A novel Quality Assurance (QA) Phantom for verification of accuracy of six degrees of freedom (6DOF) couch in both Varian and Elekta platforms

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Purpose:

- To assess the accuracy of 6 Degrees of Freedom (6DOF) couch for patient positioning in both Varian and Elekta platforms using a custom developed phantom that can be used for daily quality assurance.

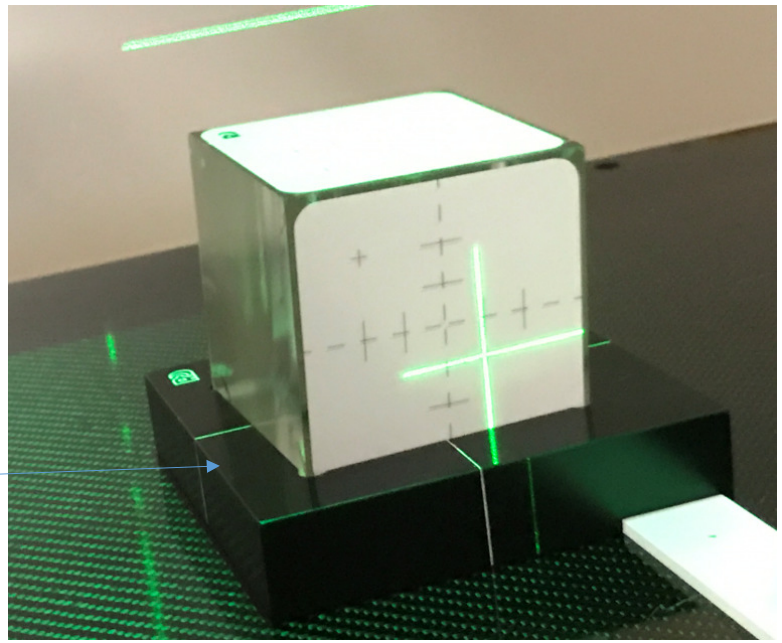
Clinical Significance:

An ideal daily QA phantom should be both precise and simple to use. We have developed and validated a QA phantom that with the aid of implanted markers can be used to verify the accuracy of six degrees of freedom (6 DOF) couch in both Varian and Elekta Linacs. The test can be performed by therapists as part of daily QA in less than 10 minutes.

QA Phantom

Phantom Description:

An 80mm acrylic cube (shown below) with external markings and various titanium and aluminum fiducial markers imbedded at accurately known positions was used in this study. The fiducials are used in the study to determine positional and angular accuracy. The cube was mounted on a novel platform that was precisely milled using a computerized numerical control (CNC) milling machine so that the cube is angled 2.5 degrees in each of the rotational axis (pitch, roll and yaw).



QA Phantom Fiducial Markers

- 4 spherical 2.38 mm Diameter Aluminum fiducials located at the axial CAX and positioned peripherally ANT, POST and lateral to center of the cube (fig 1).
- 8 Aluminum Wires 10mm long and 2mm in diameter located at the 8 vertices of the cube (fig 2)
- 3 spherical 2mm dimeter Titanium fiducials, the offset fiducials are used determine the linear position (fig 3).
- **Titanium Marker Locations in Cube:**
  One (1) at Isocenter: X; Y; Z=0 (fig 1)
  One (1) located from Isocenter: X: -2 cm; Y: -2 cm; Z: +2 cm (fig 3)
  One (1) located from Isocenter: X: +2 cm; Y: +1 cm; Z: -1 cm

