

HexaCheck 6DoF Quality Assurance Phantom Implementation for Elekta HexaPOD and BrainLAB Robotics 6D Couches

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Introduction

Image guided radiotherapy (IGRT) has become the most prominent form of patient setup correction and verification in radiotherapy. State of the art treatment delivery systems commonly incorporate 6DoF couches able to correct for rotational errors in all three directions along with translational corrections. Quality Assurance (QA) for translational registration and correction accuracy is well established and practiced at most clinics under the guidelines outlined by AAPM Task Group report (TG -142) and through the use of commercially available phantoms. In applying the same rationale, QA for 6DoF couches should follow these similar guidelines as rotational inaccuracy can also influence accurate radiation dose delivery, especially for deliveries with tighter margins such as SBRT or SRS. As of yet, few, if any, commercially available phantoms can efficiently test for rotational correction accuracy.

Standard Imaging Inc. is releasing a phantom designed to work with their current imaging QA device, the Multiple Imaging Modality Isocentricity (MIMI) Phantom. The HexaCheck acts as a base, allowing for a specific degree of rotation of the MIMI Phantom in each rotational direction. Using standard daily QA techniques, the phantom can be imaged in the treatment setup position with the known rotations in place, fused to the non-rotated CT reference image, and then corrected using the 6DoF couch. This approach allows for daily testing of 6D correction accuracy. This white paper is designed to work as a guide for initial procedures and daily use of the HexaCheck/MIMI Phantom. Specific outlines are provided for implementation using both Elekta's XVI kV-CBCT imaging with the HexaPOD couch and BrainLAB's ExacTrac kV orthogonal imaging with the Robotics 6D couch.

HexaCheck Phantom Geometry

The HexaCheck consists of a somewhat triangular base (Universal Couch Lock) with three support screws that each sit on a divot. The baseboard has an indent for a couch indexing bar such that the HexaCheck can be secured to the couch. The MIMI Phantom resides inside 4 walls which sit on three axes for rotation. The sidewalls also have horizontal lines to assist in vertical alignment. The pitch (ψ) and roll (θ) axes each have two screws and a spring-loaded peg to lock the phantom at the desired rotation. The yaw (φ) axis has only one of each and rotates on a round platform built into the base. The HexaCheck rotates the MIMI Phantom 2.5 degrees in each direction. The MIMI Phantom is secured via another screw diagonal to the rest and firmly presses the MIMI into one corner. It is designed to have the MIMI Phantom oriented in a specific direction within the base. Figures 1 and 2 outline specific characteristics of the HexaCheck and MIMI.

Figure 1.

HexaCheck and the MIMI Phantom and indices of rotation.

At A: Aluminum spring-loaded peg on the left and tightening screw to the right for the yaw (φ , black) direction.

B: Roll (θ , purple) peg and screw, additional screw located on the opposite side (not shown).

C: Pitch (ψ , green) peg and screw, additional screw located on the opposite side (not shown).

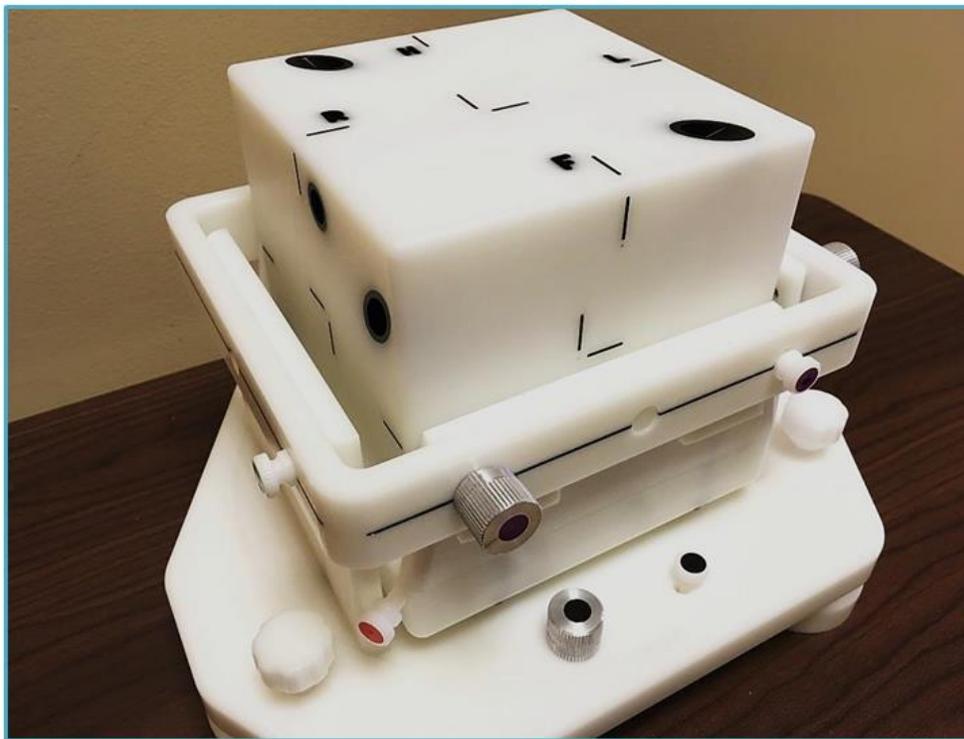
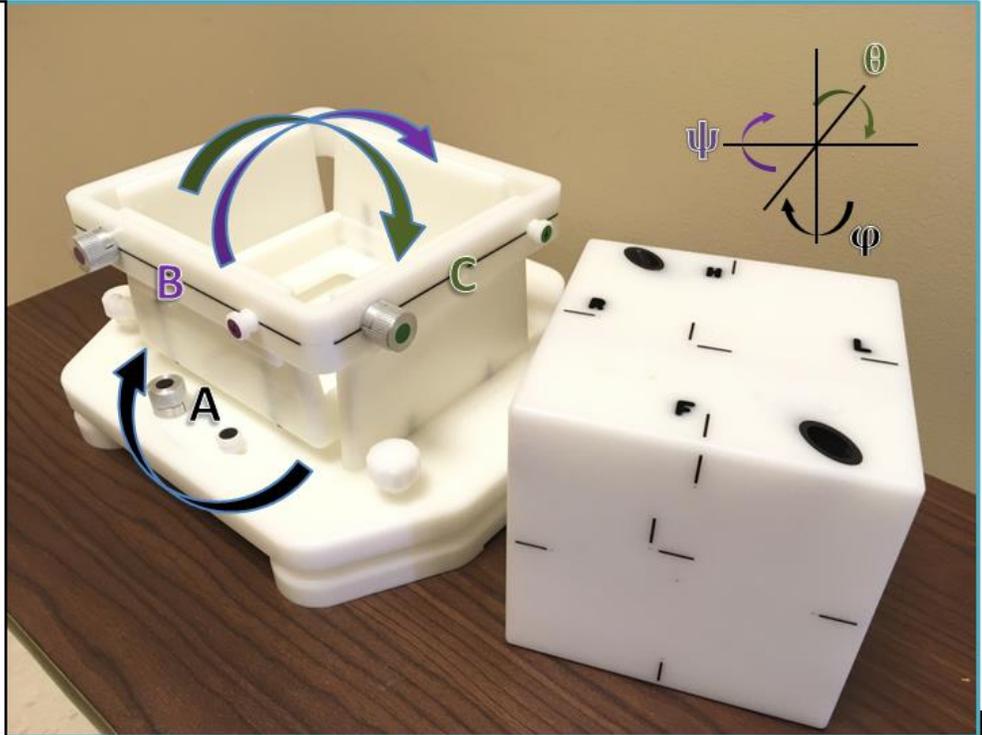


