

The Value of Combining Surface Guidance with Triggered Internal Imaging

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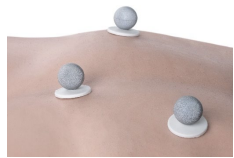
Outline

- ExacTrac Dynamic platform updates
- Radiosurgery utilization
- SGRT monitoring for CBCT setups
- Lung X-ray monitoring for CBCT setups
- Cranial treatments
- Spine treatments
- Prostate treatments
- Breast treatments

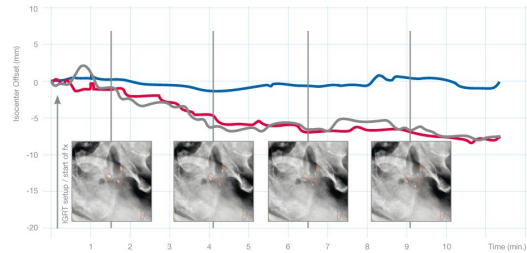


EXACTRAC PRODUCT DEVELOPMENT

Series of more technologically complex innovations



Infrared Positioning



Intrafractional Verification



Robotic Position Correction



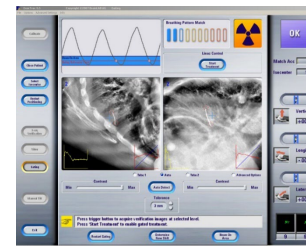
Surface Tracking
ExacTrac Dynamic (surface tracking for all linacs)



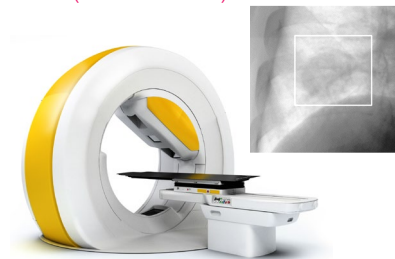
X-ray Positioning
Novalis



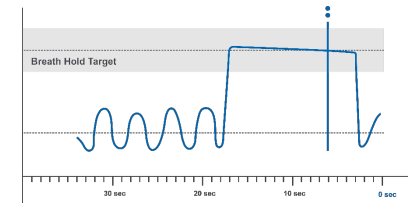
2008
Implanted Markers



2012
Dynamic Tumor Tracking
Vero (w/o markers)



2020
Respiration Correlation
ExacTrac Dynamic



SGRT GONE WRONG

Treatment room installations

What do we have here?

- PRM cameras
- ExacTrac 6.5 infrared cameras
- HumediQ cameras
- VisionRT cameras
- Calypso cameras

