailed timely effort of planning and performing the procedures are shown in **Figure 3** and **Figure 4**. The average needle tip deviation was 5.6 mm without using the robotic device (versus 4 mm, $p = 0.11$). When focusing solely on the angulated punctures of the clip in segment 8, the differences showed statistical significance for total time (490 sec vs. 900 sec, $p < 0.01$) and needle tip deviation (3.7 mm vs. 10.8 mm, $p < 0.01$). Since the robot-assisted procedures were performed without image guidance, the radiologists were not exposed to scattered radiation. Using the freehand technique, the median measured radiation exposure during image guidance was 2.4 µSv Effective Dose with a median of 6 images taken per procedure. Again, the more complex angulated procedures caused an increase in scattered x-rays, leading to a median dosage of 10.9 µSv with a median of 24 images that were taken in each procedure to control the needle position (**Figure 5** and **Figure 6**). Image guidance during procedures conducted using the freehand technique caused an additional radiation exposure for the corpse of 23.2 mGycm for in plane procedures and 123.8 mGycm for angulated procedures.

4. Discussion

In this cadaver study, we evaluated a newly available robotic guidance system that is suitable for planning and executing liver interventions based on a previously acquired CT dataset. Efficacy was assessed by comparing percutaneous robot-assisted needle placements to interventions performed using the standard freehand technique.

Regarding in plane procedures, the use of the robotic assistance device did not significantly increase accuracy or timely effort. Accuracy of in plane needle trajectories was similar for both techniques and well within the clinically sufficient ranges of 2 to 7 mm for needle tip deviation; the use of the robotic device even caused a time delay of about 60 seconds per intervention. However, significant differences in terms of accuracy could be observed in the angulated procedures: with the standard freehand technique, deviation of the needle tip from the target lesion was up to 14 mm, while the needle tip deviation with the use of the robotic device was 7 mm utmost. We believe that, in particular, the angulated and thus more complicated percutaneous procedures could benefit from such a needle guidance tool. Apart from time savings, the necessity for needle corrections would be omitted and therefore trauma to the penetrated tissues would be minimized. Subsequent peri-interventional risks in terms of bleeding or organ perforations caused by the inserted instruments could be diminished, providing an advantage for patient outcome. Additionally, the administration of local anesthesia will perfectly match the subsequent biopsy's path. With the help of the robotic device, angulations of procedures did not play any role in

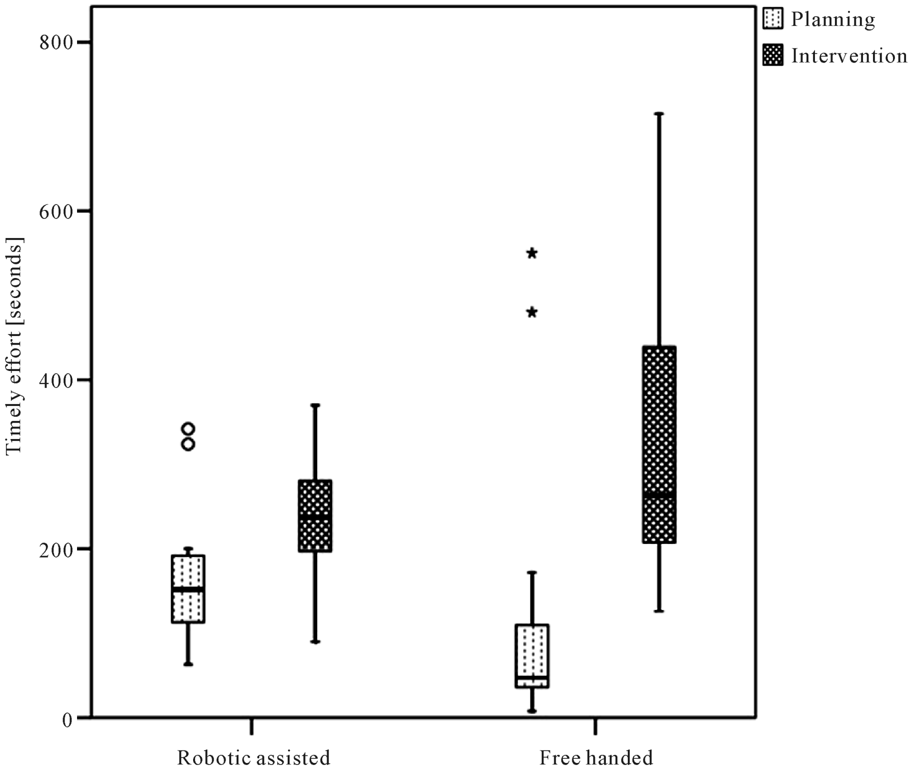

Figure 3. The time consumed during the planning and performing of liver biopsies using the standard freehand technique and with the help of the robot guidance tool.

