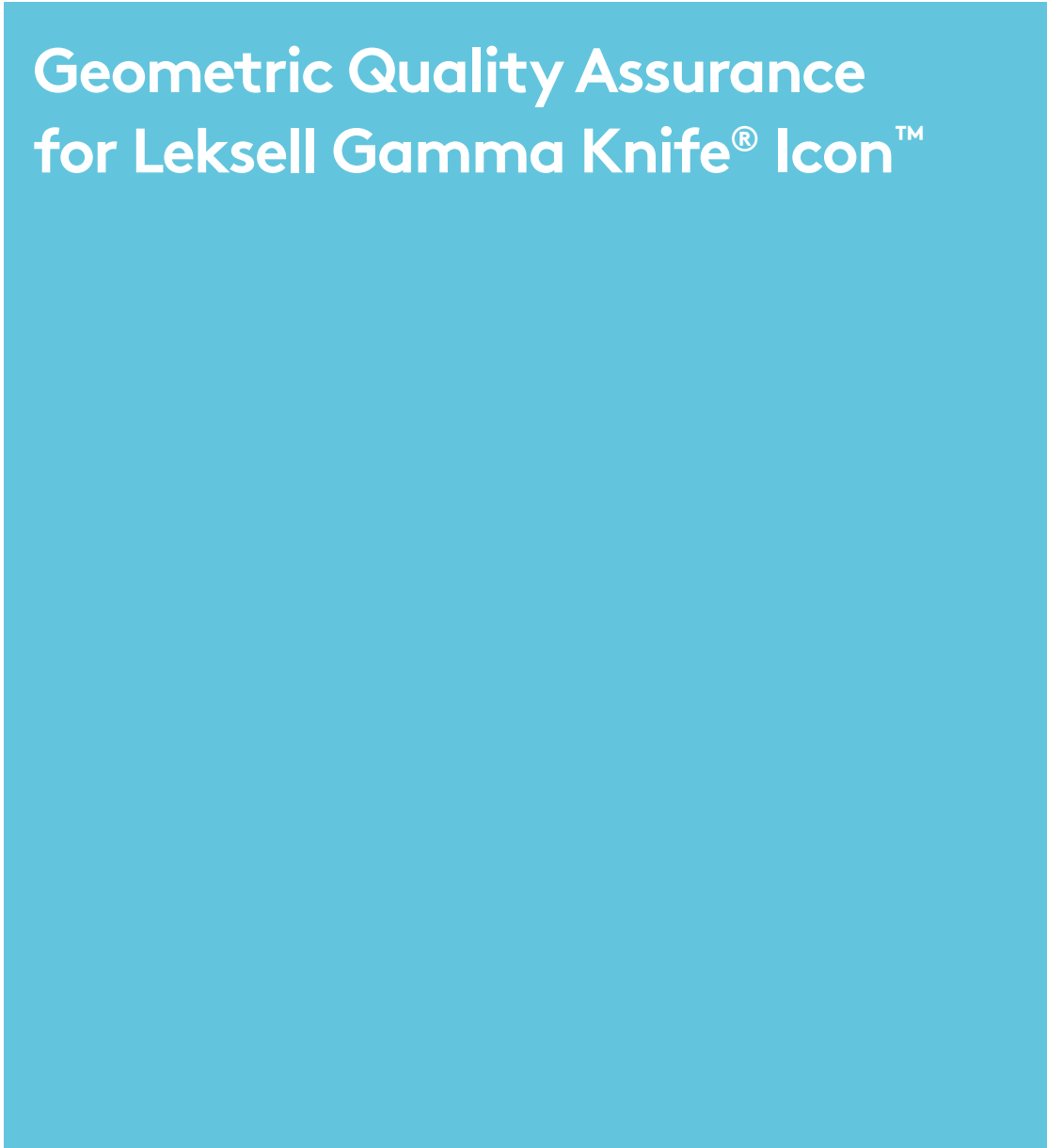
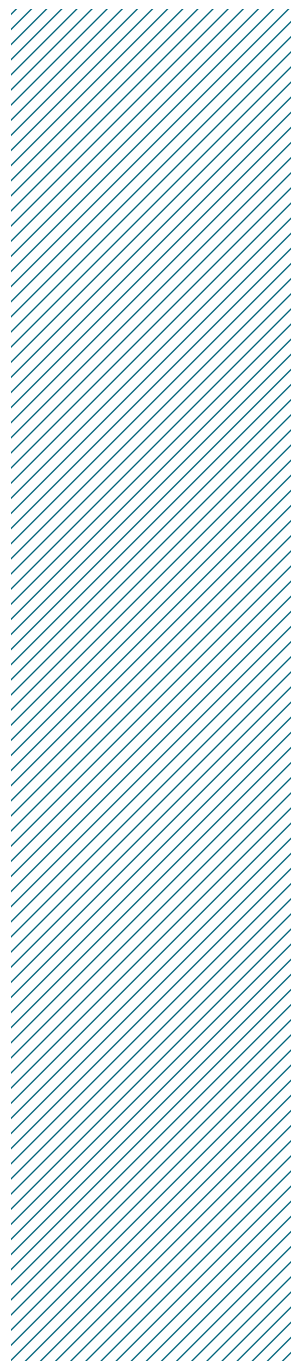
