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# A comparison of surface based and laser based setup for rectal cancer patients in radiotherapy


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Supervision

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Popularized summary in Swedish:

# Kan ytscanning användas för att förbättra positioneringen i strålterapi för patienter med rektalcancer

60 00 cancerfall rapporteras in varje år till socialstyrelsen men där numera fler än hälften botas. Detta eftersom vi blir skickligare inom området och nya behandlingstekniker utvecklas. Rektalcancer, även kallat ändtarmscancer är en cancerform som ökat under de senaste decennierna. Behandling av patienter med rektalcancer varierar beroende på var och i vilket stadie tumören befinner sig i. Oftast är behandlingen en kombination av kirurgi och strålbehandling, där strålbehandlingen ges pre-operativt. Vid preoperativ behandling genomgår patienten först strålbehandling under fem dagar eller fem veckor och opereras därefter. Patienter med mer lokalt avancerade tumörer får genomgå den långa behandlingen då det krävs att en skrumpning av tumören sker innan kirurgi.

Vid strålbehandling krävs det hög noggrannhet, precision och reproducerbarhet för att kunna leverera en hög stråldos till tumören men samtidigt skona så mycket som möjligt av den omgivande friska vävnaden. Ett problem som dyker upp då vi försöker uppnå detta är positioneringen av patienter då det krävs att patienten positioneras på samma sätt under alla fraktioner. Den konventionella positioneringen utförs idag med hjälp av hudmarkeringar och lasrar i behandlingsrummet. Då hudmarkeringarna och lasrarna sammanfaller antas patienten ligga i den korrekta behandlingspositionen. För att verifieras detta tas skiktröntgenbilder och en korrigering görs eventuellt därefter av patient positionen så att stråldosen levereras till rätt område. Dock vid röntgen erhåller patienten en extra stråldos vilket bör reduceras så mycket så möjligt. Därför tas skiktröntgenbilder istället utifrån ett protokoll och inte vartenda behandlings-fraktion. Under de fraktioner då ingen bildtagning utför används hudmarkeringar och lasrarna i behandlingsrummet för att positionera patienten. Det är därför av intresse att utforska nya tekniker som bidrar med bättre positionering för de fraktionerna utan biltagning.

Det har under de senaste åren utvecklats positioneringssystem som är snabba, icke-invasiva och viktigast av allt inte bidrar med någon extra stråldos. Exempel på sådana system är Catalyst$^{TM}$ och Sentinel tillverkade av företaget C-RAD (C-RAD positioning AB, Uppsala, Sweden). Catalyst$^{TM}$ finns idag installerat i alla behandlingsrum på Skånes universitetssjukhus (SUS) och används i dagsläget bland annat vid bröstrelaterade diagnoser men är även av intresse att användas vid andra diagnoser för att förbättra positioneringen. Syftet med detta examensarbete var att undersöka om positioneringen av patienter med rektalcancer som genomgår den korta behandlingen kan förbättras med hjälp av positionerings- och övervakningssystemet Catalyst$^{TM}$.

# Abstract

***Purpose:*** **The** Catalyst ™ is a non-ionizing and non-invasive optical scanning system that has attractive features for patient setup and monitoring, as well as for respiratory gating during, radiotherapy treatments. In this study, the conventional laser based setup was compared with the surface based setup by the Catalyst™. A new non-rigid algorithm was used taking the whole planning target volume (PTV) into account, instead of only isocenter while calculating the optimal match of the surfaces. The effects of the match result, due to various size of the reference surface as well as the setup using different camera systems, were also investigated.

***Material and Methods:*** The surface based setup technique using the Catalyst™ was evaluated by comparing the cone beam computed tomography (CBCT) match results from two groups of patients; 1) CBCT-match after conventional laser based setup and 2) CBCT-match after surface based setup. In total 37 rectal cancer patients including 84 setup verifications were compared from the different setup techniques retrospectively. The difference between the result from single and three camera system was evaluated. Additionally, the impact on setup using different cropped reference surfaces was also investigated by comparing; 1) the reference surface used for patient positioning by the Catalyst™ (original reference surface) and 2) a reference excluding a larger part of the surface above the stomach (cropped reference surface) than in 1).

***Results:*** For setup by the conventional laser based technique, 20%, 10% and 29% in lateral, longitudinal and vertical respectively of all sessions were positioned outside the 4mm tolerance. For surface based setup by the Catalyst™, the number of sessions that were positioned outside the 4mm tolerance were instead 5%, 16% and 23%. The positioning accuracy for the Catalyst™ system in absolute median (95% CI) was 1.3cm (0.7–2.2cm), 2.3cm (1.2–4.0cm) and 2.2cm (1.1–4.5cm) in lateral, longitudinal and vertical direction, respectively compared with 2.0cm (1.0–3.0cm), 2.0cm (1.0–2.0cm) and 2.0cm (1.0–5.0cm) for the laser based setup. A significant different was only observed in the lateral direction. For the comparison between single and three camera systems, a significant improvement was observed for the three camera system when comparing the median of deviation vector's absolute values. For the comparison between single and three camera systems, a significant improvement was observed for the three camera system when comparing the median of deviation vector's absolute values. No significant improvement was observed for the cropped reference surface compared to the original reference surface.

***Conclusions:*** The optical surface scanning system Catalyst™ with the novel non-rigid PTV-based algorithm can be used to improve the setup in lateral direction for rectal cancer patients. For the two remaining directions, i.e. longitudinally and vertically, this study show no difference in performance of either surface or laser based setup. However, a significant improvement was observed when comparing the setup performed by a single and three camera system, in favor for the latter. When comparing the cropped reference surface with the original no significant improvement was observed.

# Abbreviations

| | |
|---|---|
| CBCT | Cone Beam Computed Tomography |
| CT | Computed Tomography |
| ALARA | As Low As Reasonably Achievable |
| PTV | Planning Target Volume |
| TPS | Treatment Planning System |

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# 1. Introduction

Over 60 000 cancer diagnosis per year are reported to the health authorities in Sweden [1]. Nowadays more than half of all cancer patients are cured thanks to improved knowledge in the field, and the continuous development of treatment techniques [2]. One cancer type that has increased during the last decades is rectal cancer. This cancer type is usually treated with a combination of surgery and radiotherapy or surgery and chemotherapy. The choice of treatment depends on tumour location and stage. The radiotherapy treatment can be both post- or preoperative. Preoperative treatment is when the patients undergoes 5 or 28 treatment sessions of radiotherapy and thereafter a surgery. The patients receiving 28 fractions are the one with an advanced tumor where it is necessary to shrink the tumor before surgery [3].

Radiotherapy requires a high degree of accuracy, precision and reproducibility to deliver a high dose to the tumor while sparing the surrounding healthy tissue. Three structures are delineated for the treatment planning; gross tumor volume (GTV), clinical target volume (CTV) and planning target volume (PTV). The GTV is the volume that includes the visible, palpable or demonstrable extent of the tumor. The CTV structure is known as GTV with added margins for sub-clinical disease spread. To consider variations in tissue position, size and shape, as well as for variations in patient and beam position, intrafractionally and interfractionally, the CTV is delineated with added margins, these margins create the PTV structure [4]. One problem that arises in radiotherapy is the reproducibility of patient positioning.

At present, the rectal cancer patients treated at the radiotherapy department at Skåne University hospital (SUS) in Lund are positioned using the conventional laser based setup. This means that the patients are aligned in accordance with the skin markers and lasers in the treatment room. To verify the patient position, image guidance such as cone beam computed tomography (CBCT) is used to correlate the position of the patient to the reference images, that is the computed tomography (CT) scan performed during the immobilization [5]. The CBCT provide good information about the internal anatomical structures but has the disadvantage that ionizing radiation is used. Due to the ALARA (As Low As Low As Reasonably Achievable) principle, the radiation dose should be reduced as much as possible, but at the same time achieve the purpose with the irradiation [6]. An image verification protocol is therefore used for patient positioning. At those sessions where no CBCT-images is used, the patient is positioned using the laser based setup.

Therefore there is an interest in investigating new techniques for improving the positioning at those sessions where no verification image is used. One of these positioning systems is the Catalyst$^{TM}$ provided by C-RAD (C-RAD positioning AB, Uppsala, Sweden). The Catalyst$^{TM}$ is an optical surface scanning system that uses a non-rigid algorithm. At SUS it has been shown an improvement of the setup when using the Catalyst$^{TM}$ in comparison with conventional laser based setup since decreasing deviations were observed for breast related diagnosis by Kügele *et al.* [7].

Another optical surface scanning system, also provided by C-RAD is the Sentinel. The Sentinel uses a rigid algorithm and was investigated by Wikström *et al.* [8] for setup of pelvic targets. The aim of that study was to compare the setup displacement derived from the Sentinel and CBCT to quantify the applicability and accuracy of the system.

The study showed that the mean difference between the two techniques were $0.13\ (\pm 0.23)$ cm, $0.08\ (\pm 0.35)$ cm and $0.20\ (\pm 0.36)$ cm in the lateral, longitudinal and vertical directions, respectively. The study showed that the Sentinel can be used as a complement for conventional imaging techniques such as CBCT when it is not deemed necessary [8].