Figure 2.

MIMI Phantom secured to HexaCheck base.

The red screw at the bottom left is used to secure the MIMI Phantom inside. It is now ready for imaging.

Also shown are the aluminum pegs. They can be pulled part way out and twisted to prevent it from springing back into the slot. This allows for rotation on that axis jointly with the loosening and tightening of the respective screw(s).

Reference Acquisition

A reference image set must be obtained for daily use of the HexaCheck. This should be done using preferably the same CT scanner as used for patient plans. Select a high quality, high resolution acquisition such as that used for SRS. The images seen here used a 35 cm Field of View and 1.25 mm slices. Ensure that the MIMI Phantom is locked in place within the HexaCheck before imaging and confirm that there are no rotations of the HexaCheck. This can easily be checked by verifying that all of the spring-loaded pegs are completely locked in. After aligning the phantom to the external lasers, move the couch into the imaging plane within the CT gantry. Here, verify that the device is level and adjust accordingly using the three screws that support the base over the baseboard. This will compensate for rotational error due to table sag.



Figure 3: Above and left images show the HexaCheck set up and aligned to external CT lasers where positioning was zeroed. Leveling was performed using a high accuracy level and the three support screws around the base. The couch then translated the HexaCheck to the imaging plane where leveling was fine-tuned to account for table sag.

With the simulation CT acquired, the image set can be sent to any treatment planning system so that a treatment plan can be created. The treatment plan can contain the clinic-specific daily QA protocol beams. Commonly, a set of orthogonal MV beams (AP & Lat) is created with the beam isocenter set at the center BB of the MIMI. With this geometry, AP and LAT DRR images are created so that they can be used as reference images for planar kV-kV matching verification. The simulation CT can now be exported along with the plan isocenter coordinate and set as the reference CT image in the R&V. (plan, reference CT images, and DRRs are sent to the R&V for creation of a daily imaging QA patient.) For the ExacTrac system, a separate export will be needed to create a new patient in the ExacTrac patient database. The export will need to include the DICOM CT, DICOM-RT plan, and DICOM-RT structures.