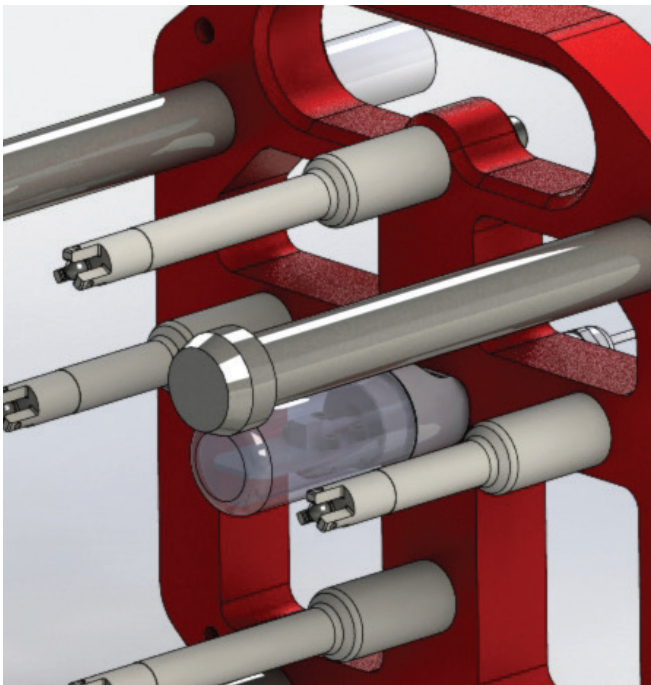