A difference between the two optical surface scanning systems is the matching algorithm. Sentinel uses a rigid algorithm while matching the live surface of the patient on the treatment couch to the reference surface obtained by CT. However, the Catalyst$^{TM}$ system uses a non-rigid matching algorithm, i.e. different areas of the surface affect the online calculated isocenter position differently. The surface closer to the calculated isocenter affect its position in a larger extent than the surface areas further away. Another difference is that the Catalyst$^{TM}$ project a light onto the skin of the patient to guide the radiotherapist to setup the patient correctly. Red light is projected to the surface were the live surface is positioned higher in the treatment room compared to the reference surface, and green light when the live surface is positioned lower.

Studies have shown good results for setup using the Catalyst$^{TM}$ for different treatment regions. Conclusions have been drawn that it allows a reduction in frequent use of CBCT for fixed tumors in relation to the surface and can be used as an complement for conventional imaging techniques [5][9].

However, a novel algorithm for Catalyst$^{TM}$ has recently been introduced which carries out surface match results based on the differences of the online calculated and planned PTV mass weighted points, instead of the online calculated and planned isocenters. An investigation of the setup accuracy, using Catalyst$^{TM}$ with the novel match algorithm is of high interest, especially for patients with long target volumes.

# 2. Aim

The aim of this master thesis was to evaluate if setup routines for patients with rectal cancer could be improved by the new algorithm of the optical surface scanning system Catalyst$^{TM}$. A clinical patient study was performed, where the conventional laser based setup was compared with the surface based setup by the Catalyst$^{TM}$. The setup difference using single and three camera systems was investigated as well as the effects of the match result due to various size of the reference surface.

# 3. Theory

## 3.1 Patient positioning in the radiotherapy workflow

The immobilization of the patient is a crucial part in radiotherapy, since the treatment requires that the patient is positioned the same way throughout the treatment chain. If the positioning is not correctly executed, there is a risk that the radiation dose will be delivered outside the planned volume.

The treatment chain starts with a CT-scan which is the first step where the patient gets skin markings to mark the reference point and a fixation that will be used each session to position the patient the same way. It is important that the patient is in the same position throughout the whole treatment chain since the treatment plan will be based on the CT-scan. After the CT-scan the GTV, CTV and PTV will be defined by a radiation oncologist. Further, an individual treatment plan will be developed for each patient, based on the CT and delineated structures.

At the first treatment session, the fixation from the CT-scan will be used and the patient will be positioned in accordance with skin markers and lasers in the treatment room. To assure that the patient is at the correct position, image guidance, such as CBCT, is performed and compared with the previous CT-scan. If needed the patient position is corrected by moving the couch.

At SUS when the number of treatment sessions is more than five, the CBCT is usually used at the first three treatment sessions to determine if the patient is positioned correctly and then performed once a week to ensure that the patient is still in the same position. For treatments equal to or less than five sessions (≤5), such as the short rectal cancer treatments at SUS, the CBCT is usually just performed at the first session if no large deviations, exceeding the tolerances are observed [10].

## 3.2 The optical surface scanning system Catalyst™

The Catalyst™ system provided by C-RAD Positioning AB, is a surface scanning camera mounted in the ceiling in the treatment room. The camera system consists of two components; a projector using LED and a CCD-camera. The system provides guidance during set-up and movement monitoring during treatment by projecting a near-invisible light onto the surface of the patient and capturing the reflection by a CCD-camera [5]. By using a non-rigid body algorithm to calculate the isocenter displacement in combination with the optical triangulation method, a 3D surface can be reconstructed [11].

*Figure 1. The Catalyst™, three camera system in the treatment room*

The Catalyst™ can be used as a single camera system or as a three camera system. For the three camera system, the cameras are mounted on the ceiling separated with an angle of 120 degrees (Figure 1). The three camera system has thus the advantage to create 360 degree surface coverage of the body.

### 3.2.1 Technical specifications of the surface scanning system

The technical specifications [12] about physical dimensions, power, light projector, environment and performance are given below (Table 1).

*Table 1. Technical specifications of the Catalyst™ system* [12]

| **Physical dimensions** | | **Environment** | |
|---|---|---|---|
| Size (*WxDxH*): | 620 mm x 280 mm x 400 mm | Operating temperature: | +10°C to +35°C (50°F to 95°F) |
| Weight: | 16 kg | **Performance** | |
| **Power** | | Scan volume (*XxYxZ*): | 800 mm x 1300 mm x 700 mm |
| Input voltage | 100-240 VAC | Measurement reproducibility: | 0.2 mm |
| Frequency: | 47-63 Hz | Long-term stability: | 0.3 mm |
| Power consumption: | 1.8 A | Scan speed: | Up to 80 3D-surfaces/s |
| **Light projection** | | Positioning accuracy: | 1 mm (rigid body) |
| Wavelengths: | 405 nm (near-invisible violet/blue), 528 nm (green), 624 nm (red) | Motion detection accuracy: | 1 mm (rigid body) |

### 3.2.2 Operating modes

When opening the Catalyst™ software system the program can be started up in *Advanced* or *Clinical mode*. The *Advanced mode* is the mode where the patient can be imported into the system, test patient can be added manually and data can be managed (Figure 2). When importing the patient into the Catalyst™ some parameters must be set, such as target tracking point, template and scan volume. There are different templates that can be chosen depending of the treatment region. In each template, the surface tolerances and target tolerances are pre-set.

To be able to use the system for positioning, monitoring and gating of patients, the mode should be switched to the *Clinical mode*. In this mode, there are three optional buttons (Figure 3). The first button is used to choose the patient. When the patient is chosen, the user can position and monitor the patient through the applications: cPosition, cMotion and cRespiration. The user is just able to continue in the direction of the yellow colored button and cannot skip any step i.e. cannot directly go to cMotion and skip the previous step, the cPosition ( Figure 4).

The second button in the starting window in *Clinical mode* is the daily check of the system which is performed daily to compensate for any drift in the hardware causing changes in the coordinate system. The third button is the one used to close this mode.

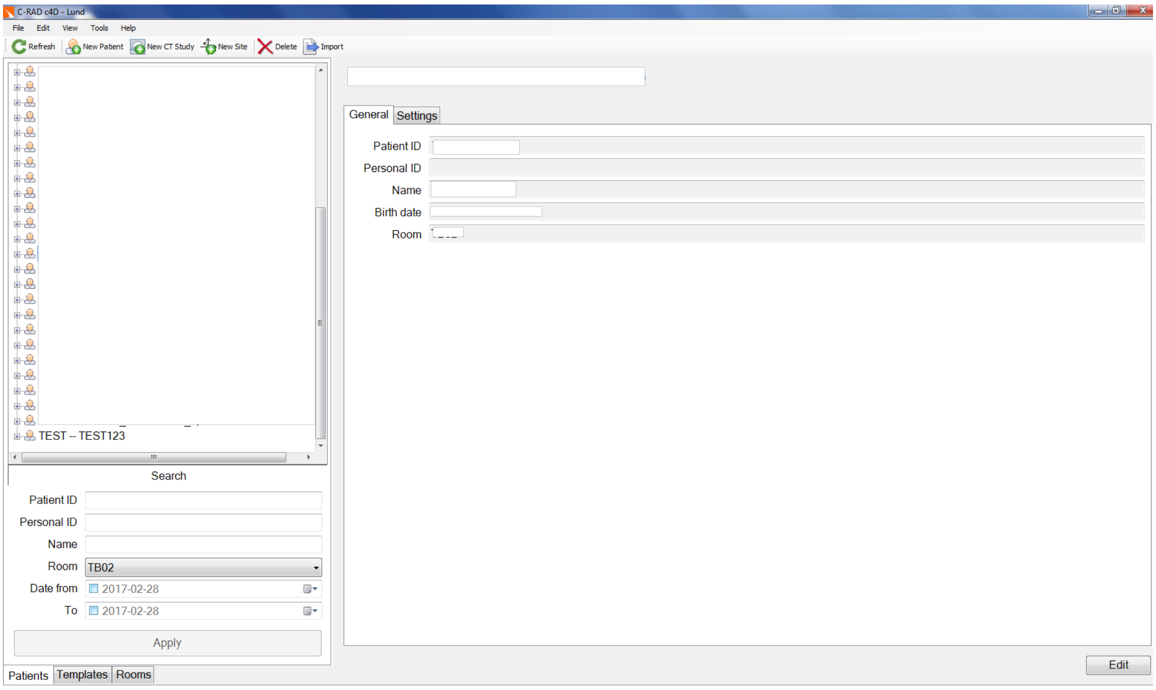


*Figure 2. The window in Advanced mode*


*Figure 3. The starting widow in Clinical mode*

*Figure 4. The bar with the cPosition, cMotion and cRespiration*

### 3.2.2.1 The optical surface scanning positioning application- cPosition

In this application, a comparison between a reference surface and a live surface is performed to be able to align the patient in the right treatment position. The reference surface can be created by importing the patient's surface structure from the treatment planning system (TPS). The patient's surface structure is created by the outer patient contour in the CT-scan performed at the immobilization. The reference surface can also be created by the Sentinel or directly by the Catalyst™ system, this means that one can create new reference surfaces with the patient on the treatment couch.

