Master of Science dissertation:

Evaluation of the Catalyst system for patient positioning during breast cancer treatment.

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A popularized summary in Swedish:

Utvärdering av systemet ”The Catalyst” för positionering under behandling av bröstcancer.

Bröstcancer är den vanligaste formen av cancer hos kvinnor. Fler än 7000 diagnostiseras med denna sjukdom varje år i Sverige. En del av behandlingen mot cancern är strålbehandling. För att strålbehandlingen ska ge goda effekter är det viktigt att det är den sjuka vävnaden som bestrålas, och att den friska vävnaden förskonas från strålningen i den mån det är möjligt. Detta uppnås genom noggranna stråldosplaner individuellt utformade för varje patient. Strålbehandling ges vanligtvis i 16 eller 25 fraktioner, det vill säga att patienten kommer tillbaka dagligen till kliniken 16 eller 25 gånger för behandling. Det är viktigt att patienten ligger i samma position vid varje tillfälle för att stråldosen ska kunna levereras exakt till tumörområdet. I denna studie har ett nytt positioneringssystem utvärderats som heter ”The Catalyst™ system” (©2011 C-RAD Positioning AB).

På Skånes Universitetssjukhus i Malmö placeras patienten under behandling liggandes i en ställning på behandlingsbritsen. Armarna placeras i skenor ovanför huvudet och ställningen lutar 7,5° bakom ryggen. Dagens rutiner går till så att under planeringsstadiet i behandlingskedjan har patienten fått tre små tatueringsprickar. Dessa används under positioneringen ihop med laserstrålar som finns i behandlingsrummet. Då prickarna och laserstrålarna sammanfaller ligger patienten i rätt läge. Nästa steg för att försäkra sig om att patienten ligger i rätt position är att ta röntgenbilder på patienten. Man korrigerar patientens position efter resultatet från röntgenbilderna och sedan kan man starta strålbehandlingen. Röntgenbilder tas vanligtvis vid de tre första fraktionerna. Därefter gör man en medelvärdeskorrektion av bordspositionen om det krävs för att få patienten i det korrekta läget. Under behandlingsgången tas även röntgenbild vid en senare fraktion för att försäkra sig om att patienten fortfarande ligger i rätt läge.

The Catalyst™ är ett positionerings och övervakningssystem som inte använder sig av röntgen för att kontrollera patientens position utan det här systemet använder sig av optisk scanning av hudytan. Detta har en självklar fördel då det inte bidrar till någon extra stråldos till patienten och kan därmed användas vid varje behandlingstillfälle. Systemet använder sig av en icke-rigid kroppsalgoritm som beräknar hur patienten ska flyttas för att hamna i rätt position. De delar av kroppen som ligger i fel position lyses upp genom att rött eller gult ljus projiceras på patienten, beroende på åt vilket håll som flytten ska ske. Då en arm belyses med rött ljus kan sjuksköterskan enkelt positionera om armen för att få den i rätt position. The Catalyst™ har även fördelen att den registrerar eventuella rörelser under bestrålningen. Skulle patienten flytta sig visar systemet detta direkt på en datorskärm så att sjuksköteskorna kan avbryta behandlingen och positionera om patienten.

För att undersöka hur The Catalyst™ fungerar i kliniken för att positionera patienter har tre studier utförts. Den första studien var en fantomstudie där fantomet flyttades inom mätvolymen för att undersöka systemets noggrannhet och mätvolymens utsträckning.

Den andra studien utfördes med hjälp att det kliniska CBCT (Cone Beam CT) systemet som tar 3D bilder av skelettet och använder en automatisk benmatchningsfunktion för att ge patientens position. Fantomet i studien hade då inre benstruktur, vilket var mer patientlikt. I studien undersöktes om CBCT systemets automatiska benmatchning och The Catalyst™ ytmatchning gav samma positioneringsresultat.

Den tredje studien var en patient studie som innefattade tretton patienter där röntgenbilder och Catalyst bilder togs vid varje behandlingstillfälle för att undersöka hur väl systemen överrensstämmer.

Resultaten från de tre studier som utförts visar att noggrannheten på systemet inte är inom en millimeter vilket är önskvärt. Systemet behöver vidare utveckling för att kunna säkert positionera patienter och The Catalyst^{TM} har potential för att lyckas med detta.

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Abstract

Purpose: The Catalyst^{TM} system was tested and compared with an X-ray image verification system for patient positioning during breast cancer treatment. Included was to find the optimal reference image and the optimal cropping method for the reference image. Parameters that could lead to an optimization of the treatment routines were also evaluated.

Method and Material: The study was divided into three parts, "Accuracy measurement of the scanning volume", "The Catalyst system correspondence with CBCT verification images on a phantom" and "The Catalyst system correspondence with planar verification images on patients."

Accuracy measurements of the scanning volume were performed with a head shaped phantom which had skin equivalent characteristics. The phantom was positioned in a coordinate table and was moved in steps of 2 millimeters in lateral and longitudinal direction in four different planes to investigate the accuracy in the scanning volume.

The CBCT study was performed with a pelvis phantom. The phantom was moved ten times and the deviation from the reference images in the CBCT system and the Catalyst^{TM} system were compared.

The Catalyst system correspondence with planar verification images on patients included thirteen patients which at every treatment fraction were positioned with On-Board Imaging (OBI, Varian©), planar verification images (kV). The positioning results were also registered with the Catalyst system. Both systems used the same reference set-up from the CT scan and the positioning results were compared. The optimal cropping method for the reference image was also evaluated.

Results: The results of the study "Accuracy measurement of the scanning volume" showed that the system has a limit at 7.5 cm above the isocenter and that the most accurate results were registered in the plane 5.0 centimeters above the isocenter. The error in the positioning result was 0-4.0 millimeters in the scanning volume. There was no detectable drift in the values in lateral, longitudinal or vertical direction.

The Catalyst^{TM} system correspondence with CBCT verification images on a phantom resulted in a high accuracy in positioning in vertical and lateral direction with a correspondence of 0-2.0 millimeters. In the longitudinal direction the results differed between 4.0-6.0 millimeter and which was probably due to a flat structure of the phantom.

The results from the patient positioning study varied depending on the patient. The optimal reference image was determined to be from the CT structure set. An optimal cropping method for the reference image was found and later used for the analysis of the patient positioning.

Conclusions: The Catalyst^{TM} system shows accurate positioning result for the phantom studies. The limitation was due to flat or spherical surfaces where the algorithm had difficulties. The flat structure did not provide enough matching information for the algorithm and for the spherical shape the optimization method found a number of solutions. This implies that it is important that the reference image in a patient situation has some structure that the system can use for matching.

In the patient positioning study the reference image for every patient were cropped in an optimal way, mainly to minimize the breathing motion. The results of the study indicated that the system does not correspond well with the planar verification images enough for all patients, possible due to that the verification image system matches due to bony structure and the Catalyst system matches due to the skin surface.

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Abbreviations and acronyms

ARIA®	
CBCT	Cone Beam Computed Tomography
CT	Computed tomography
DRR	Digitally reconstructed radiograph
OBI	On-Board Imager®, Varian®
PTV	Planning target volume

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1 Introduction

In radiotherapy the positioning of the patient is a crucial part of the treatment. The aim is to deliver a high dose to the target while minimizing the dose to the surrounding healthy tissues. Therefore it is important that the target is positioned correctly for the treatment and that the target definition is including uncertainties like organ movement and positioning errors. In the process to optimize the radiotherapy the margins of the target should be minimized. This is possible by improving the patient set up and immobilization. Target motion during treatment is a possibility that should be considered, as well as the change of patient geometry caused by weight loss or swelling during a long treatment.

The aim of this study was to evaluate a new positioning and motion detection system on the market provided by ©2011 C-RAD Positioning AB. The system is based on optical scanning of the body skin surface and will provide the user the patient position in six degrees of freedom. Parts of the system are under development together with SUSMalmö and the intention after the validation of the system is to implement it fully in clinic.

1.2 Immobilization and imaging of patient

In general, the internal motion of the tumor is caused by gastrointestinal, cardiac motion and respiratory motion. For the breast cancer patient it is an inherent challenge that the breast tissue is non-rigid and can move and deform with respect to the bony anatomy and that movement of the upper arm affects the breast muscle and then the position of the breast tissue. Consequently the fixation of the upper arm is important for a correct patient positioning. The fixation used at the couch during breast cancer treatment provides a certain degree of freedom for movement of the arm. Possible movement of the upper arm is hard to detect but the Catalyst™ system can provide with this information. In order to include motion of the target when drawing the PTV it is necessary to have large margins. As mentioned earlier this is an unwanted side effect causing that more healthy tissue gets irradiated. For patients with left sided breast cancer respiratory gating is performed at Skåne University Hospital Malmö (SUS Malmö) to avoid irradiation of the heart and the left anterior descending coronary artery. For patients with right sided breast cancer there is no gating performed. In this study all patients were women treated with breast conserving surgery and radiotherapy.

In SUS Malmö department protocol for breast cancer patients images are taken during the three first sessions of their radiotherapy treatment to determine if they are positioned correctly. Imaging is later performed at frequent intervals during the therapy to assure that the patient still is in the correct position. Studies have been made to see if daily imaging would be favourable for correct patient positioning, for the reason that it has been shown that significant errors occur frequently through the radiotherapy treatment course (1) (2) (3). LJ Bell et al studied whether daily imaging would reduce the positioning errors and draw the conclusion that daily imaging may be useful, but also that further research is necessary (4). Daily imaging without an extra radiation dose to the patient would be favourable, and this what the Catalyst™ system provide.

The Catalyst™ system is using a surface matching technique to position the patient. This technique was investigated by Cristoph Bert, M.S. et al. The aim of the study was to analyze the setup accuracy and reproducibility of the 3D surface-imaging process. The surface was in this study reconstructed with a rigid transformation, which is not the case for the Catalyst™ system. The result of the study showed greater breast topology congruence than when patients were set up by laser or portal imaging (5). This implies that the non-rigid algorithm that is the new technology in the Catalyst™ system might show an even more substantial result in the positioning. Patient set-up verification with optical body surface systems was also studied by Maria Francesca Spadea et al. The study used infrared optical localization points on for patient positioning during breast radiation therapy. The study found a significant improvement in patient set-up with error variability decreased from 3.2 to 2.1 millimeter and the irradiated field decreased from 5.7 to 3.5 millimeter. (6) These are promising results from optical scanning systems.

2. Theory

2.1 The Catalyst system

2.1.1 Product description

The Catalyst™ system is provided by ©2011 C-RAD Positioning AB.

The Catalyst™ system is an optical surface scanning system that will provide the service to control the patient positioning during set-up and treatment. This optical scanning system consists of a single scanning unit consisting of LED lights and a CCD camera (figure 1). Measurement is achievable by projecting a rapid and near-visible sequence of patterns onto the object to be scanned. The projector is mounted at an angle from the camera and, at the same time the near-visible light is projected, images of the objects surface is captured by the camera. The measurement process is using a non-rigid body algorithm (chapter 2.3) for calculating the distance between the surface and the iso-center and a high resolution 3D surface model can be reconstructed, based on the principle of optical triangulation.

Figure 1. *The Catalyst scanning unit installed in the treatment room.*

2.1.2 Technical specifications

Physical dimensions.

Size (L*W*H)	280 mm x 620 mm x 400 mm
Weight	16 kg

Power

Input voltage	100-240 VAC
Frequency	47-63 Hz
Power consumption	125 W

Performance

Scan volume (X*Y*Z)	800 mm x 1300 mm x 700 mm
Measurement reproducibility	0.2 mm
Long term stability	0.3 mm
Warm-up time	30 min

Positioning accuracy	1mm (rigid body)
Motion detection accuracy	1 mm (rigid body)
Respiratory gating accuracy	1 mm (rigid body)

Projector

Type	DLP three high-power LED
Power consumption	115 W
Measuring light	~450 nm (blue)
Projecting light	~528 nm (green) and ~624 nm (red)

Camera

Type	CCD Pike F032B GOF ASG16
Resolution	640x480 pixles

Environment

Operation temperature	+10 ^{0}C to +40°C (50^{0}F to 104°F)

2.2.1 How to operate the system

While using the system in clinical mode the user has at first only three possibilities. One is to chose a patient, the other one is to do a daily check and the third is to close the program (figure 2).

Figure 2. *Start window for The Catalyst software in "clinical mode".*

The patient can be imported to the system or added manually in an advanced mode.

After choosing the patient the user can only move in the direction which is shown in yellow color on the bar at the top of the screen (figure 3)

Figure 3. *A) Patient set-up.* *B) cPositioning.* *C) cMotion.* *D) Results.*

To achieve correct results one must make sure no object is in the way of the scanner and that the room is shielded from sun light. The patient has to be positioned within the scanning volume and if possible within 5 centimeters of the reference image.

2.2.2 cPosition

A reference image is imported as a DICOM RT file or taken by the Catalyst™ after correct set-up of the patient using the utility cPosition. In SUS Malmö this reference image at the CT simulation can be taken by two utilities. One is the Sentinell and the other is the surface registration from the CT set.

A new reference image can be taken manually in the Catalyst system when the patient has been re-positioned (figure 4). The new reference image will automatically be the reference image used at following treatments.

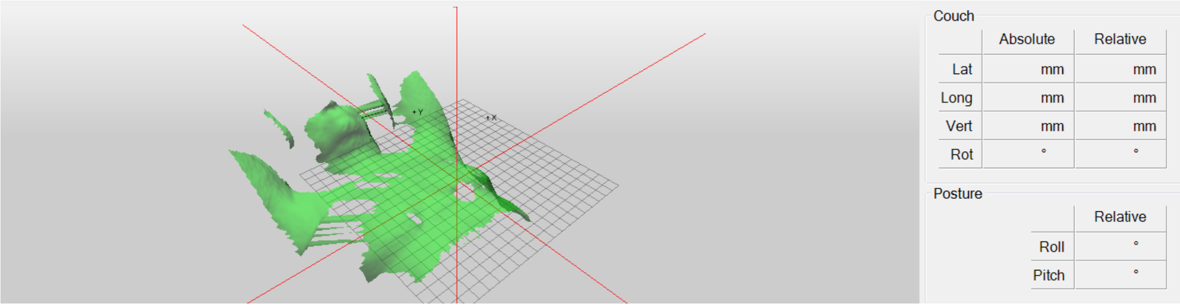


Figure 4. ***Example*** *of a reference image captured by the Catalyst system.*

A correct and safe patient set-up is facilitated by the Catalyst system in terms of color and bars showing the deviation projected directly on the patient's skin. It is critical that the patient does not change position and therefore the light that is projected on the patient's skin guide the nurse how to put the patient in the position of the reference picture. When the patient is correct positioned no color will show on the skin. If there are highlighted areas in yellow or red on the patient the affected area should be moved in correct position. These colored areas are also shown on the computer screen. The Catalyst^{TM} system does not require that any marks are placed on the patient.

When the patient is coming back for the next treatment session the system will provide all the information about the patient's position and required adjustments to position the patient identical to the reference picture.

2.2.3 Parameters

The area of interest is specified in a scan volume. The scan volume is pre set in a template that is formed after the treatment in question. The parameters set in the template are scan volume, gain and time. The LED power is set by C-RAD to 80% as a standard. The parameters time and gain is set to 5000µs and 500% for the template "RT_BRÖST" which is used in the study for the breast scan. The parameters are set in a way that as much surface as possible is detected. In the template tolerance settings for maximum out of position values are defined.

2.2.4 cMotion

The same reference picture is used throughout the treatment and to assure that the patient does not change position the system has a cMotion control. The cMotion monitors the movement of the patient during treatment delivery. This is an automatic surface rerendering that is updated after a few seconds. The algorithm operates in a way that the movement of the surface relative to the iso-point in the live picture is compared with the iso-point of the reference picture. The deviations in position are shown in a diagram and the system automatically warns if the patient is moving outside the tolerance settings. This eliminates the need of visual monitoring by the personnel during treatment. Small movements might be hard to detect by just visually look at the video screen of the patient during treatment. The

Catalyst^{TM} system has an accuracy of 1 millimeter during cMotion for rigid body (see 2.1.2 Technical specifications).

2.2.5 Advanced mode

The data that the system collects is stored in a DICOM database. Entering the system in advanced mode enables access to all the patient data. Patient ID and settings for the cPosition during setup and cMotion during treatment are visible. All the treatment sessions are listed by time and date they were performed. In this mode it is also possible to add patients manually or import patient information from DICOM-RT files.

2.2.6 Managing data

In the” Analysis tool” the data can be evaluated. This tool enables the user to analyze the positioning result between a reference image and a live image. The reference picture can be cropped so parts of the picture that only contributes with noise can be erased. The reference image is then matched with the live image. The live image is the one captured while entering treatment mode. The information about the positioning is displayed in a distance map and in calculated values. The algorithm used is a non-rigid body algorithm. The calculated values are displayed in red color if the proposed correction is outside the tolerance setting, if not the values are displayed in black.

2.3 The non-rigid body algorithm.

2.3.1. Non-linear registration.

To provide accurate information about the shift of the isocenter due to patient movement the Catalyst system is using a non-rigid body algorithm. This algorithm is a company secret but the principle behind it is presented in different articles, and especially by Hao Li et al. who were a copartner during the development of C-RAD’s algorithm.

First the system has to extract the edge data. The color structured light technique was first proposed by Zhang et al. (7). The technique has since then been developed further. Hao Li et al. are proposing in their work improvements of this technique. For us to understand the Catalyst system we have to investigate the technique behind it.

Near-visible light is projected onto the object. The digital camera later detects the structured light. If the object is not plane the light will not be structured anymore and the camera detects distorted light. The physical characteristics of the projector limit the system, due to the focus of the projector, and therefore it is only possible to project sharp images at a specific distance. Also the shape of the object might be self-occluded and this results in that the projected pattern does not exactly correspond to the acquired one. Noise from the CCD camera, unfavorable lighting circumstances and object texture are also factors that contribute to error in the surface acquisition.

The preference is to have a low number of input images, and Hao Li et al. are restricting their system to a single one. (8) The accuracy should still be high and this is approached in three steps. The first step is to take care of the color cross talk phenomena. This phenomenon is caused by uncalibrated colors emitted by the projector and acquired by the sensor. The second step is to remove dark areas from the image so that the contrast in the picture improves and the third step is an optional final smoothing if the image is too noisy.

The Catalyst™ system is using a non-rigid registration of the 3D-shaped object. This is because the object deforms during the scanning process and this brings more difficulties for the registration process. The deformation can be both rigid and non-rigid and also new parts of the object might come into view and vice versa. The optical system registers two partial scans of the object, one at the time when the reference picture is taken and one during live scan. These two scans are representing the object and are desired to match for a perfect patient positioning. The registration then requires both correspondence and a suitable wrapping function that matches both the object and the deformation. (9)

When larger surfaces, such as body parts, are being scanned large deformations arise (figure 5). Template-based registration is developed to give high-quality reconstructions. The template model minimizes noise and fills holes. Generally the estimation of correspondence of the system is made by external markers. This makes the caption of the object more accurate, but of course this is a disadvantage in medical care when it gives rise to an additional work step. The Catalyst™ system is developed with an algorithm that does not require external markers. One model that solves the registration without any external markers is described by Anguelov et al (10) who developed a joint probabilistic model that optimize point-by-point the registration of two meshes captured by the system. The method enables the discovery of movements and non-rigid deformations. This model is only one of many that can be used to solve the partial matching problem. The next step in the development of non-linear registration of surfaces is the real-time range scans using structured light scanners. (9) This kind of scan enables a dense set of range scans and gives a continuous registration of the object.

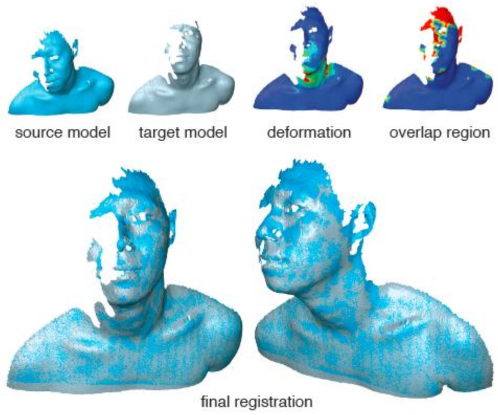


Figure 5. *The non-linear registration of the two surfaces and a non-linear optimization solution to overlap and deformation between the two surfaces(8).*

2.3.2. The isocenter shift calculation for The Catalyst system.

High sequenced near-visible light is projected onto the surface and the Catalyst™ system starts with capturing a reference image. The registration consists of the reference image and the live image registration. The calculation of the iso-center shift can be described in two main steps: Non-rigid registration algorithm that aligns the reference image to the live image and a volumetric deformable model that use the registration result to predict the influence on the live image position.

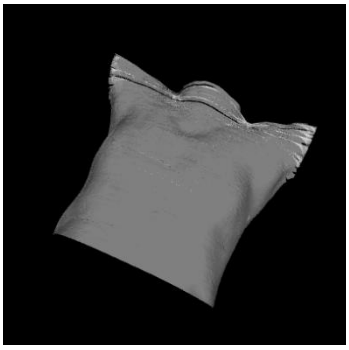


Figure 6. *Reference image*

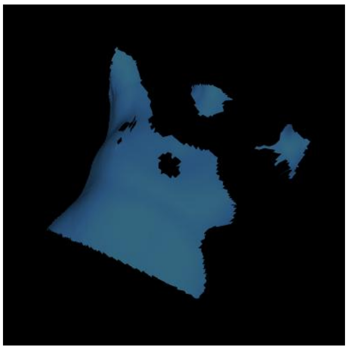


Figure 7. *Live image*

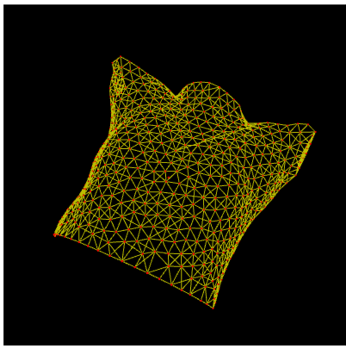


Figure 8. *Deformable node graph*

The matching between the reference image and the live image is made by a deformable node graph that consists of nodes defined by their position on the surface. The Catalyst™ system is using two node graphs simultaneous, one with a larger distance between the nodes and one with a smaller distance. The first step is to create surface meshes for the reference image (source scan) and the live image (target scan) from the scans. Then a deformation graph node is built with the reference scan by re-sampling the nodes of the reference scan and based on them create graph nodes. The core structure is now created and this structure is used to determine the deformation of the scan by the non-linear optimization. All possible deformations and transformations are from this structure transmitted to the underlying source mesh.

Between the two captures the object might have undergone rigid and non-rigid deformations (figure 9). Some parts of the scan might disappear and therefore the regions of overlap become the subset of both scans. The second step is to find associate points between the source mesh and the target mesh. This step identifies overlapping regions and points with poor correspondence are removed.

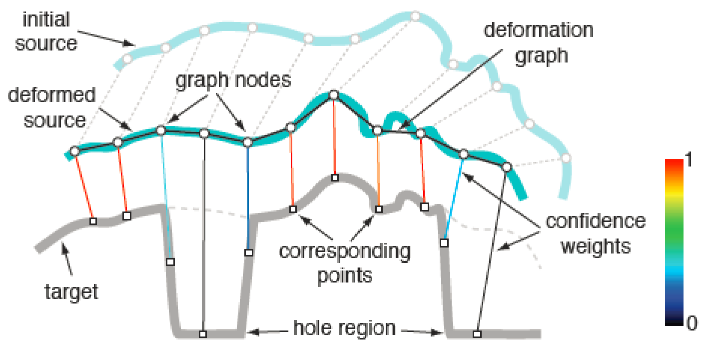


Figure 9. *Illustration of the surface matching with the non-rigid registration algorithm between the initial source and the target. The color scale shows the correspondence between the target and the deformed source.* **(9)**

The system is assigned with a global energy, which is the sum of the deformation node energy. This is defined as a combination of weighted parameters in every deformation node. The parameters included are the similarity with the connecting nodes, distance to the corresponding point and to the target surface, and the deviation from local rigidity. In the third step a non-linear optimization on the deformation node graph is applied to calculate the source mesh deformation. This is an iterative process and the deformation of the source mesh is calculated by minimizing the total energy of the system. This is constructed in a form of an energy functional acting on the system. In the optimization the systems total energy is defined and then minimized. If the vector between the reference image and the live image is great it correlates to a high energy and are penalized and vice versa. The term E_{point} and E_{plane} optimize the distance between the reference graph node and the live graph node. Two parameters control the deformation, E_{rigid} and E_{smooth}. Every transformation that deviates from a pure rigid motion is penalized by the

E_{rigid} term, and so the E_{rigid} restricts the deforming so that stretching and shearing artifacts are avoided. The E_{smooth} term is then regulating affine transformations of adjacent graph-nodes so that they are connected with each other.

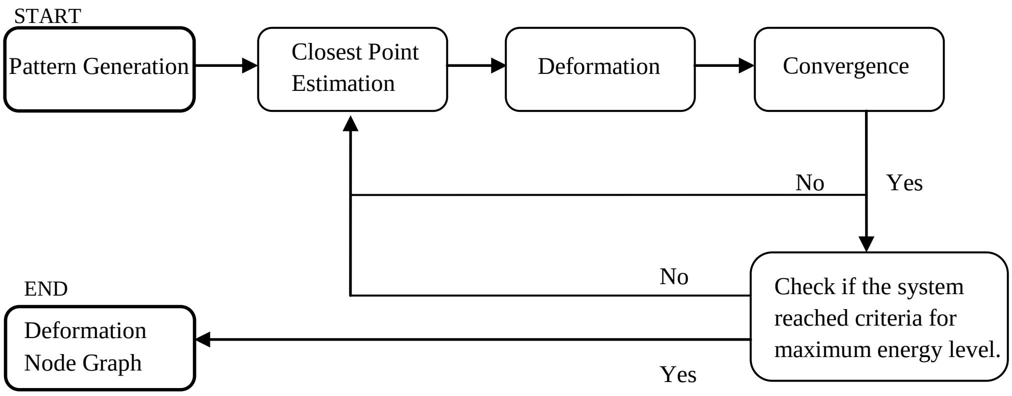
E_{point} E_{plane} E_{rigid} E_{smooth}

α, weightfactor

$$E_{tot} = \alpha_{rigid}E_{rigid} + \alpha_{smooth}E_{smooth} + \alpha_{point}E_{point} + \alpha_{plane}E_{plane}$$

The fourth step is to control the system’s global energy for convergence. The local rigidity should be maximized; if not so the process has to restart from step 2.

In the fifth step the system is controlled if it reached the criteria for maximum energy level. The mesh is stiff in the beginning and the stiffness is then gradually reduces in order to detect local deformations. If the criteria is not fulfilled the process has to go back to step 2.



When the optimization to the lowest energy state is done the next step is to transform the information on the surface down to a predefined point. This corresponds to how the position of the surface affects the iso-point. A volumetric mesh is created in order to encapsulate the target position and all triangles from the source mesh (figure 10). The volumetric mesh consists of uniformly distributed tetrahedrons and the nodes of the source mesh are related to all the nodes in the volumetric mesh.

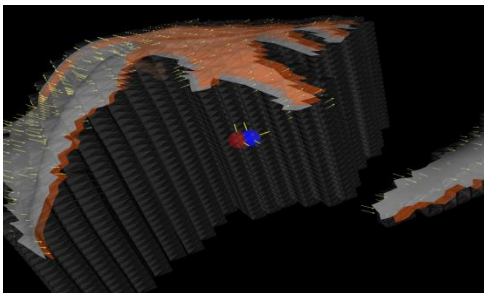


Figure 10. *Volumetric mesh.*

In this step the algorithm calculates the translation and the rotations in each node of the volumetric mesh based on the source mesh node transformation and the target position (figure 11 and 12). (9)

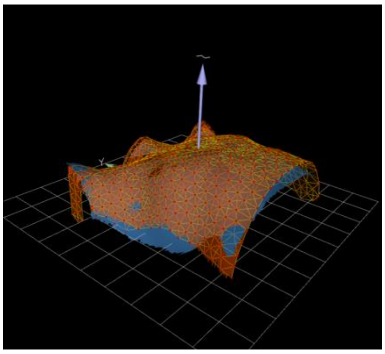


Figure 11. *Initial alignment*

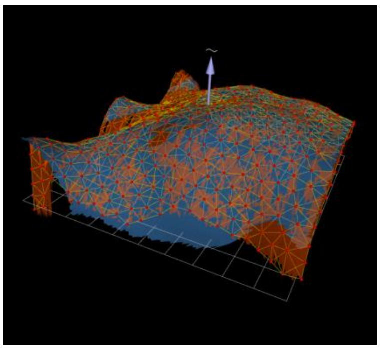


Figure 12. *Final registration result.*

3 Materials and Method

The evaluation of the Catalyst^{TM} system was performed in 3 steps:

1) Accuracy measurement of the scanning volume,
2) The Catalyst system correspondence with CBCT verification images on a phantom,
3) The Catalyst system correspondence with planar verification images on patients.

The first two studies, “Accuracy measurement of the scanning volume” and “The Catalyst system correspondence with CBCT verification images on a phantom” are phantom studies. These are performed as pre-studies to “The Catalyst system correspondence with planar verification images on patients” to evaluate some of the limitations of the system and gain knowledge of the system performance. The phantoms are chosen mainly by their light reflecting surface, necessary for the Catalyst system to be able to detect them.

The last one, “The Catalyst system correspondence with planar verification images on patients” is a patient positioning study.

3.1 Accuracy measurement of the scanning volume.

In the first step to evaluate the Catalyst^{TM} system the correspondence between actual position and the position the Catalyst^{TM} indicates was estimated. This was performed by a volumetric measurement above the isocenter, with a phantom positioned on the couch.

The measurement was performed on the Catalyst^{TM} system installed at the treatment room L22 at the Radiation Therapy Department, SUS Malmö. We have no comprehension about possible differences between the systems installed in other places and therefore this measurement is only valid for the system in room L22.