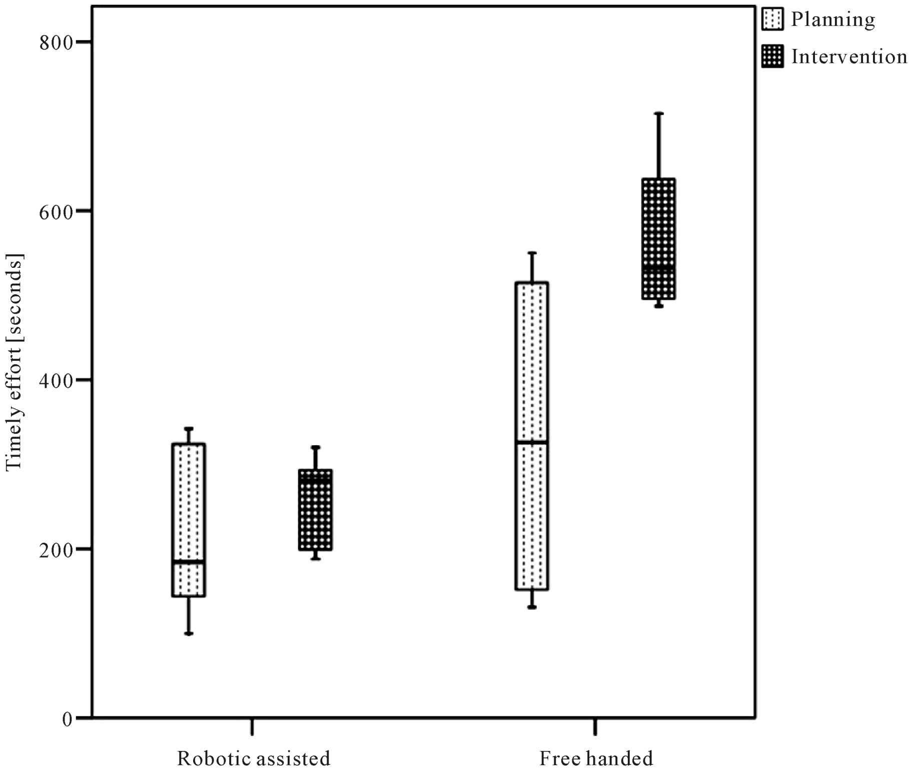

Figure 4. Solely angulated and thus more complex interventions.

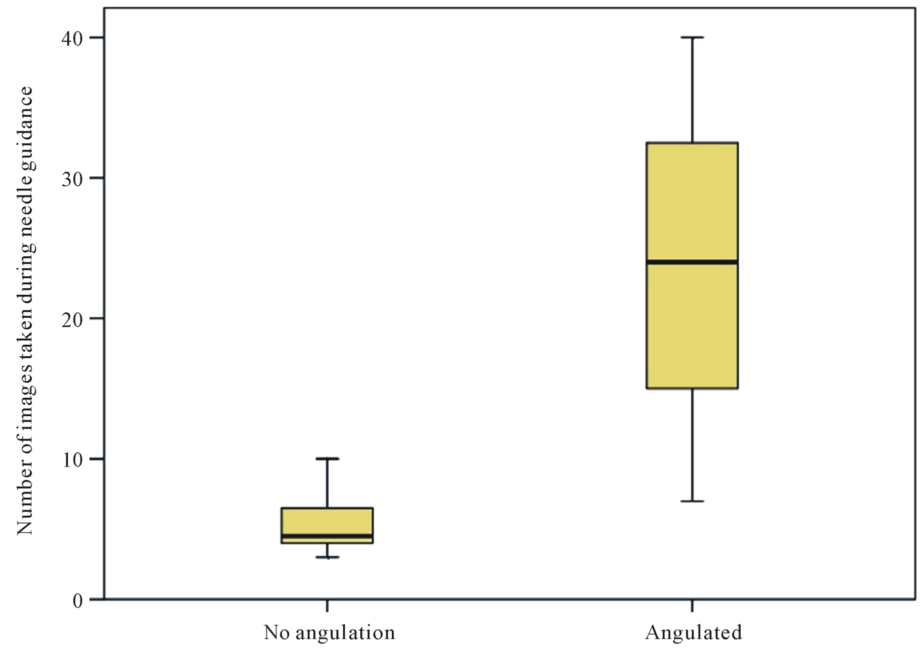

Figure 5. Number of images acquired during the standard free hand procedure for needle guidance. Angulated interventions required considerably more images.

