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FULL PAPER

Cone beam CT guidance provides superior accuracy for complex needle paths compared with CT guidance

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Objective: To determine the accuracy of cone beam CT (CBCT) guidance and CT guidance in reaching small targets in relation to needle path complexity in a phantom.
Methods: CBCT guidance combines three-dimensional CBCT imaging with fluoroscopy overlay and needle planning software to provide real-time needle guidance. The accuracy of needle positioning, quantified as deviation from a target, was assessed for inplane, angulated and double angulated needle paths. Four interventional radiologists reached four targets along the three paths using CBCT and CT guidance. Accuracies were compared between CBCT and CT for each needle path and between the three approaches within both modalities. The effect of user experience in CBCT guidance was also assessed.
Results: Accuracies for CBCT were significantly better than CT for the double angulated needle path (2.2 *vs* 6.7 mm, $p<0.001$) for all radiologists. CBCT guidance showed no significant differences between the three approaches. For CT, deviations increased with increasing needle path complexity from 3.3 mm for the inplane placements to 4.4 mm ($p=0.007$) and 6.7 mm ($p<0.001$) for the angulated and double angulated CT-guided needle placements, respectively. For double angulated needle paths, experienced CBCT users showed consistently higher accuracies than trained users [1.8 mm (range 1.2–2.2) *vs* 3.3 mm (range 2.1–7.2) deviation from target, respectively; $p=0.003$].
Conclusion: In terms of accuracy, CBCT is the preferred modality, irrespective of the level of user experience, for more difficult guidance procedures requiring double angulated needle paths as in oncological interventions.
Advances in knowledge: Accuracy of CBCT guidance has not been discussed before. CBCT guidance allows accurate needle placement irrespective of needle path complexity. For angulated and double-angulated needle paths, CBCT is more accurate than CT guidance.

Needle guidance for puncture or other minimally invasive procedures is increasing in standard interventional radiology practice. In local therapy procedures, such as percutaneous ablations, accurate placement of one or more needles is important in order to provide effective treatment [1]. This is especially the case in treatment or biopsy procedures of small lesions, in which the tip of the needle needs to be placed within a range of millimetres of the target point. Therefore, image guidance plays a significant role in accurate percutaneous needle placement [2].

Currently, most needle placement procedures are performed using CT guidance, fluoroscopy or ultrasound [3]. CT images provide good visualisation of the target and surrounding tissues. For needle guidance, however, CT has limitations mainly because it does not allow real-time feedback on needle progression. For semi-real-time imaging within the CT scanner, CT-fluoroscopy can be used at the expense of a higher radiation dose to the patient and operator [4]. Acquiring CT fluoroscopy images to check needle position takes approximately 1 s, time in which the needle cannot be progressed.

Fluoroscopy in the angiography suite, however, provides optimal patient accessibility and real-time imaging of needle progression but is limited to two-dimensional visualisation. A radiation-free technique that also provides real-time imaging is ultrasound. However, the accuracy is operator dependent and, owing to ultrasound's low penetration depth, the area of use is restricted to superficial targets and moderate-sized patients [3].

New techniques combining cone beam CT (CBCT) and fluoroscopy with dedicated needle guidance software within an angiography C-arm system aim to overcome the disadvantages of CT and allow real-time three-dimensional needle guidance in the interventional suite [5].

Several authors described the use of this CBCT with navigational tools in various types of procedures [6–19]. Braak et al [8] described the effective patient dose of CBCT guidance procedures to be reduced by 13–42% compared with CT guidance for abdominal and thoracic procedures. Other authors reported diagnostic accuracies of CBCT guidance to be comparable to or higher than other guidance modalities [14–16, 20–22]. However, until now, the accuracy of CBCT guidance for reaching small (millimetre-sized) targets has not been addressed specifically.

In clinical practice, the used needle path is determined based on the location of the target tissue and its surrounding structures. A safe needle path avoids puncturing critical structures such as large vessels or nerves. For CT imaging ease, an inplane needle path is often used. However, this might not always be the safest path. In those cases, a more complex needle path would be more suitable, complicating accurate needle placement.