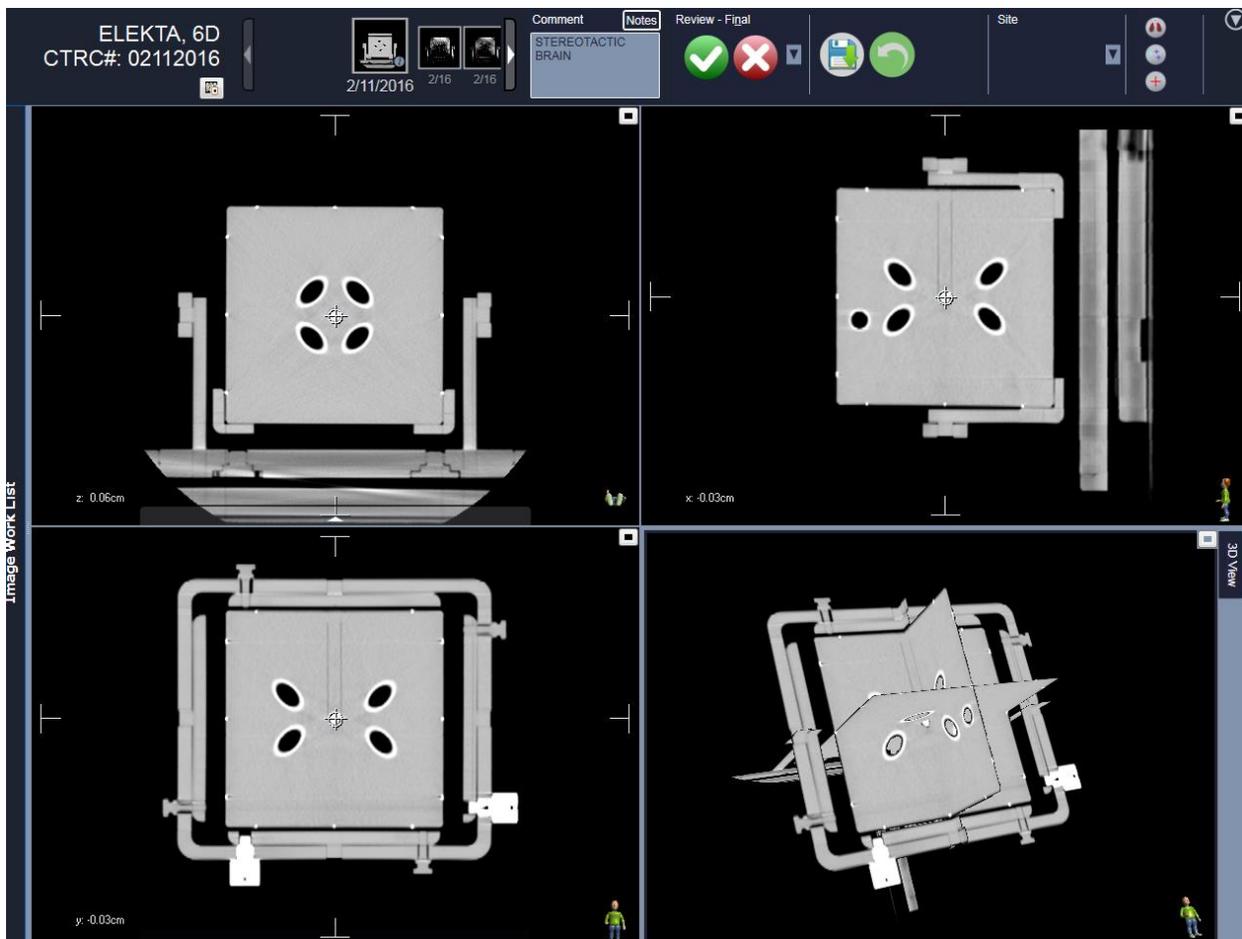


Figure 4. Above is an example high-quality CT scan of the HexaCheck/MIMI Phantom showing anterior, coronal, sagittal, and 3D slices at isocenter. Notice that all the BBs can be seen in all slices indicating no rotation and a good imaging setup.

Brainlab Robotics 6D Couch and ExacTrac Implementation

Initial Setup

Once the image set is imported, create a new patient plan for the HexaCheck within the ExacTrac software. The plan isocenter will be set at the center BB of the MIMI. With the phantom set at laser isocenter and with the optical tracker in place, a set of images is taken. Here, it is a good idea to establish what protocol will be used for the scan in order to get a clear and sufficiently detailed image. The picture shown here had good results using the standard pelvis protocol (160 mA, 160ms, 120kVp). Once an adequate image set is acquired, the ExacTrac software will register the planar image set to the CT and the suggested couch adjustments will be presented for approval. The image registration can be reviewed in a few different ways to ensure there was accurate fusion.

