SHORT COMMUNICATION

Intravenous pyelogram artefacts unique to digital tomosynthesis reconstruction

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ABSTRACT. Recent advances in technology have led to the realisation of digital tomosynthesis (DT) imaging in routine investigations such as intravenous pyelogram (IVP). The major advantage this technology has over other technologies is its ability to perform a retrospective reconstruction of an arbitrary number of coronal image planes from a single data set consisting of a series of low dose discrete projections acquired over a limited angular range using a stationary detector. It is well documented that because DT relies on an angular limited acquisition, the data set is incomplete. This, in combination with the image reconstruction algorithm, results in reconstructed images containing non-focused information from outside the immediate focal plane. This article describes and suggests the cause of two artefacts unique to DT that cannot be explained by blurring alone. We believe the two artefacts are caused by breathing during data acquisition together with a combination of other factors, including the anatomy of the renal system, the method of data acquisition and the reconstructive algorithm used. This could lead to the unaware reporting radiologist falsely diagnosing a duplex collecting system. To avoid these artefacts, we recommend DT IVP should only be used in patients who can adequately perform a breath-hold for the duration of the data acquisition. In addition, we suggest that the study should be performed with breath-held following expiration.

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Tomosynthesis relies on a series of two-dimensional (2D) radiographs acquired at varying angles to the object of interest. A coronal image plane may then be reconstructed from the 2D data by spatially translating each 2D image and superimposing each radiograph to an arbitrary reference. The magnitude of the translation of the 2D radiograph determines the height of the reconstructed coronal image plane. This relies on the fact that all objects at a particular height will suffer the same amount of parallax, while objects outside the plane of interest suffer varying degrees of parallax and contribute only noise to the image. This noise evidences itself as a series of discrete blurred versions of objects from out-of-plane structures, repeated at regular spatial intervals along the y -axis. The degree of blurring increases the further away from the plane of interest the object is. Furthermore, the magnitude and spread of these artefacts has been quantified using the artefact spread function (ASF) [1]. Much of the reported work has been in the attempt to reduce these artefacts with varying degrees of success. For example, Chekraborty et al [2], Van der Stelt et al [3], Lui et al [4] and Sone et al [5] in 1996 used high pass filters, and Sone et al [6] in 1991 used band pass filters to refine the resultant image.

For the sake of the article we will assume that the x -axis is a horizontal line on an anteroposterior (AP) radiograph and the z -axis is a vertical line, *i.e.* perpendicular and parallel to the spine, respectively. The y -axis is the depth in or out of the plane of the AP radiograph.

Description of the artefacts

A number of intravenous pyelogram (IVP) studies demonstrated apparent duplication of the renal collecting system in both the x - and z -planes in a selection of reconstructed focal planes. Figure 1a shows the image plane appearing to contain two in-focus high-contrast renal pelvises (A) and two discrete ureters (B). Similarly, the faecolith (C) in the right iliac fossa is duplicated in the reconstructed image plane.

As the observer scrolls through the image planes of the reconstructed data set, the duplicated structures in the z -plane appear to converge as shown in Figure 1b, ultimately reaching an image plane that contains no duplicated structures in the z -plane as seen in Figure 1c. The duplicated ureter in the x -plane persists in all images.

The standard planar (scout) images from the IVP series show only a single collecting system and ureter from each kidney. In addition, a CT data set obtained previously, for a separate clinical reason, was shown to

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Figure 1. Duplicated renal collecting system appearing to converge as the observer scrolls through the reconstructed data set of coronal images.

contain only one renal collecting system. An investigation was undertaken to try to obtain an explanation for this apparent duplication. At first, it appeared that both the renal pelvis and ureter duplications were caused by the same phenomenon and therefore could be described as one singular artefact. However, as discussed later in this article, we believe that their duplication has a different explanation. Therefore, this article treats the two duplications as separate artefacts.

It should be noted that these particular artefacts could not have been generated from out-of-plane structures owing to the fact these structures evidence themselves as a series of discrete blurred versions of the original object and not two well-focused similar objects, as seen in Figure 1.