White Paper

Geometric Quality Assurance for Leksell Gamma Knife[®] Icon[™]





Introduction

To ensure the geometric accuracy remains constant over time for Leksell Gamma Knife® Icon™, two QA procedures are used: the focus precision QA that ensures accuracy of the patient position system (PPS) relative to the radiation focus; and, the CBCT precision QA that ensures the accuracy of CBCT image position relative to the PPS. These are the only QA procedures required to ensure the geometric accuracy of the system.

Both procedures work in a similar way: The baseline is set during calibration of the system, and the QA procedures check the constancy of the geometric accuracy and do not require much user interaction.

This paper describes the tool, principle and algorithms for the Leksell Gamma Knife Icon (Icon) geometric QA procedures.

Background

Leksell Gamma Knife Icon has a patient positioning system (PPS) which moves the patient into the radiation focus with high accuracy. The PPS has a frame fixation related to a stereotactic coordinate system, the Leksell® coordinate system. At installation the Leksell coordinate system is calibrated in relation to the radiation focus. In order to ensure that the calibration remains constant over time a focus precision quality assurance (QA) method is used. The purpose is to verify the radiological focus position in relation to the Leksell coordinates.

The QA is performed by scanning a diode along the major axes by moving the PPS using the 4 mm collimator. The profiles acquired with the QA tool are normalized to the diode signal at the Leksell coordinate (100,100,100) and used to measure the difference compared to the system calibration.

With Icon a cone beam computerized tomography system (CBCT) is introduced to determine a stereotactic localization of the patient using

imaging. The localization of the CBCT images is calibrated to the Leksell coordinate system for a given CBCT scanning position.

To ensure the calibration of the CBCT precision, a QA procedure is used to verify that the stereotactic coordinate system determined by the CBCT system corresponds accurately to the Leksell coordinate system—i.e., that the mapping of the image and the PPS frame fixation is accurate. When performing the CBCT precision QA, a QA tool with known objects and known positions is used. This tool is scanned with the CBCT system and the coordinates of these objects are determined in the Leksell coordinate system. This is made with a dedicated function in the Icon control system. These coordinates are compared with the coordinates determined during calibration of the tool, performed during installation or maintenance of the system.

These QA procedures are all that is required to ensure and maintain the geometrical accuracy of the system. Both QA methods capture geometrical errors that have occurred since the last system calibration. For an illustration see Figures 1 and 2.

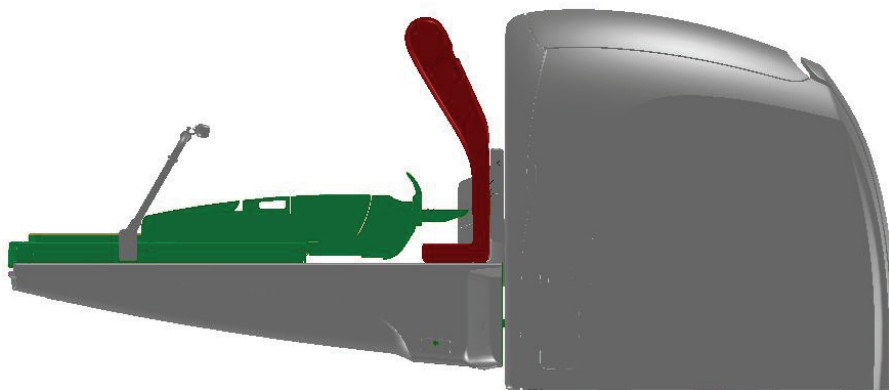


Figure 1.

PPS (green) in scan position. The CBCT precision QA ensures that the geometric relation between reconstructed images taken with the CBCT system (red) and the PPS in scan position remains constant over time.