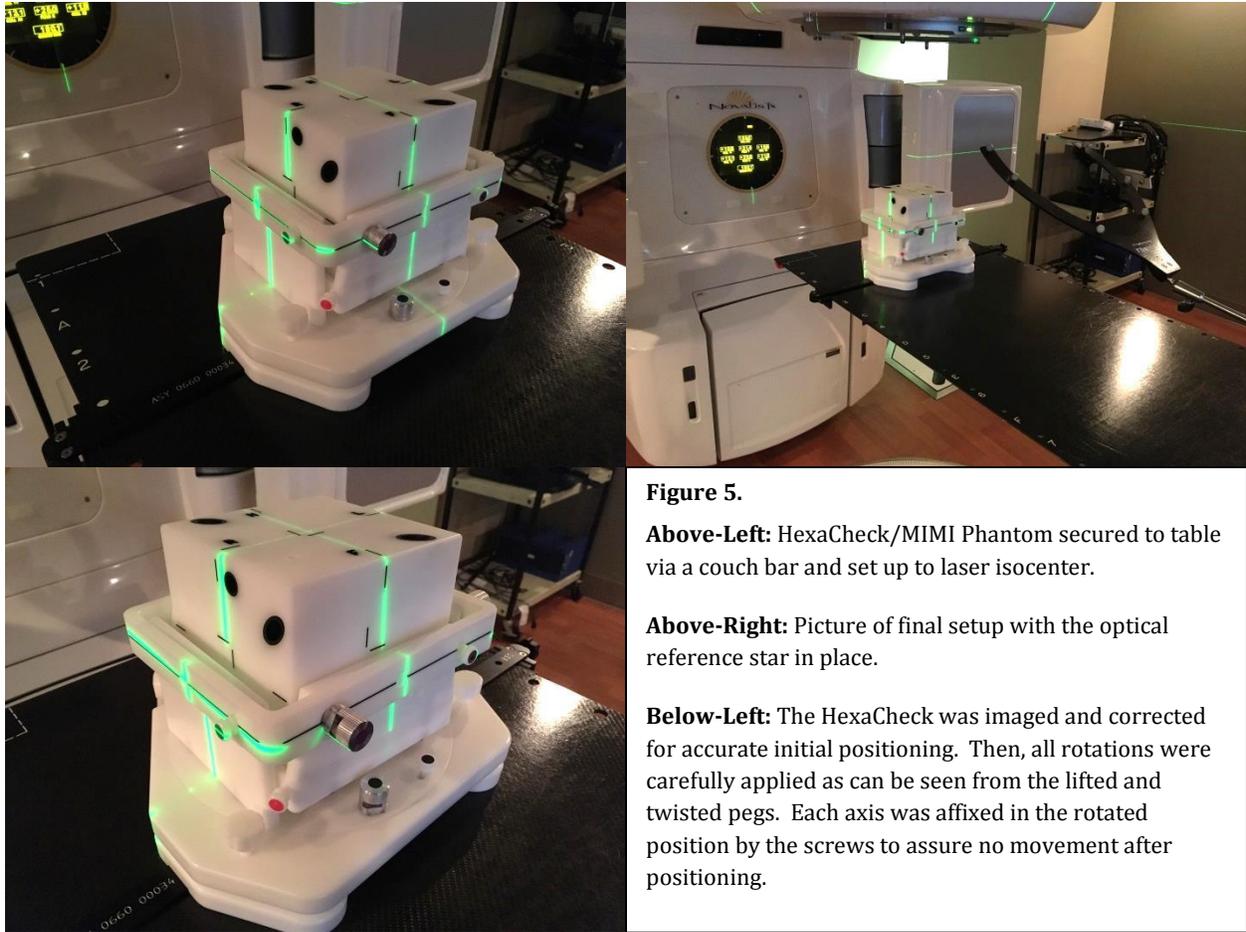


Figure 5.

Above-Left: HexaCheck/MIMI Phantom secured to table via a couch bar and set up to laser isocenter.

Above-Right: Picture of final setup with the optical reference star in place.

Below-Left: The HexaCheck was imaged and corrected for accurate initial positioning. Then, all rotations were carefully applied as can be seen from the lifted and twisted pegs. Each axis was affixed in the rotated position by the screws to assure no movement after positioning.

Daily Test Procedure

For daily QA testing, the goal is to assess the accuracy of the image registration software and the couch correction accuracy. To do this, the HexaCheck is set at the laser isocenter with no rotations. The phantom is aligned to the offset marking on the MIMI phantom and the rotations are applied in all three directions. One must ensure that the pitch, roll, and yaw rotations were fully applied to the phantom and be sure they are secured with the tightening screws. It is good practice to establish which direction of each rotation, i.e. clockwise or counter-clockwise, will be applied every time for consistency. Return to the ExacTrac control panel and take an initial positioning image. The software will now have the new corrections to account for the applied rotations. These numbers should be very close to 2.5 degrees rotation of each dimension. Apply these couch corrections and once again image the device. It should now read very close to zero for any corrections and within the setup tolerance. Images of the ExacTrac software during this process are shown below. The red marking on the example removes that portion from the registration process. As can be seen, the mark contained the aluminum bubble level attached to the HexaCheck. The registration should only be performed on the MIMI Phantom itself to avoid error from the geometric changes of the HexaCheck portion. While most of the HexaCheck is unlikely to alter the outcome, the aluminum level was deemed a possible cause for error and was thus removed. In practice, the level can simply be removed before imaging if desired.