Patients were required to hold their breath during raw data acquisition, but in a minority of cases this proved impossible for the patient, and in several of these data sets similar artefacts to those described above were observed. We believe the origin for the artefacts reported here is due to a form of movement. However, it should also be noted that patient movement tends to produce two distinct objects visible and separate on all reconstructed image planes, with an increase in blurring with object distance from the image plane, which is not seen in the case of the duplicated renal pelvises.

Thus, the investigation focused on an attempt to reproduce the artefacts artificially, and to examine separate movements in each of the three orthogonal planes as shown in Figure 2a.

Method and materials

We used a General Electric (GE, Buc, France) Volume-RAD system, which relies on the GE Definium 8000 digital X-ray system to acquire the projection images necessary for tomosynthesis reconstruction. Only the current clinical protocols were available to the authors,

which limited the number of variables that could be examined.

The clinical protocol was the IVP protocol, which involved taking 25 discrete image acquisitions over an angular range of 28.6°. A series of tomosynthesis images of a phantom were acquired using this clinical protocol. The phantom consisted of a cylindrical container, filled with water to a height of 150 mm and containing a length of 0.5 mm venflon tubing (Vygon connective tubing, Laboratoires Pharmaceutiques Vygon, Ecouen, France). The tubing contained approximately 15% contrast (Ultravist 300 (Bayer PLC, Newbury, UK)), which corresponded to the clinical protocol at our organisation. The phantom was placed 6 cm laterally (along the *x*-axis) to the central axis of the X-ray beam to mimic the anatomical location of the kidney in a patient positioned for a routine IVP.

Initially, the tubing was curved only in the *x*-*z* plane (2D) as shown above in Figure 2b and the container was moved 5 mm from position A in turn for all three orthogonal planes, Figure 2a shows this movement for *z*-axis translation, *i.e.* to position B. The movement took approximately 0.5 s and was performed roughly 2 s into the 5.4 s data acquisition time to mimic respiration.

Multiple blurred versions of the tubing in the direction of motion of the X-ray tube would be visible in reconstructed images if the movement of the tube was too slow. Therefore, the movement used in this investigation consisted of one short continuous motion so that the phantom would be in two distinct positions during the data acquisition, *i.e.* producing two discrete images of the tubing in each reconstructed image plane.

After acquisition, all images were retrospectively reconstructed using a slice interval of 5 mm, a sampling factor of 3 (SF3) and smoothed using the proprietary GE filter (Factory 2); again this is similar to the clinical protocol.

The above experiment was then repeated with movement in the *z*-axis only, together with the varying of the tube curvature in the *x*-*y* plane (3D) as shown in Figure 2c.

Figure 2. Diagrams show (a) experimental set-up with direction of induced motion, (b) phantom design with two-dimensional tubing and (c) phantom design with three-dimensional tubing.

Results

2D tubing

Phantom movement in the x - and z -axes resulted in duplication of the tubing in the x - and z -plane, respectively. Movement in the y -axis produced duplication in both the x - and z -planes.

3D tubing

A degree of convergence was seen for all tubing curvatures in the x - y plane. However, convergence from two discrete images to one single image was only seen for the largest curvature used. The results for this tubing curvature are shown in Figure 3.

Discussion

X -axis translation

Lateral movement or rotation of the patient to the lateral decubitus position during data acquisition resulted in duplication of all structures in the x -plane in our experimental data set. However, in the patient data set x -plane duplication was limited to the ureter; this implied that either the movement was not in this axis or that there was isolated movement of the ureter. Frequency of peristalsis is variable, recent dynamic studies quote a mean frequency of 3.5 waves per min [7]. The time taken to acquire a full IVP data set is 5.4 s, it is therefore possible that peristalsis occurred during acquisition; however, this is more likely to result in a contracted ureter in several of the raw projection images as the peristaltic wave

Figure 3. Coronal images of ureter phantom obtained at 20 mm intervals above the couch from reconstructed data set. (a) Two distinct upper ureters and renal pelvises. (b) Two distinct structures appearing to converge. (c) Two distinct structures overlap to appear as one single structure.

propagates the fluid bolus rather than a lateral translation of the ureter.