The study was carried out in the cPosition mode of the system and all positioning values were collected manually in this mode. No live image was captured and analyzed afterwards in the analysis tool. The reason for this approach is that this is how the nurses should work to position the patient to the correct position, 0.0.0, before treatment delivery.

We evaluated the performance and the accuracy of the positioning using a phantom with skin equivalent characteristics. The reason for this was so that the parameters ‘gain’ and ‘integration time’ could be set in the same way as for a patient. The round shape of the phantom is similar to the breast shape, since the phantom was placed with the rounded shape towards the Catalyst camera (figure 13a and 14).

The phantom was fixed to a coordinate table with sub millimeter precision. The phantom was attached to a piece of wood firmly screwed to the coordinate table in horizontal position (figure 13b). A reference picture was taken with the phantom at the isocenter. The point of isocenter was marked on the phantom with a piece of plastic material and this was made so that we could detect the isocenter in the Catalyst^{TM} system. The phantom was positioned by using the room lasers and the position was marked on it (figure 13a and figure 13b) with a pen. The isocenter was the starting point for the measurements and the exact mark of the isocenter made the measurements reproducible. The same reference image, captured in position 0.0.0, was used for the matching with the live image in all planes (figure 14).

The phantom was moved in the coordinate table to an exact position by turning the cranks to the coordinate table. The Catalyst™ system suggested a re-positioning, back to the reference image in point 0,0,0. After five seconds the values of the position that the Catalyst™ system gave was noted. This delay is caused by the time the system needs to calculate the surface and every fifth second the system updates the positioning result. The Catalyst™ system should only respond with the exact position, but this was not the case.

At every measuring point the values were drifting around the exact position and a range of values were given which caused the deviation, $\mu_{(Catalyst\ ref-SetUp\ )}$, to vary over time. For every measuring point the maximum and minimum value was noted during a time period of thirty seconds. Values were collected along the lateral axis and the longitudinal axis in steps of two millimeter. Lateral re-placement in the direction to the patient's left gives negative values and vice versa. Longitudinal re-placement gives negative values towards cranial and negative vice versa.

The measuring volume was decided to be 60 x 60 mm (along the longitudinal and lateral axis) in four different planes; isoplane, 2.5 cm, 5 cm and 7.5 cm above the isocenter (figure 31). The volume covers well a realistic positioning of a patient, and also test the boundaries of the system. It is wanted that the system suggest an accurate re-positioning value, so the nurses can perform the re-positioning of the patient fast and correct.

During the time of the experiment the camera was calibrated in the same way.

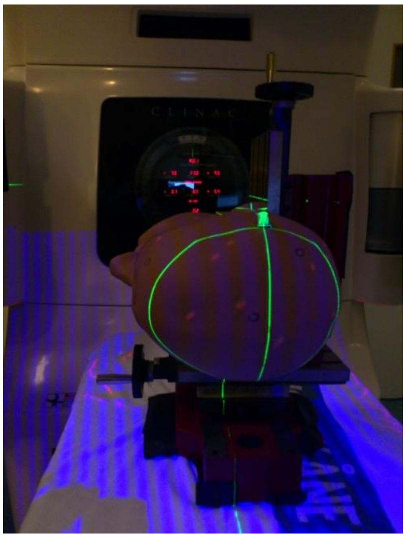


Figure 13a Phantom placed in the experimental set-up. *The plastic point on the phantom is placed in the iso-point of the system. Room lasers are used for accurate positioning.*

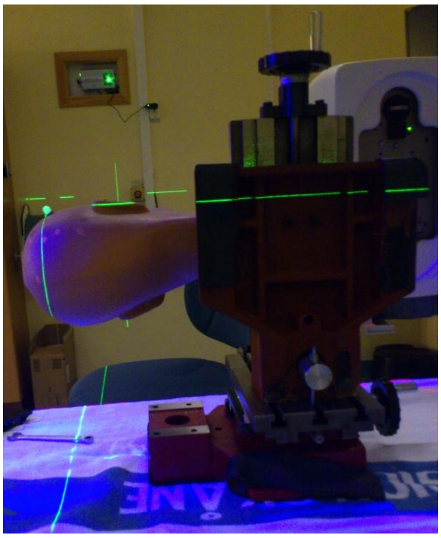


Figure 13b. Phantom placed in the experimental set-up. *From behind.*

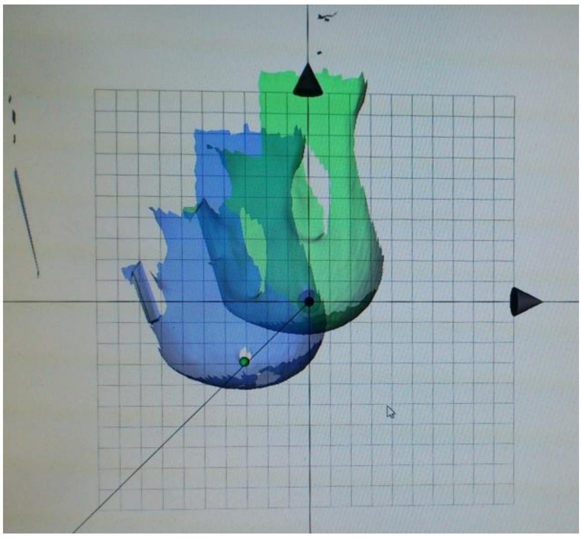


Figure 14. Live image registered shown simultaneous with the reference image. *Visualization of the registered volume in Catalyst work station.*

3.2 The Catalyst™ system correspondence with CBCT verification images on a phantom.

The motivation for this study is that it brings us one step closer to a real patient situation. The inner bony structure of the phantom was used for matching by the CBCT images and surface matching was made by the Catalyst™ system.

A pelvis phantom was scanned at the CT. The phantom had inner bone structure and a light reflecting surface. The position was marked with a pen and with CT spots. The scan was sent to the ARIA® (Oncology information system, Varian®) system. The CT structure set was then imported from the ARIA system to the treatment machine L1 SUS Malmö. By aligning the phantom to the room lasers the phantom was positioned in the isocenter at the treatment machine (figure 15). A reference image was then captured with the Catalyst™ system.

Figure 15. *The phantom placed on the couch in the treatment room L1 at SUS Malmö.*

After positioning in the isocenter the phantom was moved ten times into different positions within the measuring volume. For every new position a CBCT scan was made and a Catalyst Live Image was captured, and then matched to the reference images. The CBCT images were matched to the bony structure and the matching was performed automatically by the system. The suggested deviation from the reference images for the two systems was compared.

3.3 The Catalyst system correspondence with planar verification images on patients.

In the study the OBI (On-board Imaging®, Varian®) system and the Catalyst™ system are compared. The indicated shift in the patient positioning for the two systems should match. If this is so the Catalyst™ system could be a useful tool for positioning the patient during treatment sessions performed without verification imaging.

3.3.1 Reference image.

The Catalyst™ system was installed in the ceiling of the treatment room. The system illuminates the patient when immobilized in the correct set-up and the camera captures an image of the patient for a value of the patient position in lateral, longitudinal and vertical direction. To obtain the values of the position the captured image is compared with a reference image. The reference image used in the study was collected by the CT scanner and was the structure of the patient surface. The structure set from the CT was imported to the Catalyst™ system at the treatment room. The same CT scan was used for the dose plan and as reference images for the OBI system.

3.3.2 Positioning of the patient.

In this work the patient group consists of breast cancer patients. They are aligned to external markers placed on three positions, with reference to the isocenter. The fiducial external markers are defined at the CT simulation and are in form of three tattoos on the patient skin. Two lateral points were placed at about 2 centimeters below the breast tissue in plane with the medial set-up point and one anterior medial set-up point at midline on sternum. The markers are later a help for the nurses while positioning the patient in the treatment room, aligning the tattoos with the room lasers. The patients were treated in supine position on a breastboard (Posiboard™-2 Breastboard, CIVCO Medical Solutions) with their arms raised over the head and positioned on an arm-support and an immobilization wedge was placed under their knee for support.

Before treatment the patient positioning was verified by orthogonal kV images by the OBI system at the linear accelerator. The gantry rotation was set to 0°-270° for the left sided breasts and 180° – 270° for the right sided breasts during the orthogonal imaging. The kV images were then matched with the images from the reference set up from the CT simulation. The matching was performed by a nurse, using bony structures to align the images to assure that the patient is in the correct position. The kV images also provide information about the soft tissue contrast (11) (12). This way of positioning the patient references primarily to the bony structure. From the lateral image the matching is performed due to sternum and from the anterior-posterior image the matching is performed due to the clavicle and the top of the lung. The outer contour of the patient is not taken into consideration. The verification images are matched and results in an offset from the reference picture. If the value is within the tolerance limit (4mm for an online re-positioning (12)) the treatment can start. If the offset exceeds the tolerance value a couch movement has to be performed.

It was of importance for the study that the collection of the live image from the Catalyst™ was performed before any online couch movement. The deviation value proposed by the Catalyst™ system was compared with the deviation value suggested by the OBI system.

3.3.3 Data collection with The Catalyst system.

Data was collected for the study with the Catalyst™ system according to a specific work flow scheme. When the patient was in the correct position the next step in the work flow is the treatment mode. While passing from cPositioning to cMotion a live image is saved in the system. The data tells how well the patient's surface corresponds to the reference picture. The registration is a non-rigid registration of the surface. It is central that this step is performed before any online re-positioning that occurs after the matching of the kV-pictures.

This way of developing the work flow scheme provides the user a lot of data. All of it is not necessary for the final comparison to the verification pictures, but in the "Analyze tool" the user can choose what data is relevant for the study.

3.3.4 Analysis.

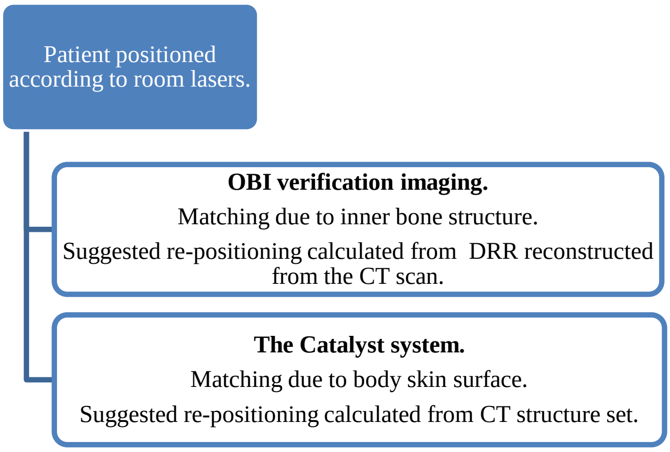


Figure 16. *Schematic representation of the patient position verification systems compared in the study.*

The study contains analyzed data from two systems, which are displayed in the schematic diagram (figure 16) above. In the analysis the deviation from the OBI system, $\mu_{(DRR-SetUp)}$, were compared to the deviation given by the Catalyst system, $\mu_{(CT\ StructureSet-SetUp\ )}$.

<u>OBI system.</u>

The matching procedure to access the positioning result was performed manually, either online by an oncology nurse or offline by Anneli Edvardsson(medical physics student). A digitally reconstructed radiograph (DRR) from the reference set up at the CT simulation was used for the matching procedure. The DRR and the live set-up image were matched by anatomical landmarks such as sternum, lung edge and clavicle. These landmarks were contoured, if visible in the image, by an oncology nurse in the DRR. The deviation, $\mu_{(DRR-SetUp)}$, were obtained.

<u>Catalyst™ system.</u>

All data collected during the study was attainable in the analyze tool in advanced mode. The reference image from the CT Structure set were cut according to the results in "Cropping the reference image" for all patients. The deviation, $\mu_{(CT\ StructureSet-SetUp\ )}$, value given by The Catalyst™ system for all patients and all treatment sessions were collected. The sessions where we suspected that a possible online movement could have occurred were eliminated in the analysis.

The deviation values in lateral, longitudinal and vertical direction were noted for every patient. The data for every individual was studied as well as compiling data for the whole study.

3.3.5 Patient selection.

In the group of thirteen women diagnosed with breast cancer, nine of them were right sided and four of them left sides. All patients were treated with breast conserving surgery before the radiotherapy. Depending on their age they received either 16 or 25 treatment fractions. No boost fractions were included in the study.

Table 1. Patient selection for the study.

Patient	Age	Prescribed Dose	Number of fractions	Recorded fractions		Diagnosis
				kV	Catalyst	
1	74	42.5	16	16	13	ca mam dx
2	75	42.5	16	16	11	ca mam dx
3	33	50.0	25	25	10	ca mam dx
4	76	42.5	16	16	12	ca mam sin
5	50	50.0	25	23	17	ca mam dx
6	59	42.5	16	11	14	ca mam dx
7	52	42.5	16	16	13	ca mam dx
8	68	42.5	16	15	6	ca mam dx
9	63	42.5	16	14	6	ca mam sin
10	67	42.5	16	14	5	ca mam sin
11	68	42.5	16	16	9	ca mam dx
12	70	50.0	25	24	7	ca mam sin
13	67	42.5	16	16	6	ca mam dx

3.3.6 Cropping the reference image.

In the analysis process the reference picture from the CT structure set was cropped. The importance of cropping the picture was investigated. In the ideal situation the reference picture would not have to be cropped at all.

The part of the image that was cropped away was the top of the arms and head. This was because the CT structure set image quality was not good enough there. The non rigid body algorithm, with the greatest weight in the iso-point, was used for calculating the positioning results. The further out from the iso-point, the less the data affect the re-positioning of the iso-center. To evaluate the cropping the reference image three different approaches were used. These are shown in figure 18, figure 19 and figure 20.

One of the results from working with the cropping of the reference images was the development of a standard cropping procedure. The results are described in the headline “4.3.2 Cropping the reference image.” and the results of the different cropping methods are displayed in table 4 and table 5.

The standard procedure developed during the study was to cut away part of the stomach and also the head and arms in those cases where they were contributing to larger errors in the positioning. The algorithm is prioritizing the area above the iso-point the most and the further out on the surface the less contribution the area has to the positioning result. Cropping the picture far out from the iso-point is then contributing to small changes in the positioning results, and this was also investigated in the study. Three different ways of cropping the reference picture were evaluated. Figure 17 shows an example of how the reference images for the study were cut. The three different cropping methods were tested on three of the patients; patient nr 11, nr 4 and nr 5. The patients were selected due to the different size of their chest.

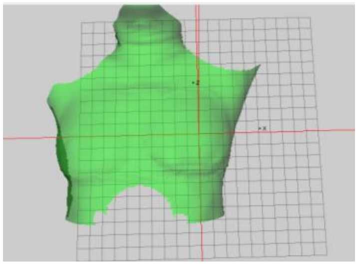


Figure 17. *Reference image from a breast cancer patient. The Reference image is imported from the CT structure set and later cropped to minimize errors due to movements.*

When the cropping of the reference image was performed the analysis with the live images could start. The required live image was chosen from a list in the analysis tool. The list displays the information about when the image was taken. The results of the matching with the non rigid body algorithm are shown in absolute and relative values. It was the relative values that were of importance for the study.

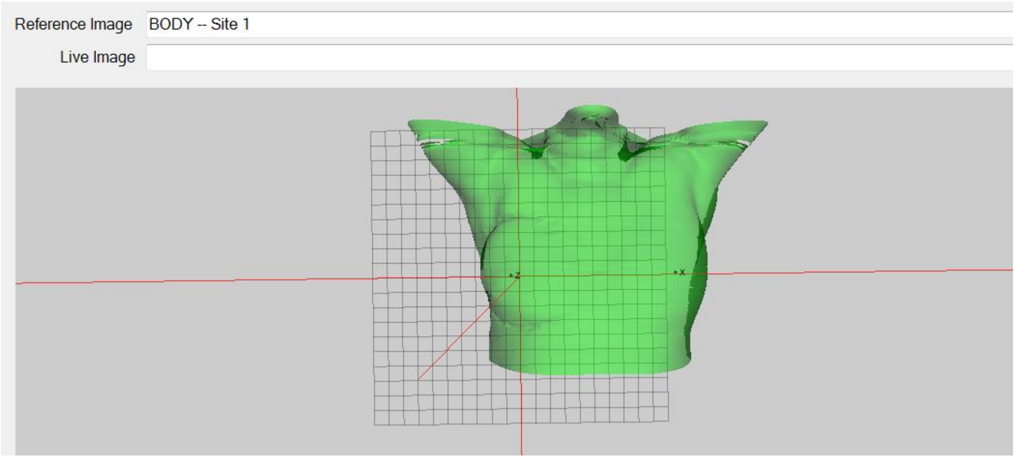


Figure 18. *Reference picture (BODY1) from the CT structure set. The image is not cropped.*

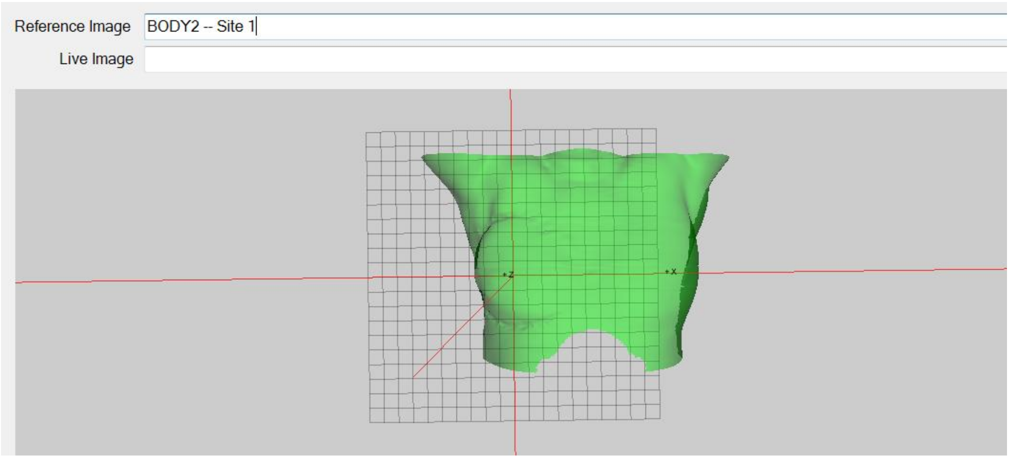


Figure 19. *Reference picture (BODY2) from the CT structure set. The image is cropped.*

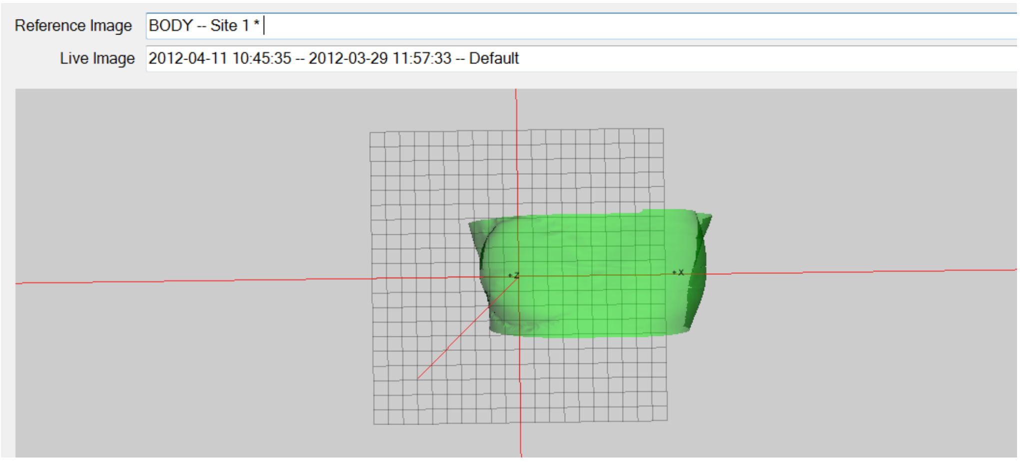


Figure 20. *Reference picture (BODY3) from the CT structure set. The image is heavily cropped.*

The different reference images (BODY1, BODY2 and BODY3) were then matched with the live images from the treatment sessions. In figure 21, figure 22 and figure 23 this is shown for one patient with the same live image from the treatment session.

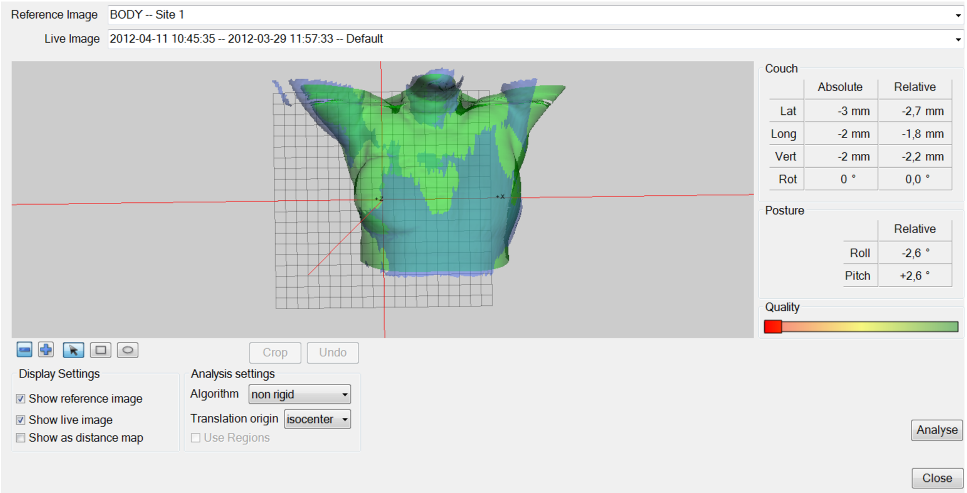


Figure 21. *Uncropped reference image (BODY1) matched with the live image through a non rigid body algorithm.*

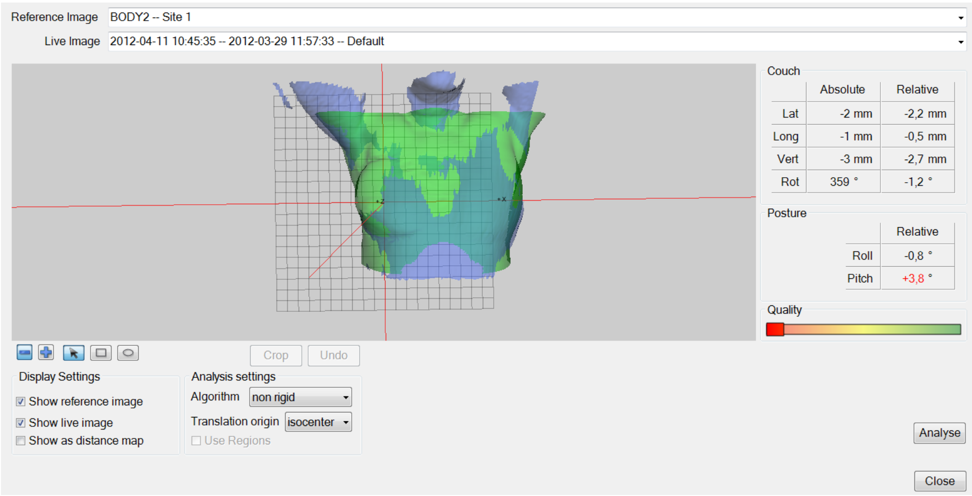


Figure 22. *Cropped reference image (BODY2) matched with a live image via a non rigid body algorithm. Parts of the image that has been cut off is parts of the upper arms, parts of the stomach and the head.*

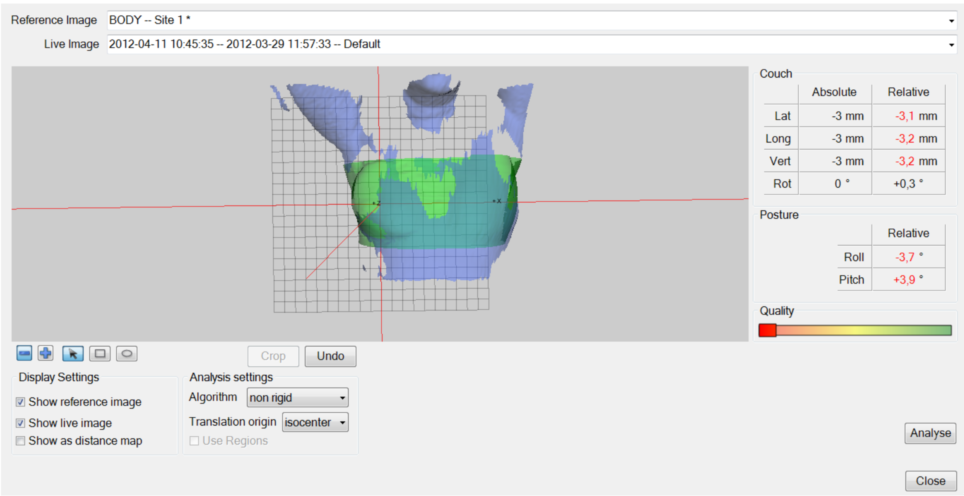


Figure 23. *Heavily cropped reference image (BODY3) matched with a live image via a non rigid body algorithm. Part of the image that has been cut off is the upper arms, stomach and the head.*

The deviation, $\mu_{(CT\ StructureSet-SetUp)}$, given by the system for every treatment session and every cropping method was noted and evaluated.

4 Results

4.1 Accuracy measurement of the scanning volume.

The measurement was performed in the isoplane, 2.5 centimeters above the isoplane, 5.0 centimeters above the isoplane and 7.5 centimeters above the isoplane. The results are included in Appendix I.

The measurement in the plane of 7.5 centimeters above the isocenter was not included since the values were not accurate or the system could not provide with any positioning values at all. The distance 7.5 cm in vertical direction to the reference image was found to be at the limits of the system.

Table 2. **Mean positioning error of the phantom given by the Catalyst™ system per measuring point.** *For every measuring point the maximum and minimum positioning value was noted during a time period of thirty seconds (see Appendix I). The table shows the mean positioning error per measuring point in lateral and longitudinal direction for three planes in vertical direction.*

Plane	Positioning error[mm]/ point in lateral direction	Positioning error [mm]/ point in longitudinal direction	Positioning error [mm]/ point independent of direction
Iso	0.69	0.55	0.62
2.5	0.46	0.85	0.65
5.0	0.68	0.28	0.48

4.2 The Catalyst system correspondence with CBCT verification images on a phantom.

The results of the study are presented in table 3.

Table 3. Positioning results from the Catalyst system and the CBCT system for ten different positions.

	The Catalyst systems positioning result [mm] $\mu_{(CT\ StructureSet-SetUp)}$			**The CBCT systems positioning result [mm]** $\mu_{(CT\ ref-SetUp)}$			**Difference in deviation results from The Catalyst™ system compared with the CBCT system presented in absolute sum[mm].**		
Session	*lat*	*long*	*vert*	*lat*	*long*	*vert*	lat	long	vert
1	0	-5	0	-1	-1	0	**1**	**4**	**0**
2	-11	11	0	-11	16	0	**0**	**5**	**0**
3	-4	-5	0	-5	-1	-1	**1**	**4**	**1**
4	3	-6	0	3	-2	-2	**0**	**4**	**2**
5	-24	-19	-6	-23		-8	**1**		**2**
6	20	21	20	20	25	20	**0**	**4**	**0**
7	11	12	-1	11	18	-1	**0**	**6**	**0**
8	-31	-33	33	-30	-32	31	**1**	**1**	**2**
9	-20	-23	22	-20	-21	20	**0**	**2**	**2**
10	-3	-8	6	-4	-4	5	**1**	**4**	**1**

4.3 The Catalyst system correspondence with planar verification images on patients.

The results of this study are presented in following manner; compiling results for all patients and individual results for each patient.

In Appendix II the results from the patient positioning study are presented individually for every one of the thirteen patients. In the appendix the positioning result in lateral, longitudinal and vertical direction at every treatment session are presented. Images from some treatment sessions are included and comments about specific images and positioning results.

4.3.1 Live image quality.

The images in figure 24 shows the reference image from the CT structure and the live image captured by the Catalyst^{TM} system in chronological order trough the course of treatment.

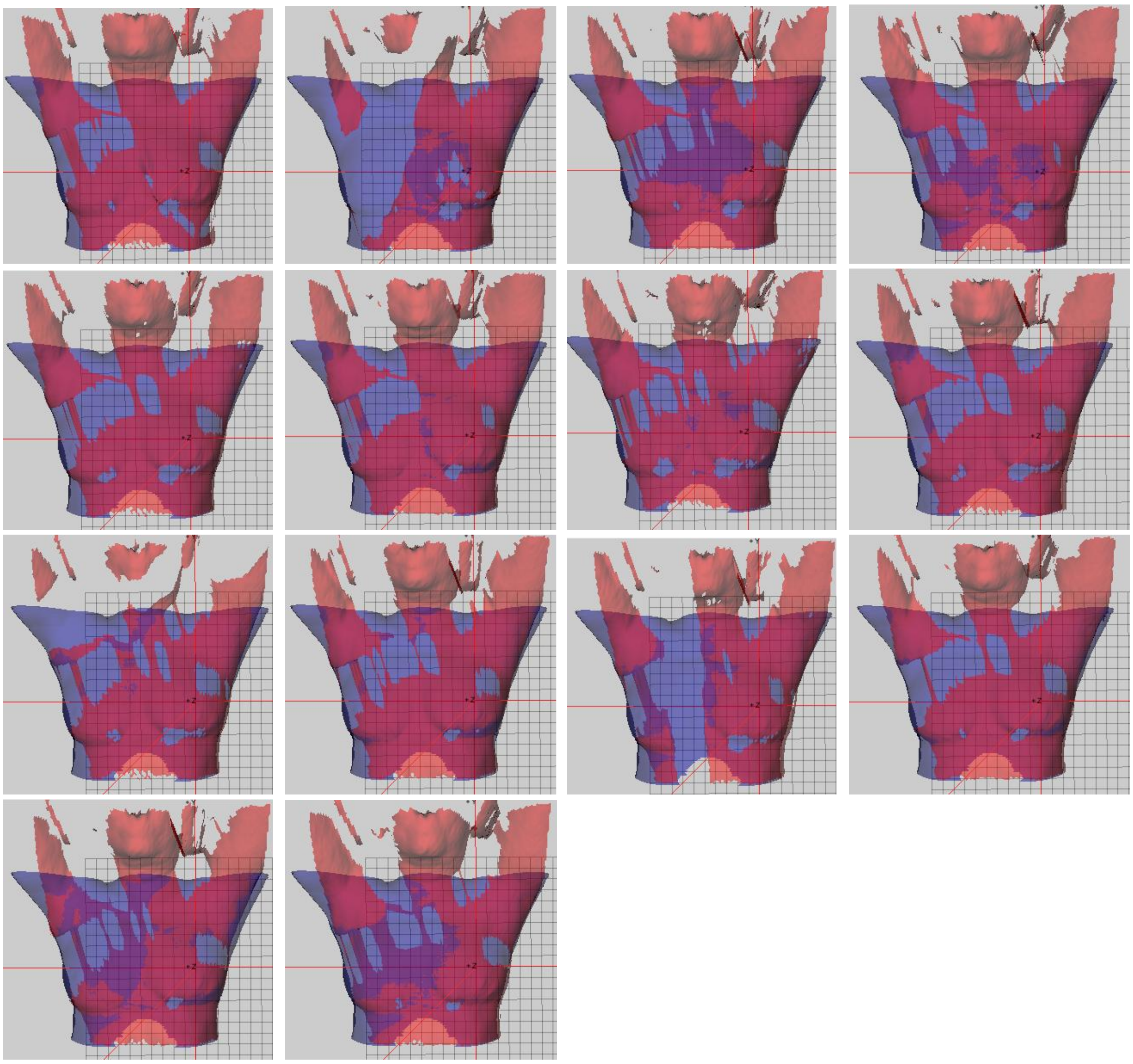


Figure 24. Quality of the reference image through the course of treatment for patient number one.