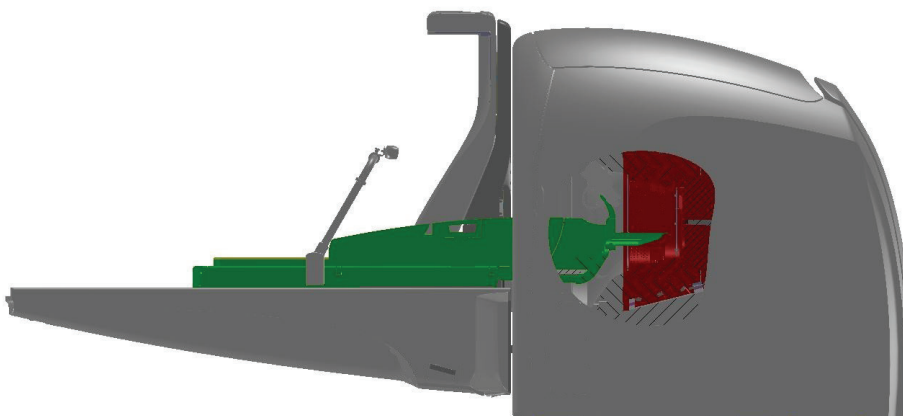
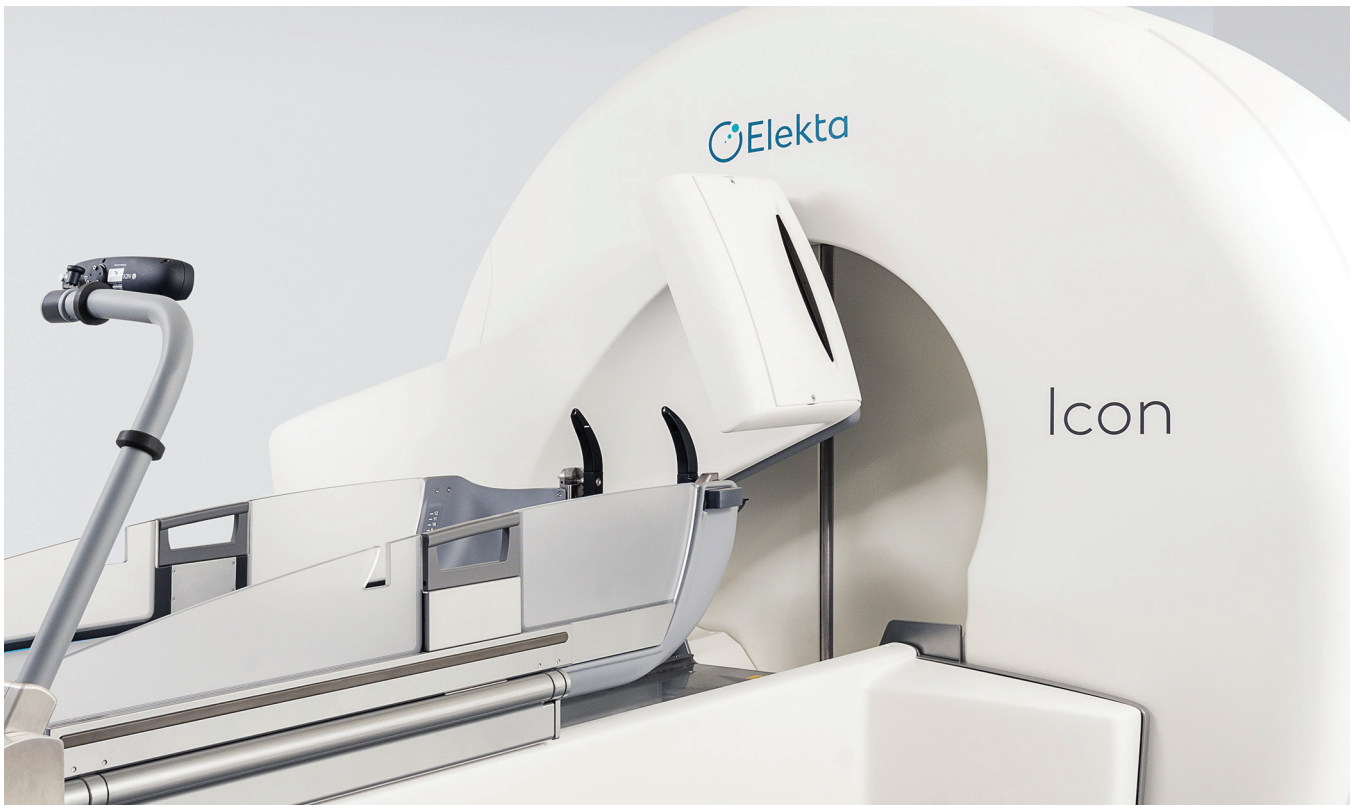


Figure 2.

PPS (green) in treatment position. The focus precision QA ensures that the geometric relation between the focus of the radiation unit (red) and the PPS in Leksell position (100,100,100) remains constant over time.



Icon QA tool

One tool is used for both the focus precision QA and the CBCT precision QA (see Figure 3). The focus precision QA uses a diode sensitive to gamma radiation that is placed at the center of the tool. During the QA procedure, the diode is moved along the x, y and z axes when irradiating with a 4 mm isocenter. This gives a signal with steep gradients corresponding to the shape of the focus, and the radiation center position is calculated by measuring the signal at the flanks.