CT images of fiducials

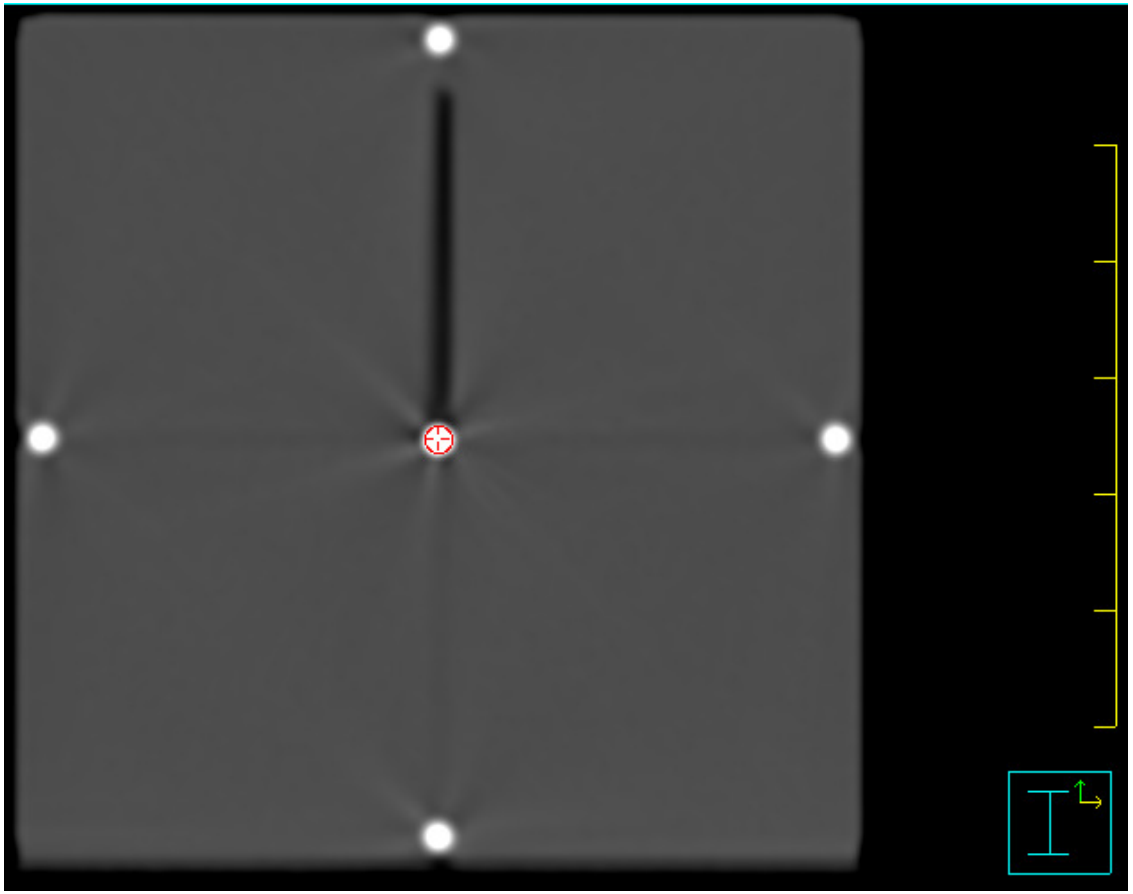


Fig 1: CA Axial cut shows 4 peripheral fiducials and the fiducial at CA

Fig 2: Wires located at the superior 4 vertices

Fig 3: Fiducial located at (-2,-2,2)

Methods:

To provide a reference image dataset, the phantom was leveled and aligned to 0◦ in all three axes and scanned in a GE CT scanner. Images were acquired with 1 mm slice thickness and reconstructed at 1 mm slice spacing. The images were transferred to the Monaco(Elekta) and Pinnacle^3 (Philips) treatment planning system respectively and the isocenter was defined at the center of the phantom image with the guidance of the titanium markers (fig1). The image and isocenter position was exported to the XVI(Elekta)/ARIA(Varian) application and used as the reference dataset for this study.

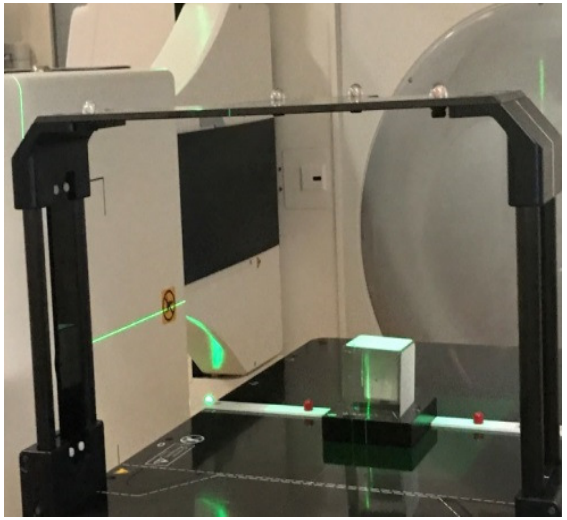
Elekta XVI:

- The XVI software enables the CBCT images to be reconstructed at high (0.5 mm), medium (1 mm), and low (2 mm) resolutions. We reconstructed the images at 1mm resolution (same as kvCT) for this study.
- Three rigid body registration algorithms (namely, gray value, bone, and seed matching) are available for matching the reference and verification image datasets. The gray value automatic registration technique uses a gray level correlation ratio algorithm[1]. The bone registration technique uses a chamfer matching algorithm[2.] The seeds matching algorithm uses the same chamfer matching algorithm as the bone algorithm, except the algorithm has been optimized to match small objects of high density that are nonlinearly separated.

- 1. . Roche, G. Malandain, X. Pennec, and N. Ayache, "The correlation ratio as a new similarity measure for multimodal image registration," in *Proceedings of the Medical Image Computing and Computer-Assisted Intervention—MICCAI'98* (Springer Verlag, Cambridge MA, 1998),pp. 1115–1124.
- 2. Brogefors, "Hierarchical chamfer matching: A parametric edge matching algorithm," IEEE Trans. Pattern Anal. Mach. Intell. **10**, 849–865 (1988).

Elekta Hexapod Couch

- The HexaPOD RT System is guided by an infrared-camera that enables patient positioning accuracy in six degrees of freedom. The HexaPOD is mounted on the base of the standard Elekta table. Movement of the HexaPOD is computer-controlled via the iGuide software and executed by means of the robotic legs. Accurate positioning is ensured by means of an optical tracking system which consists of an infrared stereo tracking camera mounted on the ceiling and set of five passive sensors. The sensors are spherical reflectors positioned at nonsymmetrical distances on a base plate. This arrangement is rigidly attached to the HexaPOD by means of a C-shaped bridge as shown below. The QA phantom is attached to the iBeam EVO Elekta table using an indexing bar as shown below



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Varian 6DOF Perfect Pitch Couch

- The Varian 6DoF couch adds a two degrees of freedom (2DoF) module to the pedestal of the already existing 4DoF TrueBeam couch. The IGRT table top is fixed permanently on the top of the new 2DoF module, so that the 2DoF module moves together with the table top. It has the following specifications: the 2DoF module is 12 cm high; can handle a maximum load of 200 kg; does not reduce the vertical travel range of the existing 4DoF couch; can pitch and roll in the range of $\pm 3.0^{o}$; has no mechanical assemblies extending into the rotation volume of the gantry head; and uses no external devices (e.g., optical cameras like Elekta) to control its position and is completely integrated within the TrueBeam control system.

Varian Perfect Pitch 6 DOF Couch

- The TrueBeam system uses the machine isocenter as the origin of its reference coordinate system. The actual mechanical rotation point (origin of the mechanical coordinate system) of the 2DoF module is away from this isocenter. Therefore, substantial translations of the couch top and couch pedestal are required to generate a pure pitch or roll change at the isocenter. The 2DoF module sits on top of the movable stage of the couch pedestal. Consequently, the mechanical rotation point of the 2DoF module moves vertically, longitudinally, and laterally relative to the isocenter, necessitating calculations to convert changes in mechanical parameters of the couch pedestal and 2DoF module into changes of the couch position/orientation in the reference (isocentric) coordinate system. *For example, a change in pitch of 3 degrees will result in approximately an 8 cm vertical change in the location of the couch top at the isocenter.*