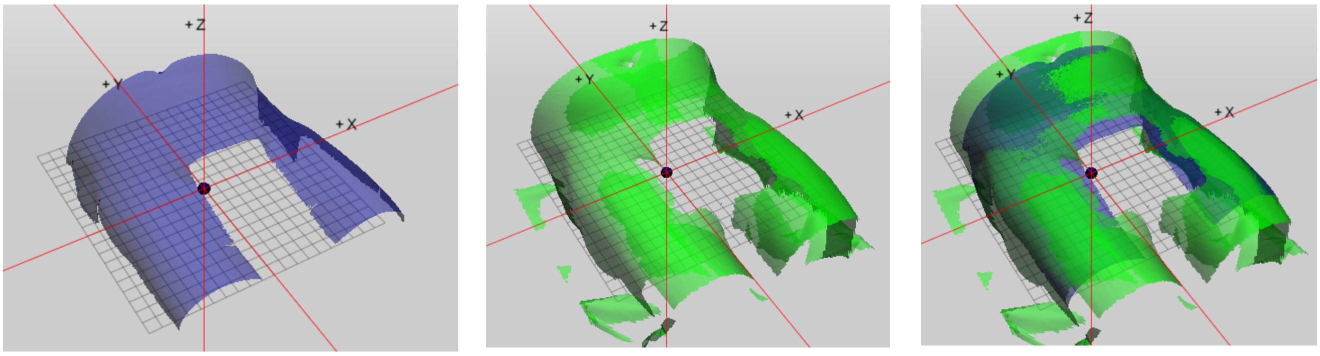


*Figure 5. a) Reference surface of the pelvic region* *b) Live surface of the pelvic region* *c) An overlay of the reference and live surface (a&b)*

Before starting the matching process the quality of the live surface should be optimized to obtain best possible surface coverage. This is performed by adjusting the camera parameters integrations time and gain. The integration time is defined as the time the system collects light reflections. By the parameter gain the saturation of the camera can be set. The time is often set individually for each patient since this parameter is dependent on the skin color of the patient.

When matching the reference and live surface (Figure 5), the Catalyst™ system suggest the adjustment needed in six degree of freedom to be done to get an agreement between the two surfaces to not exceed the pre-set surface tolerances in the template (Figure 6) [13]. A color map of the deviations is projected directly onto the patient surface and is seen on the monitor to guide the personnel how to move the patient into the correct position (Figure 7). The patient lays in the right position when no color shows on the patient's surface. The red color indicates that the area is higher in position in relation to the reference and the green color indicates the opposite i.e lower in position in relation to the reference. The color map has the advantage to make it easily to discover rotations in comparison to laser based setup.

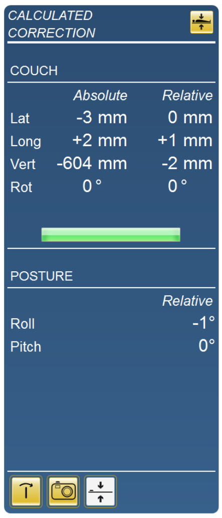


*Figure 6. The numbers displayed on the monitor*

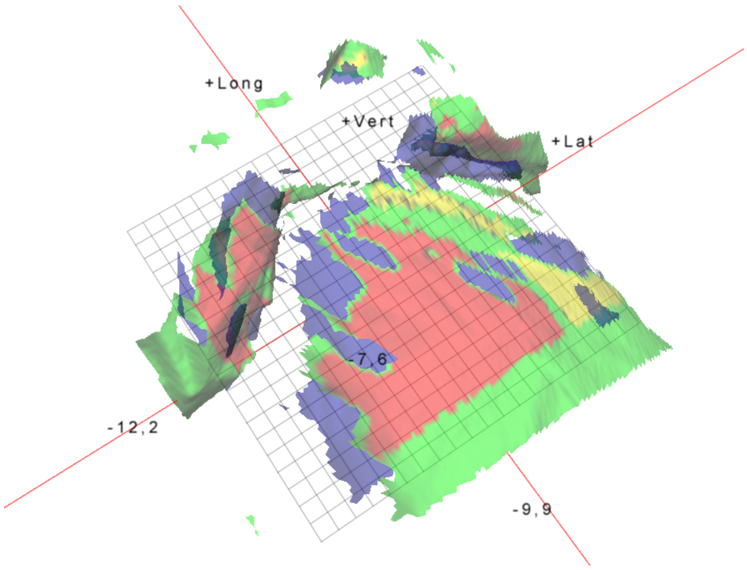


*Figure 7. Shows the color map on the monitor*

#### 3.2.2.2 The optical surface scanning patient motion monitoring application- cMotion

When the personnel have finished the positioning of the patient in cPosition, the next step is cMotion. This application is used to monitor the patient movements from outside the treatment room during the whole treatment session. When switching from cPosition to cMotion the last live surface will now become the reference surface just for today's treatment session. By the real-time surface, the system can calculate the deviation between the live surface isocenter and the reference surface isocenter. The deviation is presented as a curve, and if the patient's movement for any reason exceeds the set tolerances the personnel will directly be alerted by the system and the beam will be manually switched off. This safety interlock eliminates the necessity of visual monitoring for detecting small patient movements which may be hard.

#### 3.2.2.3 Data managing

The patient data can be managed in *Advanced mode* by using ''Analysis tool''. This tool gives the ability of analyzing the deviations between two surfaces in six degrees of freedom after treatment performance. A reference surface and a live surface (the surface after continuing to the cMoition from cPosition) can manually be chosen. The reference surface can here be cropped before analysis with the live surface which has the advantage to erase parts of the body such as artefacts that may affect the surface match result. The result of the analysis is presented in a table where the red numbers indicate that the result is outside the seated target tolerances and in black if they are within the tolerances.

### 3.2.3 Non-rigid algorithm

An object can be deformed while being scanned. The transformation that occurs might contain both a rigid part and a non- rigid part. In some cases, even new parts of the object might come into view when transforming. To handle this difficulty in the registration process, the Catalyst™ uses a non- rigid registration of the 3D-shaped object without the requirement of any external markers.

Two partial scans are registered by the system, the first one at the time of the reference scan and the second during the live scan. If the two scans representing the object coincide, the perfect patient position is obtained [11]. For the non-rigid object, the registration requires an estimation of how well the two scans correspond and a suitable warping function that match the deformation of the object. If the correspondence is false it can cause distortions that are not consistent with the object's deformation [14].

#### 3.2.3.1 Isocenter shift calculation

The process of the isocenter shift calculations can be divided in to two steps; 1) the reference surface and live image are aligned using a non-rigid registration algorithm, 2) to predict the influence on the live image, a volumetric deformable model obtained by the registration result is used. The aligning of the reference image to the live image by a non–rigid registration algorithm can be described by the following steps (Figure 8):

1. **Creating a deformable node graph**. Surface meshes of the reference image (source mesh) and the live image (target mesh) are created from the scans. A deformable graph node is then created which is a graph consisting of nodes with well-defined positions. The graph nodes of the deformation graph node are based on a re-sampling of the nodes of the reference scan. This core structure together with a non-linear optimization is used to determine the deformation of the scan. Two node graphs are used simultaneously by the system during the matching, one with smaller distances between the nodes and one with larger.

2. **Detecting corresponding point in the meshes.** Rigid and non-rigid deformations of the object might have been undergone between the captures. Parts may disappear and other overlap. The overlap will be subset of both scans. Overlapping regions between the meshes are identified and poor corresponding points are removed. Creating a global energy function, the sum of deformation node energy.

3. **Creating total energy function for optimization.** Global energy is used to assign the system. The global energy is the sum of deformation node energy. The energy of each defamation node is a combination of weighted parameters considering: distance to target surface and corresponding point, similarity to connecting nodes and deviation from the local rigidity. To calculate the source mesh deformation, a non-linear optimization is applied on the create node graph. The non-linear optimization is an iterative process where the total energy of the system is minimized. The energy function, $E_{tot}$ is controlled by four parameters; $E_{point}, E_{plane}, E_{rigid}$ and $E_{smooth}$ (). The first two parameters, $E_{point}$ and $E_{plane}$ are used to optimize the distance between the reference and live node graphs and the two remaining, $E_{rigid}$ and $E_{smooth}$, to control the deformation. All deformations that result in a transformation that deviates from pure rigid motion is penalized by the term, $E_{rigid}$. The $E_{rigid}$restriction on the deformations will therefore limit the appearance of shearing and stretching artifacts. The affine transformations of neighboring graph nodes are regulated by the term, $E_{smooth}$.

$$E_{tot} = \alpha_{point}E_{point} + \alpha_{plane}E_{plane} + \alpha_{rigid}E_{rigid} + \alpha_{smooth}E_{smooth} \qquad \textit{(Equation 1)}$$

α, weightfactor

4. **Controlling the convergence of the global energy.** The convergence of the system's global energy is controlled. If no convergence is detected, the process restarts from step 2.

