Artifacts in helical CT images

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I. Introduction

Single-slice volume CT has been used successfully in many body CT imaging applications ever since its introduction in1990. But in single-slice volume CT, the volume coverage speed performance is limited, especially in clinical applications that demand large volume scanning with critical timing requirement and optimum image quality (z axis resolution and low image artifacts), such as CT angiography with 3D, multi-planar reconstruction (MPR), and maximum intensity projection (MIP) techniques. Besides, the time duration for covering defined volumes in single-slice volume CT (several seconds) is limited by several factors, such as the ability of some patients, particularly those who are critically ill, to maintain a single breathhold during volume scanning, and the heat loading of the x-ray tube. Therefore, other methods are needed to overcome these limitations.

Spiral CT improves speed performance that acquires volume images in a short exposure time. It has offered a true 3D imaging ability and thus provided new applications such as CT angiography. But artifacts as conventional CT still exist in spiral CT such as beam hardening artifacts, sampling artifacts. In addition, partial volume artifacts are exaggerated in spiral CT because of slice sensitivity profile degradation.

I am going to discuss the differences between conventional CT and spiral CT. And then I will introduce several artifacts arise from spiral CT and some of the solution for these problems.

II. Conventional CT and Helical CT

According to the description of Bushburg (1), etc. There are mainly seven categories of geometrical design in CT:

First generation: rotate/translate, pencil beam with one detector

Second generation: rotate/translate, narrow fan beam, multiple detectors

Third generation: rotate/rotate, wide fan beam

Forth generation: rotate/stationary, with detector ring

Fifth generation: electron beam CT

Sixth generation: helical (or spiral) CT

Seventh generation: multiple detector array

Detail introduction can be found in many books. (1,2)

The helical CT scanner acquires data while table is moving (Fig1). The detector designs can be like third or fourth generation. Because of saving time in moving table between separate exposures, it saves a lot of time acquiring a set of scanning data. Some of the examination can be done during a single breath-hold that reduces inconsistency comes from inspiration.

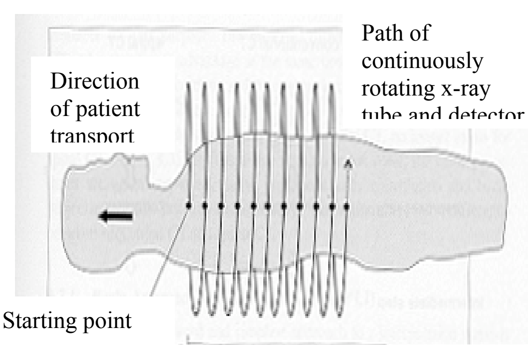

Fig. 1 Scanning principle of helical CT (3)

Because the patient moves continuously through the Gantry for a 360-degree rotation, the reconstructed image will be blurred with only the same filtered back-projection algorithm as conventional CT. That's why we should interpolate our image data before the filtered back-projection is used. This process leads to a higher noise level and artifacts such as stair-step artifact. Although the inconsistency of data arises from the acquisition can be reduced by interpolation, some inconsistency will remain exist because the cross section of an object in the scan plan may change in the longitudinal direction. It will cause some image artifacts like the changes of diameter of skull.

In the following discussion of artifacts arise from CT, I am going to focus on the unique artifact produced by helical CT, stair-step artifact, and focus on the technique related factor that can reduce stair-step artifacts.

III. Patient motion Artifacts

Motion can be voluntary or involuntary. One of the images with motion artifacts has been shown on Fig.2. No matter which kind of motion we are dealing with, the most efficient way to reduce motion artifact is to reduce our scanning time. Although it has been achieved by helical CT, the effort of reducing patient motion artifacts is still making. Methods to reduce patient motion artifacts include patient immobilization, ECG gated CT, and some correction algorithms.

Fig.2 Motion artifact (3)

IV. Metal Artifacts

Metallic materials such as prothetic devices, dental fillings, surgical clips, and electrodes produce streak artifacts on the image. (Fig.3) Several methods have been provided to remove the artifacts come from metal. One of them is metal artifact reduction (MAR) by using threshold values to define metal images and interpolate missing images to reconstruct a new image data. This method of threshold technique can also be used in reducing artifacts result from arterial wall calcification (5).

