ELEKTA

Position accuracy analysis of the stereotactic reference defined by the CBCT on Leksell Gamma Knife® Icon™

WHITE PAPER

Introduction

An image guidance system based on Cone Beam CT (CBCT) is included in Leksell Gamma Knife® Icon™. The imaging system is designed to be used for setting the stereotactic reference and to verify patient positioning for treatment. Using the CBCT system for defining the stereotactic reference puts high demand on the accuracy as well as repeatability of the system.

Method

To determine the accuracy of the stereotactic reference a propagation analysis is performed. In this analysis, each subcomponent of the imaging and radiation delivery systems is measured and modeled.

There are several components that contribute to the uncertainty, e.g. mechanical tolerances, calibration tool uncertainties and algorithmic sensitivity to non-ideal input.

The model is compared to the real system where a specifically designed end-to-end tool is used to determine the geometrical accuracy of the system.

The analysis is limited to the accuracy of the CBCT as a stereotactic reference. Uncertainties in co-registration, other imaging modalities and planning are excluded from the analysis.

CBCT to Leksell® coordinate transform

The CBCT image volume defines the stereotactic Leksell coordinates in a treatment plan, therefore this puts high requirements on accuracy, calibration and system repeatability.

To find the transform between the un-calibrated CBCT image and the radiation delivery system, a special calibration tool has been developed, see Figure 1.

The tool has six ball bearings with measured coordinates in the Leksell coordinate system. The tool is scanned by the CBCT system. To avoid reconstruction artifacts, an algorithm that uses projection images of the CBCT finds the transform between the reconstructed CBCT image coordinate system and the Leksell coordinate system.

Sources of uncertainties

There are many different sources of uncertainties that contribute to the total uncertainty in positioning. To investigate how these errors sum up, a propagation model has been developed in which each of the known errors is simulated.

The model simulates the calibration steps (including a C-arm geometric calibration), the CBCT-to-Leksell transform discussed above, and the imaging of the patient. Moreover, the model takes temperature at calibration and patient imaging into account. It also includes flexing of the system due to variation in patient weights.

For the calibration the propagation model uses the algorithms in the actual CBCT system.

Furthermore, the propagation model also includes uncertainties due to imaging and dose delivery.

Each known error is modeled as a probability distribution that depends on tolerances that can be either measured, or based on information from the manufacturer, see Table 1.

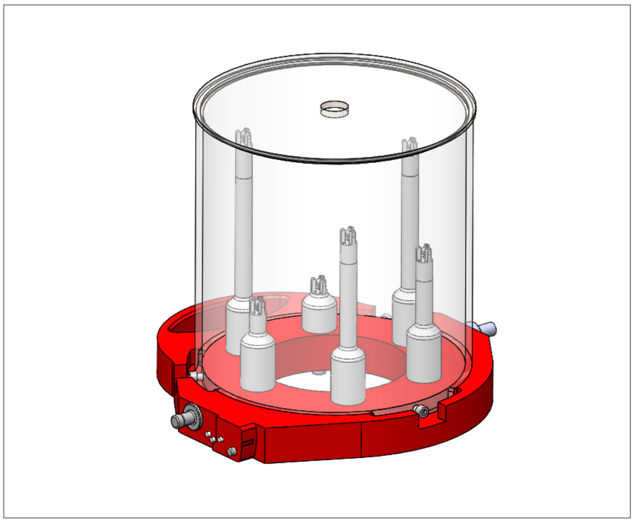

Figure 1. The CBCT-to-Leksell transform tool.

Source	Tolerance
C-arm angle encode	Manuf tolerance
Flex of c-arm	Measured
Temperature extension tilt arm	Measured
Temperature extension calibration tool	Measured
Focal spot heating	Manuf tolerance
Tool calibration measurement uncertainties	Tolerance
Patient weight	Modeled
Ball bearing detection	Measured
Couch reposition	Measured
Tilt arm repositioning	Measured
Play in fixation frame	Measured
Heat extensions detector	Not modeled
Focus precision uncertainty	Measured

Table 1. Simulated uncertainties.

Results

The uncertainty of the system is defined as the deviation between a set of known stereotactical positions before and after a simulation through the error propagation model.

The result of the analysis shows that the mean position uncertainty is small, implying that there are very small systematic errors. The standard deviation is also small, showing that the error magnification in the calibration chain is small.