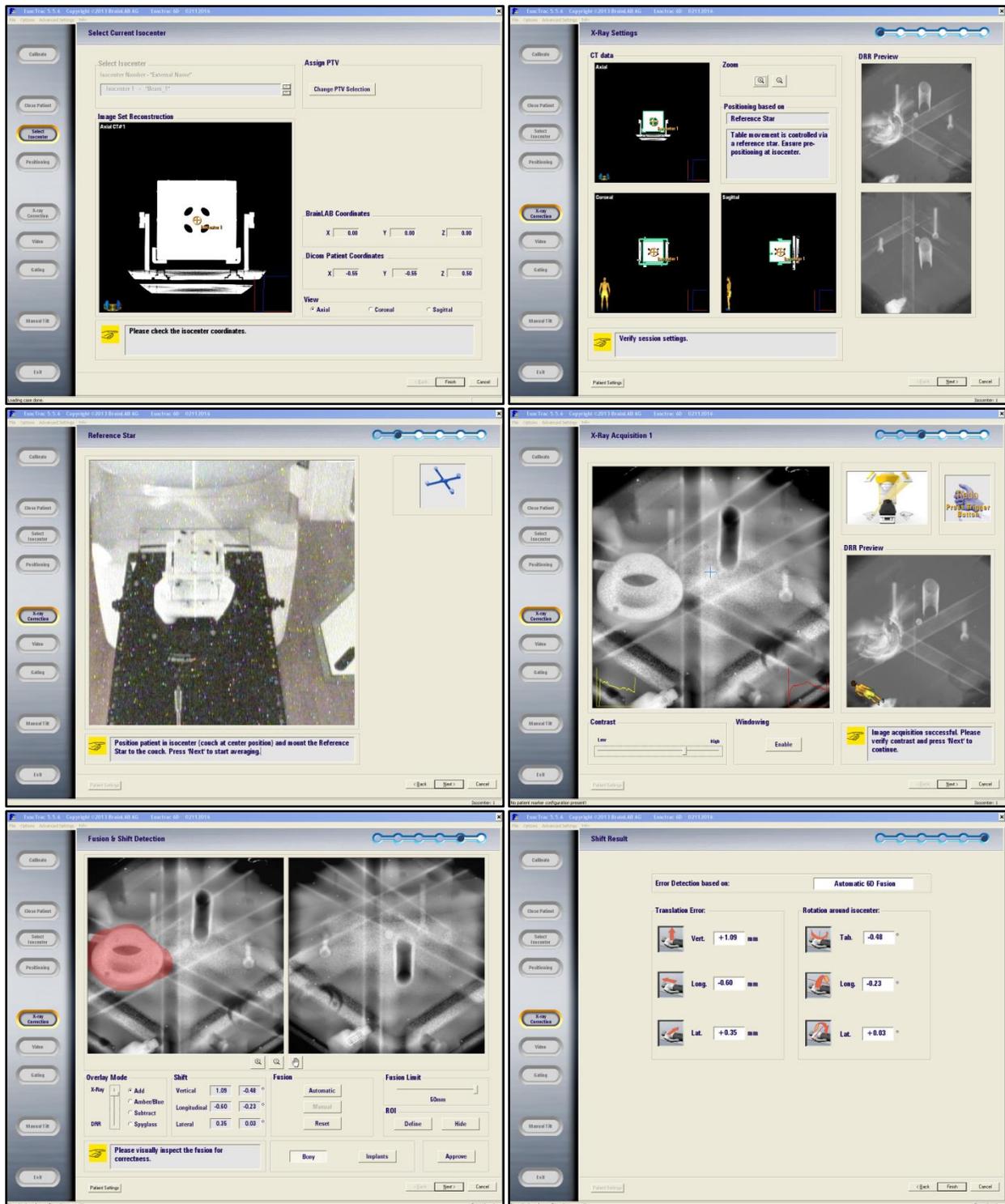


Figure 5. Top-Left: Screenshot of isocenter selection screen. Be sure this is chosen correctly.
Top-Right: Screenshot of options for patient tracking and selection of CT where fusion will take place.
Mid-Left: Screenshot of reference star visibility page.
Mid-Right: Screenshot of one of the two orthogonal images taken. Here, the window can be adjusted to preference.
Bottom-Left: Screenshot of fusion page showing several ways to view the fusion for verification. The red is a hand drawn area marked for the system to ignore, the level on the HexaCheck baseboard, which may hinder the fusion.
Bottom-Right: Screenshot of planned couch correction page after initial setup.

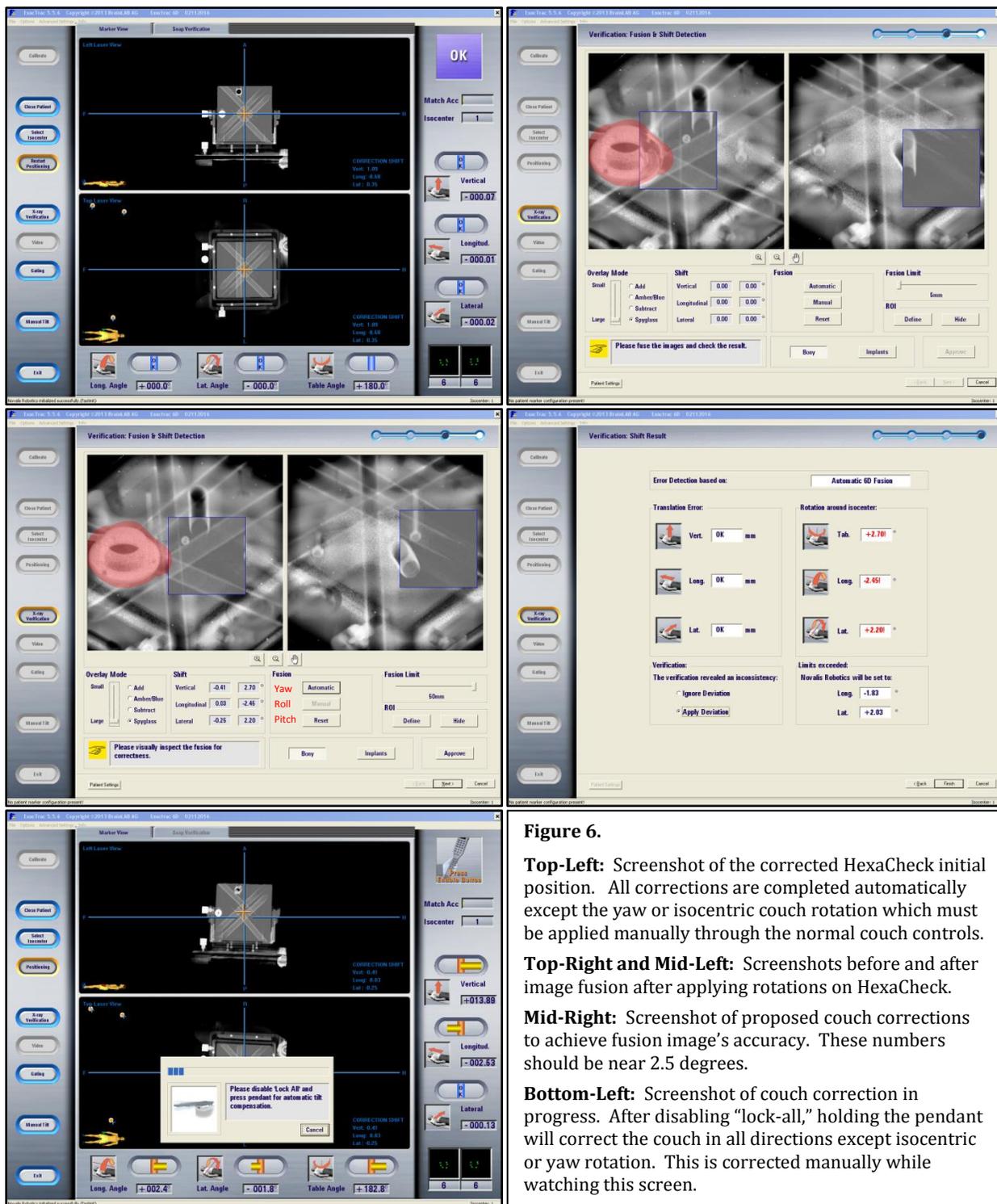


Figure 6.

Top-Left: Screenshot of the corrected HexaCheck initial position. All corrections are completed automatically except the yaw or isocentric couch rotation which must be applied manually through the normal couch controls.

Top-Right and Mid-Left: Screenshots before and after image fusion after applying rotations on HexaCheck.

Mid-Right: Screenshot of proposed couch corrections to achieve fusion image's accuracy. These numbers should be near 2.5 degrees.

Bottom-Left: Screenshot of couch correction in progress. After disabling "lock-all," holding the pendant will correct the couch in all directions except isocentric or yaw rotation. This is corrected manually while watching this screen.