5. **Controlling criteria for maximum energy level.** The criteria of maximum energy level in the system is controlled. The stiffness of mesh is gradually reduced to detect local deformations. The process has to restart from step 2 if criteria is not fulfilled.

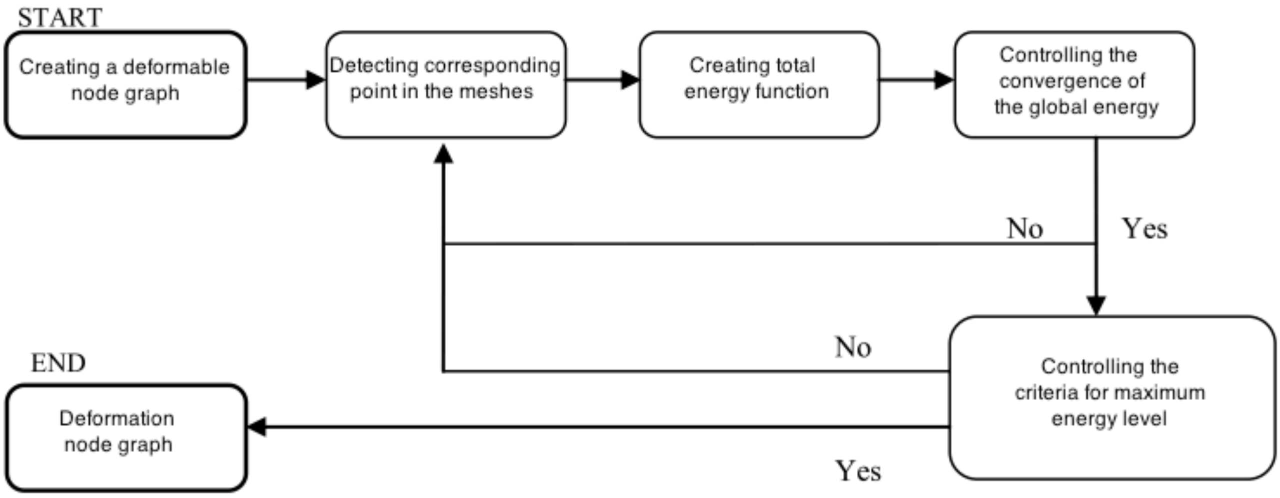


*Figure 8. A flowchart showing the steps in the matching process of the reference and live images using a non-rigid registration algorithm*

The next step is to transform the information from the surface down to a point, the iso-point which is performed by a volumetric mesh. A volumetric mesh is a mesh consisting of uniformly distributed tetrahedrons where all the nodes in the source mesh are related to the ones in the volumetric mesh. Based on the source mesh transformation and the target position, the algorithm can calculate the translation and rotation in each node of the volumetric mesh [11].

## 3.3 Sentinel

Another optical surface scanning system is the Sentinel also provided by C-RAD AB. This system can be used for both position and motion detection. The Sentinel consists of a single camera scanner mounted on the foot-end of the couch calibrated to the same isocenter as the linear accelerator. By a line laser pointing at a galvanometer controlled mirror in the top part of the camera, it enables a transversal line to be swept along the patient. The projected line is captured by a TFT (Thin Film Transistor) camera, at the bottom part of the camera and distorted due the parallax effect since the camera is mounted bellow the mirror. The 3D-coordinates of the points along the line can then be extracted by the optical triangulation. The galvanometer can be set at different positions where each position yields a contour. By repeating this process when moving the mirror several contours can be created and a surface model reconstructed. The system is able to create up to 100 contours per second and typically a 40 cm scanning length during two seconds [15].

The iterative closest point algorithm together with the stored reference surface is used to register the acquired image. The reference surface can be extracted by the CT-scan or acquired by the Sentinel system. From the registration process, the system suggests a correction of a rigid body in six degree of freedom as a couch shift [16].

### 3.3.1 Iterative closest point algorithm

The iterative closest point (ICP) algorithm is used to align one scans to another. This is performed by the two point clouds obtained by the two captured scans of the same object. The first/original cloud point is referred to as the target point cloud and the second point cloud as the source point cloud. The difference between the point clouds is that one of them is transformed relative to the other.

The ICP calculation procedure can be described in 6 steps:

1. **Selecting points.** Selecting the points for matching process in one of the point clouds.

2. **Matching each point to its correspondence**. A set of points is matched in the source point cloud to original points in target point cloud that have been transformed.

3. **Weighting of pairs.** There are different approaches of weighting. For example, larger weight at pairs having a smaller distance between the points.

4. **Rejecting specific pairs.** Points in pairs with too large distance are rejected.

5. **Assigning an error function by the point pairs.** The Euclidean distance which is the distance of the line segment connecting two matched points in the target and source point cloud, is used to get an expression of the distance between the points. For each pair in the source cloud-target cloud the Euclidean distance is squared and mean taken which gives the squared error function.

6. **Minimizing the error function**. ICP is then used to minimize the error function by its iterating process. The expression is minimized so that the transformation is able to move the source point cloud in a way to negate the rigid transformation it has undergone and bring it back to position of the target point cloud [17] [18].

# 4. Material and Methods

## 4.1 Patient positioning by the Catalyst™

The surface based setup technique using Catalyst™ was evaluated by comparing the match results from the CBCT for two groups of patients; 1) CBCT-match after conventional laser based setup and 2) CBCT-match after surface based setup by the Catalyst™. The suggested match results by the CBCT, using surface based setup, $\mu_{Catalyst}$, were compared with deviations when using the laser based setup, $\mu_{Marekers/lasers}$. The deviations suggested by a single camera, $\mu_{Catalyst,1}$ and three camera system, $\mu_{Catalyst.3}$ were also compared. Patient positioning in 84 sessions, for 37 patients were analyzed retrospectively (tattoos/lasers: n=41 session, Catalyst: n=43 session where the one camera system: *Catalyst,1* was used in 25 sessions and the three camera system: *Catalyst,3* in the remaining 18 sessions).

### 4.1.1 Exporting the patient to the Catalyst™

The CT-scan acquired during fixation process is imported to the TPS. In the TPS a structure is generated defining the patients surface, the so-called, at SUS, BODY-structure. When exporting the treatment plan to the Catalyst™ system, the BODY-structure, PTV-structure and iso-point were included. A novel algorithm using a calculated PTV mass weighted point instead of the isocenter was used. The PTV mass weighted point might be a more representative point than the isocenter for long volume target when carrying out surface based setup. The algorithm calculating the match results will thus take the PTV position into account instead of the isocenter only. The parameters in the template used; the tolerances in the translations directions, surface averaging and surface tolerance were set as in table 2.

*Table 1. Shows the tolerances set in the own created template*

| | |
|---|---|
| **Pelvis** | |
| Tolerance settings | |
| lateral | 3.0 mm |
| longitudinal | 3.0 mm |
| vertical | 3.0 mm |
| rotation | 3.0° |
| roll | 3.0° |
| pitch | 3.0° |
| Surface settings | |
| Tolerance | 5.0 mm |
| Image Surface Averaging | |
| Time | 4.0 s |

### 4.1.2 Cropping the reference surface

The reference surface was cropped so that a part of the stomach was excluded, down to the umbilicus. The surface of the legs retained as from the CT-scan except for those including artefacts. The reference body was partly cropped, to exclude the genital from the registration since that part of the body was covered during the treatment session and because the position of the genitals for men vary between the sessions. By cropping the reference surface, it means that the algorithm will not use this part for calculating the displacement needed to match the live and reference surfaces.

Ostomy pouch, the pouch was also cropped off from the reference surface since its containment could vary. In some cases, where the pouch could be folded away, the whole pouch was not totally cropped instead just a part of it. Unnecessary cropping of the reference surface, especially near the PTV mass weighted point was avoided so that the deviation could be calculated as accurately as possible.

### 4.1.3 Patient positioning during treatment sessions

At each treatment session, the patient was positioned in the same fixation used when performing the CT-scan. Rectal patients were positioned on a mattress with pillows under the head and the legs fixated in a footrest with a wedge under the knee for support (Combifix™ 3, CIVCO Medical Solutions) (Figure 9). The patient's external marker/tattoos in the lateral, longitudinal and vertical direction were first aligned with the lasers as in the conventional setup technique and after the movement to the isocenter point, lines were drawn at the patient's skin. A white paper tissue was earlier used to cover the genitals during the treatment sessions since genital hair and its position could affect the live surface. The white paper tissue saturated the camera fast because of its bright color which could give some artefacts on the live surface. For solving this problem, a black paper tissue was used to cover the genitals in this study. The black paper tissue absorbs the projected light and creates a non-signal area in the live surface, without any risk for artefacts (Figure 5b).