The CBCT precision QA uses four steel ball bearings (BBs), each 4 mm in diameter and placed so they do not shadow each other or the focus precision diode in the projection images during x-ray radiation. The BBs are distanced from each other to cover a large part of the reconstructed volume. They are also placed so three BBs positions are not colinear. There are four rods on the QA tool, used for protection and for a clearance procedure. This is not discussed in this paper. The algorithms used for the precision QA procedures are discussed later in this paper.

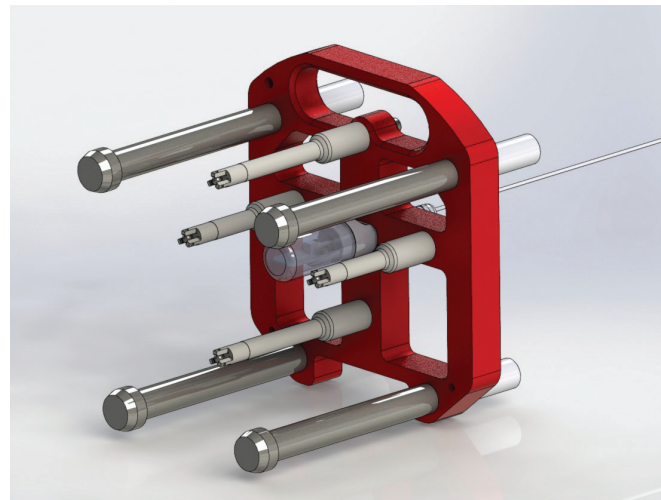


Figure 3.

The Icon QA tool. At the center there is a radiosensitive diode for the focus precision QA. Each of the four rods holds a steel ball bearing, used for the CBCT precision QA. There are also four rods used for protection of the internal structures.

Focus precision QA

Initial calibration of the focus precision QA tool

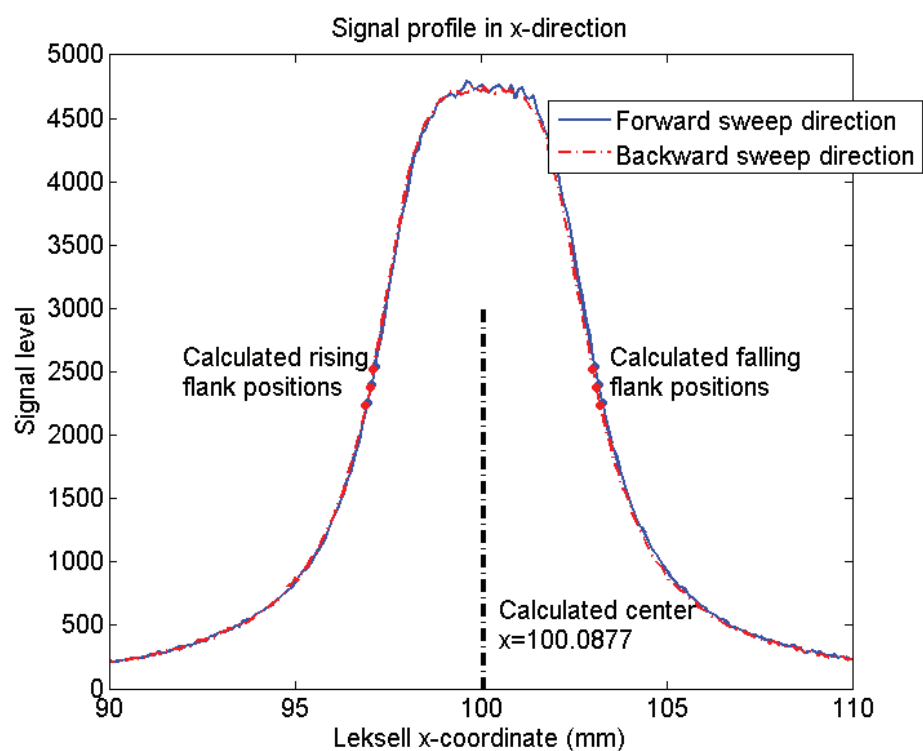
The prerequisite for a calibration of the diode in the QA tool is a calibrated Icon system. The QA tool is calibrated by finding the radiation focus with the diode. Since there is a manufacturing tolerance of the diode and the position of the diode, the exact position of the sensitive area of the diode is not known. By scanning the diode and using the algorithm described below, an offset parameter is found. The offset is applied to all subsequent focus precision QA measurements so the Leksell coordinate (100,100,100) is measured to see if the system is perfectly constant. The initial calibration is performed by a service engineer during calibration and maintenance of the system.

