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# Variations in slice sensitivity profile for various height settings in tomosynthesis imaging: Phantom study

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ABSTRACT

Understanding the properties of slice sensitivity profile (SSP), or slice thickness, is crucial for an accurate and highly reproducible diagnosis using tomosynthesis imaging. The objectives of the present study are therefore to quantitatively evaluate how the SSP with the use of a small metal bead is affected by different settings of the height from the table and the height of the center of rotation (COR) in tomosynthesis imaging except for the digital breast tomosynthesis, and visually verify the effects on tomosynthesis images. The reconstruction filters used were three types of filtered back-projection and iterative reconstructions. The SSP was measured from the full width at half maximum (FWHM-SSP) of the profile curve of the bead in the perpendicular direction (z direction) relative to the table. Two types of anthropomorphic phantoms simulating the human body, with bones and soft tissues, were used to study the effects of different settings for the COR height. In all reconstruction filters, the FWHM-SSP changed as the height of the bead varied when the bead and COR were set to the same height from the table. If the bead and the COR were set to different heights, the FWHM-SSP increased (decreased) when the height of the bead was set to be greater (less) than the height of the COR. These changes were also confirmed on the anthropomorphic phantom images of the bones and soft tissues.

## 1. Introduction

Tomosynthesis imaging is a digital tomograpic technology [1] that enables the acquisition of tomographic images of three-dimensional anatomical structures in the human body with the focal point aligned to any plane chosen that is parallel to an examination table. It was first reported in 1972 by Grant [2], as an improvement to the conventional tomographic technique reported by Plantes in the 1930s [3]. Since entering the 1990s, technical innovations and the development of flat panel detector (FPD) enabled the investigation of full-fledged clinical applications of tomosynthesis imaging. Currently, general radiography devices, x-ray fluoroscopic imaging system, and mammography devices that are capable of tomosynthesis imaging have been introduced in many facilities [4]. Tomography with conventional x-ray film can only acquire a tomographic image of one slice at a time; if tomographic images of multiple slices are needed for examination, it is then necessary to either use simultaneous multisection tomography—where images are captured with x-ray intensifying screens and x-ray films layered over one another—or to capture x-ray images multiple times with different tomographic planes. With tomosynthesis imaging, however, tomographic images of multiple different slices can be obtained in a single scan, centered on any height chosen from the table. The advantages include lower patient radiation doses compared to computed tomography (CT) [5,6], and the ability to better mitigate the effects of metal artifacts than with CT or magnetic resonance imaging (MRI). Tomosynthesis has been described as useful in reports on many different aspects, such as mammography [7–9], chest imaging [10–13], orthopedic surgery [14–19], and radiation treatment planning [20].

Tomosynthesis imaging entails imaging while simultaneously moving the x-ray tube and x-ray detector in opposite directions. The point that forms the center of the angular range, which is formed between the start and end points of irradiation with the x-ray tube and x-ray detector, is called the center of rotation (COR). Although the height of the anatomical structure of interest is already known prior to examination, imaging is preferably performed with the COR set to that height [21]. For example, when tomographic images of the lumbar

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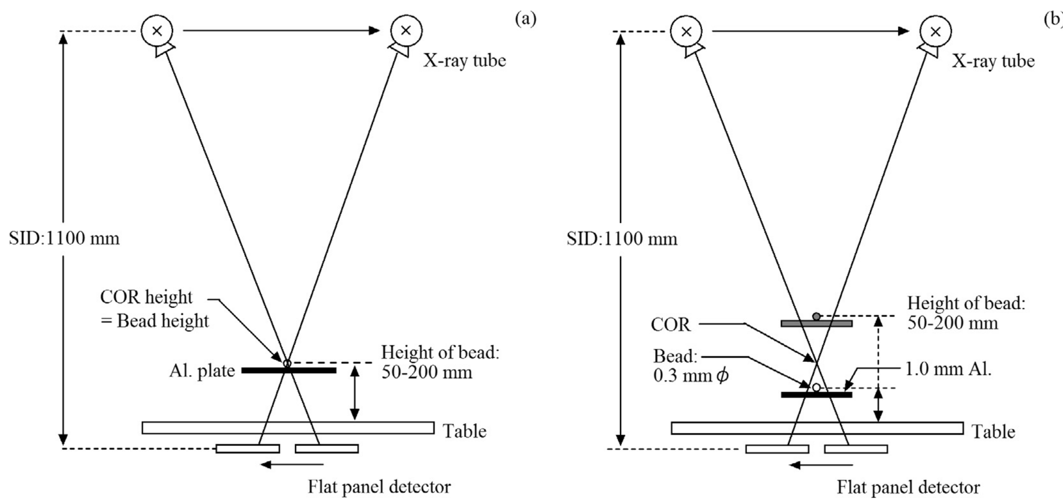


**Fig. 1.** Geometry for data acquisition in case of (a) the height of the bead match the COR and (b) the height of the bead in the image do not coincide with the COR.

spine or sternum are to be captured from a patient in the supine position on the table, the COR is set to 5 cm or 15 cm, corresponding to the respective heights from the back from the table. If, however, the height from the back where an anatomical structure is located is not known, or if multiple regions of interest with different heights exist, then it is clinical practice to set the COR to a height that is half of the thickness of the subject. Tomosynthesis imaging thus offers the ability to acquire tomographic images of anatomical structures at the same height as the COR, or even of slices of a different height from the COR.