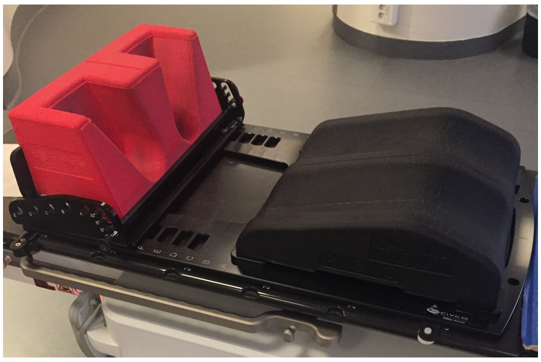

*Figure 9. The fixation for rectal cancer patients, a footrest with a wedge for knee support*

The Catalyst™ system was then started. The parameters time and gain were adjusted individually for each patient at the first treatment session so that the live surface covered as much as possible of the body and at the same time no black tissue was detectable by the system. The same values of time and gain were used during all sessions for each patient.

When switching to cPosition, the system started to calculate the deviations between the PTV mass weighted points in the reference and the live surface in lateral, longitudinal, vertical and rotations in the translations directions.

The couch position was shifted as close as possible in accordance with the suggested displacement of the system. The distance between the lasers and the iso-lines was measured before verification of the positioning.

The distance between the iso-lines and the lasers together with the result from the CBCT was used as a reference for each session to estimate if the set-up was correct. If a clear difference was observed between the iso-lines and the lasers compared with earlier sessions, a CBCT verification of the position was required.

The patient position was verified before treatment start with the integrated CBCT system at the linear accelerator. The images were then matched with the reference, that is the CT-images that the treatment plan were based on, using bone structure and soft tissue. If the offsets between the CBCT and the CT-images were within the tolerance of 4 mm, a couch shift was performed and the treatment then started. If the deviations were outside the tolerance, a verification of patient position was required at session two. If offsets were observed at second session, an individual assessment was performed by the treating doctor (Figure 10).

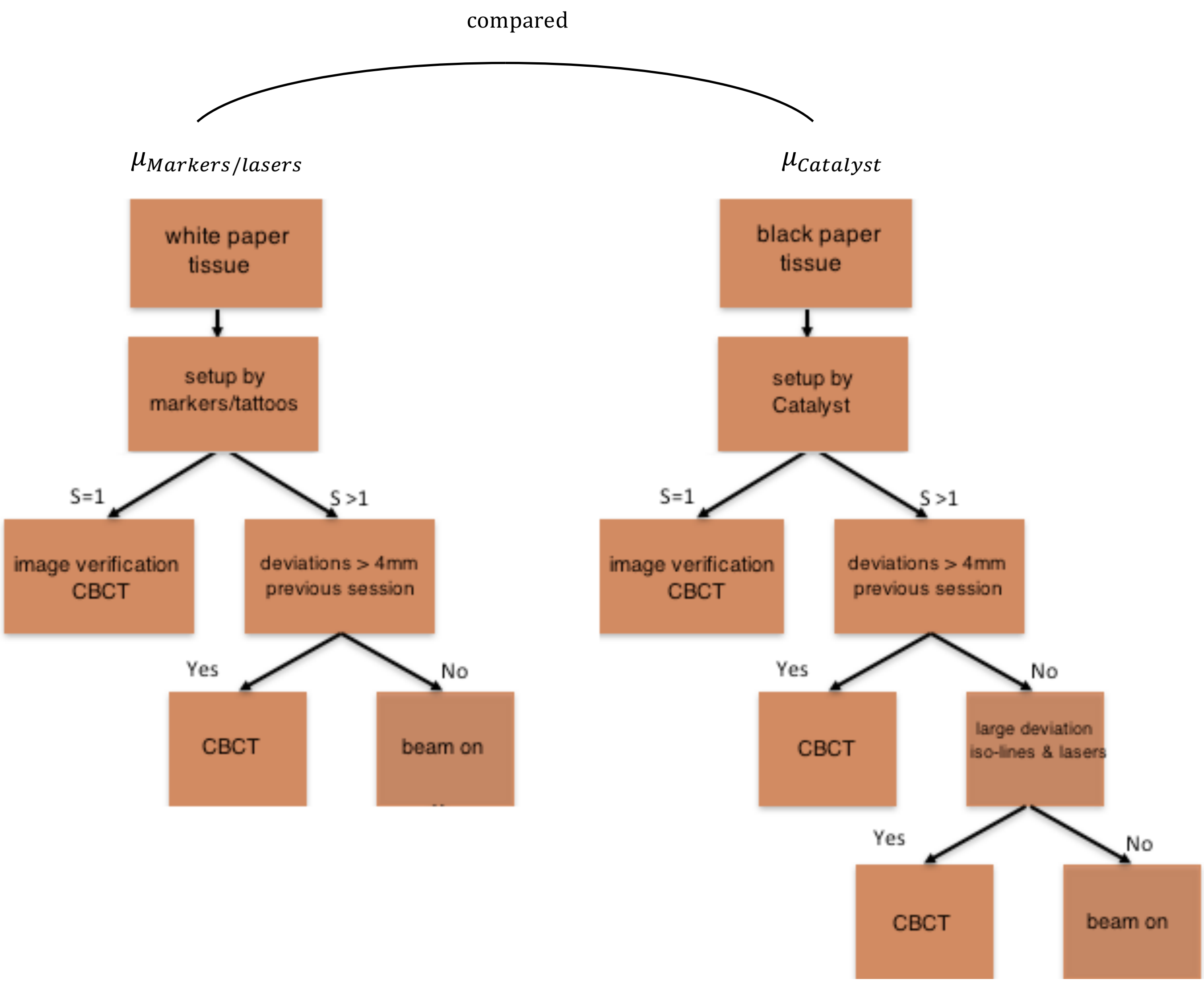


*Figure 10. A flowchart showing the procedures of the two setup techniques that were compared*

### 4.1.3 Extracted data from TPS and Catalyst™

The result from the matching process of the CT-scan and CBCT, $\mu_{Catalyst}$ and $\mu_{Markers/lasers}$. were extracted from the offline review module in the TPS. The deviations could be displayed from the matching process performed online before treatment start by an oncology nurse or offline by a medical physicist. The anatomical structures used for the matching procedure were bone and soft tissue.

## 4.2 Optimization of the reference surface of the Catalyst™ system

The reference surface cropped in two different ways were evaluated, as accordingly to Wikström *et al.* 2014 [8] evaluating the Sentinel system. In the first case the reference surface was cropped the same way as in the clinical positioning study; i.e. excluding the genital and everything above the umbilicus ($ref_{original}$). In the second case, an even larger part of the stomach was excluded compared to the first case ($ref_{cropped}$). It could have been of interest cropping the whole stomach due to breathing induced motion artefacts and stomach filling variations, this could however not be performed since the reference surface then had to be cropped close to the surface above the PTV mass weighted iso-point, which is the area of the most important data contribution to the algorithm calculating the positioning result. Figure 11 shows an example of the two different cropped reference surfaces compared.

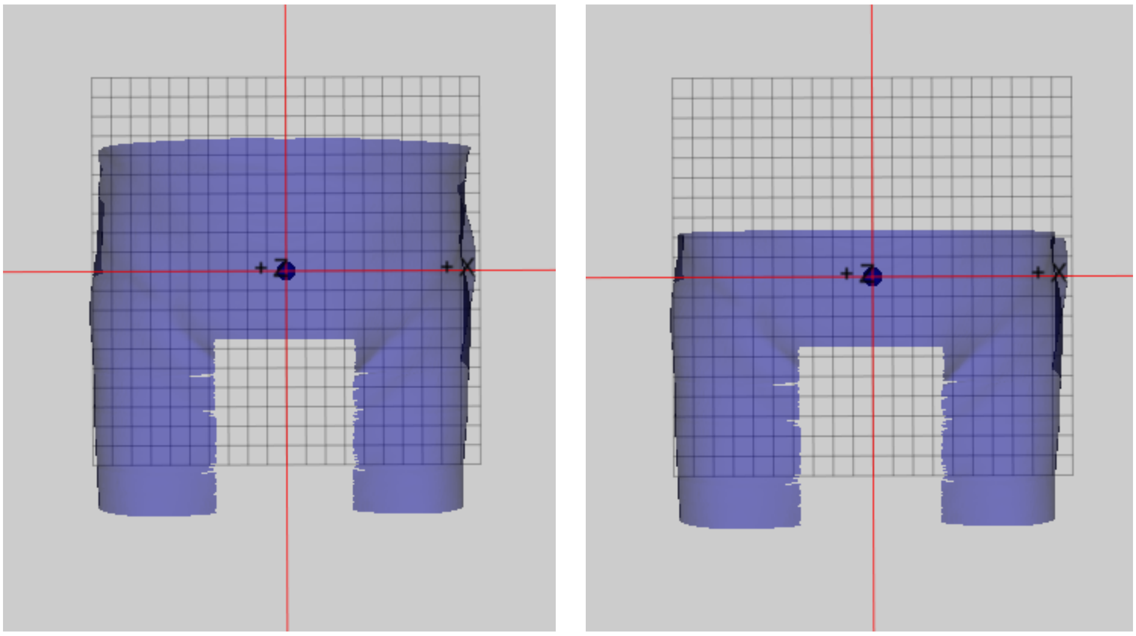

*Figure 11. The two different reference surfaces, $ref_{original}$ to the left and $ref_{cropped}$ to the right*