The largest effect on the uncertainty was found to be couch sagging for very large patients (~0.18mm for a 210kg patient) and large temperature variations, i.e. low room temperature at calibration but high temperature during scan, which could be in the order of 0.15mm for large temperature variations.

Fortunately, the sagging is in the yz-direction and the temperature variation is mainly in the x-direction. The system is calibrated with a weight of 70kg on the couch which means that for a large part of the population the sagging is very small.

End-to-end test

An end-to-end tool has been designed to measure the geometric uncertainty of the CBCT system. It uses 5 radiochromic films placed in a plane at different positions, see Figure 2. The tool may be rotated and can be oriented in a vertical and a horizontal plane.

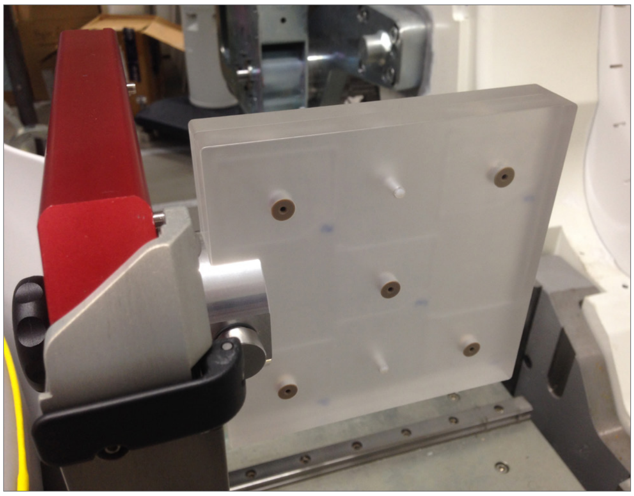

Figure 2. The end-to-end tool.

The films are placed in grooves made in the tool and needles are used to punch holes in the films. The tool is scanned with the CBCT system and by using a research prototype of the reconstruction software a small volume around the position of each of the five films is reconstructed with high resolution (0.1mm voxel pitch). A script localizes the position of the punched hole in the CBCT images and determines the Leksell coordinates. This position is then irradiated with a 4mm iso-center, see Figure 3.

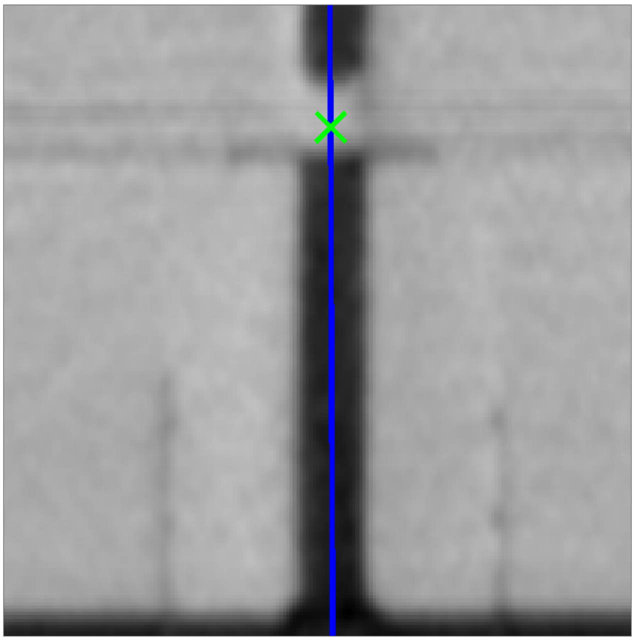

Figure 3. The tool reconstructed in high resolution in a small volume at one of the film positions. The green cross is where the shot position is planned.

The films are then scanned and evaluated. The distance between the center of the dose distribution and the punched hole is the 2D uncertainty of the system at the respective measured point. Figure 4 shows an example of an irradiated film.

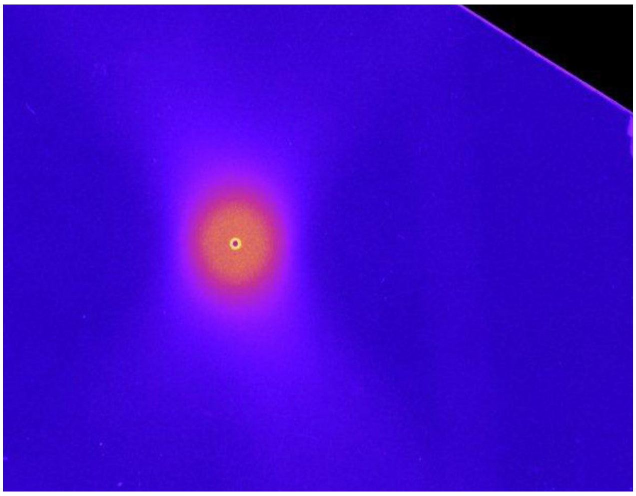

Figure 4. A film irradiated with a 4mm isocenter.