The purpose of our phantom study was to determine and compare the accuracy of CBCT and CT guidance in reaching small targets by paths with different levels of complexity under standardised conditions.

MATERIALS AND METHODS

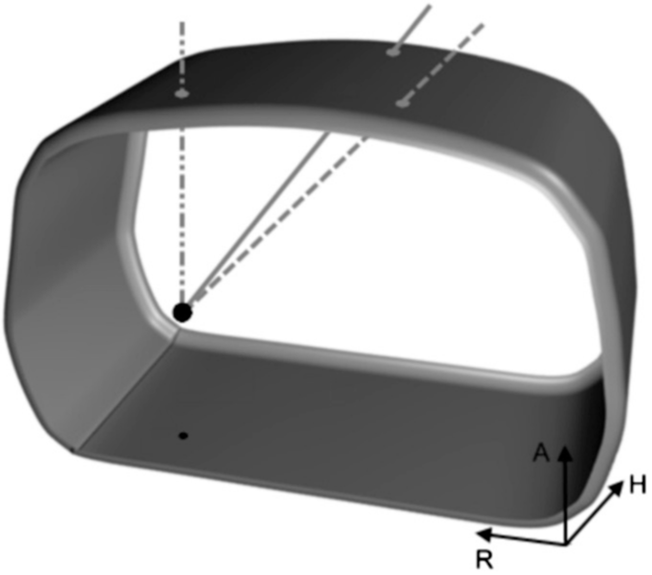
Phantom

To analyse accuracy, a modified model 057 Interventional 3D Abdominal Phantom (CIRS Inc., Norfolk, VA) was used for simulating abdominal needle placements in a standardised setting. The phantom represents a small adult abdomen (range T9/T10–L2/L3) and consists of materials mimicking tissues in CT imaging. Four 2.3 mm spheres (CT spots #119; Beekley, Bristol, UK) acting as targets were randomly spread in the phantom. The targets were spread roughly in the centre of the phantom at depths of 84, 98, 117 and 125 mm from the anterior phantom side. This represents a wide range of clinical targets in the abdomen, such as liver or kidney lesions.

Needle placement procedure

The procedures were performed using CBCT guidance (XperGuide; Allura Xper FD-20 Angio system, Philips Medical Systems, Best, Netherlands) and CT guidance (Siemens SOMATOM® Sensation 16 CT scanner; Siemens, Erlangen, Germany). Each of the four targets was reached with an 18G, 20 cm long Trocar EchoTip Needle (COOK Medical, Bloomington, IN) following three paths with different degrees of difficulty (Figure 1). First was an inplane path in which the skin entry point and the target were in the same axial plane and on a vertical line (direction of A-axis, Figure 1). The second path followed an angulated line in one axial plane (R/A plane in Figure 1). For the third and most difficult needle path, the skin entry point and target were located on a double angulated line, which means an angulated needle path crossing several axial scanning slices. Four experienced interventional radiologists (JJF, SJB, MJLVS, LJSK) were asked to reach all four targets along the three paths, as with a clinical procedure, on both modalities. They were allowed to redirect the needle towards the target but without pulling back, as this is not desirable in clinical practice owing to resulting trauma to tissue. All radiologists are experienced users of CT guidance (SJB, JJF, >5 years; MJLVS, LJSK, >10 years). All four had received hands-on training using the CBCT guidance software by a representative of the company and were given the opportunity to practice. There were, however, differences in the level of clinical experience with the guidance software. Two radiologists had performed only a few clinical guidance procedures (*i.e.* JJF, LJSK, <10), whereas two (SJB, MJLVS) had performed over 200. A slightly different path was chosen for each puncture to avoid placing the needle in a previously followed path possibly still present in the phantom material. The precise angle of the needle path does not influence or determine the difficulty of the needle placement; however, the direction of the angulation does (inplane angulated *vs* angulated through several axial planes).

