IsoCal calibration

Vendor's maximum arm readout difference, detector rotation, and source angle difference tolerances were 0.5 mm, 2º, and 3º, respectively10. The IsoCal calibration is as follows27:

1. Mount the IsoCal phantom adaptor at the end of the treatment couch. Lock the adaptor in H4 couch index position and fix it to the couch with the latch on the bottom of the adaptor.
2. Hang the IsoCal phantom on the adaptor on the front end of the couch. Then position the phantom at the isocentre.
3. Insert the partial transmission plate into interface mount on the collimator.
4. Acquire collimator shots using High Quality 6X with collimator at 4 different angles.
5. Acquire set of MV images with MV continuous imaging mode for 6X and 600 MU / min dose rate while gantry makes full rotation around the IsoCal phantom.
6. Acquire set of kV images with kV dynamic gain imaging mode while gantry makes full rotation around the IsoCal phantom.
7. The system processes the acquired data and displays for a review.

The corrections from the IsoCal calibration were applied prospectively to the x-ray source and imager arms to eliminate the geometric variation in individual CBCT projections and EPID images26. Subsequently, the centre of the CBCT volume and EPID is corrected to the machine radiation isocenter.

ExacTrac v.6.0

In the first case, an infrared optical locator was used to detect the position of six positioning marker balls on the frameless radiosurgery positioning array for pre-positioning. Second, x-ray devices on both sides of the frame were adopted to take kV-level dual oblique orthogonal films. Subsequently, bone markers were co-registered with digitally reconstructed radiographs (DRRs), by mutual information, which resulted in 6 DOF corrections, including anterior/posterior, left/ right, inferior/superior shifts, and pitch, roll, and yaw rotations.

In the second case, fiducials x‐ray verifications have to be done by acquiring patient x‐ray images from tube 1 and tube 2, and then the marker matching is done to calculate the 6 DOF shifts. Once the shifts are applied, one more x‐ray verification image has to be taken.

The calibration method of ETv6 is the following:

1. Place the ET isocenter phantom on the table, allowing all five spheres are in the camera’s field of view.
2. Orient the phantom for the gantry and match its lines with the cross-hair.
3. Calibrate to save to the actual position of the phantom.
4. Place the ET XR calibration phantom on the table, so that reflective markers are placed in the camera's field of view and metal components do not appear in calibration images.
5. Acquire x-ray images and make sure that markers are in the center of the eight circles.
6. Save the process to finish the calibration.

ExacTrac Dynamic

The system consists of an optical/thermal imaging device, which contains a blue light projector, two stereoscopic high-resolution cameras, and an integrated thermal camera35. The optical/thermal imaging device is positioned centrally above the treatment couch. Moreover, two kV X-ray tubes are mounted in the bunker floor, projecting obliquely onto two ceiling-mounted flat panel detectors, with a 300 × 300-mm2 radiation sensitive area33. The geometrical radiation field size at the isocenter is 180 × 180 mm2. The ETD flat panel detectors improved image quality and enhanced read-out speed compared to ETv6.

The high-definition structured light projector emits a pattern onto the patient’s surface detected by the two optical cameras. The stereoscopic 3D low latency data camera is used to calculate a 3D map of the patient’s surface. Moreover, a 2D thermal matrix is created from the patient's heat signal taken by the integrated thermal camera. These two matrices are matched to calculate a hybrid 3D+thermal matrix containing spatial and thermal information of each point of the patient surface34.

After the patient is roughly positioned, a region of interest (ROI) needs to be selected. Optical and thermal surface information is used during the monitoring mode, where the ROI is treated as a single rigid area34. The internal anatomy can be verified through paired stereoscopic kV X-rays. These images are then compared to the DRRs, which are calculated from the planning CT and the isocenter position, yielding a rigid body transformation by a matching algorithm (private communication with Brainlab).

The calibration method of ETD follows some similar ETv6 steps as follows:

1. Place the ET XR calibration phantom on the table, so that reflective markers are placed in the camera's field of view and metal components do not appear in calibration images.
2. Acquire x-ray images and make sure that markers are in the center of the eight circles.
3. Save the process to finish the calibration.
4. Place the Thermal to 3D calibration phantom on the table.
5. Orient the phantom for the gantry.
6. Calibrate to save to the actual position of the phantom.