The ExacTrac system showed consistent results in correcting the phantom position. This is partly due to the MIMI Phantom's unique design which incorporates 5 bone equivalent tubes that pass through the entire phantom at varying angles allowing for quick and accurate registration. This also makes it useful for automatic registration quality testing as the tubes can be easily identified and verified for precise image registration.

Elekta HexaPOD and XVI Implementation

Initial Setup

Once the image set is imported, create a new patient plan for the HexaCheck in the XVI imaging software. Select the plan isocenter (MIMI center BB) as the point of interest for the registration and extended the clip box so it encompasses the MIMI Phantom. Try not to include the HexaCheck itself as its physical geometry will have changed somewhat. Select an imaging protocol that best suits the phantom for a clear and sufficiently detailed image. The Head and Neck S20 procedure was used below. In the vault, initialize the HexaPOD and then set up the phantom to the offset position with the laser isocenter. Extend both the XVI x-ray generator and imaging panel to the proper locations and install the correct collimator, i.e. F0 and S20 in the example case. With the phantom set at laser isocenter, the HexaPOD initiated, and with the optic tracker in place, apply the rotations and acquire the CBCT. Once an adequate image set is acquired, accept the reconstruction. The XVI software will register the CBCT to the CT and the suggested couch adjustments will be presented for approval.

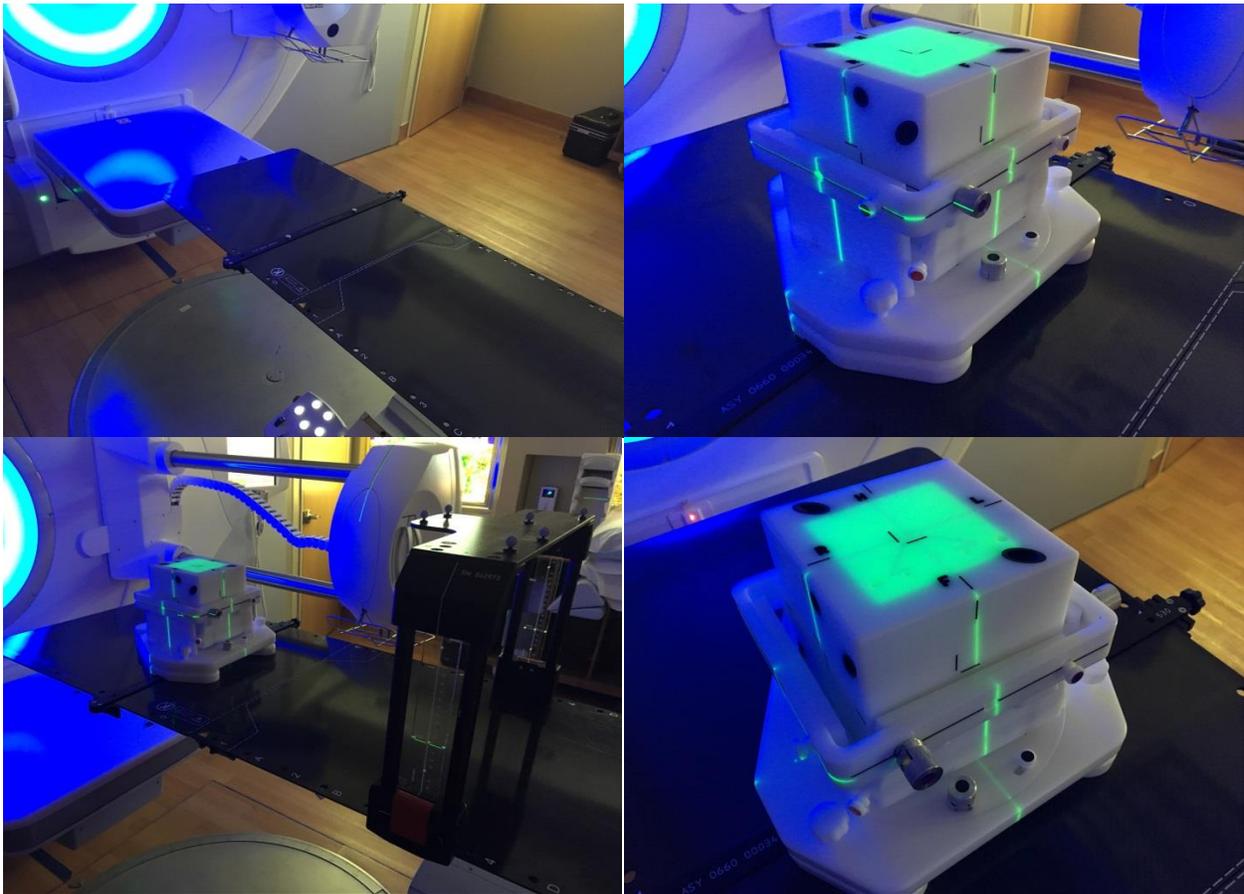


Figure 7. Top-Left: Image of the couch bar in place which secures the HexaCheck base to the table.

Top-Right: Image of the HexaCheck at laser isocenter. Be sure to initialize the HexaPOD *before* aligning to the lasers.

Bottom-Left: Image of the final setup with the HexaPOD initialized and isocenter selected, HexaCheck at laser isocenter, the x-ray tube extended and proper collimators inserted, imaging panel at proper location (not pictured), and the optical reference tracker set at the appropriate position.

Bottom-Right: Image of the HexaCheck/MIMI Phantom with all the rotations applied.