Figure 1. Outline of the interventional three-dimensional abdominal phantom showing an internal target (black dot) and three corresponding needle paths: dotted/dashed line, inplane path; dashed line, angulated path; and solid line, double angulated path. Grey spots represent the corresponding skin entry points. The axes indicate the right (R), head (H) and anterior (A) sides of the phantom.



The inplane needle paths had a mean length of 106 mm (range 84–125 mm) and no angulation in the axial plane. The angulated needle paths had a mean length of 142 mm (range 106–167) and angulations in the axial plane of 30°, 50°, 60° or 70° for the different targets. The double angulated needle paths had a mean length of 145 mm (range 128–184 mm) and angulations of 30°, 40° or 50° in the axial plane and 15°, 20° or 25° in the sagittal plane.

Cone beam CT

The CBCT guidance procedure commenced with acquisition of a CBCT scan (312 projections over 240°) and reconstruction of a three-dimensional (3D) data set. In this 3D data set, both target and skin entry point were defined by the interventional radiologist so as to create a safe needle path. The 3D data set with planned needle path was subsequently overlaid with the real-time fluoroscopy images and the projection followed the movements of the C-arm [5,6]. This allowed real-time visualisation of needle position and progression towards the target point.

The optimal imaging projections (*i.e.* rotations and angulations of the C-arm) for needle guidance were automatically calculated after the needle path was determined. The first view was the entry point view in which the skin entry point was superimposed on the target point. This view was used to position the needle at the entry point. Next, the progression view, perpendicular to the needle path, was used to monitor needle progression along the planned path allowing real-time guidance of the needle. When the needle had reached the target, an approximately 50% collimated CBCT scan was acquired to check the needle insertion accuracy in 3D. In all CBCT procedures, the same imaging protocols were used for CBCT images as well as for fluoroscopy; hence, the imaging parameters were equal. A SeeStar® needle holder (AprioMed, Uppsala, Sweden) was optionally used to support the needle during insertion according to the preference of the radiologist.

CT

The CT guidance procedure started with a scan of the entire phantom (45 slices, 120 kV, 110 mAs) to determine the entry point and needle path towards the target. After placing the needle at the entry point, repeated axial scans were acquired for progression control (6–24 slices, 120 kV, 54 mAs, 3-mm slice thickness). For the double angulated needle paths, the complete needle path was scanned to visualise needle progression towards the target.

Analysis

The CBCT and CT needle guidance procedures were compared for each of the needle paths (inplane, angulated and double angulated) based on the accuracies. The accuracy is quantified by measuring the shortest distance from the needle tip to the centre of the target, measured in millimetres in a reconstructed 3D volume. This deviation from the target was determined on the verification CBCT scan or the last acquired CT scan (see Figure 2). These measurements were performed three times by the same person (WMHB) and averaged.

As the level of experience in using CBCT guidance differed, accuracy for the experienced users was compared with that of the trained users. For the CT-guided procedures, we assessed whether there were differences in accuracies between the four radiologists.

In addition, the needle placement time from the beginning of the first scan (for needle path planning) to the end of the verification CBCT scan or the last acquired CT scan was recorded (in minutes) and compared between CBCT and CT procedures.