4.3.2 Cropping the reference image.

The deviation value, $\mu_{(CT\ StructureSet-SetUp\ )}$, was compared between the different cuts. The reference image BODY1 is uncut (figure 18) and BODY2 (figure 19) and BODY3 (figure 20) is cut. The same cropping has been performed for several patients. The results from patient nr 11, nr 4 and nr 5 are presented in table 4 and table 5.

Table 4. Comparison of deviation, $\mu_{(CT\ StructureSet-SetUp\ )}$, results for reference images BODY1 (figure 18) and BODY2 (figure 19). *Reference image BODY1 (figure 18) is uncut and reference image BODY2 is cropped (figure 19). The table shows the mean deviation in absolute sum.*

	Lat [mm]	Long [mm]	Vert[mm]	Sessions
Pat nr 11	0.70	0.71	0.36	7
Pat nr 4	0.51	0.56	0.33	11
Pat nr 5	0.37	0.27	0.13	10

Table 5. Comparison of deviation, $\mu_{(CT\ StructureSet-SetUp\ )}$, results for reference images BODY1 (figure 18) and BODY3 (figure 20). *Reference image BODY1 (figure 18) is uncut and reference image BODY3 is cropped (figure 20). The table shows the mean deviation in absolute sum.*

	Lat [mm]	Long [mm]	Vert [mm]	Sessions
Pat nr 11	0.69	1.44	0.50	7
Pat nr 4	0.76	1.09	0.48	11
Pat nr 5	0.85	1.04	0.42	10

According to the results shown in table 4 the difference between the cut BODY2 (figure 19) reference image and the BODY1 (figure 18) reference image is less than 1 millimeter in mean value in every direction, implying that cutting the reference might not be necessary. This is according to the theory where the points close to the iso-point are more valuable than point's further out in the surface. The difference shown in table 5 is greater, which is expected since the reference image BODY3 is heavily cut.

4.3.3 Compiling results.

Table 6, table 7 and table 8 shows the compiling positioning results for all the patients and all the treatment sessions. The tables show the distribution of the positioning result in absolute difference (no consideration to direction taken).

Outliers are marked in table 6 – 8 and shown in Appendix II. The outliers marked with a green ring were connected to a patient during a certain treatment session. The data collected in the live image was not enough for performing an accurate analysis. The outliers marked with a red ring are further investigated and shown in table 13. These are due to error in the patient positioning.

Table 6. Distribution in positioning result for all treatment sessions and all patients.

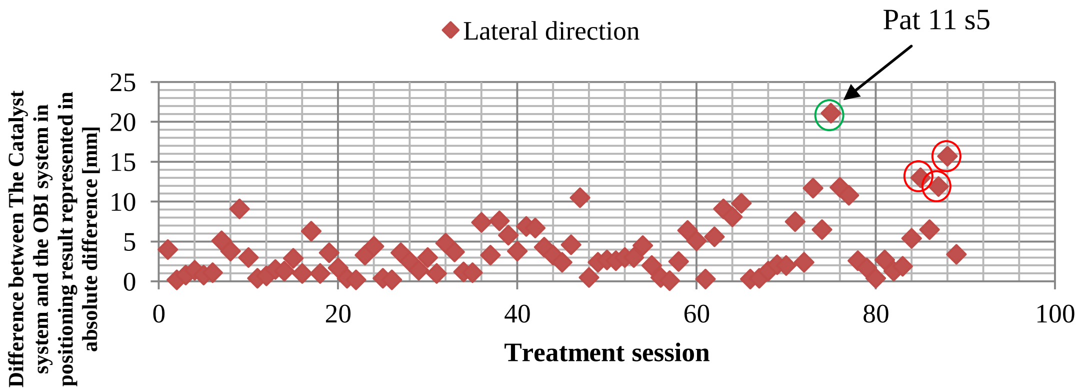


Table 7. Distribution in positioning result for all treatment sessions and all patients.

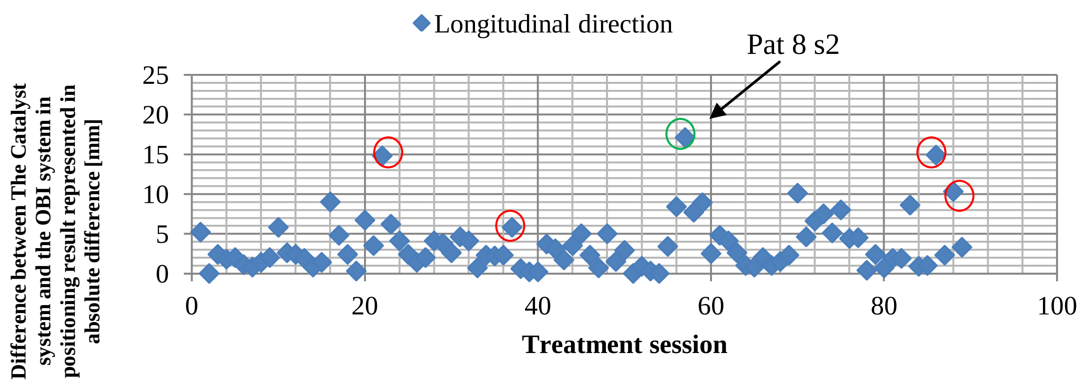


Table 8. Distribution in positioning result for all treatment sessions and all patients.

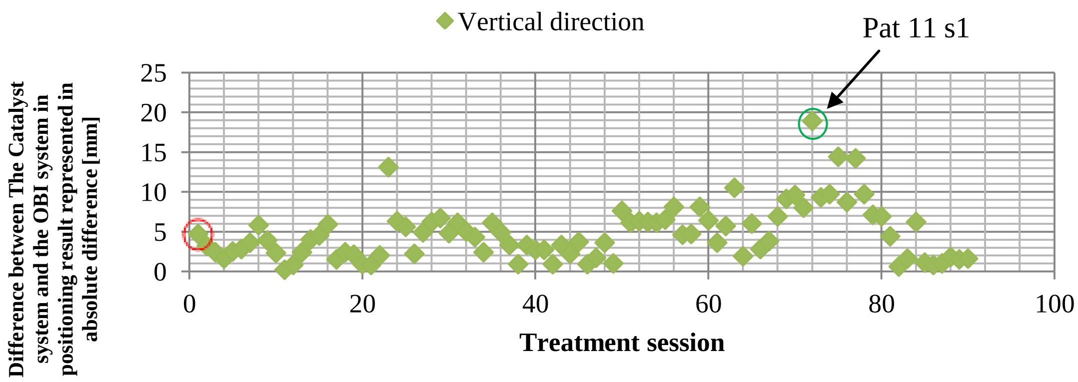


Table 9. The mean value, without consideration to direction, the two systems differ from the laser positioning system for all measuring points.

	The Catalyst system [mm]			OBI-system [mm]		
	lat	*long*	*vert*	*lat*	*long*	*vert*
Mean deviation from reference for all patients	**2.34**	**3.70**	**3.50**	**3.77**	**3.35**	**3.29**

Table 10. The mean value, with directions taken in consideration, the two systems differ from the laser positioning system for all the measuring points. *The value should be as close to zero as possible.*

	The Catalyst system [mm]			OBI-system [mm]		
	lat	*long*	*vert*	*lat*	*long*	*vert*
Mean systematic deviation for all patients	**0.05**	**0.93**	**-0.98**	**-2.55**	**1.69**	**2.09**

Table 11. Deviation values in lateral and longitudinal direction from The Catalyst system, $\mu_{(CT\ StructureSet-SetUp\ )}$, and the OBI system, $\mu_{(DRR-SetUp)}$.

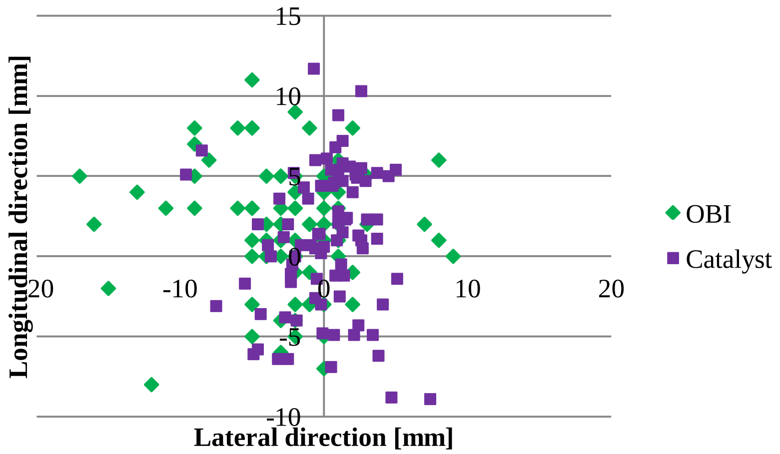
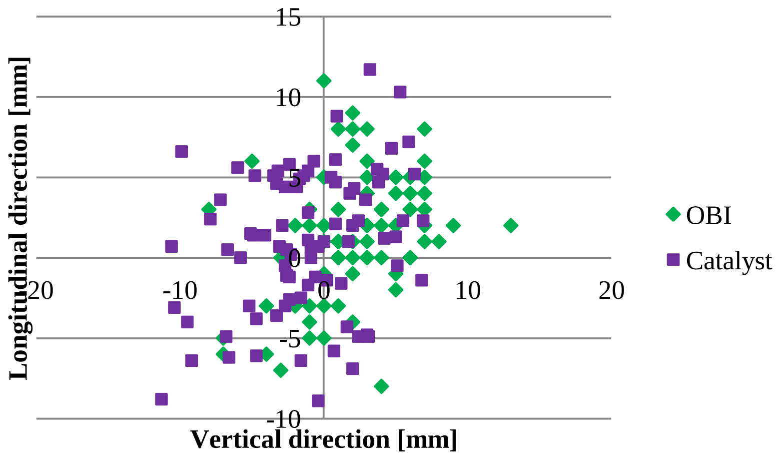


Table 12. Deviation values in vertical and longitudinal direction from The Catalyst system, $\mu_{(CT\ StructureSet-SetUp\ )}$, and the OBI system, $\mu_{(DRR-SetUp)}$.



4.3.4 Arm out of order.

Table 13. Summary of all patient cases were one arm was not correctly positioned. *The table shows the deviation from the reference of the patient position for the two systems. Large differences primarily in the longitudinal and lateral direction between the Catalyst™ system and the OBI system were noted in these cases. This is marked with a red ring in the table. The positioning results displayed in bold font are from the Catalyst system.*

Patient	Session	Lat	Long	Vert
1	2	**-0.2**	**0.2**	**-2.3**
		0.0	-5.0	-7.0
3	9	**4.7**	**-8.8**	**-11.3**
		8	6	-5
5	6	**0.8**	**6.8**	**4.7**
		-5	1	2
13	2	**2**	**4**	**1.8**
		-11	3	1
	3	**0.5**	**-6.9**	**2**
		-6	8	1
	4	**2.9**	**4.7**	**3.8**
		-9	7	2
	5	**3.7**	**2.3**	**5.5**
		-12	-8	4

See Appendix II for more information about the patient and the specific treatment sessions shown in table 13.

5 Discussion

5.1 Accuracy measurement of the scanning volume.

5.1.1 Shape of the phantom.

The values of the positioning result for the phantom varied over time. This means that the algorithm found more than one solution for the position in the optimization process. This phenomenon is explained by considering the spherical shape of the phantom. The shape causes problems for the algorithm to determine the exact position. In a patient situation this should be taken into account. The Catalyst^{TM} system is supposed to work without any external markers on the patient skin surface, but the area which is scanned has to have some structure that the system can use in order to match the surfaces. This phantom study is interesting because it poses a challenge to the system with the spherical shape. Looking at figure 25 one can see that the only distinct structure visible is the ear and a part of the nose. Keeping in mind that the graph nodes above the isocenter are weighted higher than the ones further out on the surface, the ear becomes the most important structure that the system can use in the matching process.

5.1.2 Measurement volume.

The reference image was captured with the iso-center on the surface of the phantom. The system is optimized for an isocenter a few centimeters under the skin surface. This was the case of the measurement at 2.5 centimeters, 5 centimeters and 7.5 centimeters above the isocenter, but not for the measurement in the isoplane.

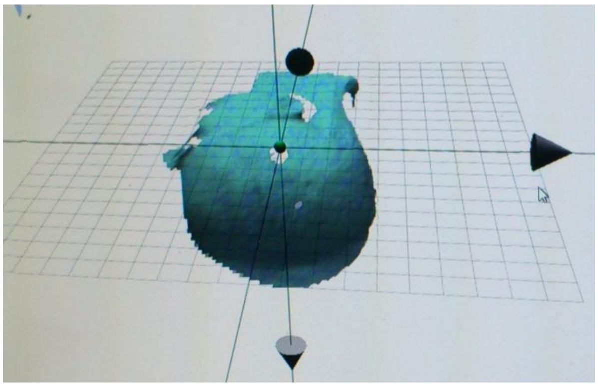


Figure 25. *Reference image and live image in the same position in the isoplane. Position 0,0,0.*

For the measurement in the isoplane the isopoint was placed on the surface of the phantom and the matching was then performed by the algorithm with surfaces that were placed under the isopoint. This is shown in figure 25, where the live and reference image are placed in the same position, overlapping each other. In the image it is visible that most of the phantom surface is placed below the isopoint, which is the green point placed in the middle of the grid. While moving the phantom in lateral or longitudinal direction the surface of the live image will always be below the isopoint (except the area vertical parallel to the iso-point). This was not the optimal measurement conditions for the Catalyst^{TM} system, but the limits for the system in the vertical direction were investigated.

5.1.3 Measurement results

The measurement showed that the result for the deviation, $\mu_{(Catalyst\ ref-SetUp\ )}$,in the isoplane differed in mean value per measuring point 0.69 millimeters in lateral direction and 0.55 millimeters in long direction (table 2).The mean value per measuring point for the plane 2.5 centimeters above the isoplane were 0.46 millimeters in lateral direction and 0.85 millimeters in longitudinal direction. The results indicate that the measurement in the isoplane did not give rise to large positioning errors, even though the measurement conditions were not optimal according to how the algorithm works.

The highest accuracy in the measurements was seen in the plane 5 centimeters above the isoplane. This is according to the specifications of the Catalyst™ system. The reason for the limit at 5 centimeter is not the distance from the iso-point to the surface, but the distance between the reference image and the live image. It is recommended that the patient is positioned within 5 centimeters to the reference image for accurate positioning results.

In the plane 7.5 centimeters above the isoplane the system could no longer provide any results. This was also according to the specifications of the Catalyst™ system. (See 1.3.2 “Technical Specifications”)

During movement in either longitudinal or lateral direction the position in the remaining directions should be stable. In the study the values were evaluated and there was no drift in these values in any direction. See Appendix I.

5.1.4 Warm-up time.

According to the specifications the camera has a warm up time of 30 minutes and the long term stability after this warm up time is 0.3 millimeters. This has been investigated and it is found that the camera is not stabile until after 2 hours of use. (Private communication, Report by Mattias Jönsson) The drift in the measuring value is up to 1 millimeter. This thermodynamic effect could be a source to an error in the positioning result.

5.1.5 Outcome of the study.

The study shows the importance of correct positioning of the phantom or patient for accurate positioning result. In future studies I recommend the user to carefully place the phantom within 5 centimeters from the reference image and that the iso-point is put a few centimeters inside the phantom for optimal measuring conditions. Also, of importance is that the phantom has enough structure that the system can use for the matching process.

It is also of importance that the system provides with stabile values of the positioning so that the couch movement can be performed correctly. The update with different positioning values ever fifth second is not optimal for this application. In this study a phantom is used standing still, and this is far from the patient case.

The limiting spherical shape could occur in a clinical situation where for example the patient is wearing a mask. It is of importance to know when the system detects enough structure to be able to present accurate positioning results. The solution presented form C-RAD after this study was to develop a function which will warn the user when there is not enough structure for the system to match on.

5.2 The Catalyst system correspondence with CBCT verification images on a phantom.

The correspondence of the phantom position given by the two systems was within two millimeters in the lateral and vertical directions. In the longitudinal direction the Catalyst system differed from the CBCT by as much as six millimeters (see table 3). The explanation for this could be that the phantom had a somewhat flat surface, with no apparent structures, which causes problems when matching the images in the Catalyst™ system (figure 26).

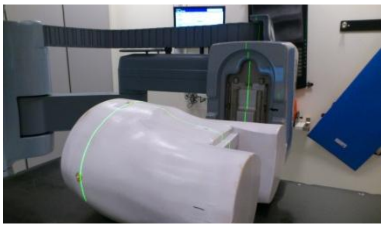


Figure 26. *Pelvis phantom used in the study. In the longitudinal direction the phantom is flat. This arise a positioning problem for the Catalyst system.*

Results clearly show the importance of having some structures in the image in order for the non-rigid body algorithm to work accurately. This should be considered when making the reference image.

You need to have some structure in the images, but the structure should also be relevant for the positioning. A surface like the one of the stomach, which moves during breathing, is not a good structure to use for the reference image. Other more solid surfaces have to be considered. For patients who are very flat the positioning results need to be closely observed. The Catalyst system is intend to be used without placing any extra marks on the patient surface, but clearly it might be of some use in cases where there is no structure or very little structure that the system can use for the matching.

5.2.1 Uncertainties in the result.

The CBCT is in this study considered to be the reference for the positioning result. We used an automatic matching method for the bone structure. The accuracy of the positioning in the study was 0.5 millimeter due to the accuracy of the couch position. (13) This uncertainty in the couch position could be a contributing factor to the positioning result.

The geometric accuracy of the OBI system with the reference to isocenter should be less than 1.5 mm and the accuracy in the 2D2D matching is less than 1 mm. The CBCT-CT (3D) has the same accuracy. (14)

The reference image used for the Catalyst™ system was taken with the camera in the treatment room. A small uncertainty, estimated to less than 1 millimeter, could arise from the manual positioning of the phantom in the isocenter.

The average uncertainty for the positioning result in the study is expected to be within 2 mm.

5.2.2 Outcome of the study.

The problem with not knowing when a structure is too flat for the system is of great importance. This has been discussed with CRAD and they will work on a solution. Their suggestion is that a warning sign will show when the system detects a surface with not enough structure to be able to achieve a correct matching and correct positioning.

5.3 The Catalyst system correspondence with planar verification images on patients.

5.3.1 The Catalyst system correspondence with the laser positioning system.

Room lasers are used as a way of positioning the patient correctly on the couch before radiotherapy treatment. It is recommended by AAPM Radiation Therapy Task Group 40 Report (2) that the lasers should be kept at a tolerance level at 2 mm, implying that the room lasers need to be aligned with the isocenter within this distance. The room lasers are controlled in a daily check every morning. The Catalyst^{TM} system is thought to be used as a complement to the laser system at every treatment fraction. The adequacy for using the Catalyst system in this manner were investigated and presented in table 10. The patients were aligned only according to the room lasers when the live images were captured and therefore no couch corrections were performed. This is the case for all treatment fractions in the clinic without verification imaging. The result in table 10 shows that the correspondence with the laser positioning system is within 1 mm in all three directions. The result in table 10 also shows that the correspondence between the laser system and OBI system is less than for the Catalyst system. This is due to the fact the Catalyst system and the room lasers both use the body contour in the positioning of the patient while in the OBI system the inner bone structure in used. This opens up for a discussion about which of the two systems can contribute to a more accurate positioning for the treatment, especially for superficial targets.

The result also implies that the Catalyst system has the same positioning quality as the room lasers, and could therefore be used complementary to these as a positioning tool during fractions without verification imaging. The amount of information about the patient position is then extended. In some cases the tattoos on the patient's skin are hard to find or are not visibly. Using the CT structure set as a reference in the Catalyst system can then be a great help to align the patient in the correct position. In the study it was also found that arm position was of importance for an accurate patient positioning. This sort of information is easily accessed with the Catalyst system.

5.3.2 The Catalyst system correspondence with the OBI system.

The clinical patient positioning is based on the OBI imaging system to minimize systematic errors in the positioning. The verification images in treatment position are matched with the reference image from the CT scanner aligning the bony structures. In the Catalyst^{TM} system the surface of the patient is used together with the surface structure set from the CT scan. The fact that one system uses the inner bone structure and the other the skin surface for patient positioning is an important difference between the two systems. In this study the reference for the evaluation of the Catalyst^{TM} system was the OBI imaging system. The sources of error in the OBI system and in the Catalyst^{TM} system are later discussed in this section

The OBI system and the Catalyst system did not always correspond with deviations in the same direction. This is further investigated in Appendix II, and has probably to do with the non-rigidity of the breast tissue. The two systems were compared with the laser system without any consideration to direction (see table 9). The results show that the overall mean value in the OBI systems deviation was 3.77 mm in lateral direction, 3.35 in longitudinal direction and 3.29 mm in vertical direction. The results shown for the Catalyst system was 2.34 mm in lateral direction, 3.70 mm in longitudinal direction and 3.5 mm in vertical direction. Both of the systems show results of the same magnitude. This implies that the Catalyst systems positioning for this patient group is not "out of range" compared with the OBI system.

The Catalyst system and the OBI system were also compared with each other. This is shown in table 6, table 7 and table 8, which show the difference in positioning result between the Catalyst system and the OBI system in absolute sum. If the two systems corresponded the difference between them should be zero. The mean deviation when outliers are excluded is in lateral direction 3.5 mm, in longitudinal direction 3.1 mm and in vertical direction 4.6 mm. The reason for this is likely once again the difference in matching structure for the two systems. Outliers of importance in the tables are marked and discussed later in this section.

5.3.3 Cropping the reference image.

The desired situation is that cropping of the reference images is something that will not be necessary clinically for every patient. The algorithm works in a way that the surface close to the iso-point is of the greatest importance and that data further out on the surface plays a smaller role in the positioning result. Still table 5 and table 5 show that cropping has an effect on the positioning result. It was of importance to investigate how different cropping methods affect the positioning result.

In table 4 the reference images were only cut due to breathing and head-movement and the mean deviations were between 0.13 mm and 0.71 mm, implying that cutting will not be needed in every patient case.

In table 5 the deviations are larger than in table 4. This implies that one should be careful when cropping the reference image, so that not too much data is lost. The results show a deviation up to 1.44 mm from the uncropped image. Even if the uncropped image is not the ideal case, one should be careful when the positioning result is affected more than one millimeter by the cropping. According to the specifications of the Catalyst system the set-up deviation is <1mm, and this will not be fulfilled if the reference image is heavily cropped.

Even if the difference in the positioning result between a cut reference image and an uncut reference image is small the cropping is still an important tool to be able to achieve results that are more precise. The upper arms are affecting the breast muscle and therefore also the position of the tumor to some degree. This might not have as great effect as the fact that the tattoo on the skin is moved with the upper arm and the laser alignment might not be correct due to the fact that the upper arm is not in the right position. The position of the head has a minor outcome on the breast tumor position and is therefore of a smaller importance. Table 14 “Body parts of importance for cropping and surface matching.” contains a guide to how to think while cropping the reference image.

Table 14. Body parts of importance for cropping and surface matching.

Degree of importance	Body part	Description
1	Upper arms	a) The tattoos’ used to align with the room laser move while moving the arm. The alignment might be less precise if the upper arm is not in the correct position. b) The movement of the upper arm affects the position of the breast.
2	Stomach	The stomach is moving while breathing. The live image is not taken at the same time during the breathing cycle and therefore this area contains an error when matched with the reference image.
3	Head	The position of the head does not affect the breast tissue. The head can be cropped if it is disturbing the surface matching.

5.3.4 Outcome of the study of “Cropping the reference image”.

The findings of this study of cropping the reference image resulted in a mean value solution of the live image from C-Rad. To avoid work with cropping the reference image a new version of the software 4.3.0 included a solution in its release. As long as larger movements are detected the live image will not be captured in this new software version. The live image that is captured will be a mean value image, created over the time of 4 seconds for reducing the effects of the movements of the stomach due to breathing.

5.4 Uncertainties in the results.

5.4.1 Data collection.

In the beginning of this study the system was not fully implemented clinically and therefore it suffered some teething problems. All the data was not collected for every patient. The number of treatment sessions recorded with the Catalyst system is 61.3% of the number of recorded kV-pictures captured.

The main reasons for this loss of data were:

1) ***The system did not run perfectly.***
   During the patient set-up there is not a long time window when the Catalyst system is supposed to capture the live image. Loss of data was many times due to software malfunction. There were also times when the camera did not work and required a new start. This button is on the camera inside the treatment room and there was not time to go in and restart the system after the patient set-up. It was also difficult for the staff to know what was wrong and inform about the problem.
   There were also examples of loss of data in the system data base. The recorded files were in the system but there was no data in it.

2) ***Online movement.***
   During the study the online movement became an issue. In this study kV images were taken at every treatment session. The nurses matched the kV images and made an online movement every time the values exceeded a threshold. These online movements were undesirable in the study with the Catalyst system. It was of great importance that the live image was captured before an eventual online movement, which was not always the case.

   The online movement was not a factor that was considered in the beginning of the study. The fact that the live image sometimes was captured after the online movement and that it was impossible to know afterwards how it was performed was not noticed until after some time.

5.4.2 Lost data.

In the analysis tool the registration of the live image was sometimes not of an acceptable quality. This is an example where one patients live image does not contain enough information for an analysis to be performed correctly. During the setup and the capture of the image nothing unusual is shown, but in the stored live image the data is lost (figure 27). These values were not included in the study.

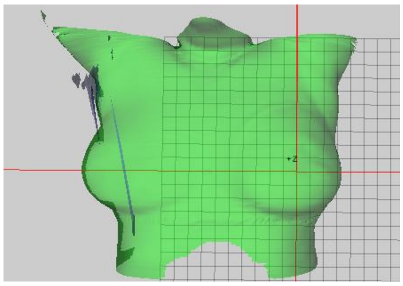


Figure 27. *Example of lost data in a live image.* *Cropped reference image and live image shown in the window of the analysis tool. The reference image is from the CT structure set and is colored green. The live image is captured by the Catalyst system and is colored blue.*

During the study kV-images was taken daily and matched and an online re-positioning was performed if necessary. If it was impossible to ensure that the online re-positioning had been performed after the live image was captured, the data was erased.

5.4.3 Manual matching of planar verification images.

Planar verification images from the OBI-system enable effective and efficient online verification for the breast cancer irradiation. The final result for the patient positioning depends on the result of the manually matched images.

In this study the images were matched by one single person with low experience in the matching procedure. To estimate the error the result from the matching was compared with the results that the more experienced staff achieved for the same images. The error was estimated to be ≤3 millimeters in all three directions.

5.4.4 The patient group.

Breast cancer patients in treatment were the subjects in this study. The tumor was removed with surgery and the remaining breast tissue was treated with radiotherapy. The breast tissue is deformable and can sometimes undergo changes through the course of treatment. The study included ninety images captured with the Catalyst^{TM} system. The images were all studied and a few selected ones are included in the Appendix II where a deeper analysis is made for every specific patient case. In Appendix II there are examples of possible swollenness of the treated breast, arms that are not fixed in the correct position and displacement of the whole breast while the rest of the body is in correct position.

The question is what structure is the most appropriate to match on, the breast surface position or the bony structure. If a patient suffers from cancer metastasis in the spine, it is the spine which is used as the primarily matching structure and not so much the sternum and ribs. In the case of breast cancer the sternum and the ribs plays a more salient role in the matching process. This seems like an obvious approach to the positioning problem. But then the question arises about the breasts. The tissue is not solid during the course of treatment (shown in several examples in Appendix 2) and possibly the surface of the breast should then be the primarily choice of matching structure for a correct treatment. This was out of the scope for this work, but could be further investigated.

The Catalyst^{TM} system can be further developed for positioning of breast cancer patients. To improve the positioning result I would suggest that weight factors in the reference image could be an option for this patient group. The positioning of the patient today is with help of three tattoo marks. One tattoo is placed on sternum and two on each side of the body on the ribs under the breasts. The Catalyst^{TM} system on the other hand uses the whole surface with the highest weighted graph nodes right above the isocenter. For this patient group it translates into the surface of the treated breast area. This introduces inaccuracy; since the patient sometimes had vasectomy and swollenness of the breast is changing during the course of treatment. If the patient would be positioned after a swollen breast the area for the PTV would be shifted and would not reach as deep as planned. It is of importance to keep the breast in the reference image, but with less value for the positioning result. I therefore suggest that a function of weight factors should be introduced to the analyze tool. These could be put on more solid landmarks like sternum and on the ribs for a more accurate positioning result. If the positioning of the patient is performed as the algorithm works today it would mean that the patient is aligned according to the breast, and not to the solid bone structure as might be preferred.