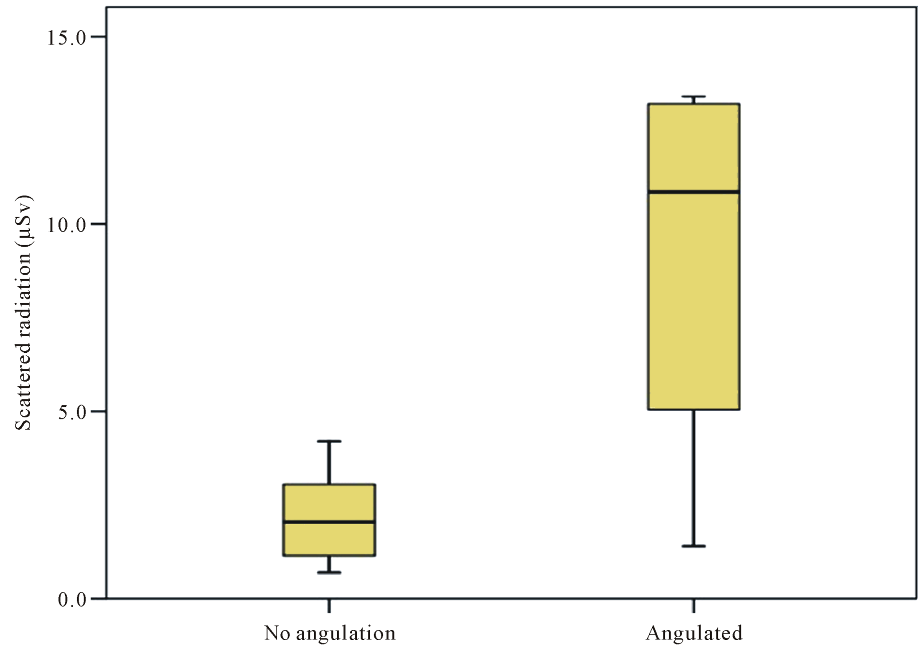

Figure 6. The subsequently increased scattered radiation exposure for the interventionalist.

terms of difficulty. Therefore, we believe that oblique but safer trajectories will be chosen more often than is currently the case with the use of such robotic devices.

When performing the interventions using the standard freehand technique, the radiologists received an amount of 2.6 to 10.4 µSv scattered radiation, and the "patient" was exposed to an additional dosage of 16 to 206 mGycm. The fact that the operators were not exposed to any scattered radiation during the robot-assisted interventions represents a significant advantage of this device. In fact, the radiologists did not wear any aprons during the robot-assisted intervention experiments; needle positions were not monitored during advancement and the procedures relied solely on the planned and aligned trajectory path. As stated before, the general use of aprons is ubiquitous; however, without the constant use of lead glasses and gloves, a certain amount of scattered X-rays will hit the attending staff during the procedure.

Important limitations of the robotic-assisted interventions are primarily the inability of the device to compensate for patient movement after having performed the planning-scan. Especially for interventions in organs that are affected by diaphragm movements, precise breathing commands would be essential for the planning scan as well as during the procedure when manipulating the needle. Sudden movements of the patient would hinder or even preclude the robot-based intervention, since the planning relies on a previously acquired dataset. A second planning scan would be necessary to update the anatomical conditions, leading to a significant increase in radiation dose for the patient. Another restriction of the system is the cumbersome dimensions and setup. Wheeling the robot onto the docking plate and initializing and setting up the device takes about 10 minutes. However, we noticed that if the robot is not properly aligned to the docking plate, the booting up procedure has to be repeated. Finally, the range of the device is somewhat limited: due to a lack of space, the device is usually placed on the opposite side of the body, which may inhibit very lateral interventions or punctures in the posterior-anterior direction. Limitations of this study include the nature of its design: without any movement of the liver, the device successfully planned and guided liver biopsies in all procedures; however, clinical studies are mandatory to assess its efficacy for patients who receive biopsy in breath-hold technique.

Nowadays, CT-guided robot-assisted interventions have to compete against devices used in Magnet Resonance Imaging (MRI)- or Cone Beam CT (CBCT)-based intervention suites [7]-[12]. The most significant advantages of MRI interventions are the avoidance of any radiation burden and excellent tissue discrimination. However, MRI-based interventions are elaborate due to the narrow access paths and the complex guidance struggling with artifacts to visualize the actual needle position. CBCT-based suites lack tissue differentiation capabilities compared to CT images. Furthermore, during the procedure, only projection radiography images are available, otherwise repetitive 3D scans would have to be performed, causing an additional dose penalty for the patient [13].

5. Conclusion

In conclusion, the proposed robotic assistance device successfully performed liver biopsies in this corpse study. Accuracy and timely effort were comparable with those of manual procedures and superior regarding angulated and thus more complex interventions. In combination with zero scattered radiation exposure for the attending staff, this device seems promising for CT-guided needle interventions.

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