Daily Test Procedure

For daily QA testing, the goal is to assess the accuracy of the image registration software and the couch correction accuracy. To do this, the HexaCheck is set at the laser isocenter with no rotations. The phantom is aligned to the off set marking on the MIMI phantom and the rotations are applied in all three directions. Fully ensure that the pitch, roll, and yaw rotations were applied to the phantom and be sure they are secured with the tightening screws. It is good practice to establish which direction of each rotation, i.e. clockwise or counter-clockwise, will be applied every time. Return to the XVI control panel and acquire the CBCT. The software will now have the new corrections to account for the applied rotations. These numbers should be very close to the actual 2.5 degree rotation of each dimension. Apply these couch corrections and ensure the phantom is positioned currently relative to the lasers. It should now read very close to zero for any corrections and within the setup tolerance. Below are some images of the XVI software through this procedure.

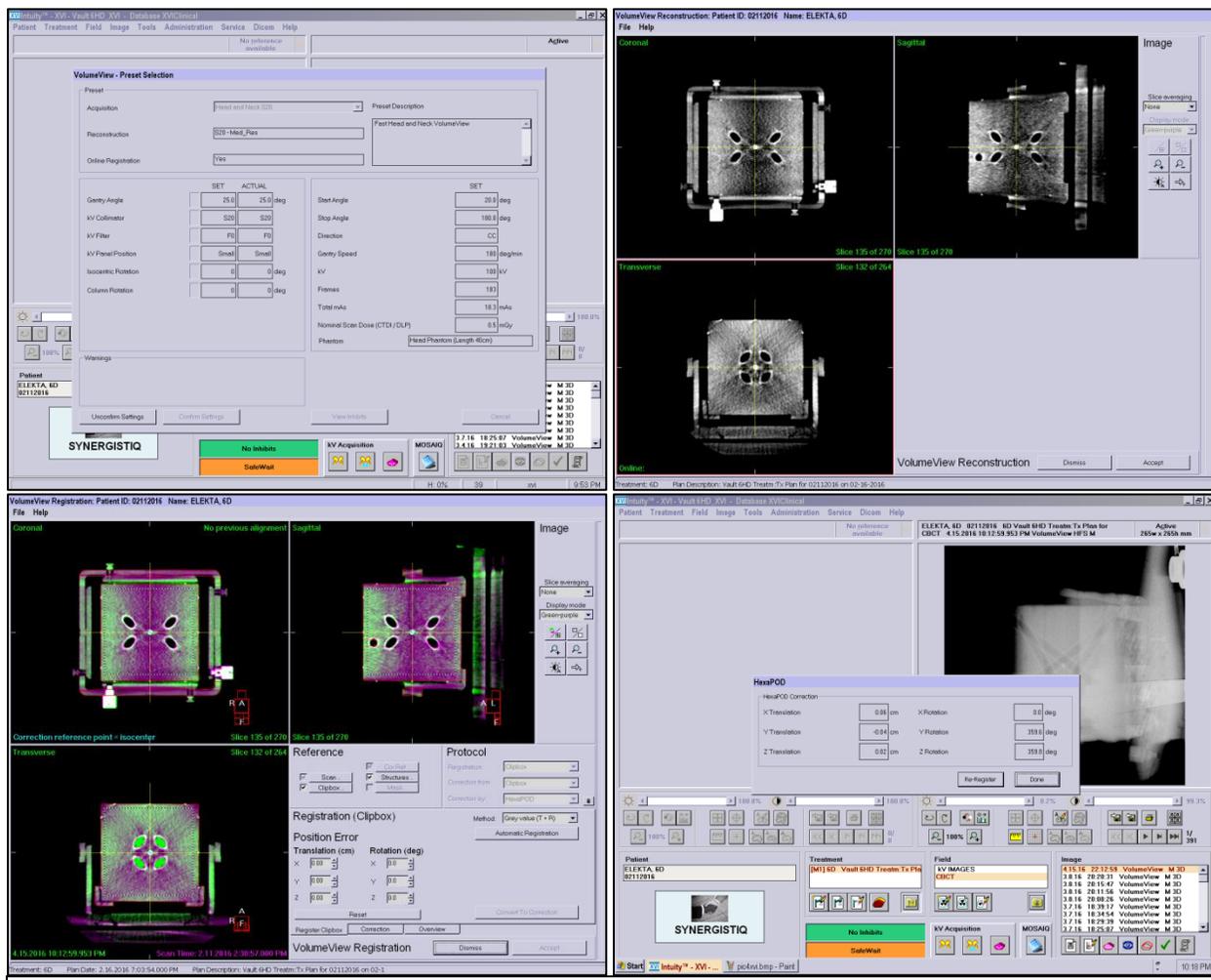
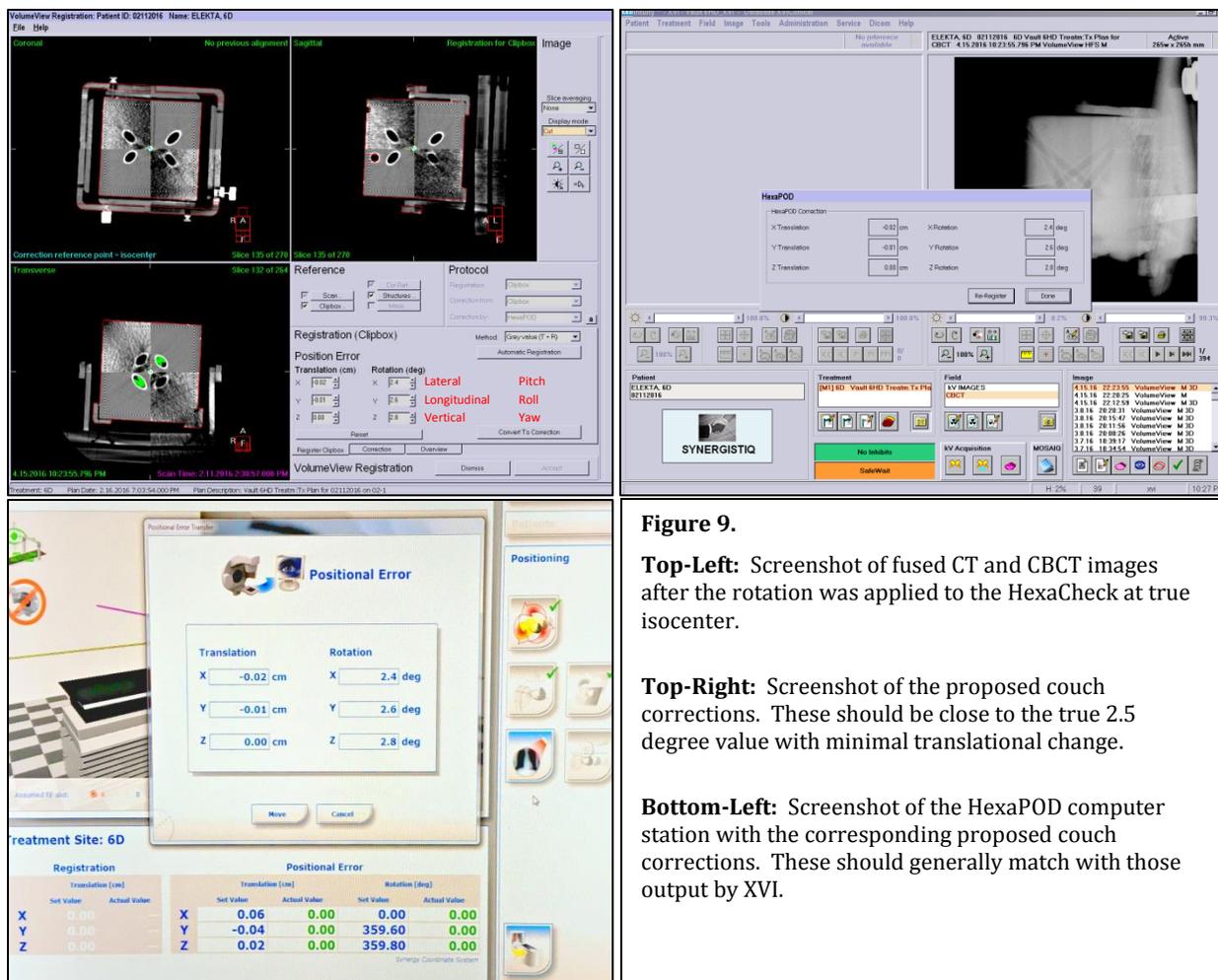