Y-axis translation

Anterior movement of the rib cage during inspiration can produce structure duplication in both the x - and z -planes. Examination of Figure 4 shows that images located along the central axis will show movement in the z -plane, while those located laterally to the central axis will increasingly evidence themselves as movement along the x -plane. We would therefore expect to find an in-focus object together with a blurred out-of-focus object in its subsequent out-of-plane position.

Therefore, assuming the X-ray beam is a point source, any movement of peripheral structures in the y -axis, such as the ureter, will be projected as two separate images in the x -plane in the reconstructed image. Consequently, the superficial structure will tend to be projected laterally to the underlying object, although it actually lies directly above it. This gives the false impression that the movement has occurred in the x -plane as shown above. Translation in the y -axis showed duplication of all structures in the x - and z -planes in our experimental data set. This was not the case with the patient dataset, which makes this scenario unlikely.

Z-axis translation

The descent of the diaphragm during inspiration will result in the caudal movement of the renal pelvis. This motion will also decrease the distance between the renal pelvis and bladder, resulting in a lax "kinked" ureter. We believe the superimposition of the straight expiration position ureter and the lax inspiratory position ureter gives the impression of two ureters wrapping round each other. Experimental evidence for this theory was not attempted as the stiffness of the tubing did not allow it to stretch and kink.

The caudal motion of the renal system in the z -axis during raw data acquisition accounts for the duplicated renal pelvis in the reconstructed planes. Careful examination of Figure 1 shows a very similar result.

Although the renal pelvis artefact is best explained with the descent of the renal pelvis during inspiration, it is unlikely that this movement occurred in isolation. It seems to be more plausible that there is a combination of scenarios, with caudal motion being the dominant factor.

Convergence

We have established that movement in the z -axis produces duplicate images of structures in the z -plane. However, the apparent convergence of a duplicated structure to a single structure is more complex. This phenomenon only occurred when a z -axis movement was coupled with tubing curved in both the x - y and x - z planes. Our experimental data suggests that there are two distinct images of the tubing in each reconstructed focal plane; however, for certain focal planes the tubing information overlaps to a varying extent giving the impression of convergence to one distinct structure. We believe this occurs owing to different parts of the tubing experiencing different levels of parallax owing to the varying height of each part of the tubing from the detector face.

Conclusions

This study provides possible explanations together with associated empirical evidence for how a confirmed single renal collecting system can appear to be both a single and duplicated structure depending on the observed image plane. We believe this is due to a combination of method of data acquisition, reconstruction algorithm, patient anatomy and patient movement (primarily respiration).

Approximately 1 in 10 patients referred to our unit for this procedure were unable to hold their breath during

Figure 4. Diagram showing apparent lateral movement from anterior movement.

data acquisition. All these patients demonstrated the translation component of the renal pelvis artefact in isolation, albeit to a varying degree. Both the translation and converging components have to date only been identified in a single patient.

Neither component of the renal pelvis artefact has been seen when movement during acquisition was not witnessed.

These artefacts are unique to DT and are not seen in conventional tomography. This is because, as described above, DT can reconstruct coronal image planes at arbitrary heights by manipulating the discrete projection images from a single data set. If this data set was acquired with patient movement, the artefacts generated from this movement will be apparent in all reconstructed images. However, a series of, for example, five coronal image planes obtained using conventional tomography will require five separate data set acquisitions (each consisting of a single projection taken with one continuous sweep of the X-ray tube), and patient movement during a single acquisition will not have an impact on previous and/or subsequent acquisitions.

Awareness of DT artefacts is important to practitioners switching from conventional tomography to DT.

To provide images with maximum clarity of the ureters, *i.e.* in their fully stretched position, and to obtain reconstructed images without the artefacts described above, we recommend that data are acquired with the patient holding their breath following full expiration rather than full inspiration. Patients who are unable to

hold their breath may prove to be unsuitable for examination with this technique.

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