The two different cropped reference surfaces were then analyzed with the live surface in the analysis tool in *Advanced mode*. The live surface used for the analysis was the one captured after the setup according to the Catalyst™, before the performance of the CBCT. The matching result, $\mu_{original}$ and $\mu_{cropped}$ when using a non-rigid algorithm for different reference surfaces was represented in a table in relative values. Hence, the difference between the displacements determined by the Catalyst™ and CBCT for the different reference surfaces, $\Delta_{original/cropped}$ were given by equation 2.

$$\Delta_{original/cropped} = \mu_{original/cropped} - \mu_{Catalyst} \qquad \textit{(Equation 2)}$$

## 4.3 Statistical tests

The normality of the obtained datasets, $\mu_{Catalyst}$, $\mu_{Markers/lasers}$, $\Delta_{original}$ and $\Delta_{cropped}$ were investigated by using a Shapiro-Wilks test ($\alpha = 0.05$). If $\mu_{Catalyst}$, $\mu_{Tattoos/lasers}$ were normally distributed datasets, an unpaired student's t-test (with the assumption of different variances) was used to investigate if the difference between the two setup techniques were statistically significant. If the test indicated that the data set was not normally distributed data, the non-parametric unpaired Wilcoxon sum-rank test was used.

To investigate if there were any difference in setup between various sizes of reference surfaces, a paired student's t-test was used if the datasets, $\Delta_{original}$ and $\Delta_{cropped}$ seemed to be normally distributed. If the Shapiro test indicated not normally distributed data, non-parametric Wilcoxon signed-rank for matched pairs was carried out instead.

# 5. Result

## 5.1 Patient positioning study

The normality tests by Shapiro-Wilks test ($\alpha$=0.05) indicated that the longitudinal and vertical component in $\mu_{Markers/lasers}$, and all components in $\mu_{Catalyst}$ were not normally distributed. Wilcoxon sum-rank Unpaired one-tailed test was carried out to examine if the surface based setup improved the setup significantly compared to laser based setup. The null hypothesis used for these tests was:

$H_0$*: There was no median difference between the deviations of the two techniques in lateral/longitudinal/vertical direction at the 0.05 level of significance (p=0.05).*

Table 3 shows the compiled result from all treatment session, 41 sessions using laser based setup and 43 sessions from surface based setup by the Catalyst$^{TM}$. The table shows also the results for the 25 sessions using the single and 18 sessions using the three camera system. Medians of deviations in absolute values together with 95% confidence interval (95% CI) for laser based setup, Catalyst$^{TM}$ setup, single camera and three camera system setups are represented in table 3.

*Table 3. Shows the medians of deviations in absolute values together with 95% confidence interval in all translation directions for different setup techniques and different camera system setup. The deviation vector's absolute medians are also given for the setup by different techniques and camera systems*

| **Datasets** | **Median $\lvert\mu_{lat}\rvert$ (95% CI) [mm]** | **Median $\lvert\mu_{long}\rvert$ (95% CI) [mm]** | **Median $\lvert\mu_{vert}\rvert$ (95% CI) [mm]** | **Median $\lvert\mu\rvert$ (95% CI) [mm]** |
|---|---|---|---|---|
| *Catalyst (n=43)* | 1.3 (0.7–2.2) | 2.3 (1.2–4.0) | 2.2 (1.1–4.5) | 4.7 (3.2-6.5) |
| *Catalyst, 1 (n=25)* | 0.9 (0.3-1.7) | 2.3 (1.1-4.8) | 2.8 (1.0-5.7) | 5.2 (3.4-7.5) |
| *Catalyst, 3 (n=18)* | 1.5 (0.8-2.4) | 2.1 (0.9-2.8) | 1.9 (1.5-2.7) | 3.6 (2.8-4.6) |
| *Markers/lasers (n=41)* | 2.0 (1.0–3.0) | 2.0 (1.0–2.0) | 2.0 (1.0–5.0) | 3.7 (2.5-5.7) |

A smaller absolute median $|\mu_{lat}|$ was observed for the surface based setup by the Catalyst™ compared with laser based setup (table 3). For the longitudinal and vertical directions, the medians were smaller for the conventional setup technique. The Wilcoxon sum rank tests showed however only a significant improvement for surface based setup in the lateral direction compared to the laser based setup (p=0.034), in favor for surface based setup. Although $|\mu_{Markers/lasers}|$ was smaller than $|\mu_{Catalyst}|$ for the other two directions no significant improvement (p=0.230) was found.

The absolute medians deviation when using the three camera system for setup was smaller in the longitudinal and vertical directions. The Wilcoxon sum rank tests showed that there was no significant improvement for the three camera systems when comparing each direction separately (p=0.136, p=0.142 and p=0.164 in lateral, longitudinal and vertical direction respectively). But when comparing the medians of the deviation vector's absolute values, $|\mu|$ for three and single camera system the Wilcoxon sum-rank test showed a significant improvement when using the three camera systems (p=0.018).

For setup by the conventional technique, 20%, 10% and 29% in lateral, longitudinal and vertical respectively of all sessions were positioned outside the 4mm tolerance. For setup by the Catalyst™ system the number of sessions that were positioned outside the 4mm were instead 5%, 16% and 23% in lateral, longitudinal and vertical respectively. For Catalyst™ setup when positioning using single camera system, the number of setups outside the 4mm tolerance were 4%, 24% and 44% compared with 6%, 0% and 6% in lateral, longitudinal, and vertical respectively for the three camera system (Figure 12, Figure 13, Figure 14).

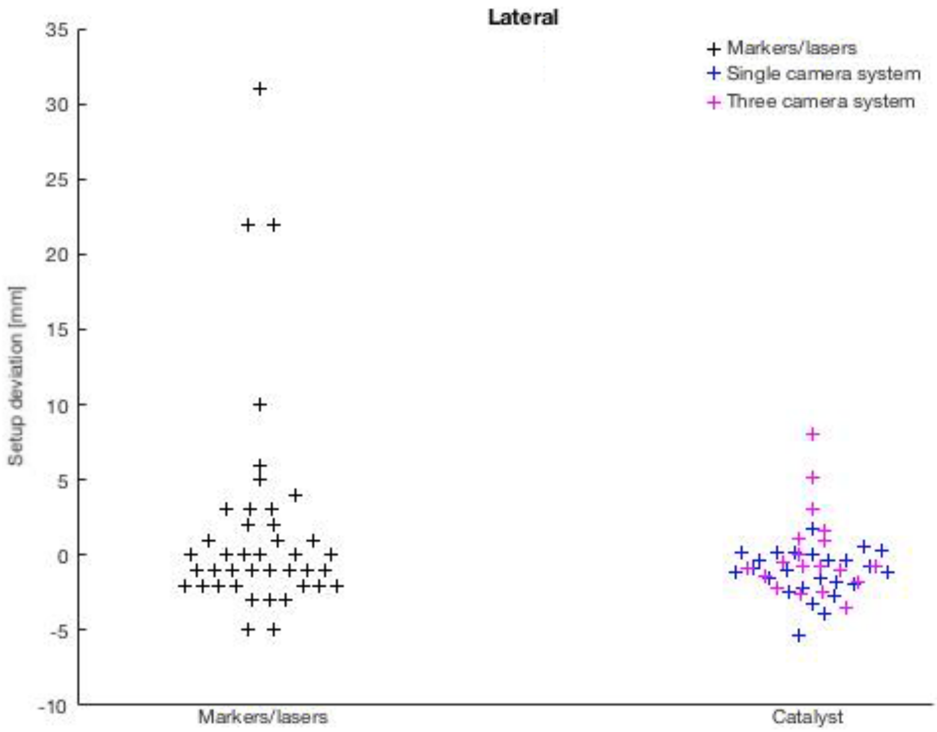


*Figure 12. Bees warm plot showing the setup deviations from the two setup techniques; Markers/lasers and Catalyst$^{TM}$ in lateral direction*