Statistical analysis

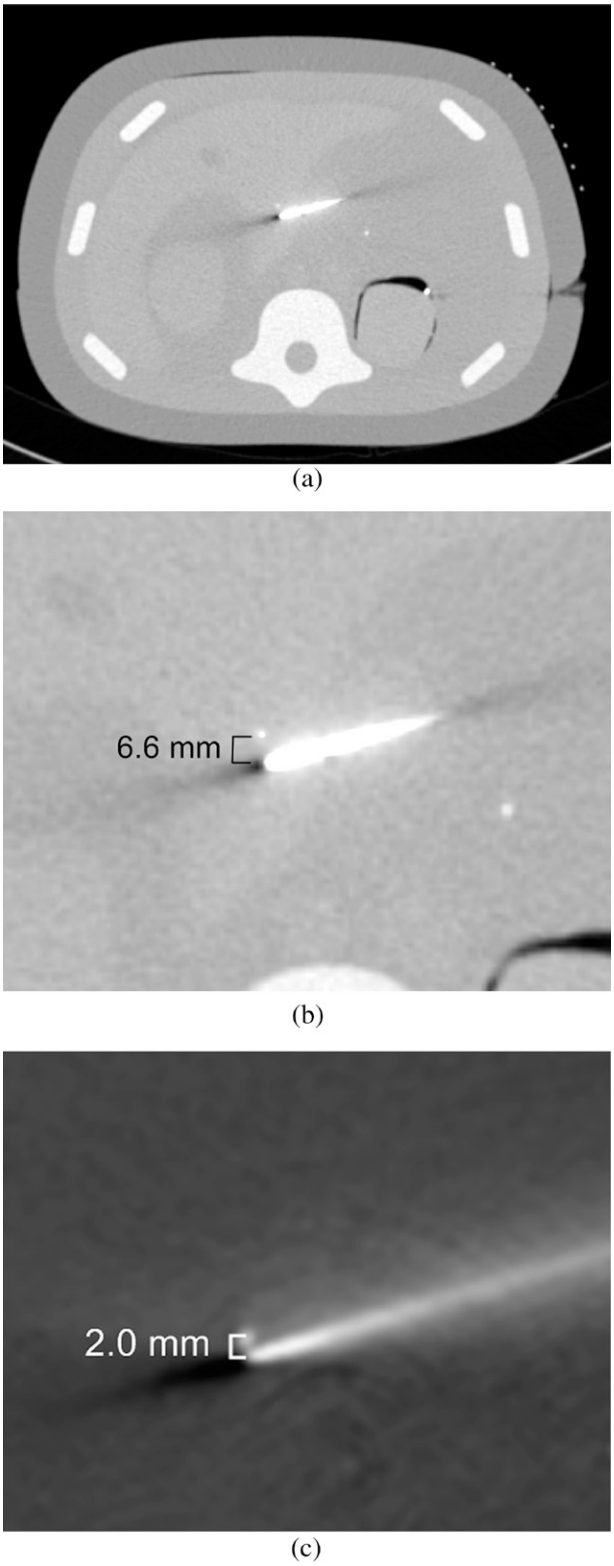
Statistical analysis was performed with SPSS® v. 18.0 (SPSS, Inc., Chicago, IL). The Mann–Whitney test was used to compare the groups. Two-sided p-values ≤0.05 were considered statistically significant. All values are represented as median (range).

RESULTS

Accuracy

The accuracies for both CBCT- and CT-guided procedures are represented in Figure 3. The distance between the needle and the

Figure 2. (a) CT image used for measurement of deviation between target centre and needle tip in an angulated needle placement. Slice thickness is 3 mm. (b) Enlargement of the CT image in (a) with distance measurement indicated in black. (c) Axial view of CBCT volume with measurement of distance between target centre and tip of angulated placed needle in white. All images show the same target with the needle following an angulated needle path placed by the same interventional radiologist.



(a)

(b)

(c)

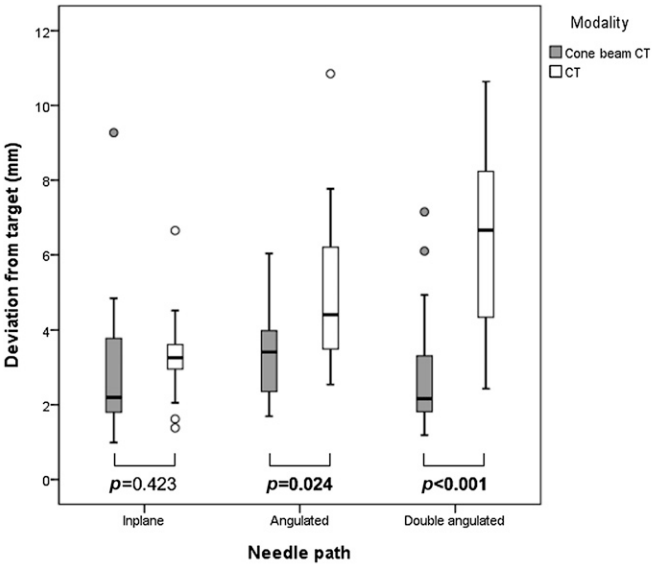


Figure 3. Boxplot showing deviation of the needle tip from target point for both cone beam CT (grey) and CT-guided procedures (white) for the three needle paths separately.