Algorithm

The diode is moved through the 4 mm radiation focus in the x, y and z directions giving three profiles. For each profile the positions of the 47%, 50% and 53% levels relative to the maximum value of the profiles are found on the rising and falling edges. The process is repeated by moving the diode through the focus in the reverse direction. For each coordinate direction this gives 12 positions, and the mean of these positions for each coordinate direction gives the radiation focus position. See Figure 4 for an illustration.

Figure 4.

The signal from the diode when scanning the 4 mm isocenter back and forward in the x direction. An algorithm finds the positions of the 47%, 50% and 53% levels relative to the maximum signal value on the rising and falling edges of the two profiles, 12 points total. The mean value of the 12 points gives the isocenter in the x direction.



Each time QA is performed the algorithm calculates the radial distance between the measured position and the position (100,100,100).

CBCT precision QA

Initial calibration of the CBCT precision QA tool

The prerequisite for calibration of the BBs, used in the CBCT precision QA procedure, is a calibrated Icon and a calibrated CBCT system. The positions of the BBs are found using the algorithm below. In order to minimize user interaction and thus have a fully automatic algorithm, the positions of the projected steel ball bearings in the first projection image are stored as well. This is explained below. The initial calibration is performed by a service engineer during calibration and maintenance of the system.

Algorithm

The goal of the algorithm is to find the position of the QA tool BBs in a CBCT reconstructed volume. Using reconstructed images to determine the position of the BBs can be a problem due to reconstruction artifacts, especially if the BBs are made of a high attenuating material. Instead the algorithm is based on projection images from a CBCT scan in which each of the projected BBs is clearly visible.

To find the position of the projected BBs in the first projection image, stored reference positions of the projected BBs are used. (The reference positions are stored during calibration of the system.) For each BB the centroid is calculated in a sub-region centered in an estimated start position. The sub region is large enough to include large geometric uncertainties but small enough not to include neighboring BBs or the diode. The centroid gives the 2D position of all projected BBs in the first projection image. Comparing a consecutive series of projection images, the BBs will move along elliptical paths in relatively small steps. The movement between two consecutive projection images is small enough to use a simple tracing algorithm. To calculate the BB positions in the next projection image a sub region is centered around the found position in the previous projection image. This gives a third requirement for the sub

region size and that is large enough to include the position of the BB in the following projection image. Repeating the process for all projection images gives the 2D position of all BBs in all projections.

To find the 3D position of the BBs, the same geometric information as in the CBCT reconstruction algorithm is used. Knowing where the detector is for each projection image and knowing where on the projection image the BBs are projected, a 3D position can be assigned to each projected BB on the detector. Simultaneously knowing the position of the x-ray tube for each projection image, a 3D line can be drawn in space between the x-ray source and the projected BB on the detector. If the lines for the same BB are drawn for all the projection images in a scan, the set of lines will form a sheaf (see Figure 5).