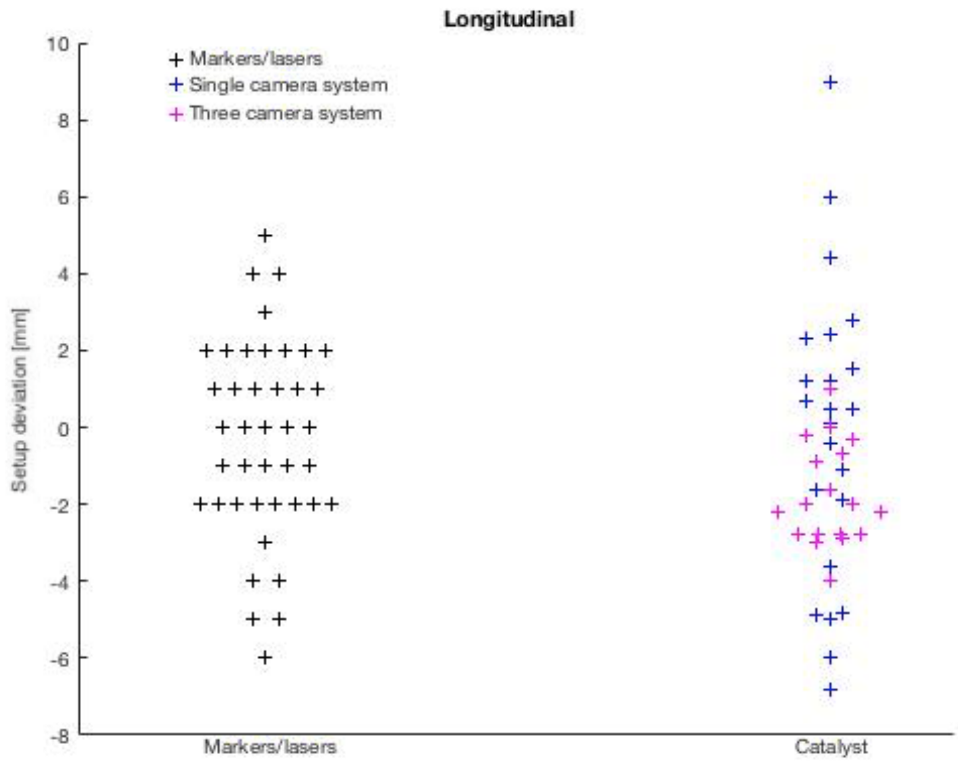


*Figure 13. Bees warm plot showing the setup deviations from the two setup techniques; Markers/lasers and Catalyst$^{TM}$ in longitudinal direction*

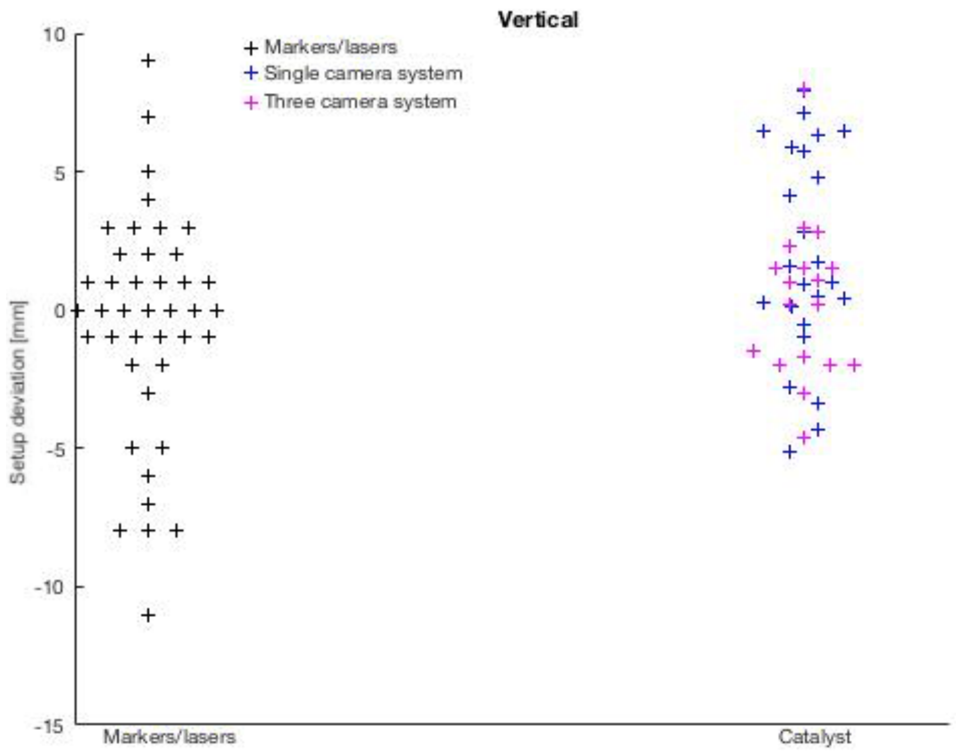


*Figure 14. Bees warm plot showing the setup deviations from the two setup techniques; Markers/lasers and Catalyst™ in vertical direction*

## 5.2 Optimization the reference surface of the Catalyst™ system

The Shapiro-Wilks ($\alpha$=0.05) tests showed that only the lateral component in $\Delta_{original}$ of all data in $\Delta_{original}$ and $\Delta_{cropped}$ was normally distributed. A Wilcoxon signed rank test was carried out to investigate if there were statistical significant difference between the reference surfaces in any translation direction. The null hypothesis used for these tests was:

*$H_0$: There was no median difference between the deviations for the two reference surfaces (original and cropped) in lateral/longitudinal/vertical direction at the 0.05 level of significance ($\alpha$=0.05).*

Table 4 shows the compiled result from 41 sessions. The table shows the medians of deviations in absolute values and the medians of deviation vector's absolute values together with 95% confidence interval (95% CI).

*Table 4. Shows the medians of deviations in absolute values together with 95% confidence interval in all translation directions when using different cropped reference surfaces. The deviations vector's absolute medians are also given for the different cropped reference surfaces*

| Datasets | **Median $\lvert\Delta_{lat}\rvert$ (95% CI) [mm]** | **Median $\lvert\Delta_{long}\rvert$ (95% CI) [mm]** | **Median $\lvert\Delta_{vert}\rvert$ (95% CI) [mm]** | **Median $\lvert\Delta\rvert$ (95% CI) [mm]** |
|---|---|---|---|---|
| *Original* | 1.5 (0.6–2.9) | 2.3 (1.4–3.7) | 1.8 (1.3–3.4) | 4.4 (3.5-6.5) |
| *Cropped* | 1.7 (0.4–2.7) | 2.3 (0.7–4.2) | 1.9 (1.0–3.5) | 4.3 (2.8-7.3) |

All absolute deviation medians in all directions when using the reference surface as in the patient positioning study were smaller than for the cropped reference. The Wilcoxon signed-rank tests showed no significant improvement when using the cropped reference surface compared to the original in any direction, $|\Delta_{lat}|$ , $|\Delta_{long}|$ and $|\Delta_{vert}|$ (p=0.176, p=0.440 and p=0.323 in lateral, longitudinal and vertical direction, respectively). The comparing the medians of deviation vector's absolute values, $|\Delta|$ for the two reference surfaces neither showed a significant improvement was observed for the cropped reference surface.

# 6. Discussion

## 6.1 Patient positioning

Setup deviations from the positioning according to the Catalyst™ system were compared with the setup deviations from laser based setup for patient treated in the pelvic region. An accuracy of 1.3cm (0.7-2.2cm), 2.3cm (1.2-4.0cm) and 2.2 cm (1.1-4.5cm) in lateral, longitudinal and vertical direction respectively were obtained when positioning with the Catalyst™. The absolute median value for the lateral direction for Catalyst™ based setup was significantly smaller (p=0.034) than for laser based setup. As shown in figure 12, fewer outliers were detected when using the Catalyst™ for setup in the lateral direction. The explanation for this could be that the lateral skin marker from the fixation is usually placed at the stomach and is often covered by body hair which makes it harder for the nurses to see the skin marker when positioning the patients at the treatment sessions. Instead of aligning the lateral using one marker, the Catalyst™ has the advantage to use to use the whole surface.

Additionally, the Catalyst™ had the main benefit to verify the pose and position of target area. If, for example the legs were misaligned it was directly identified by the scanning system. This gave the ability to correct the position before treatment start which result in a good starting point when aligning the patient. Some of the misaligning could affect the treatment volume, and may be hard to detect by just looking at a limited number of CBCT images. The system also had the advantage to detect patient weight changes without looking at the CBCT images (Figure 15).

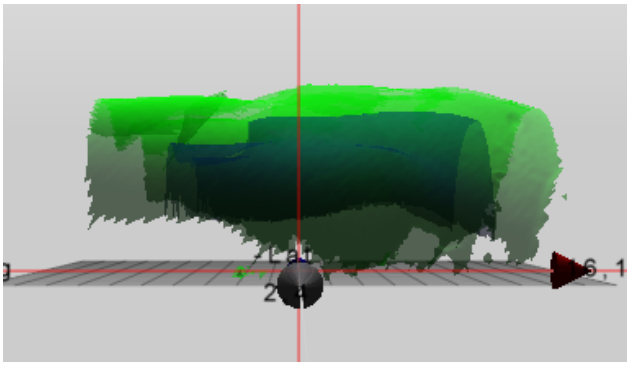

*Figure 15. Shows the reference surface in blue and live surface in green. Illustrates a weight gain for a patient between the CT-scan and treatment session.*

There were some things observed during the study that could have affected the result such as; stomach height variation and live surface coverage. The largest setup deviations by the Catalyst™ were observed in longitudinal and vertical direction due to variation in stomach high between the reference and live surfaces.