I think it is important to look how the routines looks like today and then with the Catalyst™ system imitate them in a clinically sustainable way.

5.4.5 Live image quality.

The quality of the live images varied through the course of treatment, see figure 24. It is of importance that the live images maintain a high quality over time. During this study I investigated how the parameters gain and integration time should be set to obtain the highest possible image quality. The live images still show some difference in quality even if the same optimal parameters were set for every treatment session. The reason for this has to be further investigated and it is desirable that the live image quality be improved.

Shadows for the camera could be observed for many patients in the cranial direction from the breasts and this phenomenon arise from the fact that the camera cannot detect the reflected light from this area due to the angle of the patient chest and the camera position in the room ceiling. The live image then has holes in the area of shadows and cannot be used in the matching processes. The size of the area is different for every patient. In patient cases where the stomach is large it can shadow the whole chest area and no information about the patient's breast position can be obtained (figure 28).

Figure 28. *The angle at which the camera is installed in the treatment room ceiling limits the imaging. The first figure is the normal patient case. Shadows could arise above the breast. The second figure shows a patient were the breast will not show at all in the live image due to the large stomach.*

5.4.6 Snapshot

The live image is also problematic in that way that it is a snapshot of the patient position. The image might be captured in an unfortunate moment when the patient was taking a large breath. There is an example of this in Appendix II (see patient 10, session 4).

5.4.7 Arm out of order.

In table 6, table 7 and table 8 out-liners are marked with a red ring around them. The values were studied closer and the large deviation was found to be caused by incorrect positioning of an arm. Table 13 shows a summary of all patient cases where one arm was not correct positioned. In Appendix II there is a deeper analysis of the images from these patients and sessions.

Primarily the result shows that the positioning in lateral and longitudinal direction was affected. In lateral direction deviations up to 15.7 mm were observed and in longitudinal direction 14.9 mm were observed (table 13). These are large deviations from the correct position. There was a disturbing fact that the OBI verification images and the Catalyst images suggested re-positioning in opposite directions. By visually studying the Catalyst live images it was possible to see the change of the breast position due to the arm misplacement and also in some cases see in what direction the breast should be moved to be in the correct position.

To easily visualize this we will look closer in table 13 and session 5 for patient 13. The OBI system suggest large couch movements in lateral and longitudinal direction that would require repositioning, while the Catalyst systems is within the limit of 6 millimeters in all three directions (figure 29).

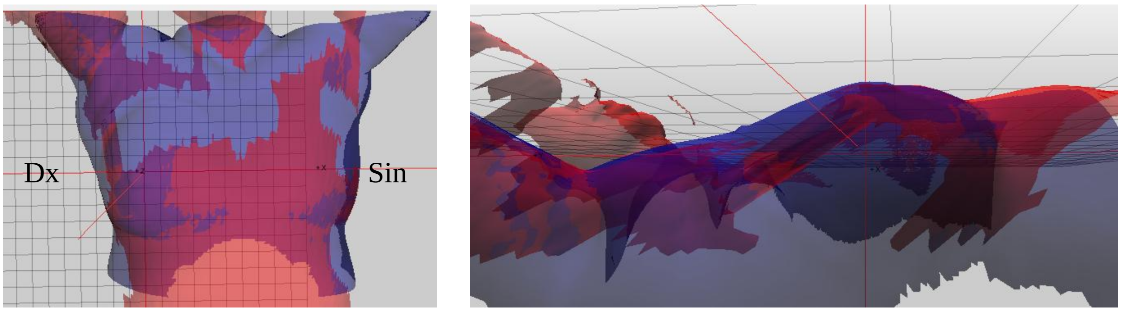


Figure 29. *Patient 13, Session 5. The patient's right breast receives the treatment and the iso-point is marked in the breast. The image to the right shows the alignment of the right breast.*

The Catalyst images from this session show that there was no significant displacement between the two surfaces above the breast to be treated on the right side. On the left side of the body the two surfaces are not aligned as well as on the right side, possibly due to the stretched arm.

The OBI system suggested a re-positioning of -12 millimeters in the lateral direction and -8 millimeters in the longitudinal direction (table 13). If the patient was misplaced this much it would clearly show in the Catalyst images. The result implies that the positioning result from the OBI system gets affected by the misplaced arm. This assumption needs further investigation. The immobilization breastboard (Posiboard^{TM}-2 Breastboard, CIVCO Medical Solutions) is made out of hard carbon material. While stretching up the arm the scapular might push towards the hard bed and the position changes. The breast tissue is out of place as shown in figure 30. If the spine also is affected by this stretching is not known. The tattoos' are still in the correct positions.

For patient thirteen there was also no re-positioning after the field images (MV) that is captured after the orthogonal kV images. This implies that the positioning results that the Catalyst system shows was not seen in the OBI system for all the sessions where the arm was out of position. Further this patient had to have an online movement performed during the thirteen first treatment sessions out of the sixteen treatment sessions total. The fact that online movement had to be performed in 80% of all the treatment sessions implies that the positioning of the patient was not easily done. To avoid this kind of time consuming positioning problem the Catalyst color map that is projected onto the patient's skin surface could have been used to position the patients arm.

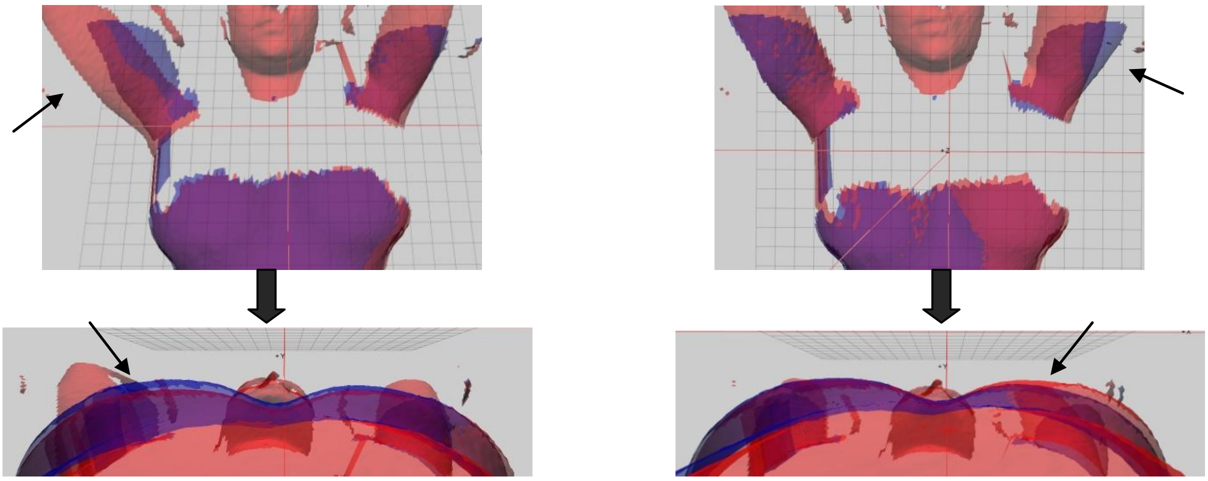


Figure 30. *The figure shows the correlation between smaller arm misplacements and the position of the breast tissue. The patient was placed in the immobilization breast board (Posiboard™-2 Breastboard, CIVCO Medical Solutions).*

For treatment outcome the size of the field outside the breast contour does not matter, but if the new suggested positioning from the OBI system causes a re-placement that would translate into more of the lung tissue ending up in the field there could be a negative health effect. This has to be further investigated.

6 Conclusions

To explore the feasibility of using the Catalyst™ system as a patient positioning system three studies has been carried out

1) Accuracy measurement of the scanning volume,
2) The Catalyst™ system correspondence with CBCT verification images on a phantom, and
3) The Catalyst™ system correspondence with planar verification images on patients.

The two phantom studies showed a high accuracy of the positioning result within the scanning volume. The results were 0-4.0 mm in all three directions for the recommended plane 5 cm above the iso-center in the study “Accuracy measurement of the scanning volume”(table 19-21, Appendix I). In the study “The Catalyst™ system correspondence with CBCT verification images on a phantom”, the accuracy was 4.0-6.0 mm in longitudinal direction and 0-2.0 mm in vertical and lateral directions (table 3). The limitation for the system was the lack of structure of the phantoms. The issue was addressed and resulted in that a function will be developed that will give a warning for lack of structure.

The conclusions of the third study, “The Catalyst™ system correspondence with planar verification images on patients” were:

- Cropping the reference image

For the breast cancer patients the upper arms, the stomach and the head position were graded by importance in for the positioning result. As a result of the study, to avoid errors in the positioning result due to breathing, a mean value solution of the live image in cPosition was developed by CRAD.

- Arm out of order.

Larger deviations between the Catalyst system and the OBI system were found in patient cases were one arm was not right positioned. The misplaced arm caused online movement in up to 80% of the sessions for one of the patients. This is a time consuming chore and could be avoided by using the Catalyst system for correct positioning.

- The Catalyst system correspondence with the OBI system.

The patient study showed a mean deviation from with the OBI system that was 3.5 millimeters in lateral direction, 3.1 in longitudinal direction and 4.6 millimeters in vertical direction. The difference was caused by the fact that the OBI system matches due to bony structure and the Catalyst system due to the skin surface. The Catalyst system cannot replace the verification imaging for positioning in all cases, but the advantages with using the body surface while positioning and motion detection during imaging and treatment makes it a valuable tool for correct and safe treatment delivery.

- The Catalyst system correspondence with the laser positioning system.

The Catalyst system has a correspondence with the laser system within 1 millimeter in all three directions for patient positioning. The result also implies that the Catalyst system has the same positioning quality as the room lasers, and could therefore be used complementary to these as a positioning tool during fractions without verification imaging. Since the system uses the whole body surface additional information is given and can therefore advantageously be used for positioning of the patients.

7 Future prospects

The Catalyst system provides possibilities to position and monitor the patients in a new way. The monitoring detects every movement a patient makes and the nurses can easily follow this in real time. There is a great value in having positioning results even at fractions where there is no verification imaging. The room lasers do not provide as much information about the true patient position, and this is shown in the study when the arm was not correctly positioned. This would be detected when using the Catalyst system.

In the phantom studies lack of structure had a negative influence on the positioning result. A warning function has to be implemented so the user is aware when the surface scanned by the system does not contain enough structure for an accurate positioning result.

The question whether the inner bone structure or the outer surface is the most accurate structure to use when positioning the patient needs further investigation. In the case of breast cancer treatment in this study the whole breast area is supposed to be included in the PTV and receive dose and it might be better to position the patient according to the surface. The system might need a few adjustments for the patient group of breast cancer patients, due to the changeable tissue of the breast. One suggestion is to position the patient after sternum and the ribs, and after this result see how the breast is positioned.

For the future the system should be evaluated for a diversity of patient groups. Aspects as improvement of patient safety could be studied and also possible time gain that arise from a fast and secure positioning of the patients. The cMotion mode enables studying the patient movement during treatment, which also can lead to improved treatment routines.

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Appendix I

The appendix contains results from the study ''Accuracy measurement of the scanning volume''.

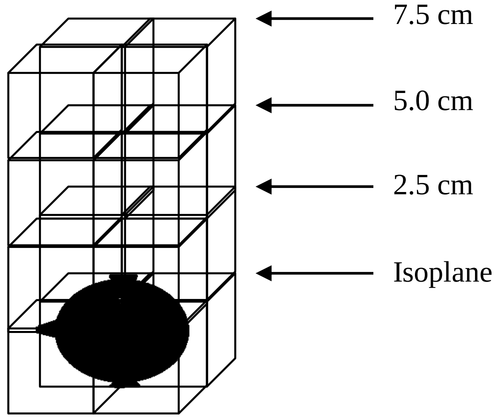


Figure 31. *Phantom positioned where the reference image was captured. The phantom was moved along the lateral and longitudinal direction in the planes shown in the image.*

Isoplane

Start position. The phantom is aligned with the room lasers with the plastic piece in the isocenter point. The reference image for the measurement in all planes is captured in this position.

Table 15. Positioning results in lateral direction in the isoplane. *The phantom is moved along the lateral axis in the isoplane. The reference image used is captured in the isocenter plane. Values presented on the y-axis are the maximum deviations from the true position given by the system. The values are expected to be zero in all positions along the axis.*

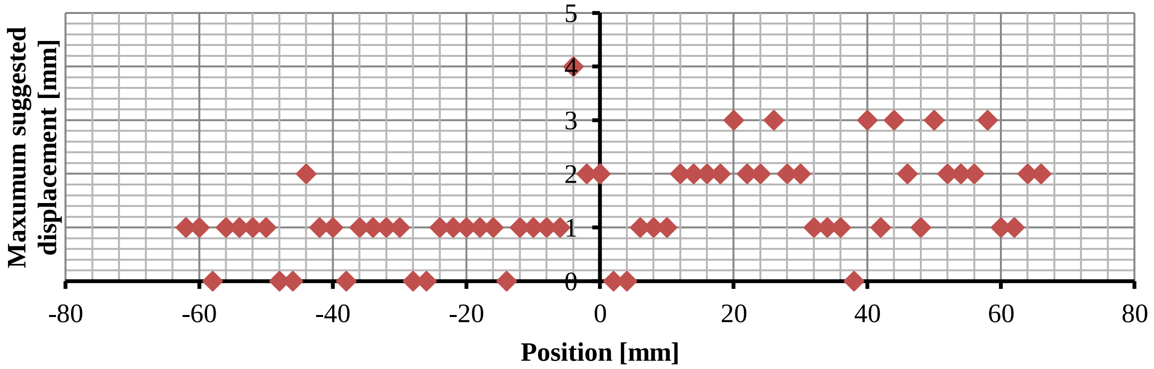
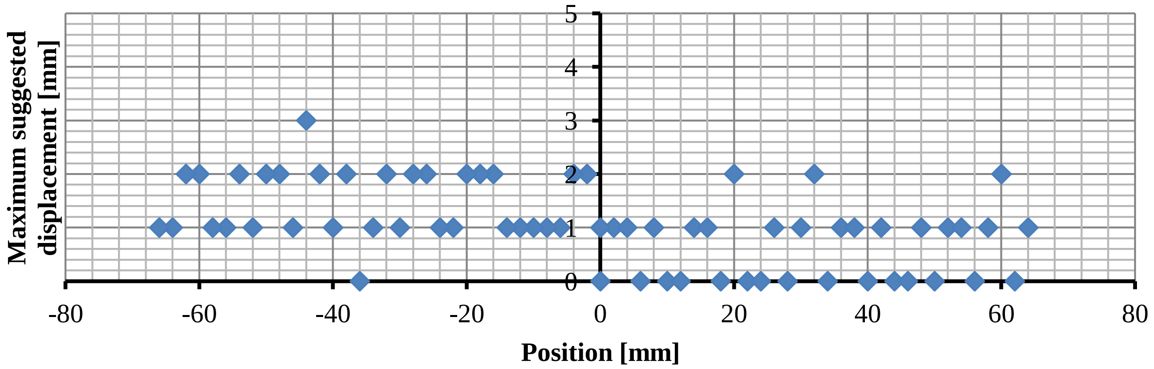


Table 16. Positioning results in longitudinal direction in the isoplane. *The phantom is moved along the longitudinal axis in the isoplane. The reference image used is captured in the isocenter plane. Values presented on the y-axis are the maximum deviations from the true position given by the system. The values are expected to be zero in all positions along the axis.*



Plane 2.5 centimeters above isocenter

Table 17. Positioning results in lateral direction 2.5 centimeters above the isocenter. *The phantom is moved along the lateral axis 2.5 centimeters above the isocenter. The reference image used is captured in the isocenter plane. Values presented on the y-axis are the maximum deviations from the true position given by the system. The values are expected to be zero in all positions along the axis.*

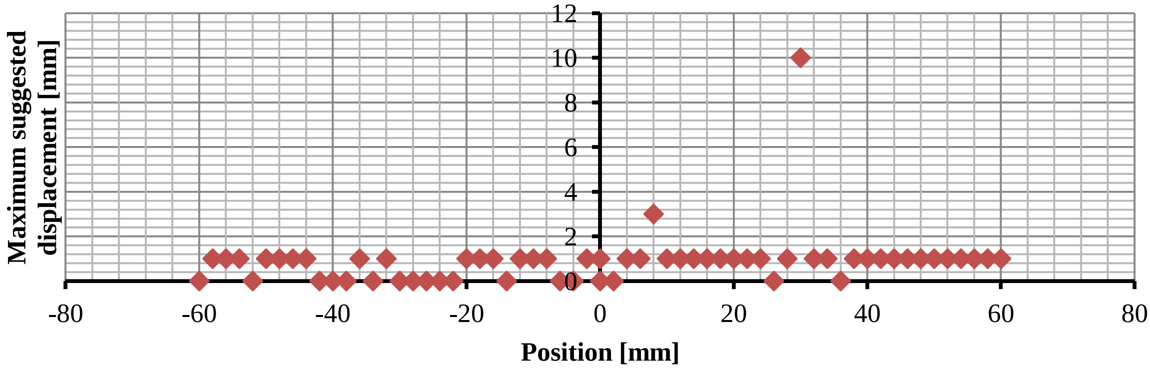
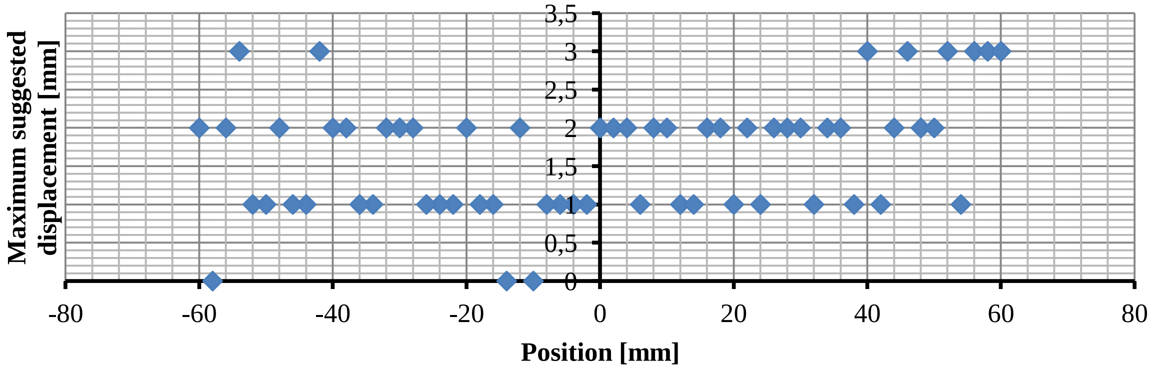


Table 18. Positioning results in longitudinal direction 2.5 centimeters above the isocenter. *The phantom is moved along the longitudinal axis 2.5 centimeters above the isocenter. The reference image used is captured in the isocenter plane. Values presented on the y-axis are the maximum deviations from the true position given by the system. The values are expected to be zero in all positions along the axis.*



Plane 5.0 centimeters above isocenter

The Catalyst^{TM} system shows the most accurate positioning results in this plane. Any drift in the positioning results in longitudinal and vertical direction was investigated while moving the phantom along the lateral axis. No drift in the results was found (table 20 and table 21).

Table 19. Positioning results in lateral direction 5.0 centimeters above the isocenter. *The phantom is moved along the lateral axis 5.0 centimeters above the isocenter. The reference image used is captured in the isocenter plane. Values presented on the y-axis are the maximum deviations from the true position given by the system. The values are expected to be zero in all positions along the axis.*

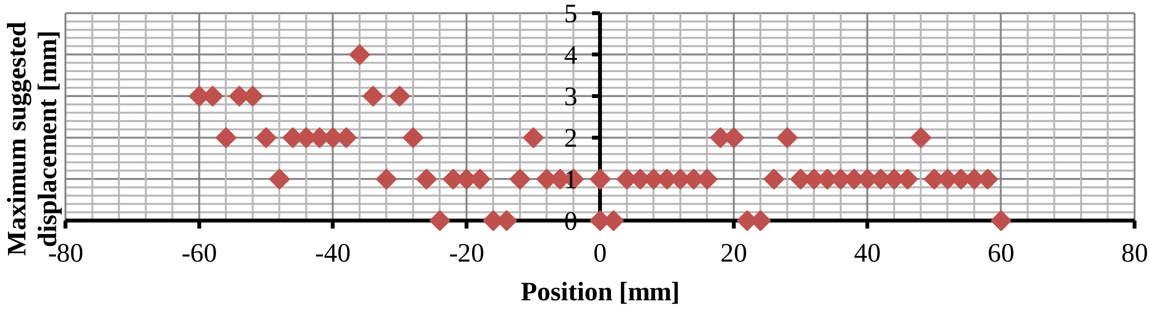


Table 20. Positioning results in longitudinal direction 5.0 centimeters above the isocenter. *The phantom is moved along the lateral axis 5.0 centimeters above the isocenter. The reference image used is captured in the isocenter plane. Values presented on the y-axis are the maximum deviations from the true position given by the system. The values are expected to be zero in all positions along the axis.*

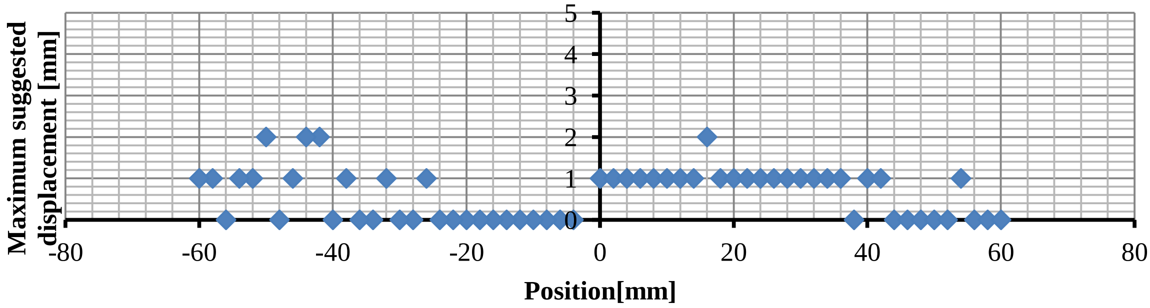
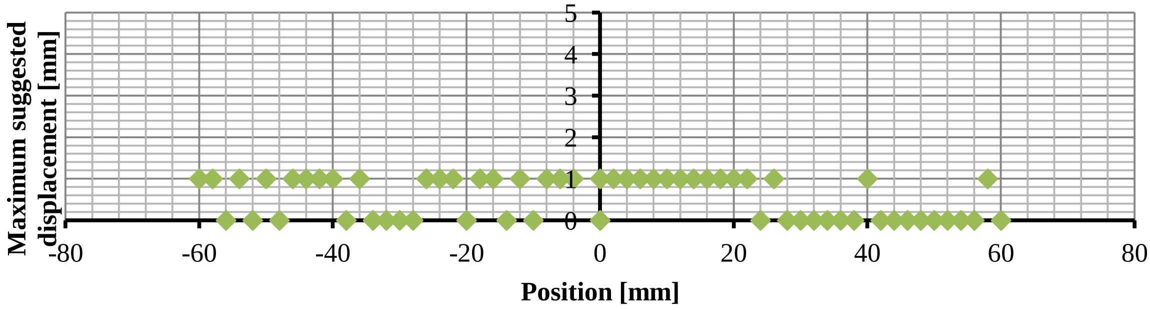


Table 21. Positioning results in vertical direction 5.0 centimeters above the isocenter. *The phantom is moved along the lateral axis 5.0 centimeters above the isocenter. The reference image used is captured in the isocenter plane. Values presented on the y-axis are the maximum deviations from the true position given by the system. The values are expected to be zero in all positions along the axis.*



The phantom is moved along the longitudinal axis and any possible drift in lateral and vertical direction was also investigated.

Table 22. Positioning results in longitudinal direction 5.0 centimeters above the isocenter. *The phantom is moved along the longitudinal axis 5.0 centimeters above the isocenter. The reference image used is captured in the isocenter plane. Values presented on the y-axis are the maximum deviations from the true position given by the system. The values are expected to be zero in all positions along the axis.*

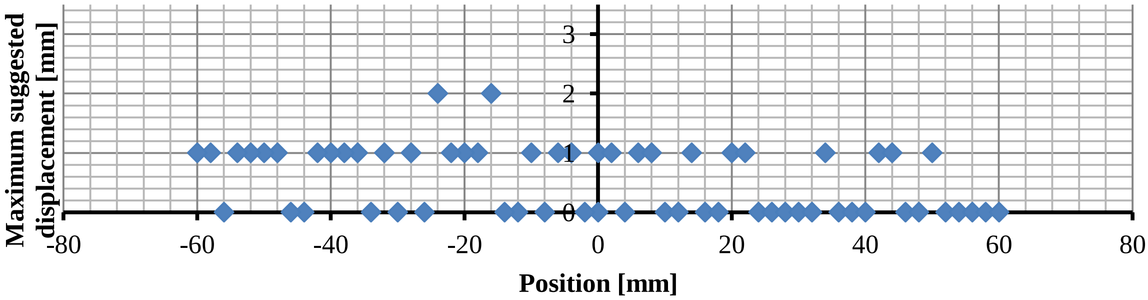


Table 23. Positioning results in lateral direction 5.0 centimeters above the isocenter. *The phantom is moved along the longitudinal axis 5.0 centimeters above the isocenter. The reference image used is captured in the isocenter plane. Values presented on the y-axis are the maximum deviations from the true position given by the system. The values are expected to be zero in all positions along the axis.*

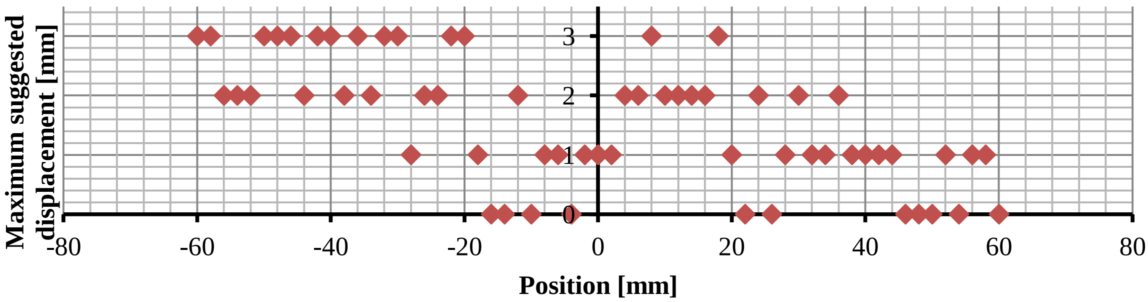
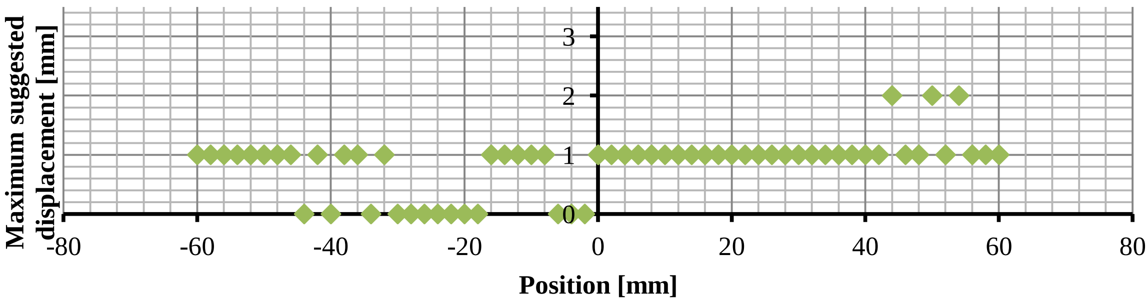


Table 24. Positioning results in vertical direction 5.0 centimeters above the isocenter. *The phantom is moved along the longitudinal axis 5.0 centimeters above the isocenter. The reference image used is captured in the isocenter plane. Values presented on the y-axis are the maximum deviations from the true position given by the system. The values are expected to be zero in all positions along the axis.*



Compiling result

Table 25. Mean error in positioning result per measuring point in the three measuring planes.

Plane	Mean error / Measuring point [mm]	
	Lateral direction	*Longitudinal direction*
Isoplane	0.69	0.55
2.5 cm	0.46	0.85
5.0 cm	0.68	0.28

Appendix II

This appendix contains results from thirteen breast cancer patients that were included in the study "The Catalyst systems correspondence with planar verification images on patients".

Patient nr 1.

Table 26. The Catalyst™ system correspondence with planar verification images on patients. *The results from the Catalyst™ system and the On-Board Imaging ® (Varian®) are presented. Only sessions with recorded data are shown in the table. The suggested deviation in position from the reference images are presented in millimeter, together with the difference in the values presented by the two systems.*

	Deviation [mm]						**Difference in positioning result [mm]**		
	The Catalyst system $\mu_{(CT\ StructureSet-SetUp)}$			**OBI-system** $\mu_{(DRR-SetUp)}$					
Session	*lat*	*long*	*vert*	*lat*	*long*	*vert*	*lat*	*long*	*vert*
1	-2			2			**4**		
2	-0.2	0.2	-2.3	0	-5	-7	**0.2**	**5.2**	**4.7**
3	-0.2	-3	-5.2	-1	-3	-2	**0.8**	**0**	**3.2**
4	-0.6	-2.6	-2.4	-2	-5	0	**1.4**	**2.4**	**2.4**
5	0.8	-1.2	-2.4	0	-3	-4	**0.8**	**1.8**	**1.6**
6	-1.9	-4	-9.5	-3	-6	-7	**1.1**	**2**	**2.5**
7	2.1	-4.9	-6.8	-3	-6	-4	**5.1**	**1.1**	**2.8**
8	3.8	-6.2	-6.6	0	-7	-3	**3.8**	**0.8**	**3.6**

Maximum difference.

Lat	5.1 mm	Session 7
Long	5.2 mm	Session 2
Vert	4.7 mm	Session 2

Minimal difference.