Fig.3 Metal artifact (4)

V. Beam Hardening Artifacts

Beam hardening is a phenomenon results from the increase of mean energy of the x-ray beam when it passes through object. Therefore, the CT numbers of certain structures change and induce some artifacts. This kind of artifact can be reduced or eliminated with a filter that ensures the uniformity of the beam at the detectors.

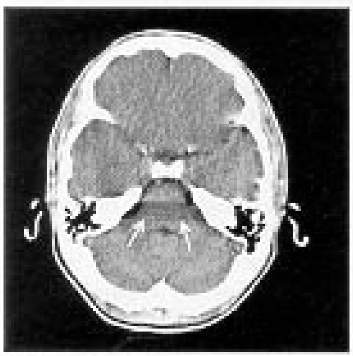

Fig.4 Beam hardening artifact. The density of tissue behind dense bone changes because of beam hardening artifact. (3)

VI. Partial Volume Artifacts

Partial volume artifacts arise when a voxel contains many types of tissue. It will produce a CT number as an average of all types of tissue. This is the source of partial volume effect and will appear as bands and streaks. (Fig.5)The posterior cranial fossa is the most critical region to produce partial volume artifact.

Using thinner slice and some computer algorithms can reduce partial volume artifacts.

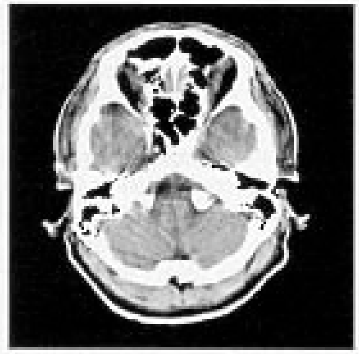

Fig.5 Partial volume artifact (3)

VII. Stair-step Artifacts

Apart from the well-recognized effects on the section-sensitivity profile and average image noise, the particular geometry helical CT causes complex periodic asymmetries and inconsistencies in the volumetric data sets that give rise to less-recognized effects such as variable noise distribution and section thickness a cross the transverse plane and longitudinal aliasing. These phenomena appear as artifacts on transverse images and as stair-steps, or strips (zebra artifact) on multiplanar reformation or 3-D rendered images. (Fig. 6)

One of the studies talking about stair-step artifact has a detail analysis about the effects of acquisition parameters and object position on the magnitude, frequency, and subjective appearance. (6)

In the analysis of the report, the height (in the longitudinal direction) of stair-step artifacts arising from 45^0 inclined objects is directly proportional to the distance between samples of projection data in the longitudinal direction, which equals half the TI (table index) when a 180^0 linear interpolation algorithm is used and when the reconstruction interval is sufficiently small (no more than 1/2 TI) Accordingly, artifacts are directly proportional to the beam collimation with constant pitch.

The definition of pitch is that beam width (mm) divided by TI (mm per gantry rotation), which is the number of 360^0 tube rotations, also means table speed. A higher pitch results a looser helical scanning data, which will induce more inconsistency between scanning plan. From the experiment data in this paper, for a given TI, 1.0 and 2.0 pitches yield a comparable artifact magnitude, while 1.0 is slightly preferable. But pitch 3.0 increases artifacts dramatically.

When the object scanned is positioned off the isocenter of the scanner, the height of the stair-steps is around doubled the TI distance. That is to say, position in the isocenter can help reduce stair-step artifacts a lot. And as pitch increases, the relative increase in artifacts when scanning off center diminished.

This experiment also includes four-channel helical CT. And the results is that the single–channel helical CT performance is always bigger than four-. Especially when the size of stair-steps is compared between single- and four- channel helical CT, single-channel helical CT has about three times larger stair-steps arising form inclined objects than does four-channel helical CT for any given TI as long as the object is located at or close to the isocenter.

As we can see that artifacts are proportional to TI, there is a tradeoff between the maximum covered volume and the occurrence of artifacts, particularly in anatomic structures that are located off the isocenter. And the scanning time may last longer because of smaller collimation to achieve smaller artifact.

All of the results show that a fully consideration about the scanning technique should be taken into account when we are trying to scan a patient.

Fig. 6 A) Streak artifact. B) Correction of the artifact by adaptive filtering.(4)

References:

VIII. Conclusion

Although the invention of helical CT has improved the image quality and capability a lot, its disadvantage resulted from artifacts is still a problem that needs to concern about. The operator dependent characteristic appears that the education of technician is also an important aspect in reducing artifacts.

References

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