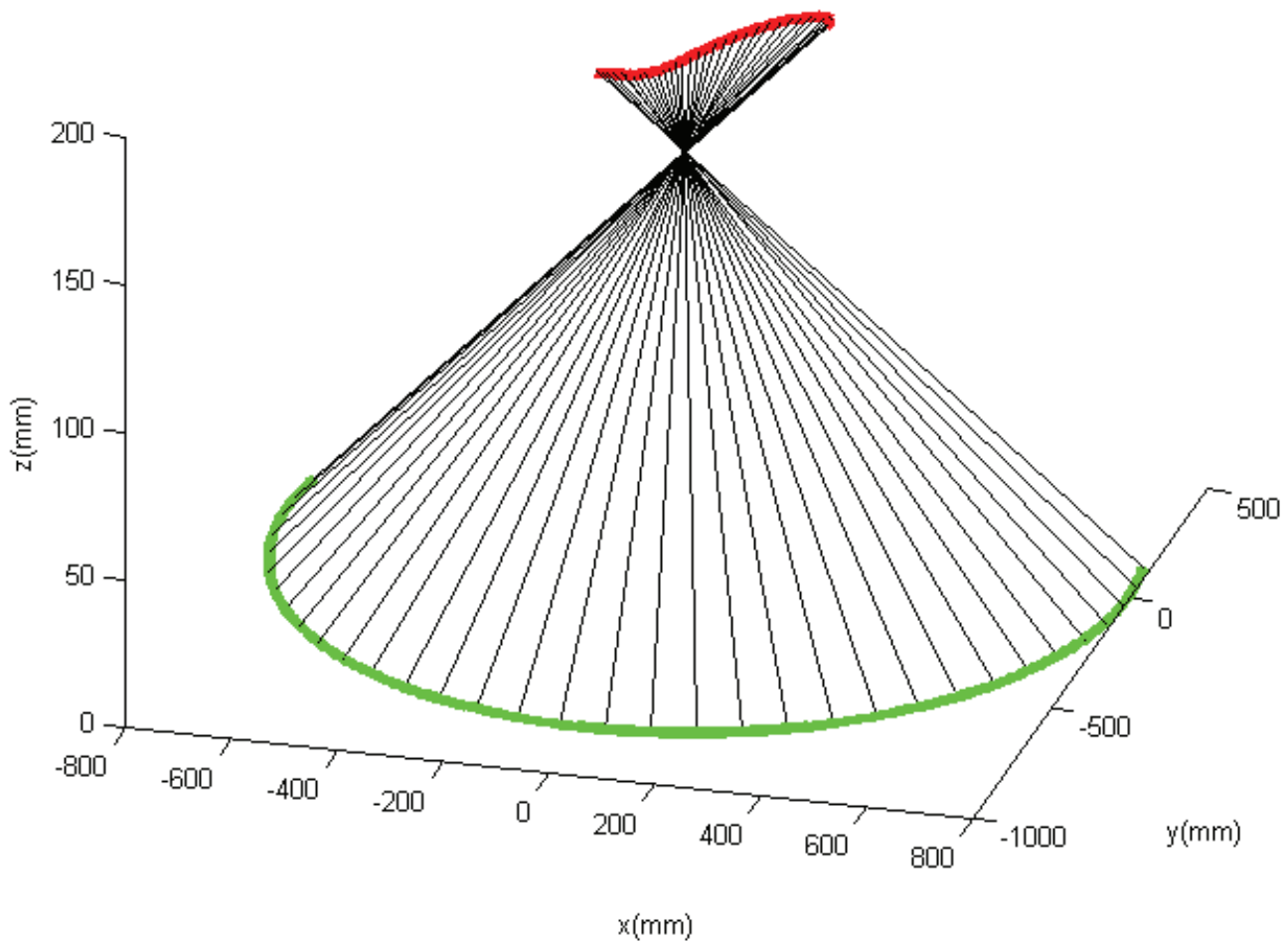


Figure 5.

Principle of determination of BB position in 3D. Green is the path of the x-ray tube and red is the path of the projected BB in 3D. Lines are connected between the spot and BB positions for each c-arm angle. The point closest to all lines is calculated using least square algorithm.



In a perfect system all lines will meet in a point which is the position of the BB in 3D. But due to flex and noise and other imperfections, this is not the case. Instead, the point that minimizes the sum of square distance to all lines is used as the position of the steel ball. This method mimics the geometrical properties of the reconstruction algorithm. By repeating the process for each of the BBs, all four 3D positions are determined.