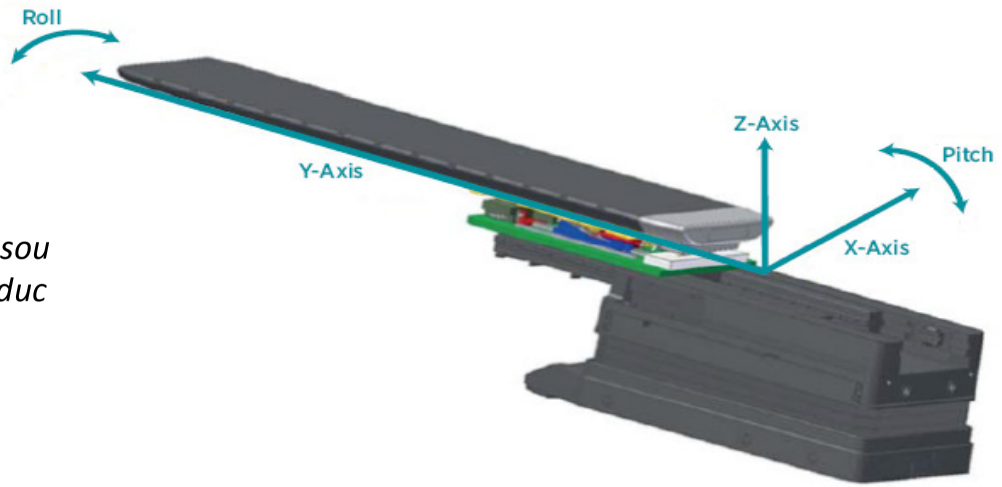


Image taken from *https://www.varian.com/sites/default/files/resource_attachments/PerfectPitchCouch6DoF_ProductBrief_RAD10264A_January2013.pdf:*

Methods:

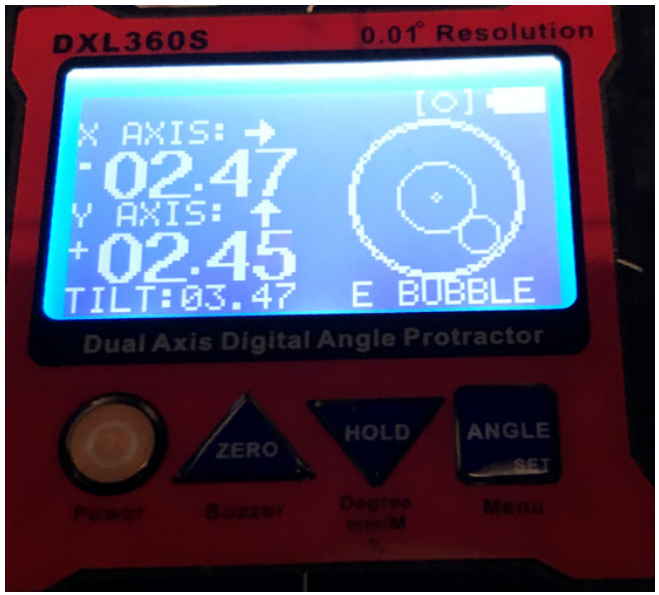
- The baseline accuracy of each 6DOF couch was measured using a dual axis digital protractor (Model DXL360S) as shown below

Methods:

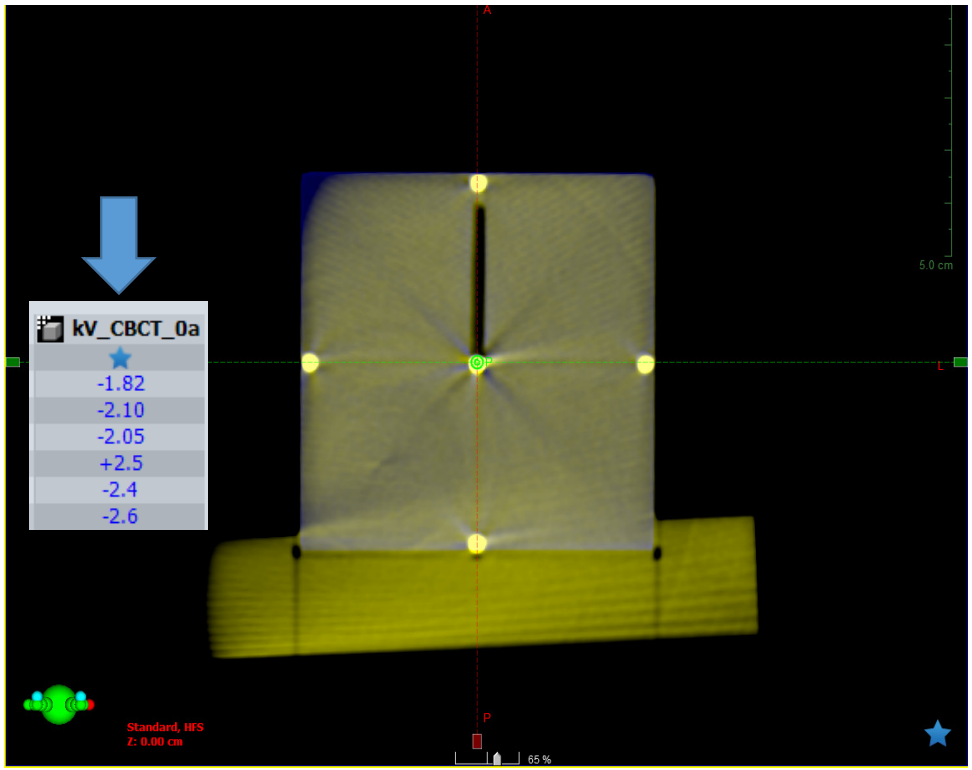
- CBCT images were acquired in both Varian True Beam and Elekta Versa linacs and analyzed using the vendor supplied software. The 6DOF couch was adjusted based on the alignment of markers and aluminum wires embedded in the acrylic cube.
- We used the Head and Neck CBCT protocol on the XVI platform in the study. A scan angle of 200 degrees using 100 kV and 36.6 mAs was used
- Varian OBI used the Head, full fan, half trajectory CBCT protocol. Total scan angle 200 degrees, 100 kV and 150 mAs.