Lat	0.2 mm	Session 2
Long	0.0 mm	Session 2
Vert	1.6 mm	Session 5

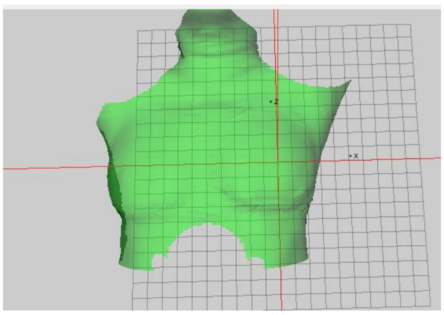


Figure 32. Reference image for patient number one..

Table 27. Deviation of the patient by the Catalyst system and the OBI system. *Lateral direction.*

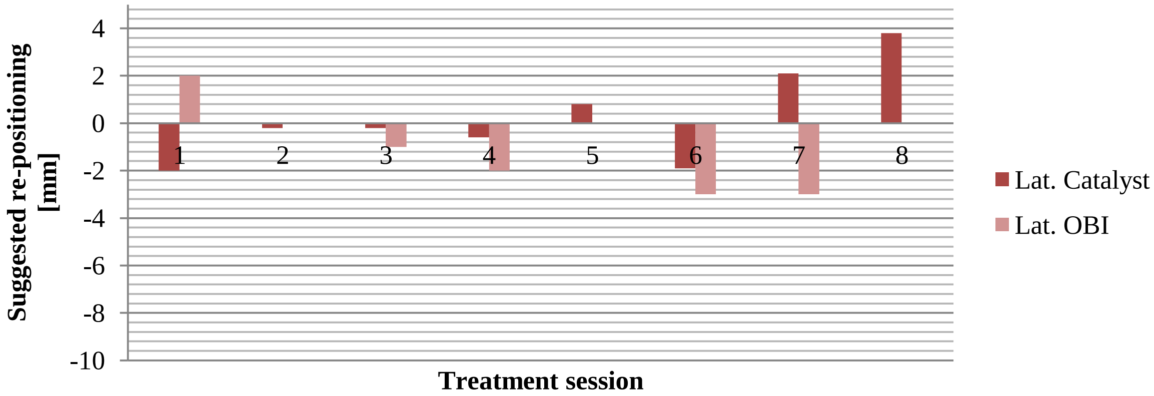


Table 28. Deviation of the patient by the Catalyst system and the OBI system. *Longitudinal direction.*

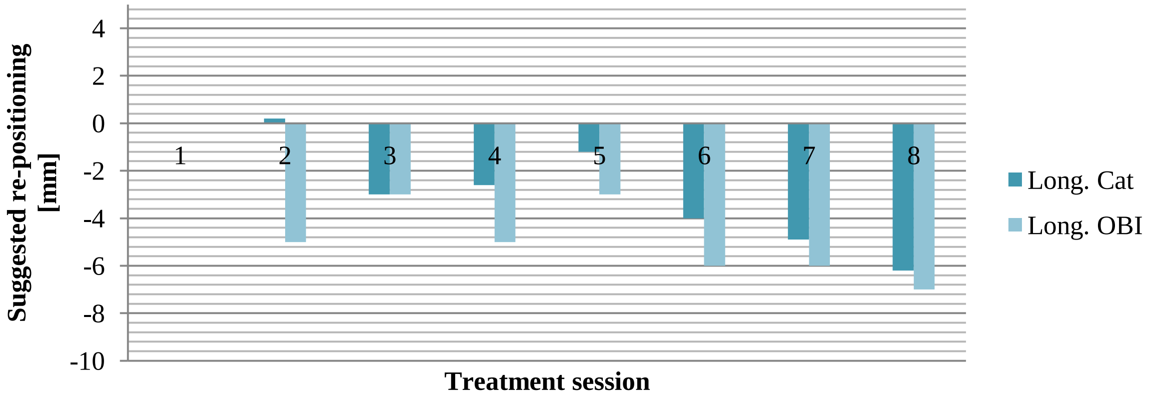
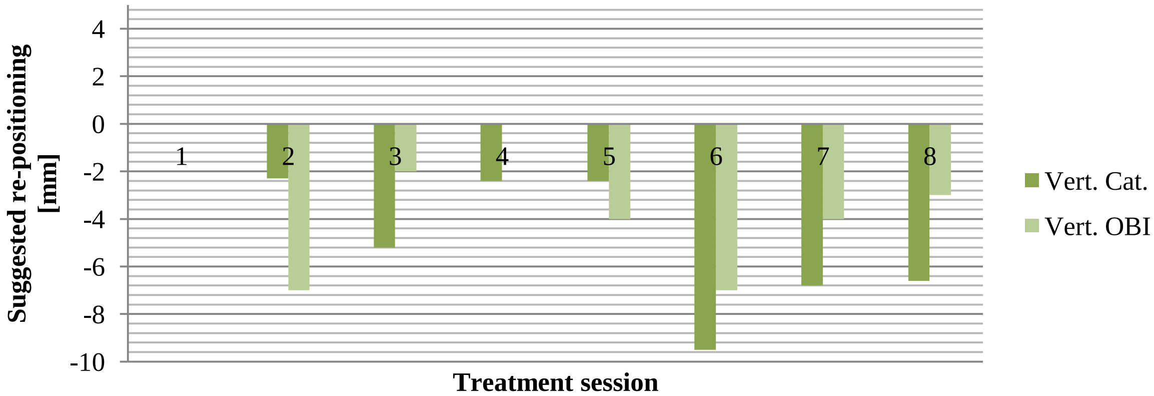


Table 29. Deviation of the patient by the Catalyst system and the OBI system. *Vertical direction.*



Comments.

<u>Live image with reference image, Session 2:</u>

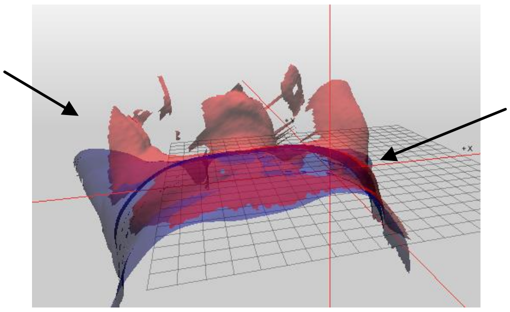


Figure 32b.

Possible swollenness of the breast is the reason for the difference in the result compared to the planar verification images. The position of the arm on the right side is not correct. The arm position is a bit more stretched than for the reference set-up (figure 32 b).

<u>Live image, Session 7:</u>

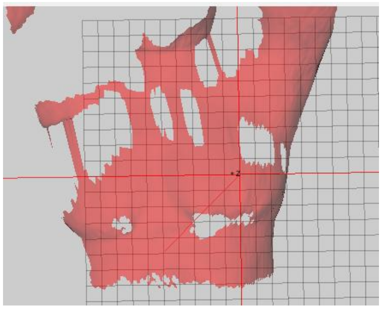


Figure 32c.

Holes around the breast – contributing to uncertainties in the positioning result (figure 32c).

Patient nr 2.

Table 30. The Catalyst™ system correspondence with planar verification images on patients. *The results from the Catalyst™ system and the On-Board Imaging ® (Varian®) are presented. Only sessions with recorded data are shown in the table. The suggested deviation in position from the reference images are presented in millimeter, together with the difference in the values presented by the two systems.*

	Deviation [mm]						**Difference in positioning result [mm]**		
	The Catalyst system $\mu_{(CT\ StructureSet-SetUp)}$			**OBI-system** $\mu_{(DRR-SetUp)}$					
Session	*lat*	*long*	*vert*	*lat*	*long*	*vert*	*lat*	*long*	*vert*
1	5.1	-1.4	6.8	-4	0	1	**9.1**	**1.4**	**5.8**
2	-2	0	-0.9	1	2	3	**3**	**2**	**3.9**
3			4.5			0			**4.5**
4	-4.6	-5.8	0.7	-5	0	3	**0.4**	**5.8**	**2.3**
5	-2.3	-1.6	1.2	-3	1	1	**0.7**	**2.6**	**0.2**
6	-0.5	-1.4	0.2	1	1	1	**1.5**	**2.4**	**0.8**
7	0.7	-4.9	2.4	2	-3	0	**1.3**	**1.9**	**2.4**
8	-0.1	-4.8	3	-3	-4	-1	**2.9**	**0.8**	**4**

Maximum difference.

Lat	9.1 mm	Session 1
Long	5.8 mm	Session 4
Vert	4.5 mm	Session 3

Minimal difference.

Lat	0.4 mm	Session 4
Long	0.8 mm	Session 8
Vert	0.2 mm	Session 5

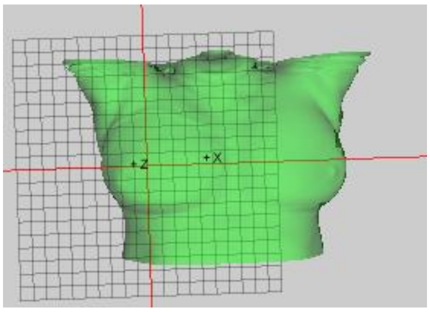


Figure 33. Reference image for patient number two.

Table 31. **Deviation of the patient by the Catalyst system and the OBI system.** *Lateral direction.*

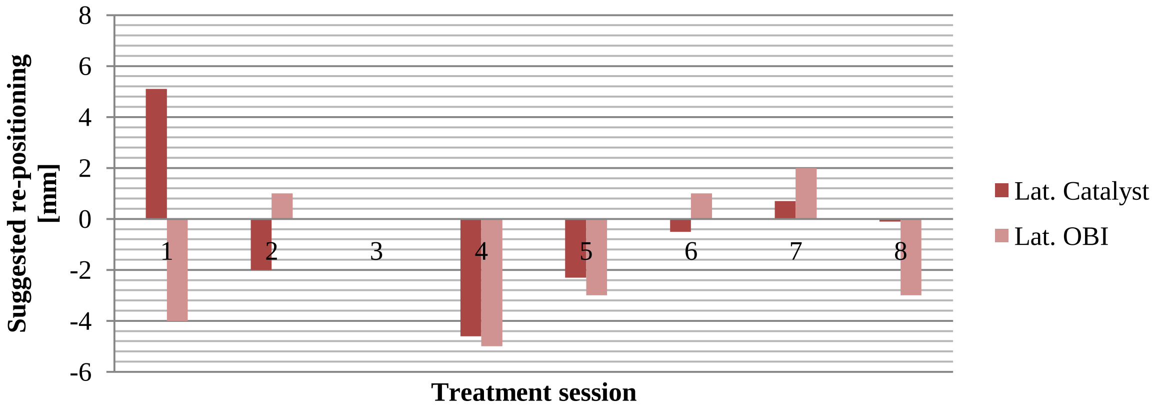


Table 32. **Deviation of the patient by the Catalyst system and the OBI system.** *Longitudinal direction.*

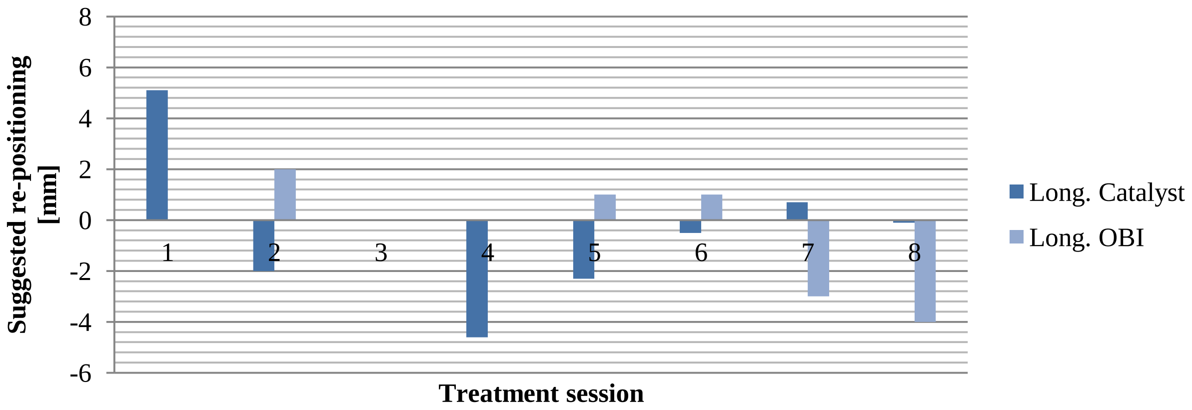
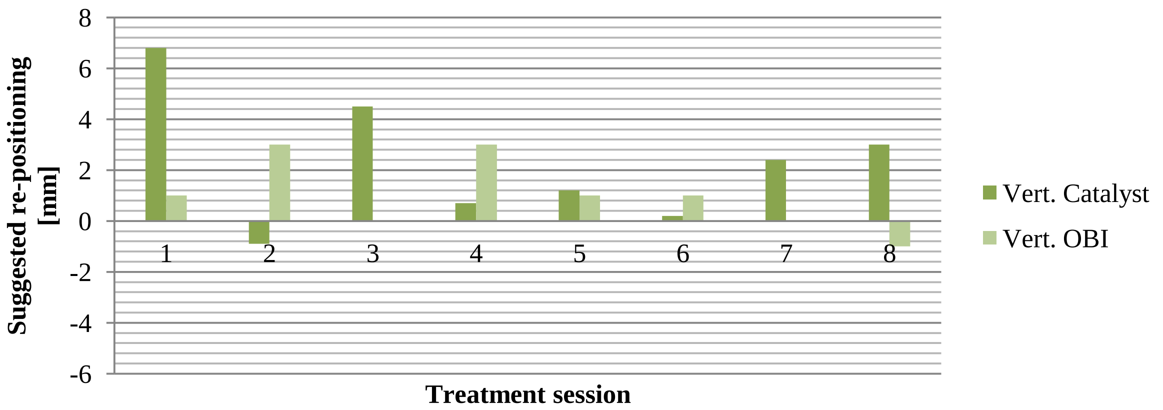


Table 33. **Deviation of the patient by the Catalyst system and the OBI system.** *Vertical direction.*



Comments.

Live and reference image, Session 1:

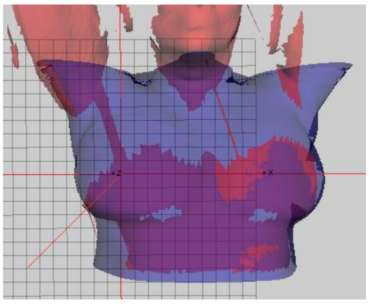


Figure 33a.

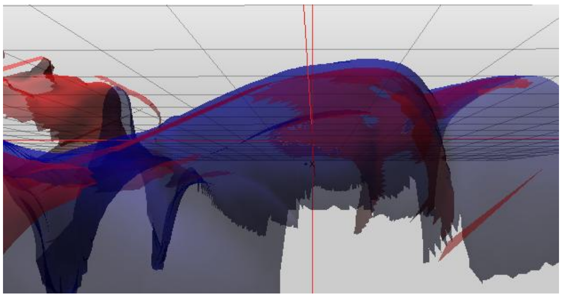


Figure 33b. Breast Dexter

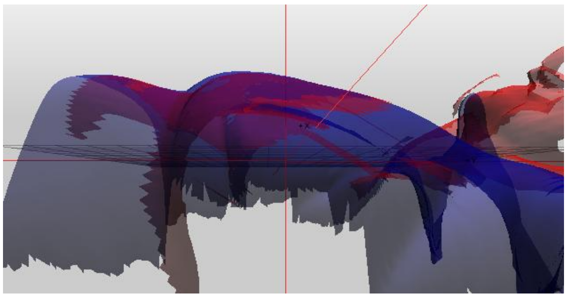


Figure 33c. Breast Sinister

The live images quality could be improved for a more accurate result. There is still structure in the images that the system can use for the matching (figure 33a).

Observing the images one can see that the left sided breast is in a better position in vertical direction than the right breast (figure 33b and figure 33c). One possible explanation for positioning result can be that the right sided breast was swollen during the CT scan and the swelling decreased before the first treatment session. Small changes like this are without the Catalyst™ system difficult to detect. The swelling might come back more or less during the course of treatment.

Live and reference image, Session 4:

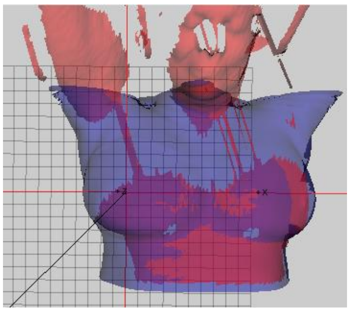


Figure 33d.

It is not possible to see from the live image if the positioning result from the Catalyst™ system is accurate or not. There is no information about the left arms position (figure 33d).

Patient nr 3.

Table 34. The Catalyst™ system correspondence with planar verification images on patients. *The results from the Catalyst™ system and the On-Board Imaging ® (Varian®) are presented. Only sessions with recorded data are shown in the table. The suggested deviation in position from the reference images are presented in millimeter, together with the difference in the values presented by the two systems.*

	Deviation [mm]						**Difference in positioning result [mm]**		
	The Catalyst system $\mu_{(CT\ StructureSet-SetUp)}$			**OBI-system** $\mu_{(DRR-SetUp)}$					
Session	*lat*	*long*	*vert*	*lat*	*long*	*vert*	*lat*	*long*	*vert*
1	0	0.6	-0.9	-1	2	5	**1**	**1.4**	**5.9**
2			0.5			-1			**1.5**
3	1.3	5.8	-2.4	1	2	0	**0.3**	**3.8**	**2.4**
4	1	8.8	0.9	0	4	3	**1**	**4.8**	**2.1**
5	0.6	4.4	-1.9	-3	2	-1	**3.6**	**2.4**	**0.9**
6	1.3	4.7	0.8	3	5	0	**1.7**	**0.3**	**0.8**
7	2.4	1.3	5	2	8	7	**0.4**	**6.7**	**2**
8	1.2	-0.5	5.1	1	3	-8	**0.2**	**3.5**	**13.1**
9	4.7	-8.8	-11.3	8	6	-5	**3.3**	**14.8**	**6.3**

Maximum difference.

Lat	3.6 mm	Session 5
Long	14.8 mm	Session 9
Vert	13.1 mm	Session 8

Minimal difference.

Lat	0.2 mm	Session 8
Long	0.3 mm	Session 6
Vert	0.8 mm	Session 6

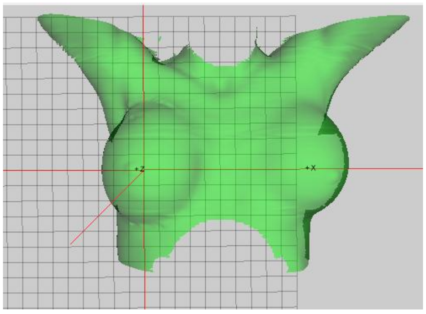


Figure 34. Reference image for patient number three.

Table 35. Deviation of the patient by the Catalyst system and the OBI system. *Lateral direction.*

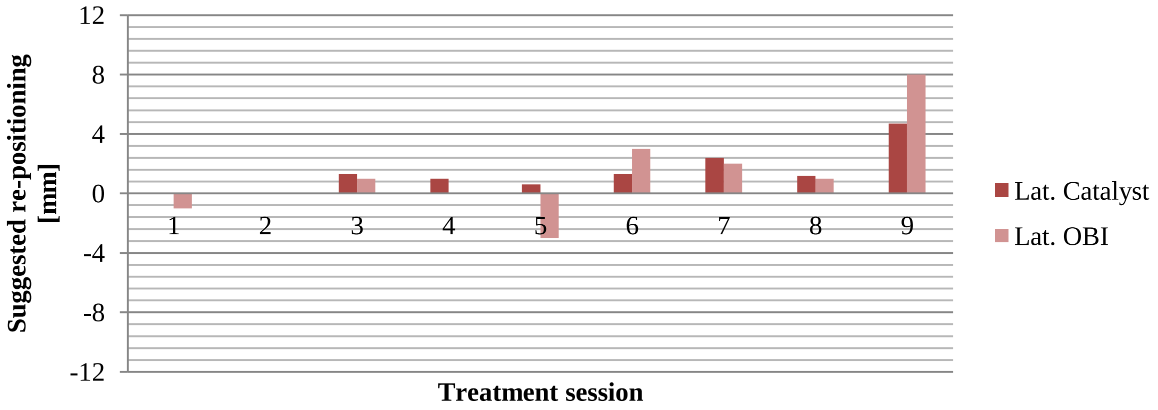


Table 36. Deviation of the patient by the Catalyst system and the OBI system. *Longitudinal direction.*

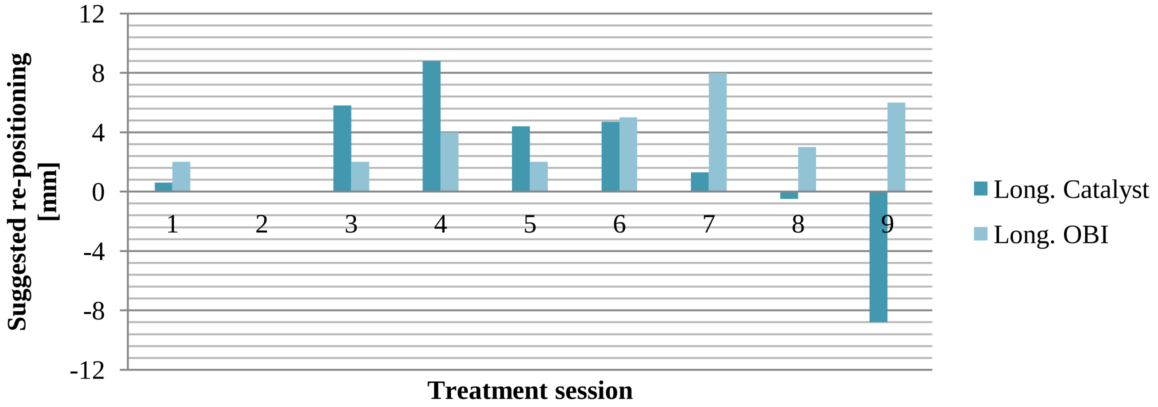
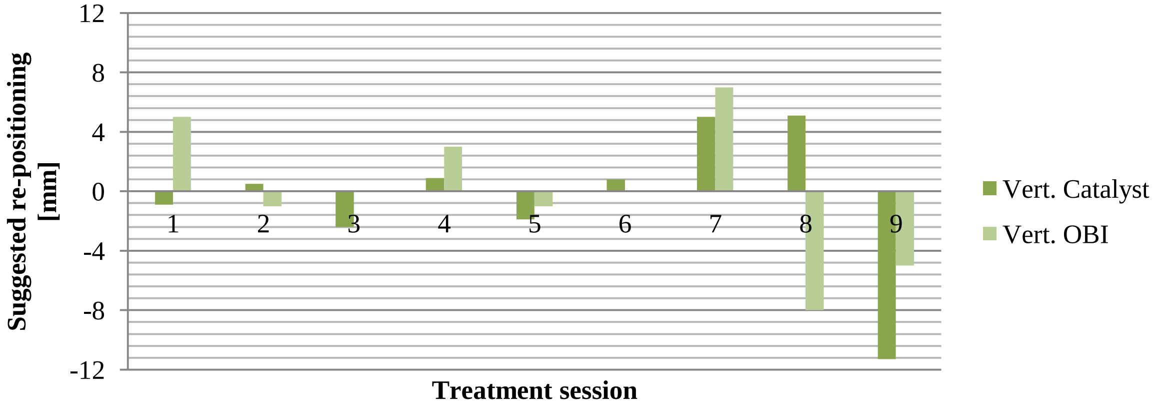


Table 37. Deviation of the patient by the Catalyst system and the OBI system. *Vertical direction.*



Comments.

<u>Live and reference image, Session 8:</u>

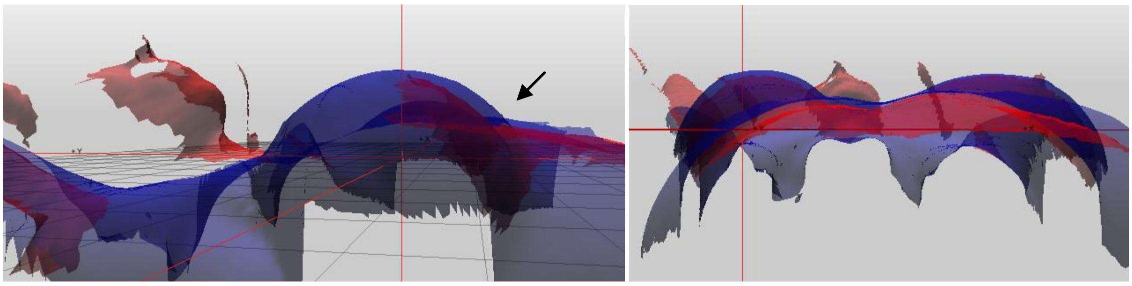


Figure 34 a and b.

From a visually observing the surface images the deviation in the longitudinal direction should be a negative value (figure 34a and b). The OBI system suggests +3.0 mm and the Catalyst™ system suggest -0.5 mm.

<u>Live and reference image, Session 9:</u>

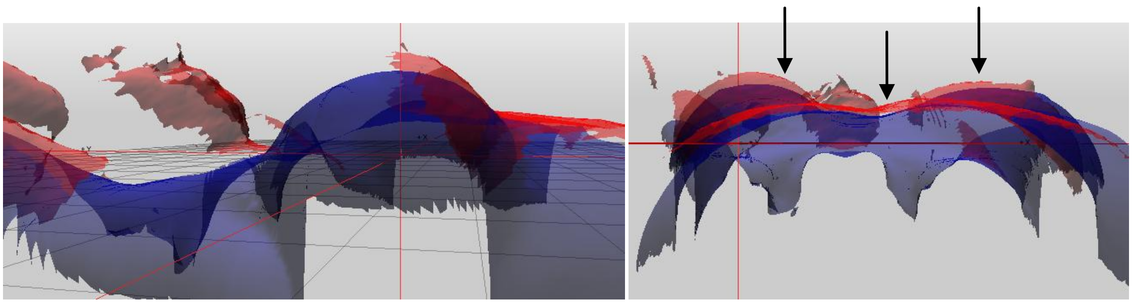


Figure 34 c and d. Arm out of position.

The position of the right arm is not correct. It is stretched and the breast dx follow the movement. The most salient observation is the displacement in the vertical direction. The Catalyst™ system suggests a re-positioning of -8.8 mm and the OBI system +6 mm. It is in this case obvious by visually observing the images that the Catalyst™ system suggests the correct re-positioning result according to its surface matching.

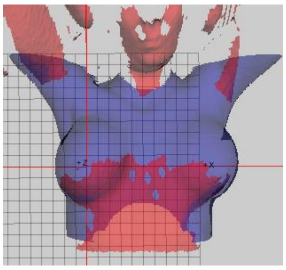


Figure 34e.

The left arm is not in the correct position (figure 34 e). It looks like the patients arm is more stretched and this might affect the positioning result. The difference in deviation positioning value in the longitudinal direction was 14.8 millimeter. This measurement is further investigated in “Arm out of order” page 37 and page 46.

Patient nr 4.

Table 38. The Catalyst™ system correspondence with planar verification images on patients. *The results from the Catalyst™ system and the On-Board Imaging ® (Varian®) are presented. Only sessions with recorded data are shown in the table. The suggested deviation in position from the reference images are presented in millimeter, together with the difference in the values presented by the two systems.*

	Deviation [mm]						Difference in positioning result [mm]		
	The Catalyst system $\mu_{(CT\ StructureSet-SetUp)}$			OBI-system $\mu_{(DRR-SetUp)}$					
Session	*lat*	*long*	*vert*	*lat*	*long*	*vert*	*lat*	*long*	*vert*
1	1.4	-1.2	-0.6	-3	5	5	**4.4**	**6.2**	**5.6**
2	0.4			0			**0.4**		
3	0.2	6.1	0.8	0	2	3	**0.2**	**4.1**	**2.2**
4	1.6	2.4	-7.9	-2	0	-3	**3.6**	**2.4**	**4.9**
5	0.5	5.4	-3.2	-2	4	3	**2.5**	**1.4**	**6.2**
6	-0.6	6	-0.7	-2	4	6	**1.4**	**2**	**6.7**
7	1	5.1	-4.8	-2	1	0	**3**	**4.1**	**4.8**
8	1	2.8	-1.1	2	-1	5	**1**	**3.8**	**6.1**
9	1.8	5.6	-6	-3	3	-1	**4.8**	**2.6**	**5**
10	0.7	4.6	-3.3	-3	0	1	**3.7**	**4.6**	**4.3**
11	2.2	5.1	-1.4	1	1	1	**1.2**	**4.1**	**2.4**
12	-0.9	0.7	-3.1	-2	0	3	**1.1**	**0.7**	**6.1**

Maximum difference.

Lat	4.8 mm	Session 9
Long	6.2 mm	Session 1
Vert	6.7 mm	Session 6

Minimal difference.

Lat	0.2 mm	Session 3
Long	0.7 mm	Session 12
Vert	2.2 mm	Session 3

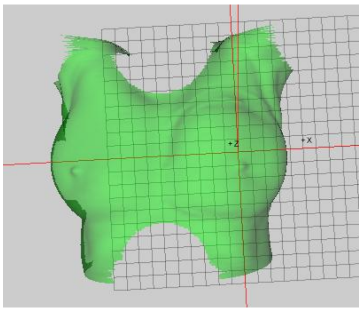


Figure 35. Reference image of patient number four.