The slice sensitivity profile (SSP) is often used to describe a system's resolving power in the perpendicular direction with respect to the reconstructed planes (z resolution), and the full width at half maximum of SSP (FWHM-SSP) is evaluated as the slice thickness. Although the SSP is one of the most important image quality metrics for tomosynthesis, cautious investigation is required for this analysis. In theory, the SSP can be measured via imaging a small metal bead whose size is significantly smaller than the slice thickness of the acquisition system [24]. The previous study evaluated the SSP using a small bead with 0.3 mm in diameter [30]. Moreover, the structures at other depths (out-of-focus) generate artifacts in the different reconstructed planes owing to the limited angular range and number of projections in tomosynthesis imaging. Several studies have been evaluated regarding this type of artifacts using artifact spread function (ASF) [22–26].

In the digital breast tomosynthesis (DBT) systems, the most comprehensive quality assurance (QA) and a quality control (QC) protocol has recently been proposed by the European Reference Organisation for Quality Assured Breast Screening and Diagnostic Services (EUREF) [27]. Moreover, specific QC protocols for DBT have been reported in different screening programs [28,29]. In these reports, the image quality factors such as the SSP and the ASF had been evaluated in DBT. However, there are no specific guidelines for QA and QC in chest and bone tomosynthesis that is provided in general radiography and/or fluoroscopic imaging systems. In addition, the geometry of motion of the x-ray tube and/or detector is different between DBT system and general radiography and/or fluoroscopic imaging system. Therefore, it is necessary to evaluate the image quality even in these systems other than the DBT system.

The SSP in tomosynthesis imaging depends on not only on the angular range but also on the image reconstruction algorithm. An accurate knowledge of the properties of the z resolution is significant because radiological technologists have to set the optimal conditions such as setting the COR and selecting the image reconstruction algorithm for the imaging. It is also important that the clinical radiologists interpreting the images should understand the properties of the z resolution for the imaging. Understanding the z resolution is therefore important from the point of view of the radiological technologists as well as administrators who operate the system. In previous studies regarding evaluating the z resolution in tomosynthesis imaging [23–26,30], the SSP was measured with the height of the COR set to match the height from the table. To our knowledge, none have reported studies regarding the SSP in various combinations from the height of the table and the height of the COR. Moreover, no investigation regarding the z resolution or slice thickness has been reported using anthropomorphic phantom that approximates clinical practice.

The objectives of the present study are therefore to quantitatively evaluate how the SSP with the use of a small metal bead is affected by different settings of the height from the table and the height of the COR in tomosynthesis imaging except for DBT, and visually verify the effects on tomosynthesis images. We used anthropomorphic phantoms for chest and bones (orthopedic area) for evaluating tomosynthesis imaging except for breast imaging.

## 2. Materials and methods

### 2.1. Image acquisition

The tomosynthesis imaging system used was the SONIALVISION G4 (Shimadzu Corporation, Kyoto, Japan), which can acquire two-dimensional projected digital radiographic images, fluoroscopic images, and tomosynthesis images. The x-ray detector was a cesium iodide indirect conversion-type FPD, with a pixel size, effective number of pixels, and detector surface area of $0.139 \times 0.139$, $2880 \times 2880$, and $432 \times 432\,\text{mm}^2$, respectively. The pixel size of the tomosynthesis image is $0.278 \times 0.278\,\text{mm}^2$, owing to pixel binning during image reconstruction. The source-to-image receptor distance (SID) of the tomosynthesis imaging is 1100 mm. The angular range used for the tomosynthesis imaging was 40°—which is commonly used in clinical practice (such as head, thoracoabdominal, or limb images)—as well as 20° in some of the experiments. The projection time for acquiring the tomosynthesis images is approximately 5 s, for both angular ranges of 40° and 20°. A stainless-steel bead (simply called “the bead” hereafter) with a diameter of 0.3 mm was used to measure the SSP of tomosynthesis images. Fig. 1 and Table 1 show the geometric arrangement and acquisition parameters, respectively, for acquiring the tomosynthesis images.

The SSP of tomosynthesis image was evaluated by measuring the SSP with the same height as that of the COR, modified within a range of 50 mm–200 mm over the table (Fig. 1(a)), and with the COR and bead set to different heights (Fig. 1(b)). In these experiments, the bead height was changed 50 mm at a time, and the measurements taken with the