Results for ExacTrac v6.0 and Dynamic:

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ExacTrac v6.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| DATA | | | | | CBCT | | | | EPID | | | | | | | | | | | | | | | | | | | |
| T0G0C0 | | T0G180C0 | | T0G90C90 | | T0G270C90 | | T270G0C90 | | T315G0C90 | | T45G0C90 | | T90G0C90 | | Shifts | | |  |
| Mets | Volume [cc] | Size [mm] | Dist2iso [mm] | Location | long [mm] | lat [mm] | vert [mm] | 3D displ. [mm] | long [mm] | lat [mm] | long [mm] | lat [mm] | long [mm] | vert [mm] | long [mm] | vert [mm] | long [mm] | lat [mm] | long [mm] | lat [mm] | long [mm] | lat [mm] | long [mm] | lat [mm] | dX [mm] | dY [mm] | dZ [mm] | 3D displ. [mm] |
| M01 | 0,216 | 7,8 | 61 | FRO L | 0,2 | 0,6 | 0,1 | 0,64 | -0,5 | -0,6 | -0,1 | -0,7 | -0,5 | 0,4 | -0,4 | 0,4 | -0,5 | -0,4 | -0,6 | -0,7 | 0,2 | -0,1 | 0,1 | 0,1 | 0,09 | -0,1 | -0,05 | 0,65 |
| M02 | 0,236 | 8,0 | 52 | PAR L | 0,3 | 0,6 | 0,5 | 0,84 | -0,3 | 0,4 | -0,2 | -0,6 | -0,2 | 0,5 | -0,1 | 0,1 | -0,5 | 0,5 | -0,3 | 0,2 | -0,3 | 0 | 0,1 | 0,2 | -0,06 | -0,26 | -0,05 | 0,73 |
| M03 | 0,226 | 8,0 | 48 | TEM L | 0,3 | 0,8 | 0,3 | 0,91 | -0,6 | 0 | 0,1 | 0,1 | -0,3 | 0,6 | -0,3 | 0,5 | -0,4 | 0,1 | -0,2 | -0,1 | 0,1 | 0,3 | -0,1 | 0,5 | 0,17 | -0,12 | 0 | 0,91 |
| M04 | 0,637 | 11,1 | 63 | FRO R | 0,6 | 0,5 | 0,2 | 0,81 | -0,4 | 0,1 | -0,1 | -0,9 | -0,1 | 0,5 | 0,1 | -0,6 | -0,1 | -0,6 | -0,4 | -0,8 | 0,1 | -0,5 | 0,2 | 0,3 | 0,03 | -0,07 | -0,1 | 0,68 |
| M05 | 2,141 | 16,7 | 49 | TEM R | 0,5 | 0,4 | 0,6 | 0,88 | -0,6 | -0,3 | -0,6 | -0,2 | 0,1 | -0,4 | 0,1 | -0,8 | -0,1 | -0,1 | -0,1 | -0,1 | 0,5 | 0 | 0,1 | 0,1 | -0,25 | -0,12 | 0 | 0,94 |
| M06 | 0,708 | 11,5 | 50 | OCC | 0,5 | 0,5 | 0,5 | 0,87 | -0,1 | 0,4 | -0,3 | 0,7 | 0,1 | 0,3 | -0,1 | 0 | -0,2 | 0,4 | -0,1 | -0,2 | 0 | 0,4 | 0,1 | 0,7 | 0,09 | 0,01 | 0,1 | 0,75 |
| M07 | 2,019 | 16,1 | 47 | TEM R | 0,4 | 0,4 | 0,6 | 0,82 | -0,1 | -0,6 | -0,2 | -0,5 | 0,1 | 0,6 | 0,3 | -0,4 | -0,2 | -0,6 | -0,1 | -0,5 | 0,5 | -0,3 | 0,1 | 0,1 | 0,10 | -0,22 | -0,1 | 0,77 |
| M08 | 2,092 | 16,3 | 57 | CEREB | 0,5 | 0,4 | 0,5 | 0,81 | 0,1 | 0 | 0 | 0,3 | 0,1 | 0,5 | 0 | -0,7 | 0 | 0,3 | -0,1 | -0,1 | 0,4 | 0,3 | 0,2 | 0,1 | 0,02 | -0,01 | 0,05 | 0,57 |