Table 39. Deviation of the patient by the Catalyst system and the OBI system. *Lateral direction.*

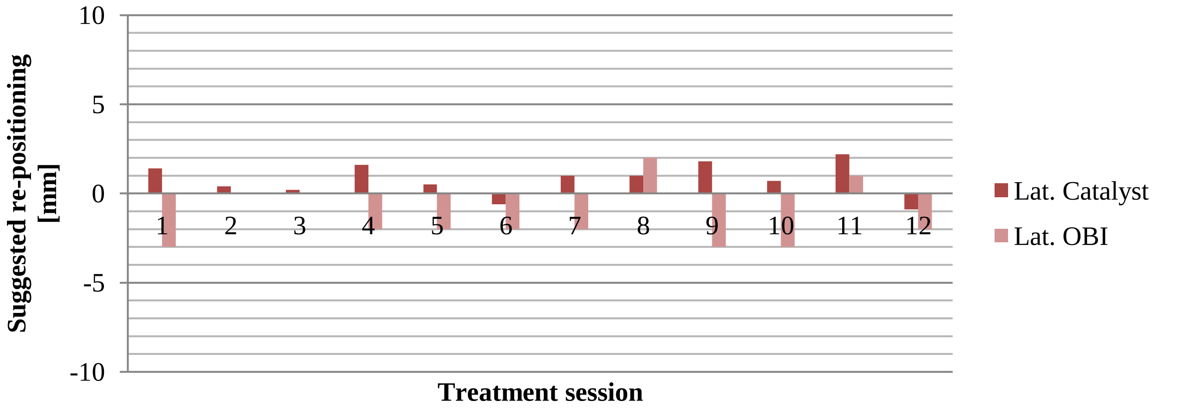


Table 40. Deviation of the patient by the Catalyst system and the OBI system. *Longitudinal direction.*

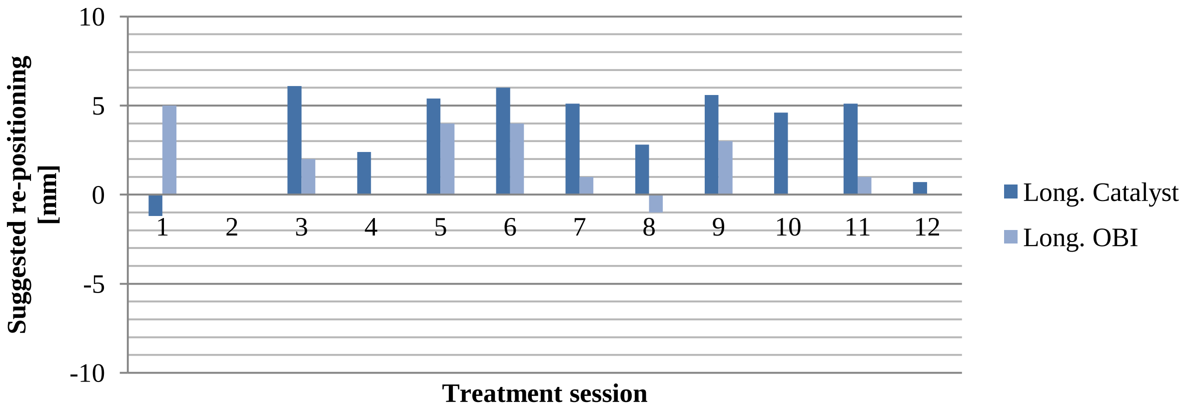
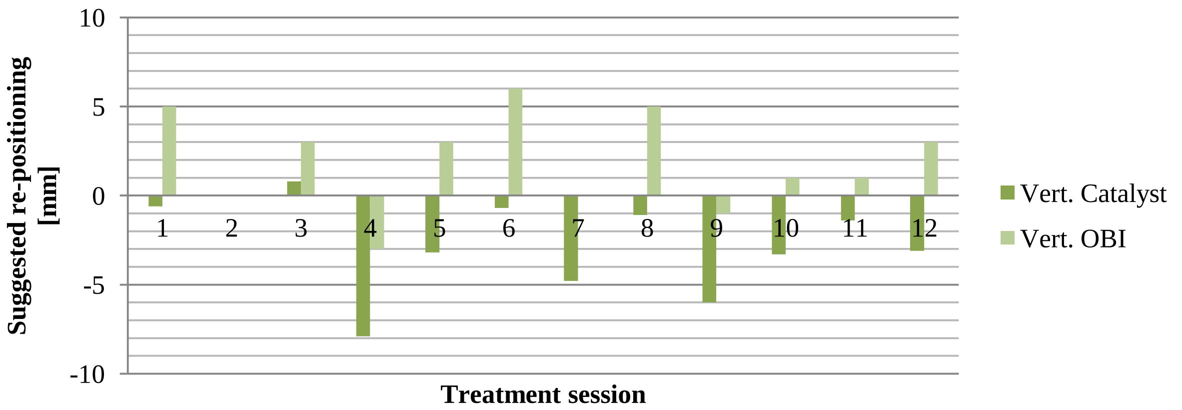


Table 41. Deviation of the patient by the Catalyst system and the OBI system. *Vertical direction.*



Comments.

Live image, Session 1:

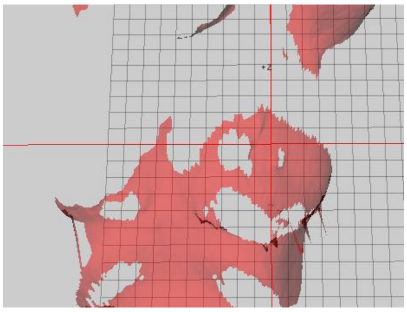


Figure 35a.

The live image contains a lot of holes. The holes do not contribute to data for the matching algorithm (figure 35 a).

Live and reference image, Session 6:

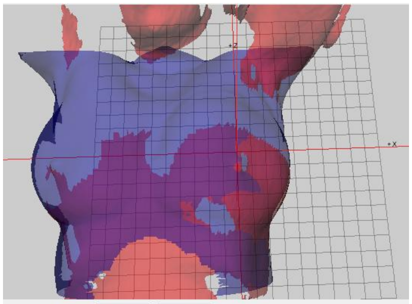


Figure 35b.

The Catalyst™ system only shows a deviation over 1 millimeter in the longitudinal direction, while the OBI shows both in the longitudinal and the vertical direction. It is difficult to draw any conclusions based on the images in the Analyze tool, but after reviewing this case there is a possibility that the large deviation arise from an error in the manual matching of the verification images.

Patient nr 5.

Table 42. The Catalyst™ system correspondence with planar verification images on patients. *The results from the Catalyst™ system and the On-Board Imaging ® (Varian®) are presented. Only sessions with recorded data are shown in the table. The suggested deviation in position from the reference images are presented in millimeter, together with the difference in the values presented by the two systems.*

	Deviation [mm]						**Difference in positioning result [mm]**		
	The Catalyst system $\mu_{(CT\ StructureSet-SetUp)}$			**OBI-system** $\mu_{(DRR-SetUp)}$					
Session	*lat*	*long*	*vert*	*lat*	*long*	*vert*	*lat*	*long*	*vert*
1			4.9			0			**4.9**
2			3.3			0			**3.3**
3	2.4	5.3		-5	3		**7.4**	**2.3**	
4	1.3	7.2	5.9	-2	5	5	**3.3**	**2.2**	**0.9**
5	2.6	10.3	5.3	-5	8	2	**7.6**	**2.3**	**3.3**
6	0.8	6.8	4.7	-5	1	2	**5.8**	**5.8**	**2.7**
7	-0.2	4.4	-2.7	-4	5	0	**3.8**	**0.6**	**2.7**
8	-2.1	5.2	4.1	-9	5	5	**6.9**	**0.2**	**0.9**
9	3.7	5.2	6.3	-3	5	3	**6.7**	**0.2**	**3.3**
10	-0.7	11.7	3.2	-5	8	1	**4.3**	**3.7**	**2.2**
11	2.3	4.9	-1.7	-1	8	2	**3.3**	**3.1**	**3.7**
12	-1.4	4.3	2.1	1	6	3	**2.4**	**1.7**	**0.9**
13	2.6	5.5	3.7	-2	9	2	**4.6**	**3.5**	**1.7**

Maximum difference.

Lat	7.6 mm	Session 5
Long	5.8 mm	Session 6
Vert	4.9 mm	Session 1

Minimal difference.

Lat	2.4 mm	Session 12
Long	0.2 mm	Session 8 and 9
Vert	0.9 mm	Session4, 8 and 12

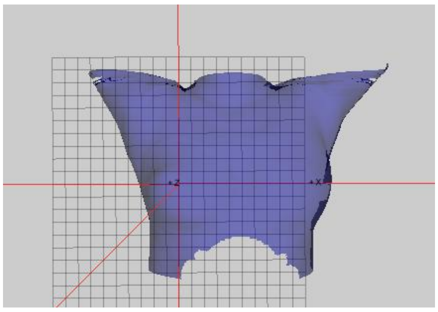


Figure 36. Reference image of patient number five.

Table 43. Deviation of the patient by the Catalyst system and the OBI system. *Lateral direction.*

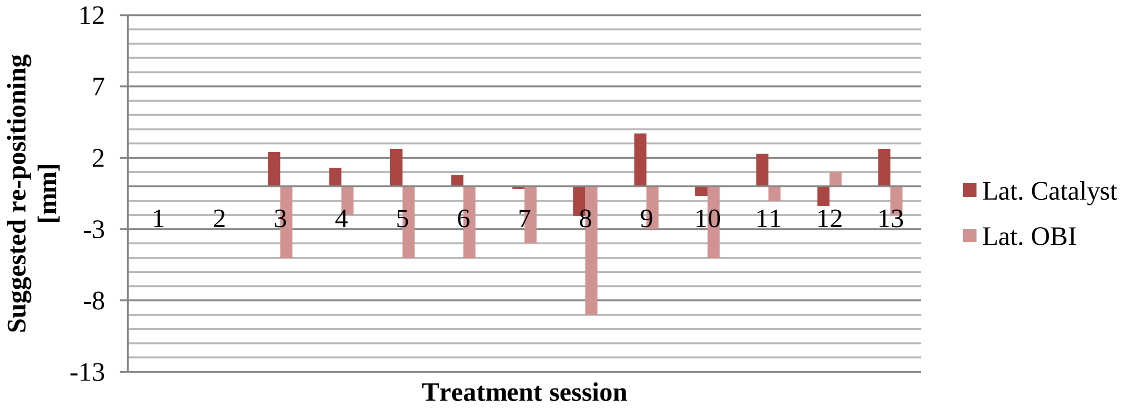


Table 44. Deviation of the patient by the Catalyst system and the OBI system. *Longitudinal direction.*

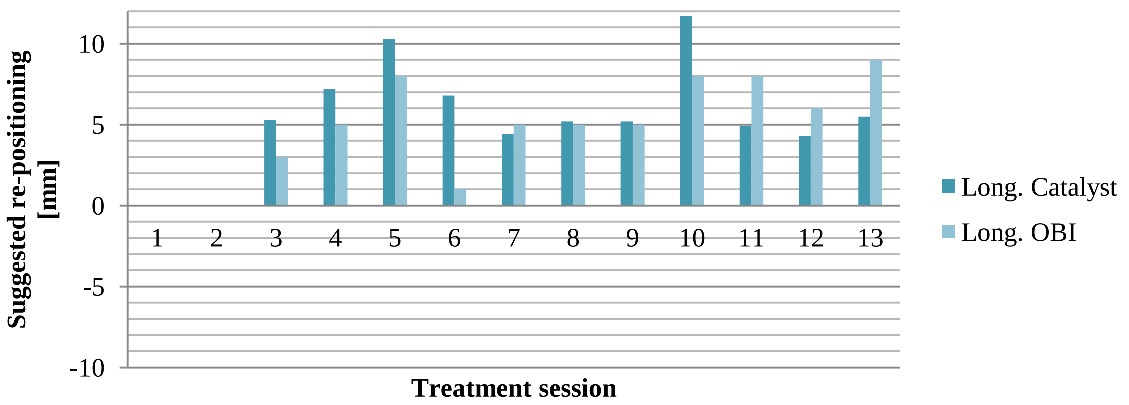
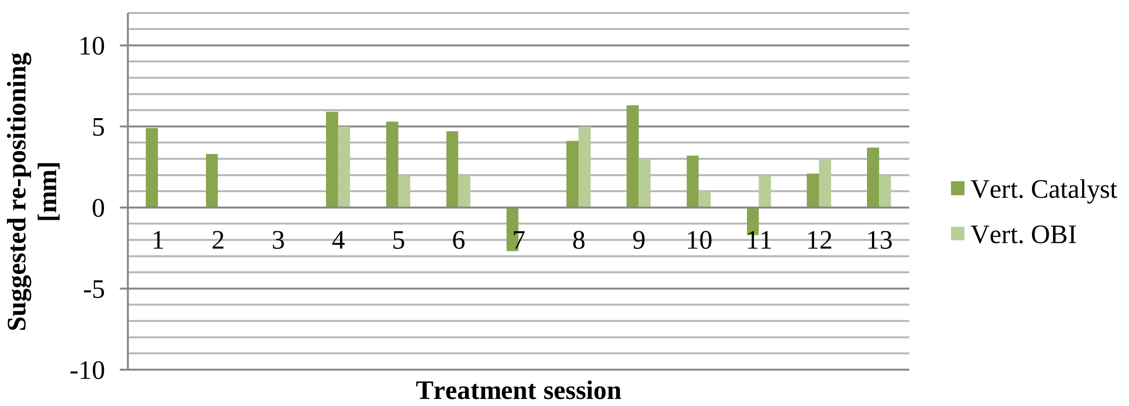


Table 45. Deviation of the patient by the Catalyst system and the OBI system. *Vertical direction.*



Comments.

Live and reference image, Session 5:

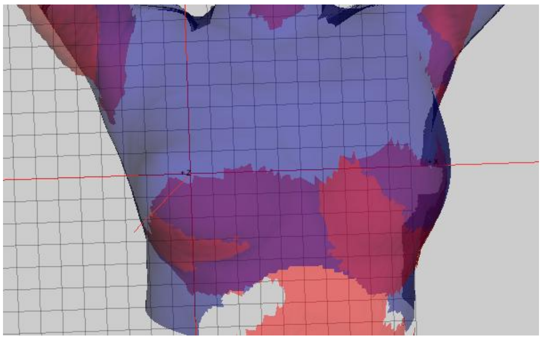


Figure 36a.

The detector is limited by the shape of the patient's chest (figure 36a). The angle with which the chest is leaning backwards is too large and this results in a shadow that the Catalyst system cannot detect.

Live and reference image, Session 6:

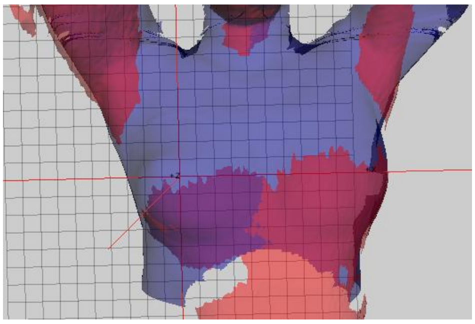


Figure 36b.

The patient is lying with one arm more stretched up (figure 36b). The positioning result is further investigated in "Arm out of order" page 37 and page 46.

Patient nr 6.

Table 46. The Catalyst™ system correspondence with planar verification images on patients. *The results from the Catalyst™ system and the On-Board Imaging ® (Varian®) are presented. Only sessions with recorded data are shown in the table. The suggested deviation in position from the reference images are presented in millimeter, together with the difference in the values presented by the two systems.*

	Deviation [mm]						Difference in positioning result [mm]		
	The Catalyst system $\mu_{(CT\ StructureSet-SetUp)}$			OBI-system $\mu_{(DRR-SetUp)}$					
Session	*lat*	*long*	*vert*	*lat*	*long*	*vert*	*lat*	*long*	*vert*
1		-5			0			**5**	
2		0.7			3			**2.3**	
3	1.5	2.3	2.4	-9	3	6	**10.5**	**0.7**	**3.6**
4	-2.5	2	2	-2	-3	1	**0.5**	**5**	**1**

Maximum difference.

Lat	10.5 mm	Session 3
Long	5.0 mm	Session 1 and 4
Vert	3.6 mm	Session 3

Minimal difference.

Lat	0.5 mm	Session 4
Long	0.7 mm	Session 3
Vert	1.0 mm	Session 1

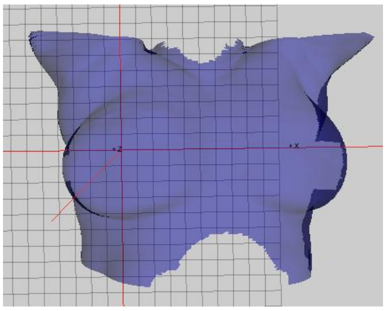


Figure 37. Reference image of patient number six.

Table 47. Deviation of the patient by the Catalyst system and the OBI system. *Lateral direction.*

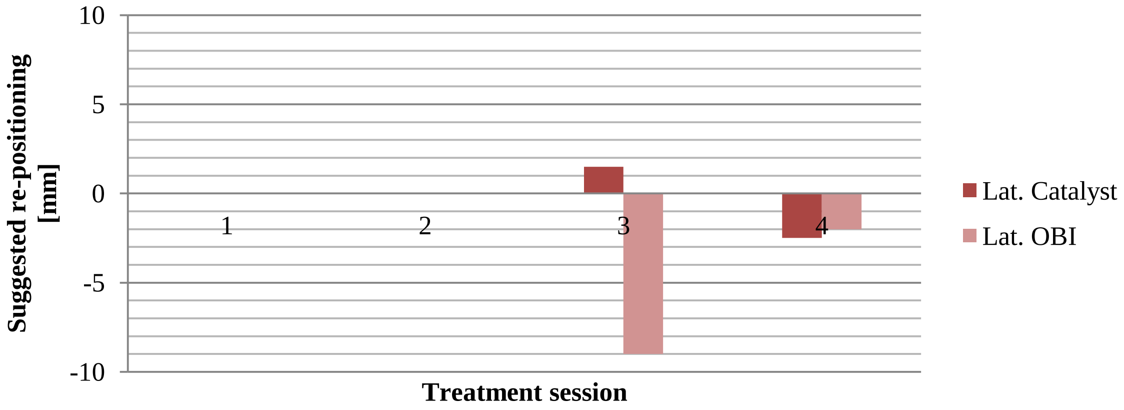


Table 48. Deviation of the patient by the Catalyst system and the OBI system. *Longitudinal direction.*

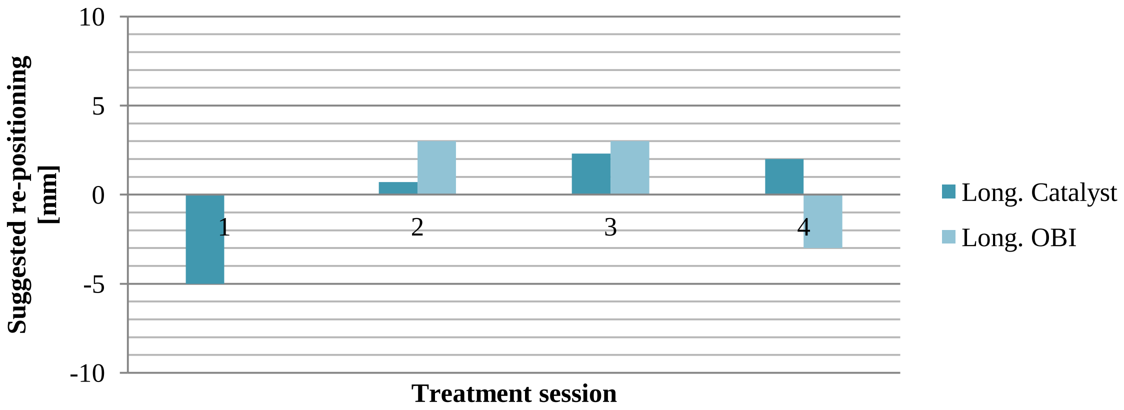
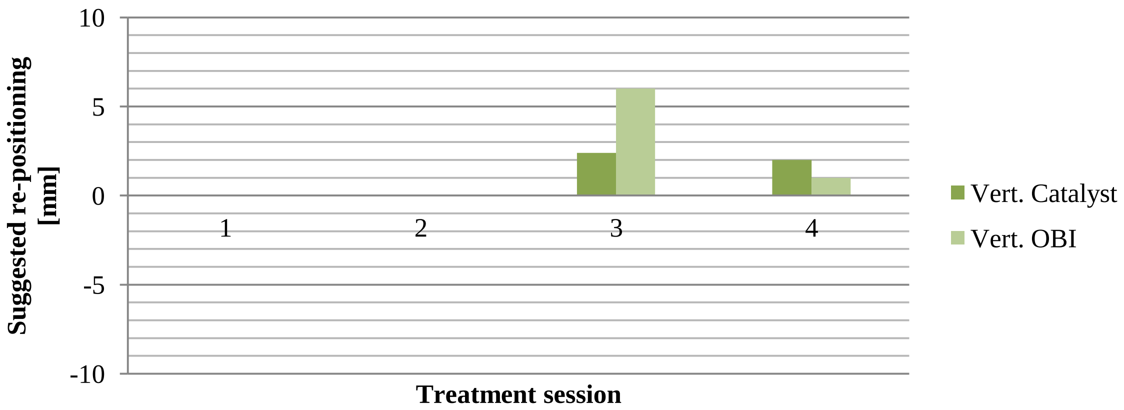


Table 49. Deviation of the patient by the Catalyst system and the OBI system. *Vertical direction.*



Comments.

This patient was particularly difficult to position. In eight sessions out of ten an online movement had to be done of the couch. The values when an online movement had to be done are not included in the results. The patient also had difficulties to lie still during treatment.

Live and reference image, Session 3:

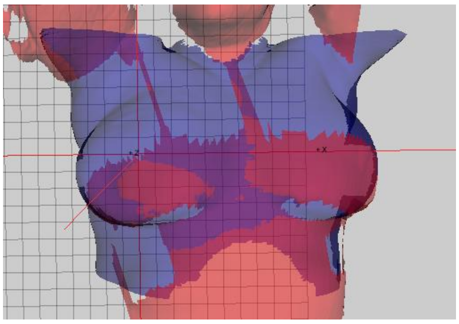


Figure 37a.

Difficult to decide by viewing the images how much in the lateral direction the patient should be moved (figure 37a). The most obvious error in the positioning during this treatment session is the upper arm position for the patents left arm. From these images it is difficult to decide where the arm starts and where the arm ends in lateral direction and the displacement of the arm is not possible to detect. The left arms position should not affect the positioning result of the right breast significantly, but the error in the positioning should be avoided as much as possible.

Patient nr 7.

Table 50. The Catalyst™ system correspondence with planar verification images on patients. *The results from the Catalyst™ system and the On-Board Imaging ® (Varian®) are presented. Only sessions with recorded data are shown in the table. The suggested deviation in position from the reference images are presented in millimeter, together with the difference in the values presented by the two systems.*

	Deviation [mm]						Difference in positioning result [mm]		
	The Catalyst system $\mu_{(CT\ StructureSet-SetUp)}$			OBI-system $\mu_{(DRR-SetUp)}$					
Session	*lat*	*long*	*vert*	*lat*	*long*	*vert*	*lat*	*long*	*vert*
1	-0.6	0.5	-2.6	-3	2	5	**2.4**	**1.5**	**7.6**
2	3.7	1.1	-1.1	1	4	5	**2.7**	**2.9**	**6.1**
3	2.6	1	1.7	0	1	8	**2.6**	**0**	**6.3**
4	1	2.1	0.8	-2	3	7	**3**	**0.9**	**6.2**
5	3	2.3	6.9	0	2	13	**3**	**0.3**	**6.1**
6	4.5	5	0.5	0	5	7	**4.5**	**0**	**6.5**
7	5	5.4	-1.1	3	2	7	**2**	**3.4**	**8.1**

Maximum difference.

Lat	4.5 mm	Session 6
Long	3.4 mm	Session 7
Vert	8.1 mm	Session 7

Minimal difference.

Lat	2.0 mm	Session 7
Long	0.0 mm	Session 3 and 6
Vert	6.1 mm	Session 2 and 5

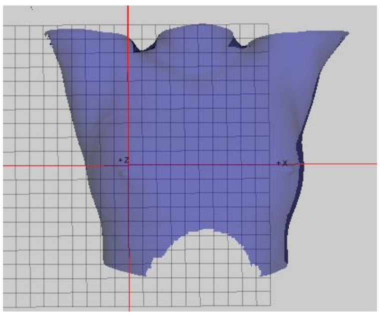


Figure 38. Reference image of patient number seven.

Table 51. Deviation of the patient by the Catalyst system and the OBI system. *Lateral direction.*

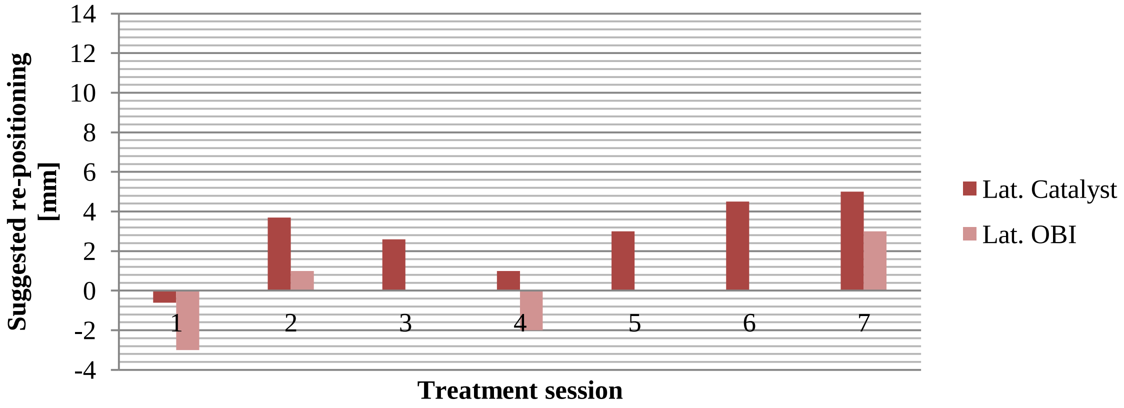


Table 52. Deviation of the patient by the Catalyst system and the OBI system. *Longitudinal direction.*

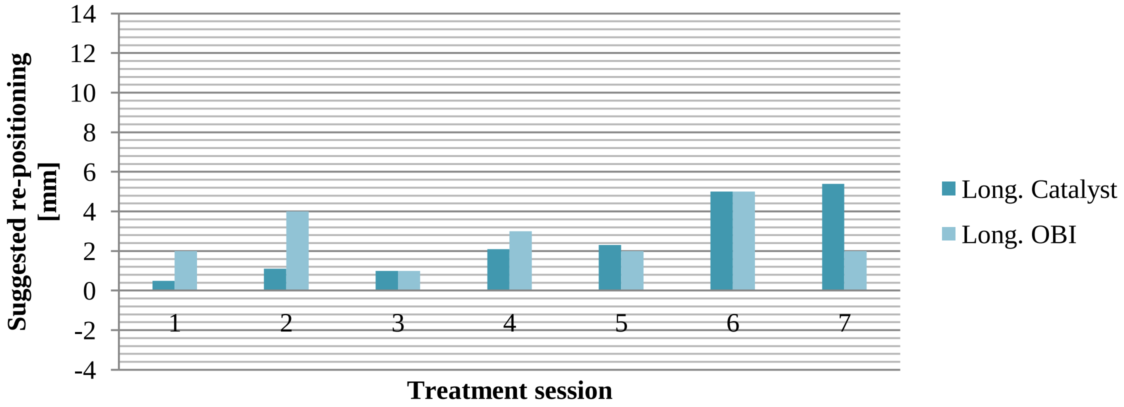
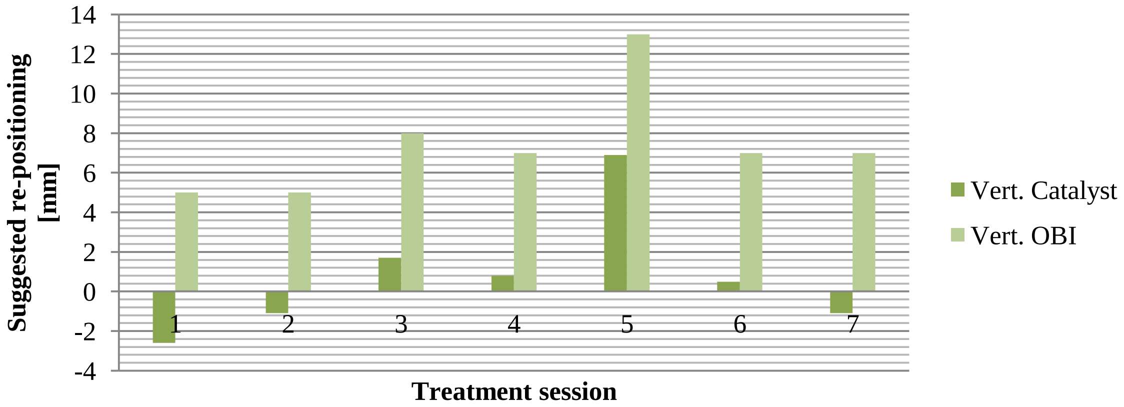


Table 53. Deviation of the patient by the Catalyst system and the OBI system. *Vertical direction.*



Comments.

<u>Reference image:</u>

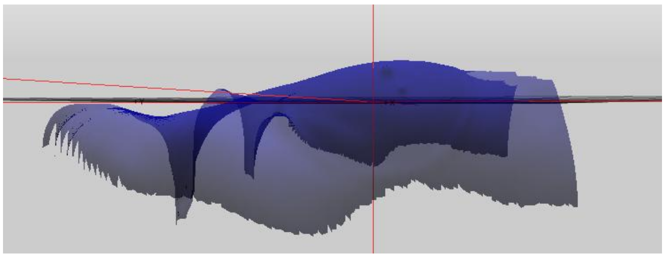


Figure 38a.

The reference image of the patient is flat and does not hold a lot of structure (figure 38a). The lack of structure is a factor that contributes to error in positioning result. The algorithm needs structure to be able to match the reference image and the live image in a correct way. In the study "The Catalyst system correspondence with CBCT verification images on a phantom" included in this thesis it is discussed the flat structure of the phantom pronouncedly contributes to error in the positioning result. The limit for how flat the structure can be is not yet investigated.

<u>Live image, Session 7:</u>

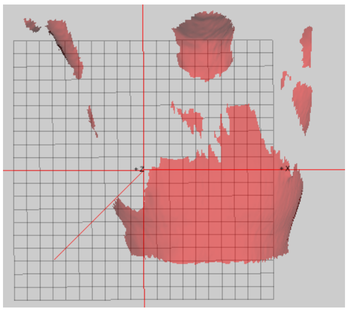


Figure 38b.