target centre is smaller using CBCT guidance, *i.e.* more accurate. The difference between CBCT and CT guidance is statistically significant for the angulated paths [3.4 mm (1.7–6.0) *vs* 4.4 mm (2.5–10.9), respectively] ($p=0.024$) and double angulated paths [2.2 mm (1.2–7.2) *vs* 6.7 mm (2.4–10.6), respectively] ($p<0.001$).

With CT guidance, the accuracy decreases with increasing level of difficulty. The accuracies of both the angulated ($p=0.007$) and double angulated ($p<0.001$) paths are significantly worse than the inplane path. With the increasing median deviation distance, the range of the deviation distances also increases from 5.3 mm for the inplane path to over 8 mm for the angulated and double angulated paths. For CBCT guidance, however, the three needle paths result in the same level of accuracy (approximately 3 mm) and there are no significant differences between the three paths (Figure 3).

Experience level

The accuracies for the trained and experienced CBCT users are presented in Table 1. With a median of 2.1 mm (1.0–3.9) for all three needle paths and all needles placed within 4 mm of the target point, the experienced users are more accurate than the trained CBCT users [median 3.7 mm (1.5–9.3)] ($p=0.002$). The ranges of accuracies achieved by trained users are larger than the ranges of the experienced users, whereas the median values are comparable. Comparing the two levels of experience results in statistically significant difference for the double angulated needle paths [3.3 mm (2.1–7.2) *vs* 1.8 mm (1.2–2.2) for the trained and experienced CBCT users, respectively] ($p=0.003$). For this double angulated needle path, both trained and experienced users show statistically significant better accuracies using CBCT guidance than using CT guidance (p-values are 0.016 and <0.001, respectively). For the inplane and angulated needle paths, the differences between trained and experienced users are not statistically significant [2.9 mm (1.5–9.3) *vs* 2.1 mm (1.0–3.8) and 3.8 mm (2.0–6.0) *vs* 3.2 mm (1.7–3.9) for inplane and angulated needle paths, respectively]. Comparing the three needle paths within the group of trained users, there are no significant differences. For the experienced users, however, the double angulated needle path shows a small but significant increase (1.4 mm) in accuracy compared with the angulated needle path ($p=0.015$). The small range and low median value of the double angulated path compared with the other paths might be explained by the limited number of radiologists.

For the CT-guided procedures, there are no statistically significant differences between the four radiologists. This indicates that the large spread in accuracy for the double angulated path is not influenced by experience in using CT guidance.

Needle placement time

There were no significant differences between CBCT and CT guidance for any of the used needle paths. A slight increase in placement time was only statistically significant between the inplane and double angulated paths for both CBCT [7 min (4–13) *vs* 9.5 min (7–13) ($p=0.015$)] and CT guidance [6 min (4–11) *vs* 8 min (5–13) ($p=0.018$)].

DISCUSSION

The salient result of the presented phantom study is that effective needle guidance with approximately 3 mm accuracy was found to be feasible using CBCT guidance irrespective of the difficulty of the needle path. This contrasts with CT guidance, where the accuracy decreases significantly with increasing level of difficulty, resulting in deviations from target of up to 7 mm for the double angulated path. The level of experience in using CBCT is another factor influencing accuracy, as the results indicate a learning curve for more difficult needle paths. However, even the less experienced users achieved significantly better accuracies compared with CT-guided needle placements. The small but significant increase in accuracy for the experienced users of CBCT guidance between the angulated and double angulated needle paths is unsuspected.