Figure 8. Top-Left: Screenshot of setup verification screen. The protocol must already be in place in the patient plan for HexaCheck within MOSAIQ if using this system.

Top-Right: Screenshot of the reconstructed CBCT. Accept this after verifying an accurate image.

Bottom-Left: Screenshot of the fusion display. Automatic Grayscale registration should work well with this phantom but bone registration can also be tested using the MIMI Phantom.

Bottom-Right: Screenshot of proposed couch corrections. This should match that shown on the HexaPOD computer.



The MIMI Phantom’s unique design incorporates 5 bone equivalent tubes that pass through the entire phantom at varying angles allowing for quick and accurate registration. This makes it useful for automatic registration quality testing as the tubes can be easily identified and verified for precise image registration. This also allows testing of both the grayscale registration and the bone matching registration available on XVI.

Conclusions

This method of testing should accurately assess the 6DoF image-guided positioning accuracy of your system in both the software and physical couch correction aspect. The software is tested since the true rotational shift is known and can thus be verified in the correction proposed by XVI. The physical aspect is assessed by retaking the CBCT after correction and analyzing the residual error in couch position. This yields an overall accuracy of the combined system.

Test Frequency

TG 142 recommends translational alignment and couch correction testing for each treatment day. If a 6DoF couch is being used clinically, it would thus follow accordingly that each day 6D corrections of a 6DoF couch should be performed using a rotational positioning/repositioning phantom.

References

1. Klein EE, et al. Task Group 142 report: Quality assurance of medical accelerators. Med Phys. 36(9). 2009
2. Stump, K. (2010). Elekta XVI Volumetric Imaging and Registration QA with the MIMI Phantom.
3. Basavatia A, Tomé WA. Multiple Imaging Modality Isocentricity (MIMI) Test. Med Phys. 35(6). p2776. 2008.

Appendix A

Sample workflow using the HexaCheck phantom: The procedure listed below looks to assess the imaging and treatment coordinate coincidence as well as the positioning/repositioning accuracy using a 6 degree of freedom couch top.

Workflow step for Daily 6DoF couch QA testing (CBCT/MV/kV testing)

1. Place the indexing bar on the couch top
2. Secure HexaCheck phantom to the indexing bar on the couch top
3. Zero out the rotations on the HexaCheck
4. Place MIMI phantom in the HexaCheck and secure with tightening screw
5. Align the MIMI phantom to the offset markings
6. Apply pitch, roll, and yaw deviations on the HexaCheck
7. Acquire the kV-CBCT and proceed with phantom image registration
8. Ensure translational and rotation corrections are as follows (Translational $\pm 1.0\text{mm}$; Rotational $\pm 1.0^\circ$)

Direction	Displacement
Left-Right	12 mm
Ant-Post	14 mm
Sup-Inf	10 mm
Roll	2.5°
Pitch	2.5°
Yaw	2.5°

9. Apply the registration shift corrections
10. Verify that lasers coincide with center of MIMI phantom ($\pm 2.0\text{mm}$)
11. Document any laser offsets
12. If testing kV-kV match, acquire AP and Lat kV radiographs and ensure that the MIMI isocenter coincides with the DRRs.
13. If testing MV-MV match, acquire AP and Lat MV port film and ensure that the MIMI isocenter coincides with the DRRs.