This live image lacks the highest weighted graph nodes for the non-rigid body algorithm (figure 38b). This affects the result of deviation in a negative way. The reason for the poor data collection in the area above the iso-center might be the tilted shape of the patient's body which causes a shadow for the Catalyst^{TM} system.

Patient nr 8.

Table 54. The Catalyst^{TM} system correspondence with planar verification images on patients. *The results from the Catalyst^{TM} system and the On-Board Imaging ® (Varian®) are presented. Only sessions with recorded data are shown in the table. The suggested deviation in position from the reference images are presented in millimeter, together with the difference in the values presented by the two systems.*

	Deviation [mm]						**Difference in positioning result [mm]**		
	The Catalyst system $\mu_{(CT\ StructureSet-SetUp)}$			**OBI-system** $\mu_{(DRR-SetUp)}$					
Session	*lat*	*long*	*vert*	*lat*	*long*	*vert*	*lat*	*long*	*vert*
1	-2.5	-6.4	-1.6	-3	2	3	**0.5**	**8.4**	**4.6**
2	-4.9	-6.1	-4.7	-5	11	0	**0.1**	**17.1**	**4.7**
3	-5.5	-1.7	-1.1	-8	6	7	**2.5**	**7.7**	**8.1**
4	7.4	-8.9	-0.4	1	0	6	**6.4**	**8.9**	**6.4**
5	1.1	-2.5	-1.6	-4	0	2	**5.1**	**2.5**	**3.6**
6	-2.7	-3.8	-4.7	-3	1	1	**0.3**	**4.8**	**5.7**

Maximum difference.

Lat	6.4 mm	Session 4
Long	17.1 mm	Session 2
Vert	8.1 mm	Session 3

Minimal difference.

Lat	0.1 mm	Session 2
Long	2.5 mm	Session 5
Vert	3.6 mm	Session 5

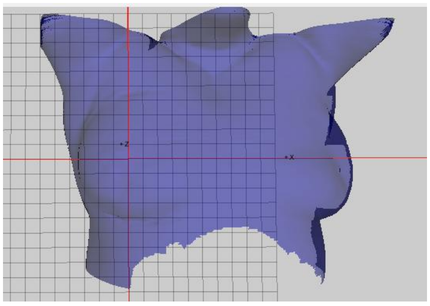


Figure 39. Reference image of patient number eight.

Table 55. Deviation of the patient by the Catalyst system and the OBI system. *Lateral direction.*

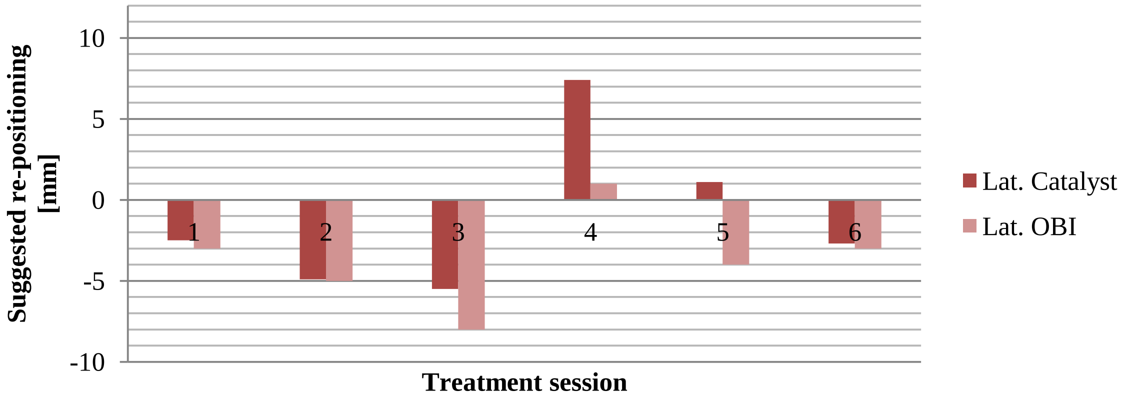


Table 56. Deviation of the patient by the Catalyst system and the OBI system. *Longitudinal direction.*

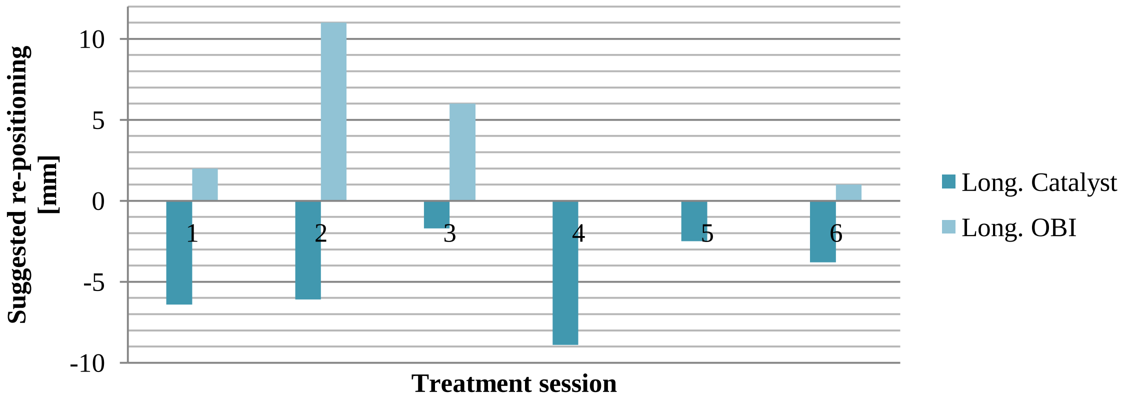
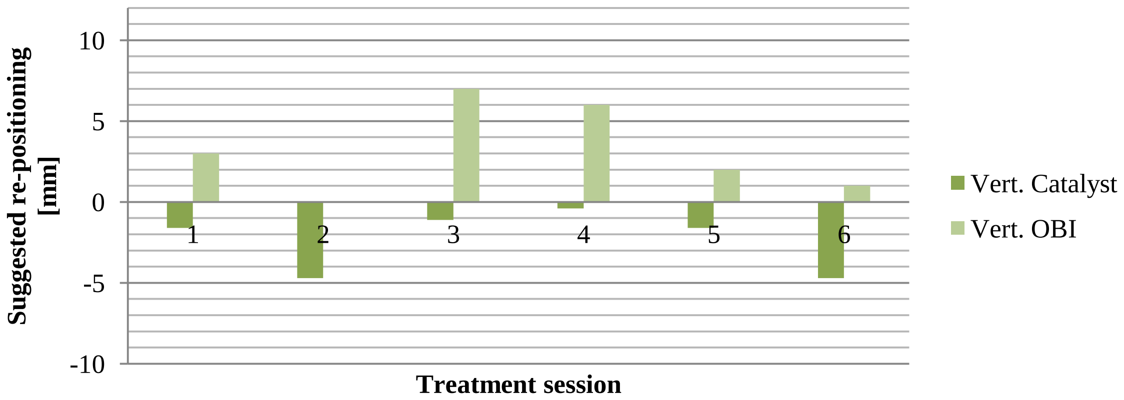


Table 57. Deviation of the patient by the Catalyst system and the OBI system. *Vertical direction.*



Comments.

Live and reference image, Session 2:

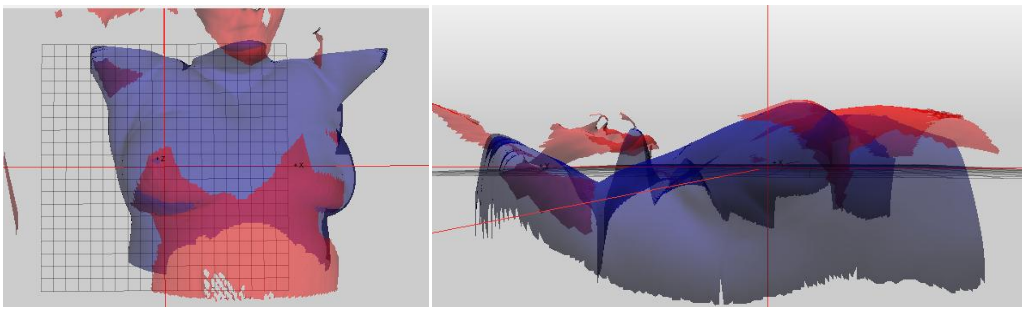
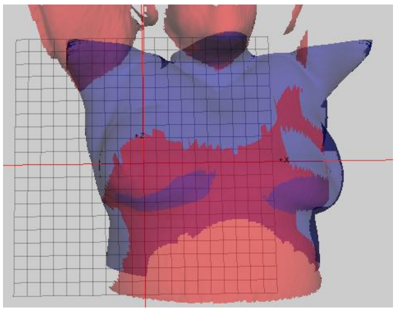
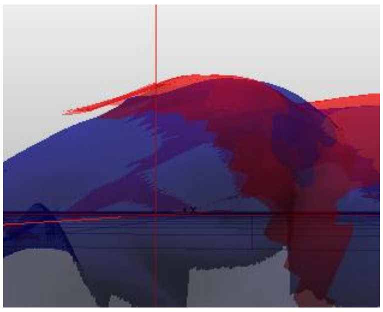


Figure 39 a and b.

During this session the positioning result from the two systems differed 17.1 millimeters in longitudinal direction. The Catalyst™ system responded with a negative value of -6.1 mm for the deviation and the OBI system with a positive value of +11 mm. Just by observing the images from the Catalyst™ system you can see that the value of the deviation in the longitudinal direction should be a negative value (figure 39 a and b). The reasons for this kind of mismatch between the two systems have to be further investigated.

Live and reference image from Session 4:





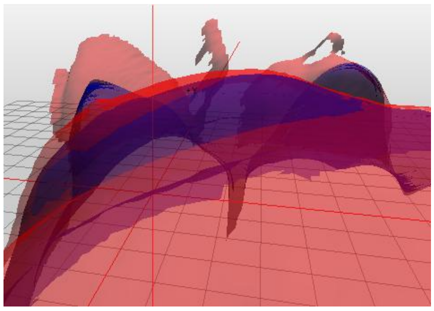


Figure 39 c) **d) Brest dx from the side.** **e)Breast dx from below**

During this session the Catalyst™ system and the OBI are giving contradictory results. The Catalyst™ suggests movement in lateral direction +7.4 mm, in longitudinal direction -8.9 mm and in vertical direction -0.4 mm. The OBI system suggest in lateral direction 1 mm, in longitudinal direction 0 mm and in vertical direction 6 mm. From a visual judgment of the images it is difficult to decide how the re-positioning should be performed. The breast tissue is soft and moveable. When visually examining this case it looks like it would be favourable to position the patient after the deviation result from the OBI system after looking at **Fel! Hittar inte referenskälla.** d and e.

Patient nr 9.

Table 58. The Catalyst™ system correspondence with planar verification images on patients. *The results from the Catalyst™ system and the On-Board Imaging ® (Varian®) are presented. Only sessions with recorded data are shown in the table. The suggested deviation in position from the reference images are presented in millimeter, together with the difference in the values presented by the two systems.*

	Deviation [mm]						**Difference in positioning result [mm]**		
	The Catalyst system $\mu_{(CT\ StructureSet-SetUp)}$			**OBI-system** $\mu_{(DRR-SetUp)}$					
Session	*lat*	*long*	*vert*	*lat*	*long*	*vert*	*lat*	*long*	*vert*
1	-9.6	5.1	-3.5	-4	1	7	**5.6**	**4.1**	**10.5**
2	-1.1	3.6	2.9	8	1	1	**9.1**	**2.6**	**1.9**
3	0.9	1	0	9	0	6	**8.1**	**1**	**6**
4	-2.8	1.2	4.2	7	2	7	**9.8**	**0.8**	**2.8**

Maximum difference.

Lat	9.8 mm	Session 4
Long	4.1 mm	Session 1
Vert	10.5 mm	Session 1

Minimal difference.

Lat	5.6 mm	Session 1
Long	1.0 mm	Session 3
Vert	1.9 mm	Session 2

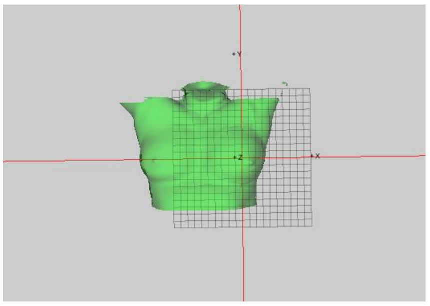


Figure 40. Reference image of patient number nine.

Table 59. Deviation of the patient by the Catalyst system and the OBI system. *Lateral direction.*

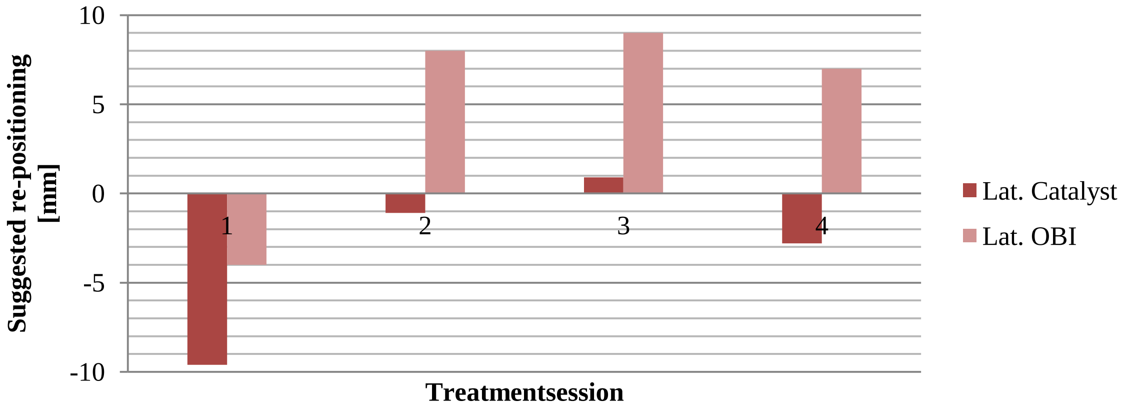


Table 60. Deviation of the patient by the Catalyst system and the OBI system. *Longitudinal direction.*

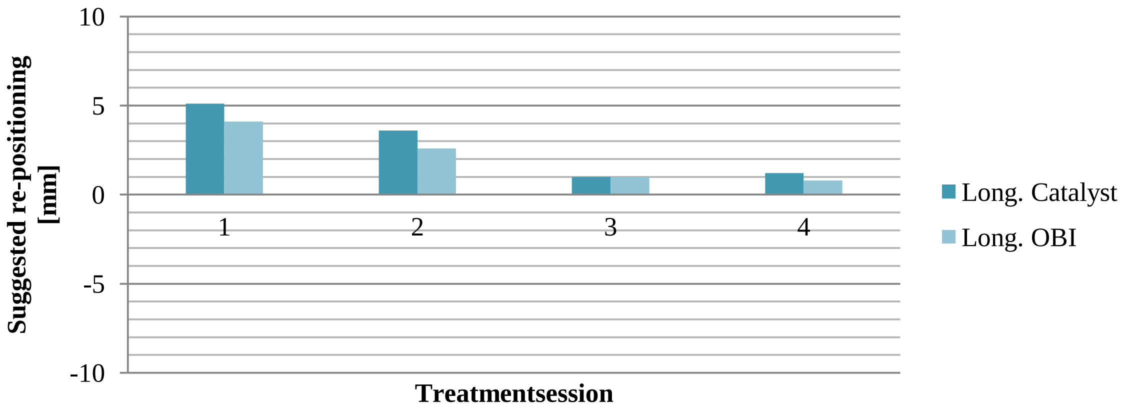
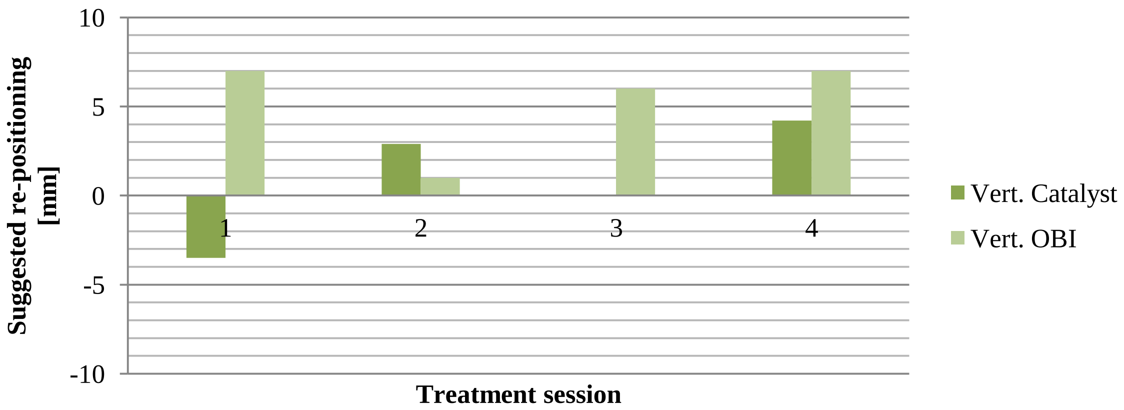


Table 61. Deviation of the patient by the Catalyst system and the OBI system. *Vertical direction.*



Comments.

<u>Live and reference image from Session 1-4:</u>

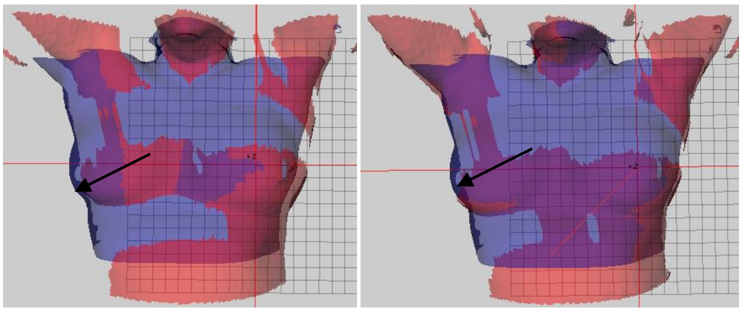
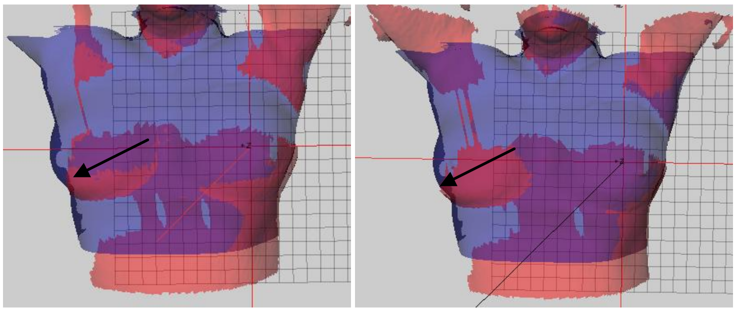


Figure 40 a) Session 1 **b)** Session 2



c) Session 3 **d)** Session 4.

The OBI-system shows that there is no good positioning in any of these cases in lateral direction (figure 40). This is visible on the Catalyst™ images as well, but the system does not respond with correct values in the analysis tool. Only in the images from session one the Catalyst™ system detects the disposition in the lateral direction. In the fourth session the Catalyst™ system even suggest a re-positioning of the patient in the opposite direction to the OBI system. It is noticeable that the Catalyst™ system sometimes has difficulty with finding the correct values in the lateral direction.

Patient nr 10.

Table 62. The Catalyst™ system correspondence with planar verification images on patients. *The results from the Catalyst™ system and the On-Board Imaging ® (Varian®) are presented. Only sessions with recorded data are shown in the table. The suggested deviation in position from the reference images are presented in millimeter, together with the difference in the values presented by the two systems.*

	Deviation [mm]						**Difference in positioning result [mm]**		
	The Catalyst system $\mu_{(CT\ StructureSet-SetUp)}$			**OBI-system** $\mu_{(DRR-SetUp)}$					
Session	*lat*	*long*	*vert*	*lat*	*long*	*vert*	*lat*	*long*	*vert*
1	-3.7	0	-5.8	-4	2	-2	**0.3**	**2**	**3.8**
2	-4.6	2	-2.9	-5	3	4	**0.4**	**1**	**6.9**
3	1.3	1.5	-5.1	0	3	4	**1.3**	**1.5**	**9.1**
4	-3.9	0.7	-10.6	-6	3	-1	**2.1**	**2.3**	**9.6**

Maximum difference.

Lat	2.1 mm	Session 4
Long	2.3 mm	Session 4
Vert	9.6 mm	Session 4

Minimal difference.

Lat	0.3 mm	Session 1
Long	1.0 mm	Session 2
Vert	3.8 mm	Session 1

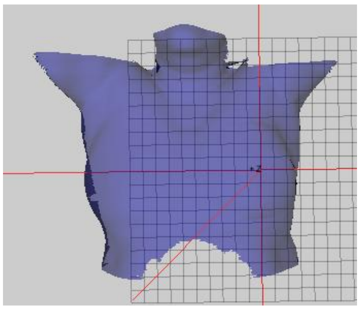


Figure 41. Reference image of patient number ten.

Table 63. Deviation of the patient by the Catalyst system and the OBI system. *Lateral direction.*

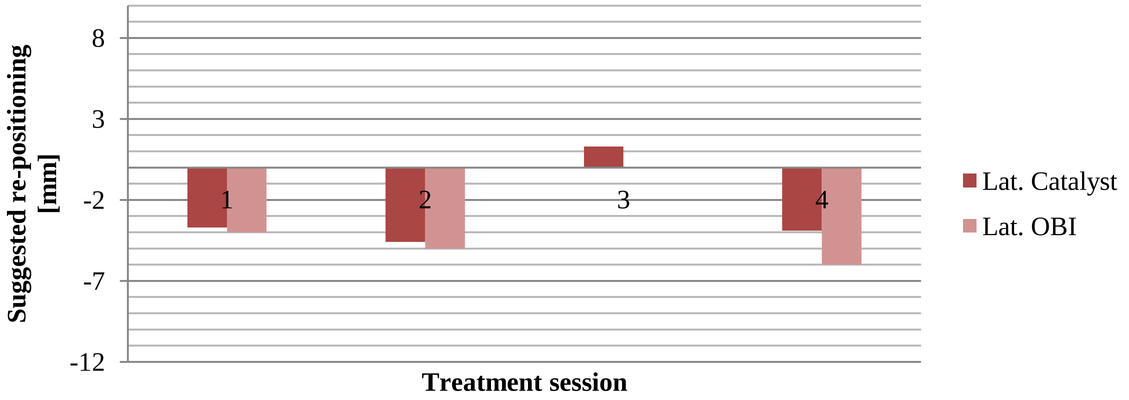


Table 64. Deviation of the patient by the Catalyst system and the OBI system. *Longitudinal direction.*

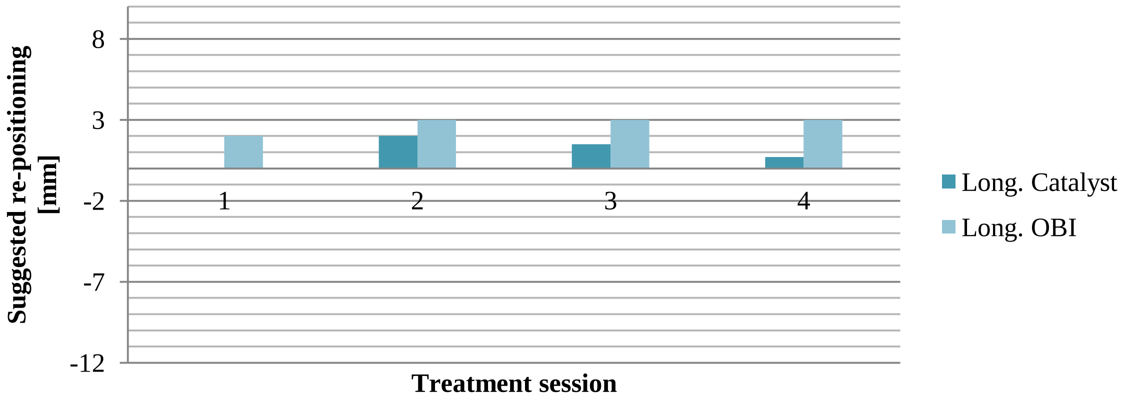
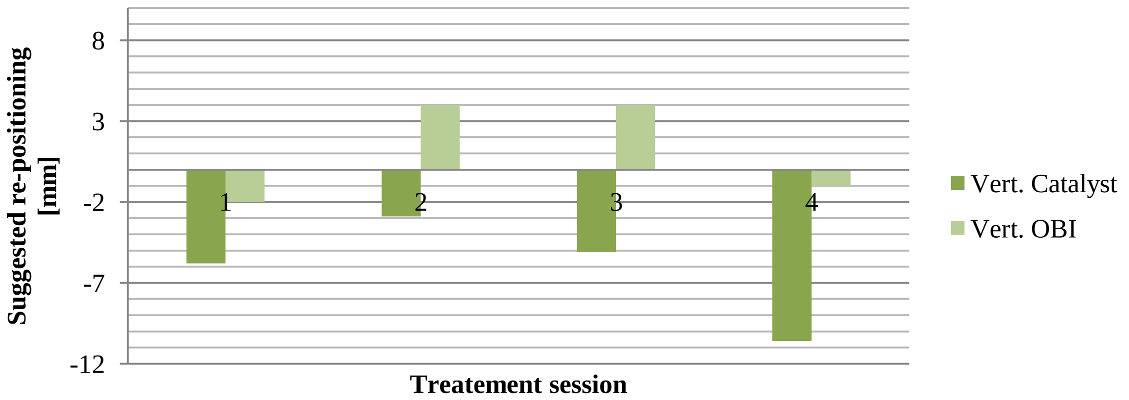


Table 65. Deviation of the patient by the Catalyst system and the OBI system. *Vertical direction.*



Comments.

Live and reference image, Session 4:

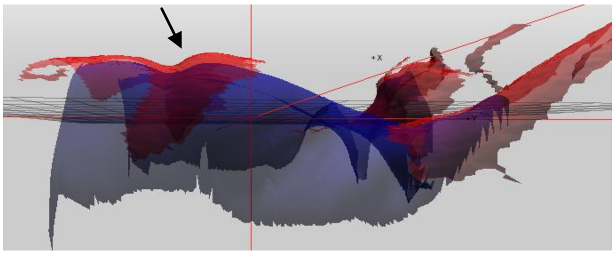


Figure 41a.

By visually looking at the images it is obvious that the surface of the live image is higher up than the reference image (figure 41a). The Catalyst™ system suggests a re-placement of the patient of -10.1 mm in the vertical direction, while the OBI system suggests -1 mm. The large difference between the two systems in the vertical direction could have been caused by breathing. In this software version of the Catalyst™ system there was no high precision recording during movements. In this case the live image might have been captured during an unfortunate part of the breathing cycle. This is not a problem while using the system in a clinical situation, since it is constantly updating the position.

Live image from Session 5 (not included in the result):

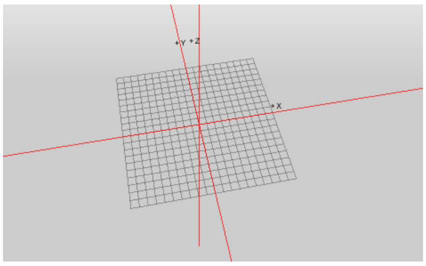


Figure 41b.

Live image is registered in the system, but there is no image when opening the live image in the Analysis tool.

Patient nr 11.

Table 66. The Catalyst™ system correspondence with planar verification images on patients. *The results from the Catalyst™ system and the On-Board Imaging ® (Varian®) are presented. Only sessions with recorded data are shown in the table. The suggested deviation in position from the reference images are presented in millimeters, together with the difference in the values presented by the two systems.*

	Deviation [mm]						Difference in positioning result [mm]		
	The Catalyst system $\mu_{(CT\ StructureSet-SetUp)}$			OBI-system $\mu_{(DRR-SetUp)}$					
Session	*lat*	*long*	*vert*	*lat*	*long*	*vert*	*lat*	*long*	*vert*
1	-8.5	6.6	-9.9	-16	2	9	**7.5**	**4.6**	**18.9**
2	-4.4	-3.6	-3.3	-2	3	6	**2.4**	**6.6**	**9.3**
3	2.7	0.5	-6.7	-9	8	3	**11.7**	**7.5**	**9.7**
4	-7.5	-3.1	-10.4	-1	2	4	**6.5**	**5.1**	**14.4**
5	4.1	-3	-2.7	-17	5	6	**21.1**	**8**	**8.7**
6	-3.2	-6.4	-9.2	-15	-2	5	**11.8**	**4.4**	**14.2**
7	-2.2	-0.5	-2.7	-13	4	7	**10.8**	**4.5**	**9.7**

Maximum difference.

Lat	21.1 mm	Session 5
Long	8.0 mm	Session 5
Vert	18.9 mm	Session 1

Minimal difference.

Lat	2.4 mm	Session 2
Long	4.4 mm	Session 6
Vert	8.7 mm	Session 5

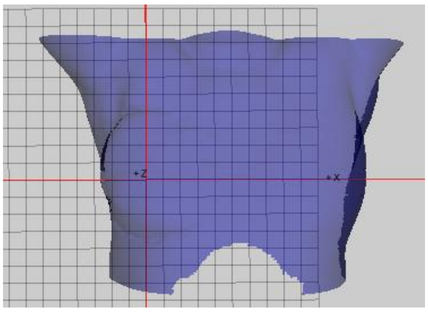


Figure 42. Reference image of patient number eleven.