Table 1. Overview of the achieved deviations from target (in millimetres) using CBCT guidance by the user experience level

Deviation from target (mm)	Trained users	Experienced users	*p*-value
Inplane	2.9 (1.5–9.3)	2.1 (1.0–3.8)	NS
Angulated	3.8 (2.0–6.0)	3.2 (1.7–3.9)	NS
Double angulated	3.3 (2.1–7.2)	1.8 (1.2–2.2)	0.003

CBCT, cone beam CT; NS, not significant.
Values presented as median (range).

A possible explanation for this finding might be that the perceived complexity of the needle path leads to needle placement with more care and attention. However, this was not observed in the trained user group. The significant difference might also be caused by the small spread in the observed accuracies.

This study shows no differences in needle placement time between CBCT and CT. The measured time is only an indication for the time needed to actually place the needle. Total procedure time in clinical practice comprises more aspects, such as patient preparation and treatment time. Kothary et al [17] reported that CBCT image reconstruction and review did not add significantly to total procedure time. Other authors have reported mean intervention times for different types of procedures of 10–30 min, with ranges from 3 to 96 min [6,15,23]. Our phantom study results are in the lower part of the range with 4–13 min for all needle placements.

This study is, to the best of our knowledge, the first to evaluate accuracy of needle guidance with regards to the level of complexity of the used needle path. Some authors have reported achieved accuracies using CBCT guidance in small patient groups to be <5 mm in most of their cases [9–11,13]; however, these groups are small and there is no or little information on the used needle paths. Nonetheless, this suggests that accuracies of around 3 mm can be reached in clinical practice also, irrespective of the complexity of the needle path and the user experience level.

Accurate needle placement is essential for effective treatment in local therapy. However, a minimal deviation from the target, in the order of a few millimetres, will not always affect the treatment outcome. A deviation of about 7 mm as observed in the case of the double angulated procedures using CT guidance, however, can be expected to impact the treatment outcome. For instance, the targeted small high contrast nidus in radiofrequency ablations of osteoid osteoma is most often <10 mm [11]. Here, as the ablation zone is approximately 2 cm around the needle tip, a deviation from the target point of >5 mm will result in partial treatment, or even worse, missing the nidus completely. Our phantom study results show that needle placement within 5 mm of the target point is most commonly achieved using CBCT guidance. We therefore suggest that these procedures are performed using CBCT guidance.

Some limitations in our study need to be addressed. As we used solid targets of 2.3 mm inside the phantom, the maximal experimental accuracy to be achieved was limited to 1–2 mm.

The radiation dose was not addressed in this study, partly because the small abdominal phantom used resulted in dose values that are not representative for patient care. Moreover, a comparison of effective patient doses between CBCT and CT guidance has already been provided by Braak et al [8] who reported a 13–42% dose reduction for CBCT guidance compared with CT guidance. However, when compared with CT, CBCT guidance likely results in a higher operator dose [24]. Therefore, appropriate shielding should be used [25]. To reduce the operator hand dose, needle guidance devices such as laser guidance can be used [26].

We have quantified accuracies of needle guidance using a model for high-contrast lesions. Clearly, the success of needle placement depends on the visibility of the target and surrounding tissues. Low-contrast targets are not always easily visible in CBCT images. Therefore, other methods of visualisation of the target tissue should be used. One method is contrast enhancement by administering a contrast agent. Another method is to bring images of other modalities into the angiography suite by image registration with prior acquired CT or MR images that do visualise the target and surrounding tissues [27].

As our study was a phantom study, all puncture conditions were optimised. In clinical practice, the conditions and the patient could result in increased deviation from the target. A factor influencing accuracy, irrespective of the guiding modality, is movement of either patient or target tissue. In CBCT-guided procedures, patient movement such as breathing results in a mismatch between the fluoroscopy overlay and the planned path on CBCT images. In our phantom study, this was not an issue, but in clinical practice, this is likely to influence procedure accuracy. For this reason, we are currently investigating methods that take into account breathing motions so as to improve accuracy of CBCT-guided needle placement in tissues affected by breathing.

CONCLUSION

In conclusion, CBCT shows significantly higher accuracy than CT in reaching small targets, requiring more difficult needle path approaches irrespective of operator experience.

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