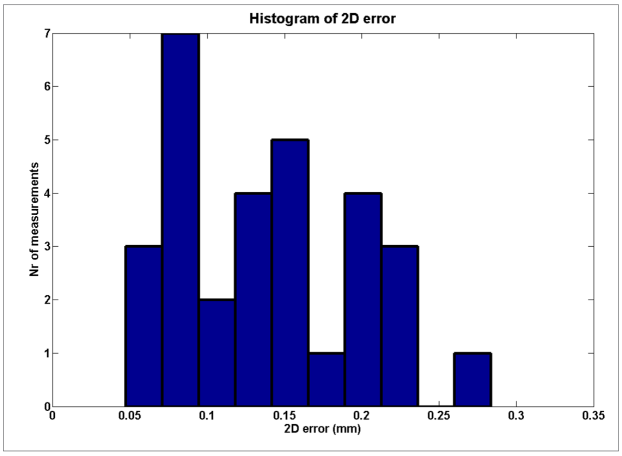

Figure 5. 2D result of the end-to-end tests.

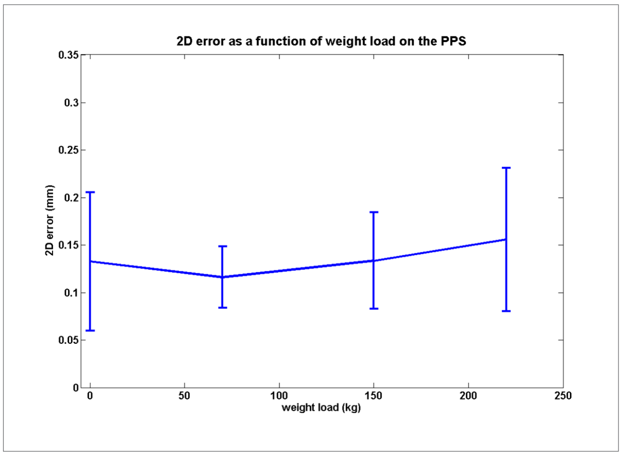

Figure 6. Test with different weights on the couch.

Six tests were performed. The tests show that the mean uncertainty was less than 0.2mm with a standard deviation of less than 0.1mm. The result can be seen in Figure 5.

There were a few outliers in the test (absent in the histogram). The probable cause is that some of the films moved after the holes were made due to a flaw in the tool design.

A test applying different weights on the couch (0, 70, 150 and 210kg) was also performed. The results can be seen in Figure 6, showing highest accuracy at the calibration weight, 70kg and an increase of uncertainty with higher and lower weights.

Summary and conclusions

The theoretical model predicts sub-millimeter accuracy in positioning which is supported by end-to-end measurements. Using the CBCT as a stereotactic reference therefore gives high accuracy in patient positioning.

ABOUT ELEKTA

A human care company, Elekta pioneers significant innovations and clinical solutions harnessing both external and internal radiation therapy for treating cancer and brain disorders. Elekta provides intelligent and resource-efficient technologies that improve, prolong and save patient lives. We go beyond collaboration, seeking long-term relationships built on trust with a shared vision, and inspiring confidence among healthcare providers and their patients.

elekta.com @elekta /elekta /company/elekta

Corporate Head Office:

Elekta AB (publ)
Box 7593, SE-103 93 Stockholm, Sweden
Tel +46 8 587 254 00
Fax +46 8 587 255 00
info@elekta.com

Regional Sales, Marketing and Service:

North America
Tel +1 770 300 9725
Fax +1 770 448 6338
info.america@elekta.com

Europe, Middle East, Africa, Eastern Europe, Latin America
Tel +46 8 587 254 00
Fax +46 8 587 255 00
info.europe@elekta.com

Asia Pacific
Tel +852 2891 2208
Fax +852 2575 7133
info.asia@elekta.com

ELEKTA