| M09 | 0,667 | 11,7 | 46 | CEREB | 0,3 | 0,2 | 0,4 | 0,54 | 0,1 | -0,4 | -0,1 | 0,1 | -0,1 | 0,3 | 0,1 | 0,3 | -0,4 | 0,1 | -0,1 | -0,4 | 0,3 | 0,1 | 0,1 | 0,1 | 0,12 | -0,1 | -0,1 | 0,40 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ExacTrac Dynamic | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| DATA | | | | | CBCT | | | | EPID | | | | | | | | | | | | | | | | | | | |
| T0G0C0 | | T0G180C0 | | T0G90C90 | | T0G270C90 | | T270G0C90 | | T315G0C90 | | T45G0C90 | | T90G0C90 | | Shifts | | |  |
| Mets | Volume [cc] | Size [mm] | Dist2iso [mm] | Location | long [mm] | lat [mm] | vert [mm] | 3D displ. [mm] | long [mm] | lat [mm] | long [mm] | lat [mm] | long [mm] | vert [mm] | long [mm] | vert [mm] | long [mm] | lat [mm] | long [mm] | lat [mm] | long [mm] | lat [mm] | long [mm] | lat [mm] | dX [mm] | dY [mm] | dZ [mm] | 3D displ. [mm] |
| M01 | 0,216 | 7,8 | 61 | FRO L | 0,2 | 0,4 | 0,1 | 0,46 | -0,1 | -0,1 | -0,3 | 0,1 | 0,2 | -0,3 | 0,3 | -0,5 | -0,3 | 0,4 | -0,2 | 0,3 | -0,1 | 0 | -0,1 | 0 | -0,24 | 0,06 | -0,05 | 0,44 |
| M02 | 0,236 | 8,0 | 52 | PAR L | 0,3 | 0,3 | 0,4 | 0,58 | -0,5 | 0 | -0,3 | 0,1 | -0,1 | 0 | 0 | -0,4 | -0,3 | 0,1 | -0,1 | 0 | 0 | 0 | 0 | -0,2 | -0,20 | -0,05 | -0,05 | 0,32 |
| M03 | 0,226 | 8,0 | 48 | TEM L | 0,2 | 0,1 | 0,1 | 0,24 | -0,2 | 0,1 | -0,2 | -0,2 | 0,1 | -0,3 | -0,2 | -0,1 | 0,1 | 0,3 | -0,2 | 0,2 | -0,2 | 0,1 | -0,2 | 0 | -0,16 | 0,15 | 0,10 | 0,34 |
| M04 | 0,637 | 11,1 | 63 | FRO R | 0,4 | 0,4 | 0,1 | 0,57 | -0,1 | 0,1 | 0 | -0,1 | -0,2 | 0,1 | -0,2 | -0,3 | 0,3 | 0,3 | 0 | 0,1 | 0,3 | -0,2 | 0,3 | -0,2 | -0,11 | -0,05 | 0,00 | 0,42 |
| M05 | 2,141 | 16,7 | 49 | TEM R | 0,3 | 0,1 | 0,3 | 0,44 | 0 | 0,1 | -0,1 | -0,1 | -0,1 | 0,1 | 0,2 | -0,1 | -0,1 | 0 | 0 | -0,1 | 0,3 | -0,1 | -0,4 | 0,4 | 0,07 | 0,07 | -0,05 | 0,46 |
| M06 | 0,708 | 11,5 | 50 | OCC | 0,1 | 0,4 | 0,3 | 0,51 | 0 | 0,1 | -0,1 | -0,1 | 0 | -0,1 | -0,1 | -0,2 | -0,3 | 0,1 | 0,1 | 0,1 | 0,2 | -0,3 | 0,2 | -0,3 | -0,12 | -0,10 | 0,05 | 0,28 |
| M07 | 2,019 | 16,1 | 47 | TEM R | 0,3 | 0,1 | 0,1 | 0,33 | -0,3 | 0,2 | -0,1 | -0,1 | 0,2 | -0,1 | 0 | -0,2 | 0,1 | 0,4 | -0,2 | 0 | 0 | -0,1 | -0,1 | -0,1 | -0,17 | 0,07 | 0,10 | 0,41 |
| M08 | 2,092 | 16,3 | 57 | CEREB | 0,1 | 0,3 | 0,5 | 0,59 | 0,1 | 0,1 | 0,2 | -0,2 | -0,1 | 0,1 | -0,3 | -0,1 | -0,2 | 0,2 | 0,1 | 0,1 | 0,3 | 0,1 | 0,3 | -0,3 | 0,01 | -0,03 | 0,10 | 0,25 |
| M09 | 0,667 | 11,7 | 46 | CEREB | 0,2 | 0,2 | 0,4 | 0,49 | -0,2 | 0,1 | -0,2 | 0,1 | 0,1 | -0,2 | -0,1 | -0,1 | -0,1 | 0,1 | -0,1 | 0 | 0 | -0,1 | 0,1 | -0,4 | -0,18 | -0,08 | 0,10 | 0,26 |