This variation could be observed due to several reasons such as different stages in the breathing cycle between the captures of the surfaces, variation in stomach filling and weight change during treatment.

Since no CBCT images were taken each session it was hard to know the exact reason to the variation. It is most likely that the gas varies in the stomach because flatuance is one of the side effects when irradiating in the gastrointestinal system. The calculation algorithm has the hardest weighting closest to the PTV mass weighted iso-point. Hence, the system suggests a displacement to mainly match the upper part of the body instead on the legs, which result in a mismatch between the surfaces at the legs (Figure 16). Since the matching process of the CBCT and CT-scan was performed using the bone structure the abdominal high contributed to an error in the setup by the system.

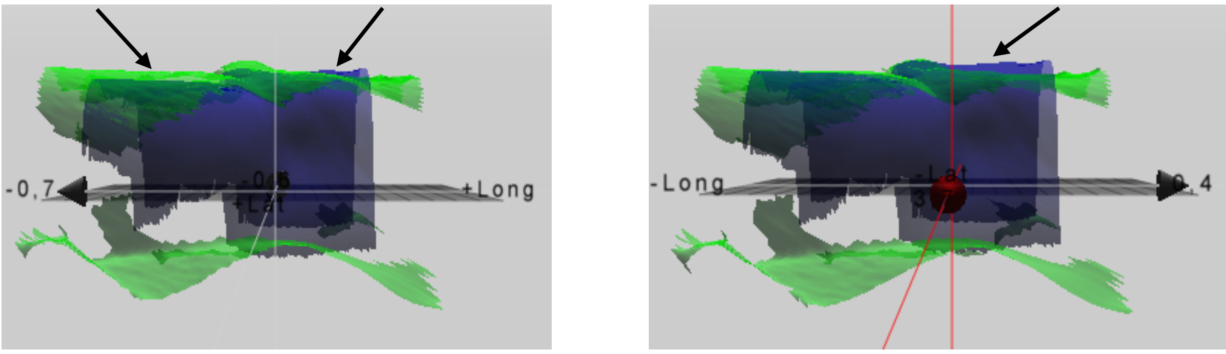


*Figure16. Reference surface in blur and live surface in green. Figure to the left shows patient setup according to the Catalyst™ and to the right, after corrected setup according to the CBCT*

Breast cancer patients can develop a non-rigid deformation after surgery during the radiotherapy. This issue has showed no problem to be handled by the Catalyst™ system when positioning the patients. The difference between the two cases of the deformations is that the breast constitutes a smaller part of the body region scanned by the system, compared to the abdominal. An explanation for this can be that the abdomen covers a larger part in relation to the body used for matching which makes it harder for the system to handle the deformation. Another difference is that the isocenter and the PTV is superficial for breast targets in contrast to rectal targets where it is more deeply located. The deeply located target together with the large deformation could probably result in a poor correspondence between the surface and the PTV mass weighted iso-point.

To solve this problem a solution would be to crop the reference surface excluding the whole stomach as Wikström *et. al* [8] performed in their study. A similar investigation was performed in this study when evaluation if the cropped reference surface could improve the positioning compared to the originally used reference surface. More about that in section 6.2 Optimizing the reference surface. Another solution could be to change the weighting of the algorithm to limit the influence of the stomach.

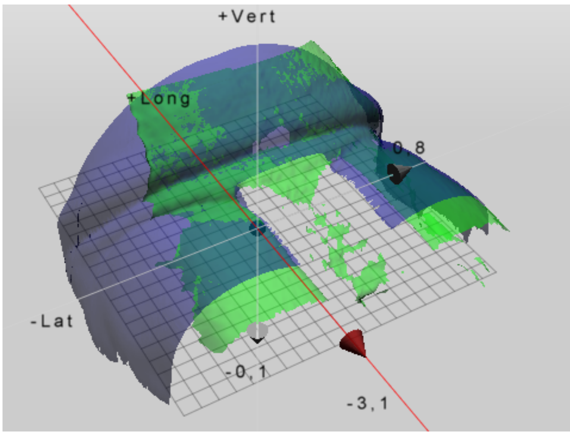

*Figure 17. The reference surface in blue and live surface in green. Shows a live surface with objects in the systems scanning field*

The coverage of the live surfaces could vary between the sessions for the same patient although the same optimized parameters, time and gain were used throughout the whole treatment period. One of the reasons could be that the distance in between the Catalyst™ system and the patient was not completely free and disturbing the cameras view. This results in a loss of a part of the live surface and contributes to an error when suggesting the displacement. The reason for that was that the grid on the gantry and the handle mounted on the ceiling were covering the camera view (Figure 17). The gantry was rotated to not affect the live surface. The handle was adjusted in the end of the study to minimize the coverage of the live surface but could not be removed totally since it then would be useless. Small movements of the handle were in some cases detected by the system, which was hard to prevent. The movements resulted in a recount of the deviations continuously, which made it impossible to align the patients according to the Catalyst™.

There could also be things placed on the patient body or skin that affected the suggested displacements calculated by the system. For example, clothes in the scanning field resulted in a deformed surface not representing the contour of the body. The magnitude of influence on the calculations depends on how far the clothes are located from the PTV mass weighted isocenter. The clothes can be removed from the scanning field which is no problem if the nurses are observant.

The absolute medians for the three camera system in both longitudinal and vertical direction were smaller than for single camera system. The percentage of sessions positioned outside the 4mm tolerance were lower for the three camera system in longitudinal and vertical. The improvement could be due to that a 360-degree body was used for the matching process and therefore more accurate setup was possible.

Since a large number of sessions were positioned outside the 4mm tolerance when setup by the conventional method, the question is if the number of CBCT are sufficient, i.e to acquire one CBCT the first session followed by no other verification images if no large deviations were observed. The rectal cancer treatment has a curative purpose and an increased number of verification images would increase the accuracy of the patient setup.

Wikströms et al. [8], Walter *et al.* [5] and Stieler *et al.* [19] have performed similar studies comparing the laser based setup with surface based setup and have shown similar result as presented in this study. But there are some difficulties when comparing all studies, for instance the collected data was not normally distributed in this study, however mean values was presented in the other studies. Further, in this study we investigate setup for rectal cancer patients only, however the pelvic targets that have been included in the other studies were not defined.

When looking at the medians of deviation vector's absolute values for the Catalyst, 4.7 (3.2-6.5) mm and the markers/lasers, 3.7 (2.5-5.7) mm, the median for the markers/lasers was slightly lower than the for the Catalyst. This result was similar to Wikströms *et als.* [8] result when comparing the skin-marks-only group, 0.38 (0.34-0.42) cm with the Sentinel using the full CT-scan as a reference, 0.46 (0.40-0.52) cm. However, the median of deviation vector's absolute values for Catalyst using the three camera system, 3.6 (2.8-4.6) mm was lower in comparison with the markers/lasers, 3.7 (2.5-5.7) mm. But to investigate if the three camera system actually results in a significantly improved setup compared to the markers/lasers future data collection is needed to balance the groups.

## 6.2 Optimization of the reference surface of the Catalyst™ system

Wikström *et al.* [8] showed that the setup deviation can vary depending on the size of the reference surface for setup by the Sentinel system. For that reason, a similar investigation was performed for the Catalyst™ system. The reference surfaces used for setup with the Catalyst™ were compared with cropped references surfaces were a larger part of the surface above the stomach was excluded.

The medians of deviations of the cropped references were larger than for the original ones in all directions. The result was not consistent with Wikström*s et.als* [8] result for various sizes of reference surfaces. A smaller median of deviation vector's absolute value was observed for the cropped reference surface compared with the original by Wikström*s et.als* [8]. The result from this study showed a similar median of deviation vector's absolute value for the original reference surface. The reason for this is probably due to that the non-rigid deformation algorithm used by the Catalyst™ has the greatest weight close to the PTV mass weighted iso-point. So, when cropping near the PTV mass weighted point, too much of important data will be removed which can affect the deviation calculations by the system.

# 7. Conclusions

This study showed that by using the optical surface scanning system Catalyst™ for rectal cancer patients the setup is improved compared to conventional laser based setup, however only significant improved in the lateral direction. No significant improvement was found for surface based setup in the longitudinal and vertical directions. Hence, the surface based setup has the additional advantages, such as verifying the pose, position and weight changes compared to the laser based setup.

The cropped reference surface showed no significant improvement in setup compared to the original for the patients enrolled in this study. However, a significant improvement was observed for setup performed by three camera system compared with single camera system.

# 8. Future prospects

From the already collected data one could investigate correlation between the deviation and BMI. All data of isocenter movements during the treatment sessions in this study can be used to investigate how the target movement affect the doses. From this one could evaluate the doses to target and organs of risk due to intra fractional movements during treatment session.

It would be interesting to compare the setup deviations from the three camera system and single camera system with the laser based setup. To be able to perform this further data collection is needed for both the one and three-camera system to get balance the groups. It would also be interesting to perform a study for other targets in the pelvic region where more CBCT are acquired during the treatment to be able to determine random and systematic errors.

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