Error measure

At installation of the CBCT system the reference positions of the BBs are determined. When the CBCT

precision QA is performed, a rigid transformation between the measured BBs and the reference BB positions are found using a least squares algorithm.

Test points evenly distributed in the image volume are then transformed using the found transformation. The maximum deviation between the test points and corresponding transformed test points gives the deviation. The software view on how the deviation is presented can be seen in Figure 6.

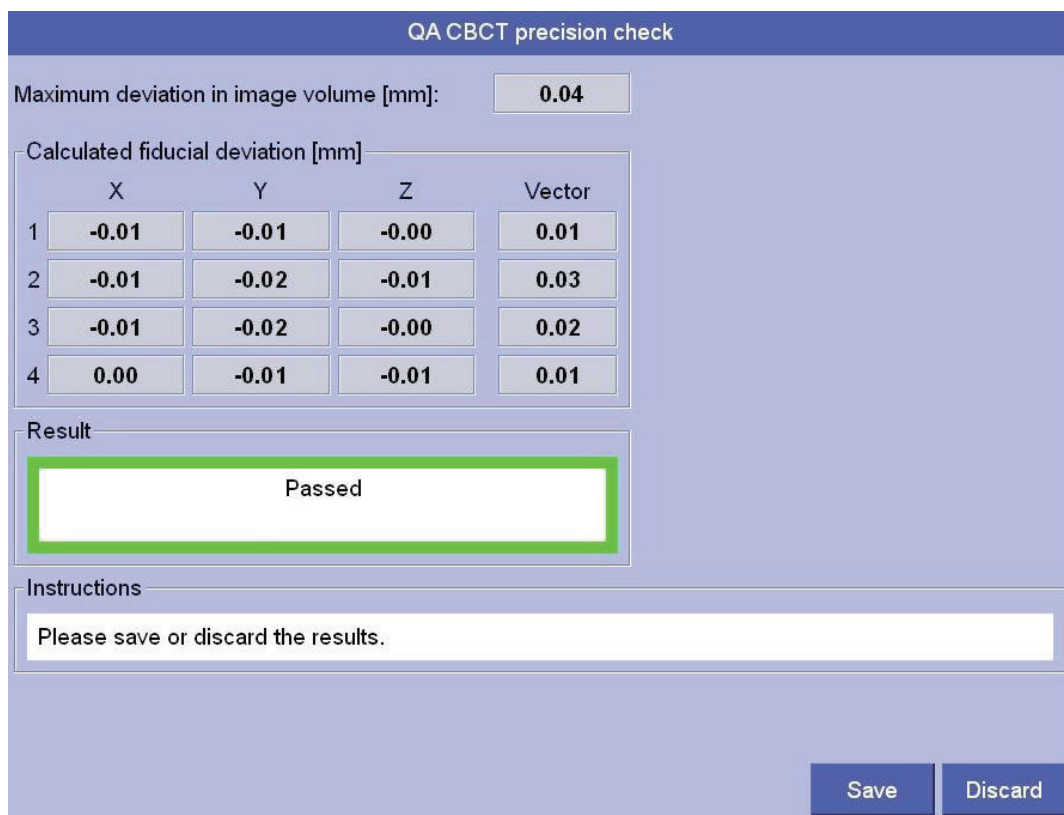


Figure 6. View of CBCT precision QA tool in software. The maximum deviation is presented on the top line.



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Elekta Offices

Elekta AB

Box 7593
SE-103 93
Stockholm, Sweden

T +46 8 587 254 00
F +46 8 587 255 00

Europe

T +46 8 587 254 00
F +46 8 587 255 00

Turkey, India, Middle East & Africa

T +90 216 474 3500
F +90 216 474 3406

North & Central America including the Caribbean

T +1 770 300 9725
F +1 770 448 6338

South America & Cuba

T +55 11 5054 4550
F +55 11 5054 4568

Asia Pacific

T +852 2891 2208
F +852 2575 7133

Japan

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