Table 67. **Deviation of the patient by the Catalyst system and the OBI system.** *Lateral direction.*

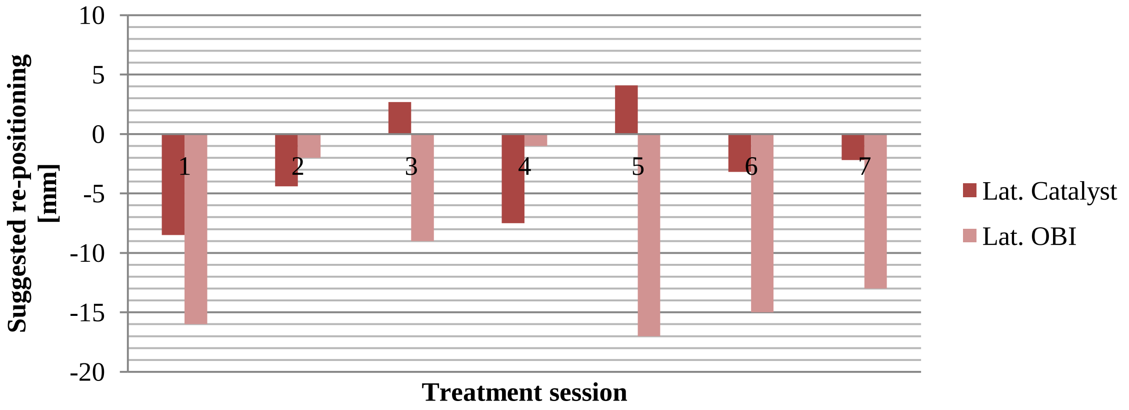


Table 68. **Deviation of the patient by the Catalyst system and the OBI system.** *Longitudinal direction.*

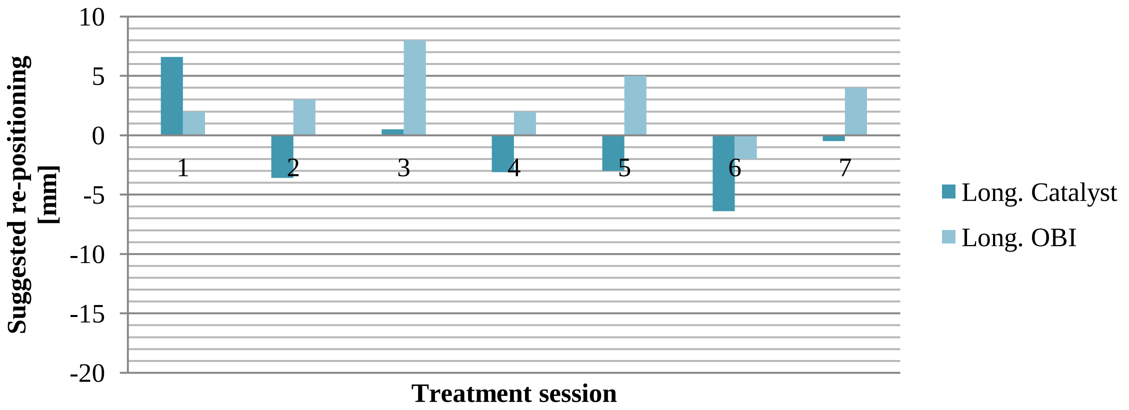
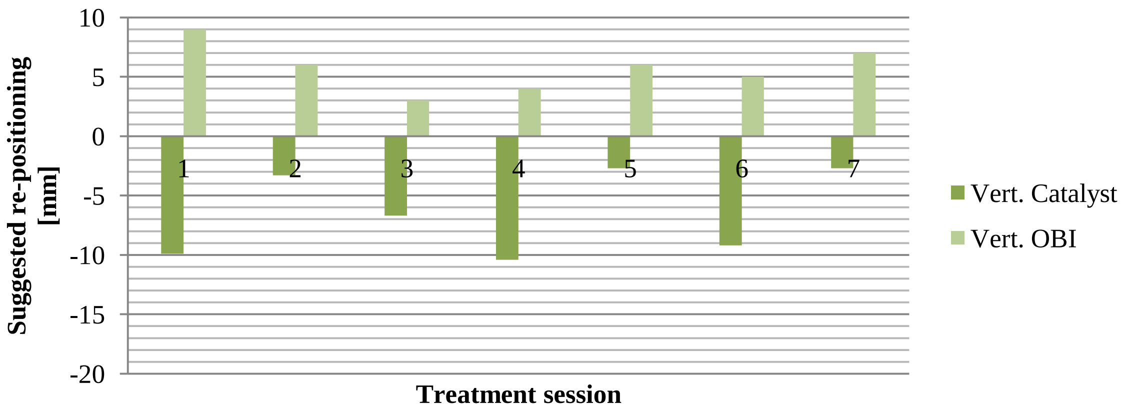


Table 69. **Deviation of the patient by the Catalyst system and the OBI system.** *Vertical direction.*



Comments.

Live and reference image, Session 1:

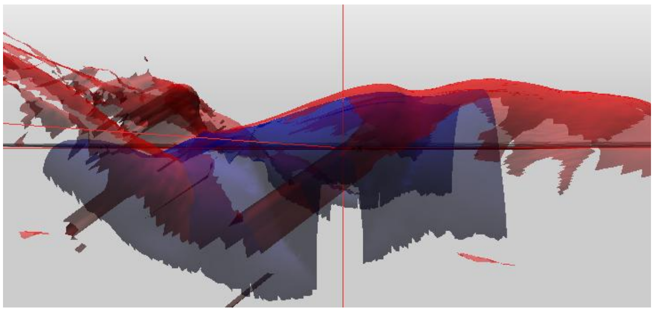


Figure 42a.

The Catalyst™ suggest that the patient should be moved -9.9 mm in the vertical direction to be in correct position. This is visible in the live image (figure 42a). The OBI system suggests a movement of + 9.0 mm. This would be in the wrong direction according to the images from the Catalyst system. The difference between the two systems seems to be too large to be caused by breathing only. Another possibility is that the patient moved in the time span between the imaging done by the OBI system and the imaging done by the Catalyst™ system. However, the staff was placing diodes on the patient for measurement during the treatment session and probably would have seen any movement of this magnitude.

Another possible explanation is that the Catalyst system has difficulties to find the correct position in the lateral direction for the patient and therefore the values in the vertical direction do not correspond well enough with the OBI system.

Live and reference image, Session 5:

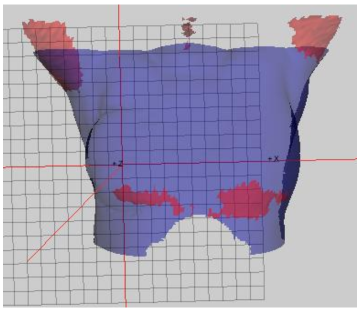


Figure 42b.

In this live image there is almost no data collected (figure 42b). The reason for this is that the template had been changed (2400 µs/400%), for unknown reasons, and therefore the camera settings are not set optimal. There is not enough data in this image for the system to calculate a true positioning result.

Patient nr 12.

Table 70. The Catalyst™ system correspondence with planar verification images on patients. *The results from the Catalyst™ system and the On-Board Imaging ® (Varian®) are presented. Only sessions with recorded data are shown in the table. The suggested deviation in position from the reference images are presented in millimeter, together with the difference in the values presented by the two systems.*

	Deviation [mm]						**Difference in positioning result [mm]**		
	The Catalyst system $\mu_{(CT\ StructureSet-SetUp)}$			**OBI-system** $\mu_{(DRR-SetUp)}$					
Session	*lat*	*long*	*vert*	*lat*	*long*	*vert*	*lat*	*long*	*vert*
1	-0.4	1.4	-4.1	-3	1	3	**2.6**	**0.4**	**7.1**
2	-0.3	1.4	-4.9	-2	-1	2	**1.7**	**2.4**	**6.9**
3	-1.6	0.7	-0.4	-2	0	4	**0.4**	**0.7**	**4.4**
4	-2.3	-1.1	-2.6	-5	-3	-2	**2.7**	**1.9**	**0.6**
5	-2.3	-1.1	-2.6	-1	-3	-1	**1.3**	**1.9**	**1.6**
6	-3.1	3.6	-7.2	-5	-5	-1	**1.9**	**8.6**	**6.2**

Maximum difference.

Lat	2.6 mm	Session 1
Long	8.6 mm	Session 6
Vert	7.1 mm	Session 1

Minimal difference.

Lat	0.4 mm	Session 3
Long	0.4 mm	Session 1
Vert	0.6 mm	Session 4

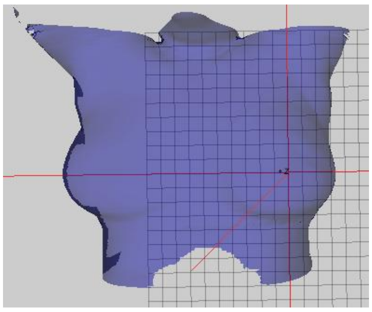


Figure 43. Reference image of patient number twelve.

Table 71. Deviation of the patient by the Catalyst system and the OBI system. *Lateral direction.*

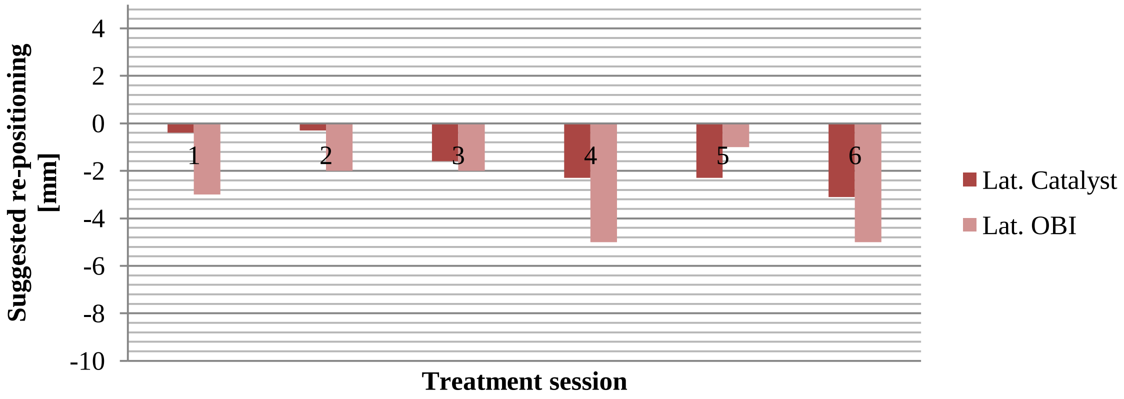


Table 72. Deviation of the patient by the Catalyst system and the OBI system. *Longitudinal direction..*

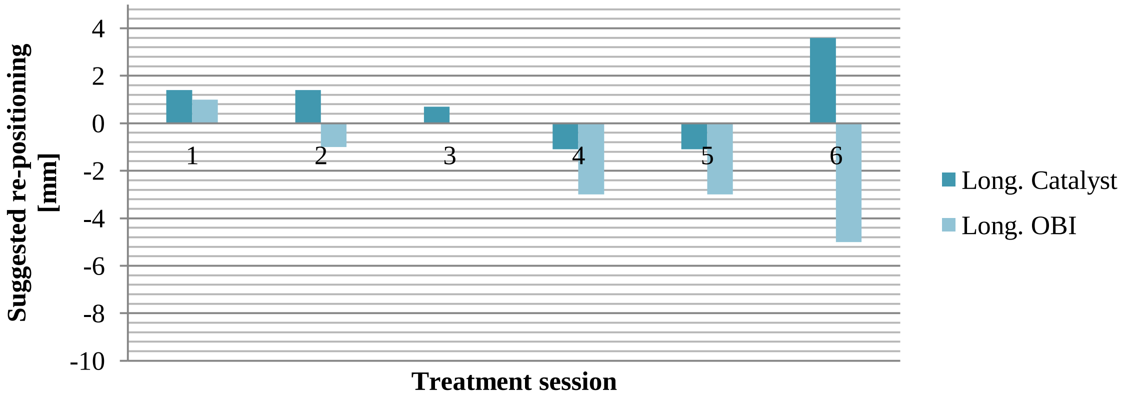
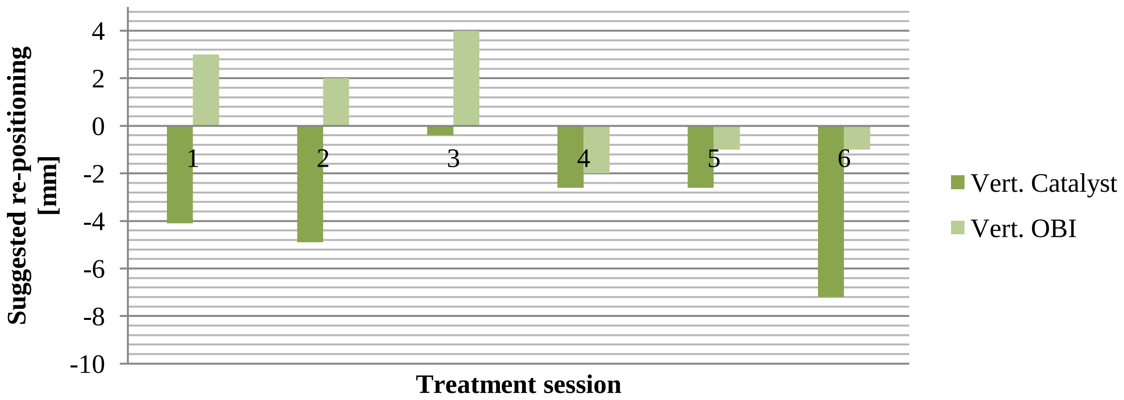


Table 73. Deviation of the patient by the Catalyst system and the OBI system. *Vertical direction.*



Comments.

<u>Live and reference image, Session 1:</u>

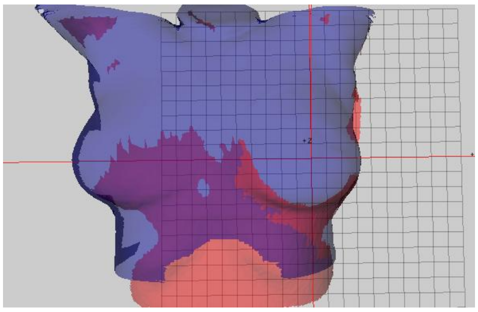


Figure 43a.

Not enough data above the iso-point for a high precision result in the positioning (figure 43 a). This is caused by a change in the integration time to only 2400 µs and the gain factor set to 400%. This is not the optimal settings for capturing a high quality live image. The settings were changed to the correct values for the rest of the treatments.

<u>Live and reference image, Session 6:</u>

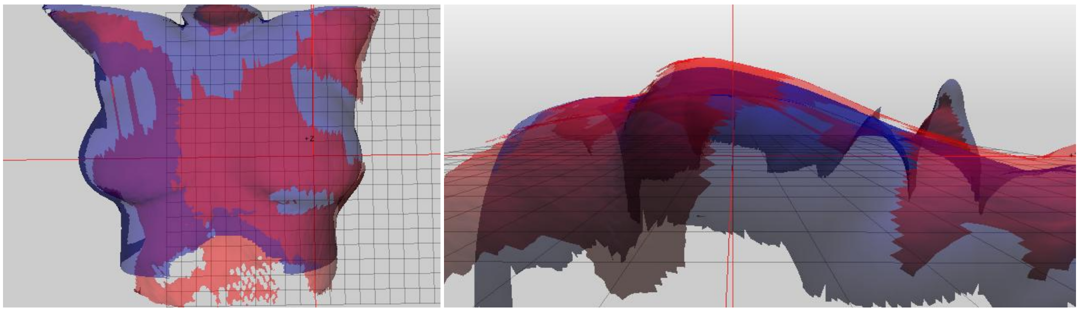


Figure 43 b and c.

The Catalyst^{TM} system suggests a re-positioning of 3.6 mm in the longitudinal direction and the OBI system suggests a re-positioning of -5.0 mm. It is difficult when viewing the Catalyst^{TM} systems images to be able to see if the longitudinal position should be moved in negative or positive direction (figure 43 b and c).

Patient nr 13.

Table 74. The Catalyst™ system correspondence with planar verification images on patients. *The results from the Catalyst™ system and the On-Board Imaging ® (Varian®) are presented. Only sessions with recorded data are shown in the table. The suggested deviation in position from the reference images are presented in millimeter, together with the difference in the values presented by the two systems.*

	Deviation [mm]						**Difference in positioning result [mm]**		
	The Catalyst system $\mu_{(CT\ StructureSet-SetUp)}$			**OBI-system** $\mu_{(DRR-SetUp)}$					
Session	*lat*	*long*	*vert*	*lat*	*long*	*vert*	*lat*	*long*	*vert*
1	3.4	-4.9	3.1	-2	-4	2	**5.4**	**0.9**	**1.1**
2	2	4	1.8	-11	3	1	**13**	**1**	**0.8**
3	0.5	-6.9	2	-6	8	1	**6.5**	**14.9**	**1**
4	2.9	4.7	3.8	-9	7	2	**11.9**	**2.3**	**1.8**
5	3.7	2.3	5.5	-12	-8	4	**15.7**	**10.3**	**1.5**
6	2.4	-4.3	1.6	-1	-1	0	**3.4**	**3.3**	**1.6**

Maximum difference.

Lat	15.7 mm	Session 5
Long	14.9 mm	Session 3
Vert	1.8 mm	Session 4

Minimal difference.

Lat	3.4 mm	Session 6
Long	0.9 mm	Session 1
Vert	0.8 mm	Session 2

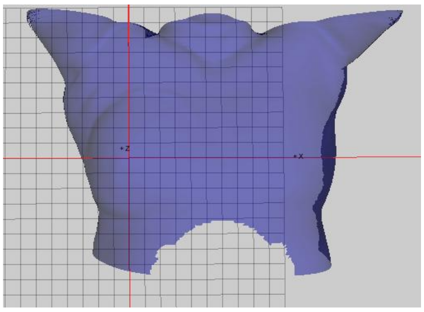


Figure 44. Reference image of patient number thirteen.

Table 75. Deviation of the patient by the Catalyst system and the OBI system. *Lateral direction.*

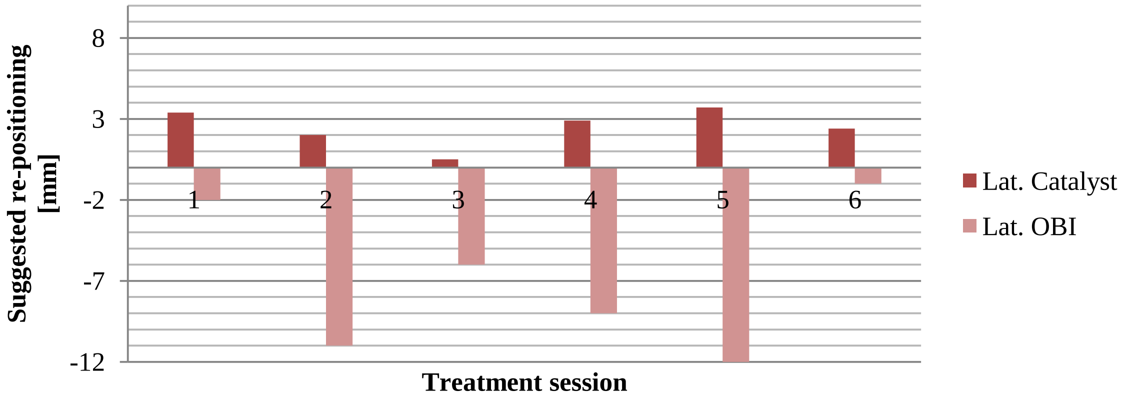


Table 76. Deviation of the patient by the Catalyst system and the OBI system. *Longitudinal direction.*

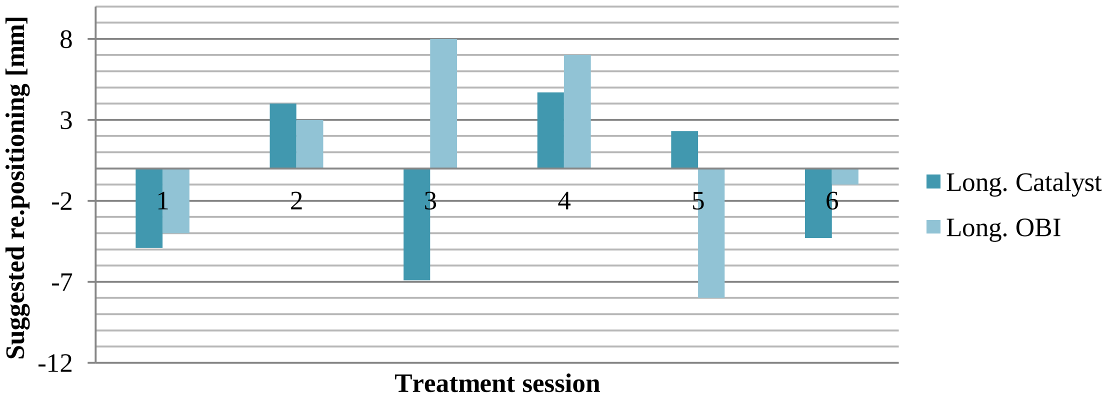
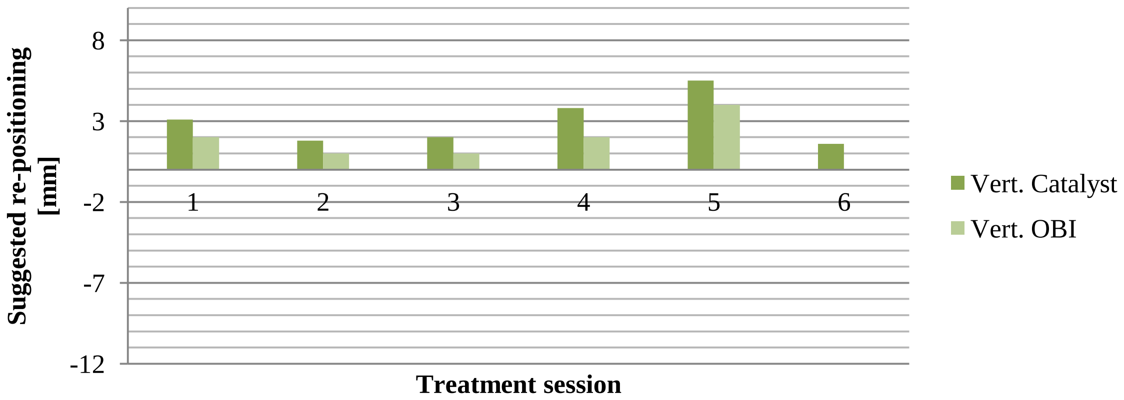


Table 77. Deviation of the patient by the Catalyst system and the OBI system. *Vertical direction.*



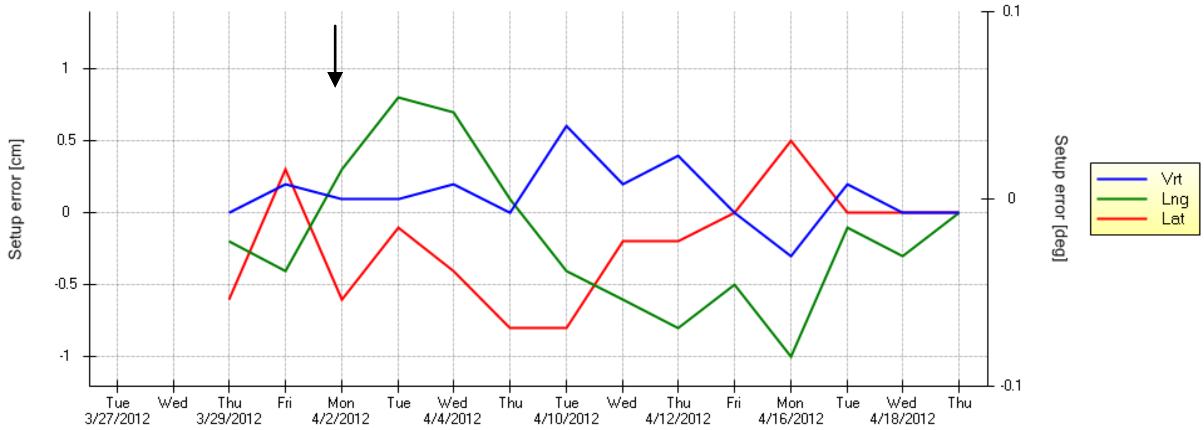
Comments.

This patient had to have an online movement performed during the thirteen first treatment sessions out of the sixteen treatment sessions total. The fact that online movement had to be performed in 80% of all the treatment sessions implies that the positioning of the patient was difficult. The positioning results from the Catalyst™ system included in Table 74 are only the values collected before any online movement was performed.

The results from the OBI-matching are shown in Table 78.

Table 78. Online OBI Match Results. *Difference of final online matched position and initial couch position in. Only treatment sessions with performed online movement are shown in the table. In this patient case it includes the first thirteen sessions.*

Session 2



The curves for the longitudinal and the lateral direction show great deviations through the course of treatment. It is also in those two directions the Catalyst™ and the OBI system does not correspond with each other (see Table 75 and Table 76).

Obviously there is a problem with the patient set-up through the course of treatment. The nurses are positioning the patient according to the tattoos' and still the OBI system shows that the positioning is not correct.

A presentation of the Catalyst™ images:

<u>Live and reference image, Session 2:</u>

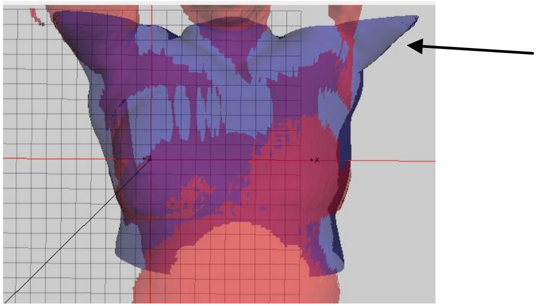


Figure 44a.

The patients left arm is not in the correct position according to the live image (figure 44a).

Live and reference image, Session 3:

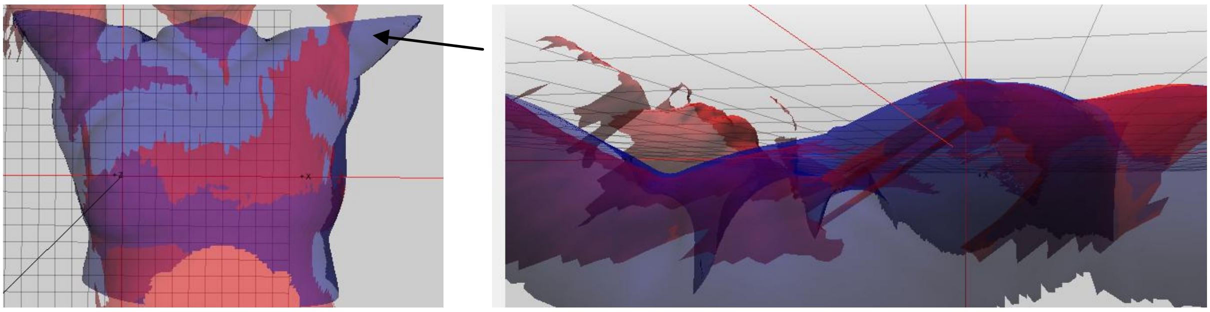


Figure 44 b and c.

The two systems differ in the deviation in the longitudinal direction. The displacement seems to arise from the fact that the left arm is not in the correct position and that the whole right side of the body is affected by this displacement (figure 44 b and c). Because of this fact the right side of the body was cropped in the reference image and a new position analysis were performed (figure 44 d). The result showed a suggested re-placement of -8.8 millimeters in longitudinal direction, not closer to the deviation result from the OBI system. By visually studying the images from the Catalyst system one can see that the suggested re-placement should be a negative value. The OBI system suggests a re-positioning of +8 millimeters. This would put the patient even further away from the reference set-up according to the Catalyst™ imaging system. Positioning the patient with help of the Catalyst system's color map on the patient might have helped the arm positioning and improved the position result with the kV images.

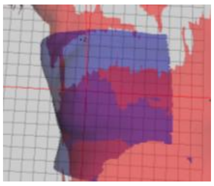


Figure 44d. *Test with new cropped reference image.*

Live and reference image, Session 4:

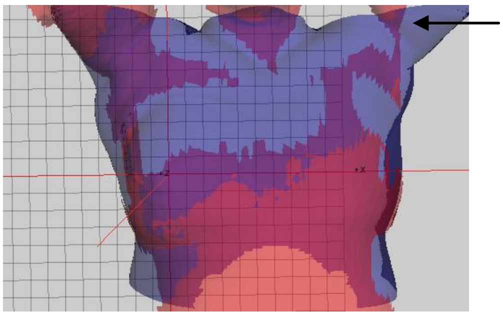


Figure 44e.

The patients left arm is not in the correct position according to the live image (figure 44e).

Live and reference image, Session 5:

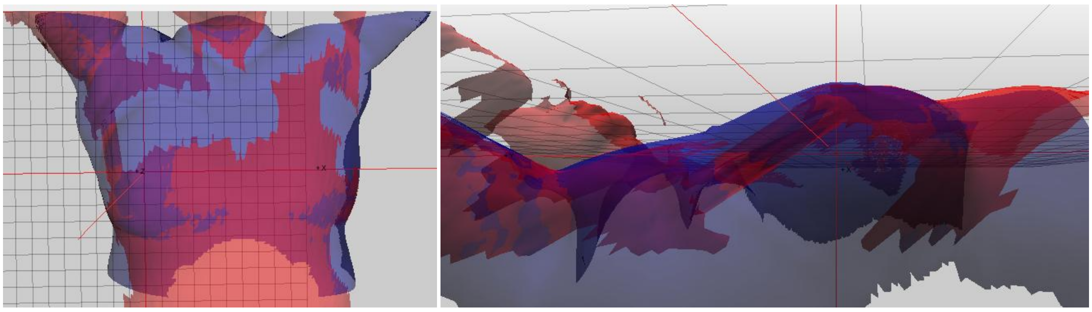


Figure 44 f and g.

The OBI system suggests a re-positioning of -12 millimeters in the lateral direction and -8 millimeters in the longitudinal direction. By visually observing the images from The Catalyst system's 'Analysis tool' there is no such significant displacement (figure 44 f and g). From the images it is visible that there is a displacement in the vertical direction, which both the systems suggest.

Conclusion:

In general the patients left arm is not in the correct position through the course of treatment and could be a factor that contributes to error in the positioning result. From visually judging the images there is no significant difference between the reference image and the live image, which implies that the positioning result from the OBI system gets more affected by the misplaced arm. This is an assumption that needs further investigation. The color map projected on the patient's skin surface is recommended to be used more frequently for correct position set-up.

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