Results:

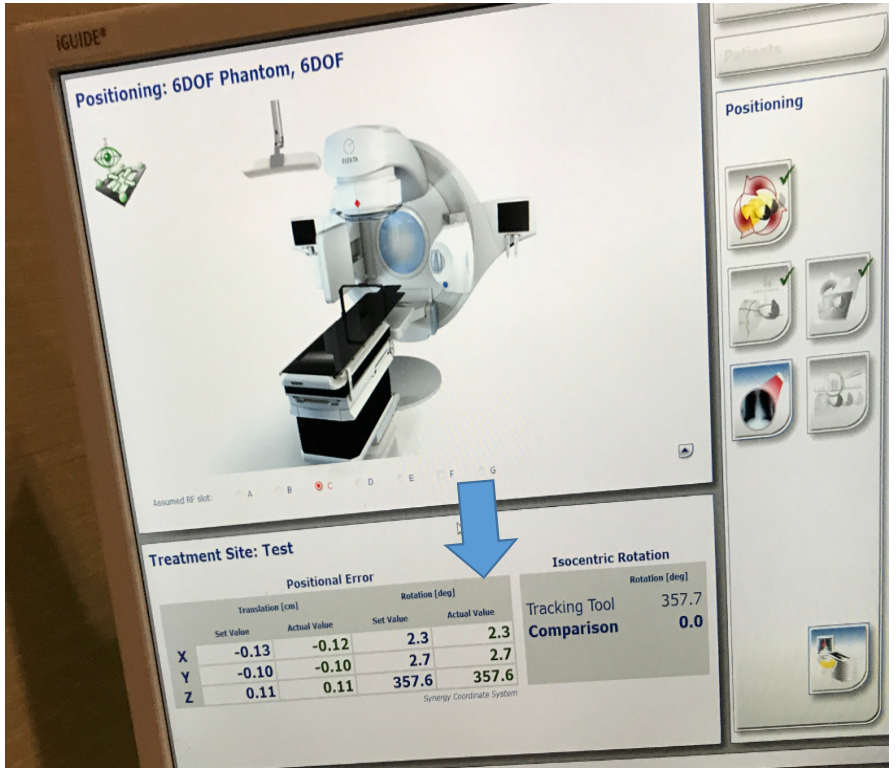
- In both the Elekta and Varian platforms the vendor supplied software correctly calculated the rotational off set introduced in all 3 rotational axis within ± 0.2^{o}. The X and Y rotation off set (2.5 degrees)can be verified using dual axis protractor as shown below



Results in Varian & Elekta:



VARIAN



Elekta

Conclusions:

- We have validated a custom developed phantom that can be used for daily QA of 6DOF couches to ensure accurate patient positioning in highly conformal treatments.
- The Seed matching algorithm in the Elekta XVI software automatically detected all the implanted titanium markers and accurately registered the kvCT and CBCT images with correct rotational offsets while in the Varian OBI manually guided alignment was necessary.
- The current QA device can test the performance of the 6DOF couch on a True Beam (version 2.5) and Elekta Hexapod couches with an alignment accuracy of ± 0.2 degree. This phantom has been integrated as part of daily QA on our linacs.