Still need in-room X-ray imaging





SURFACE

THERMAL

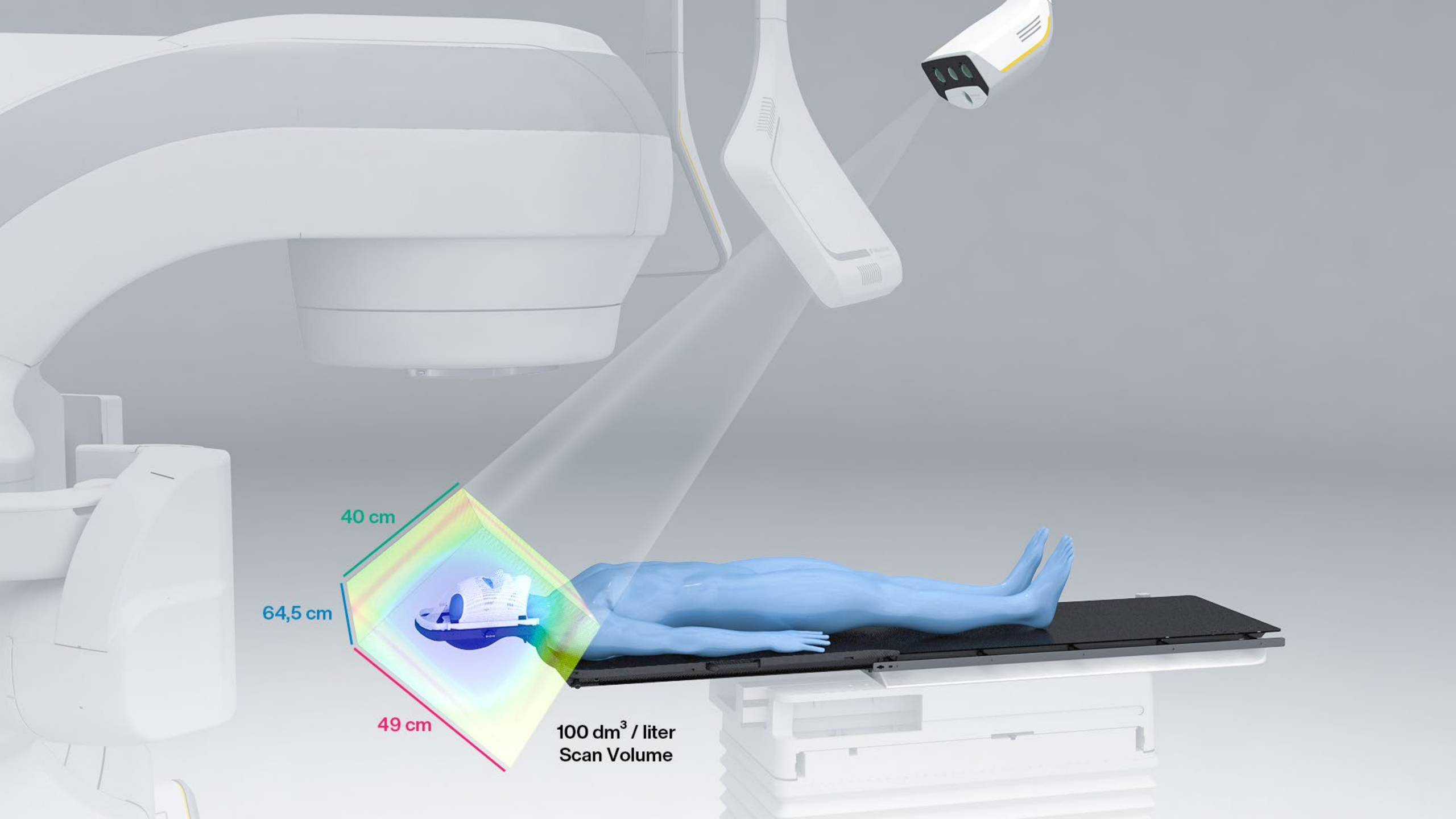
X - RAY

Structure light emitter



BRAINLAB

ExacTrac Dynamic



40 cm

64,5 cm

49 cm

100 dm³ / liter
Scan Volume



General

Registration frame rate

- 15 – 20 fps

Far field-of-view

- 645 x 490 mm

Measurement range

- 400 mm

Scan volume

Far field-of-view x measurement range
= 100 dm³/L = 3,5 ft³

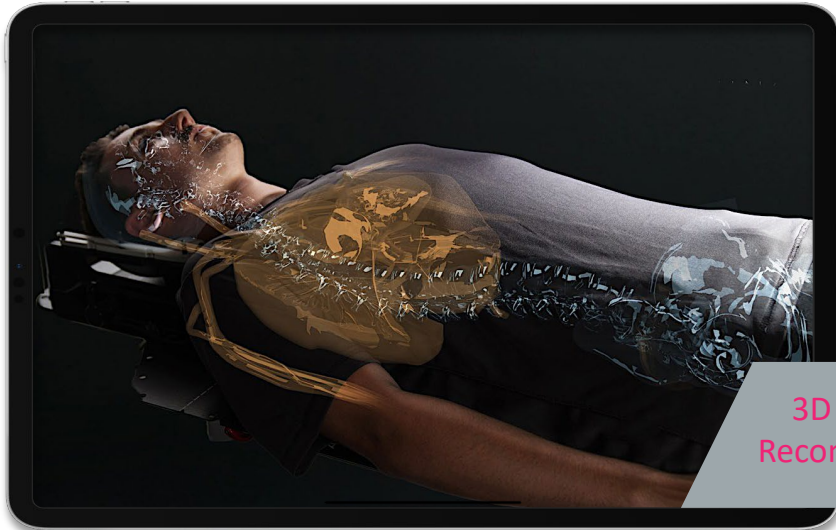
Image acquisition

- Patient's surface and thermal signature

FUNDAMENTALS OF IGRT

Direct anatomical visualization vs. surrogate tracking

In-Room anatomical imaging



3D Model
Reconstitution

In-Room Surface Matching

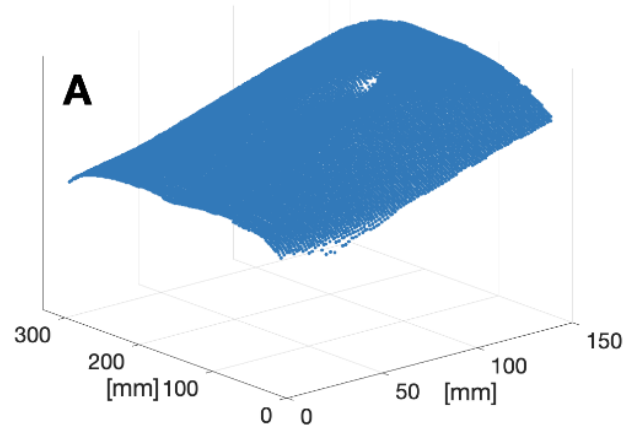


Surrogate
Model Check

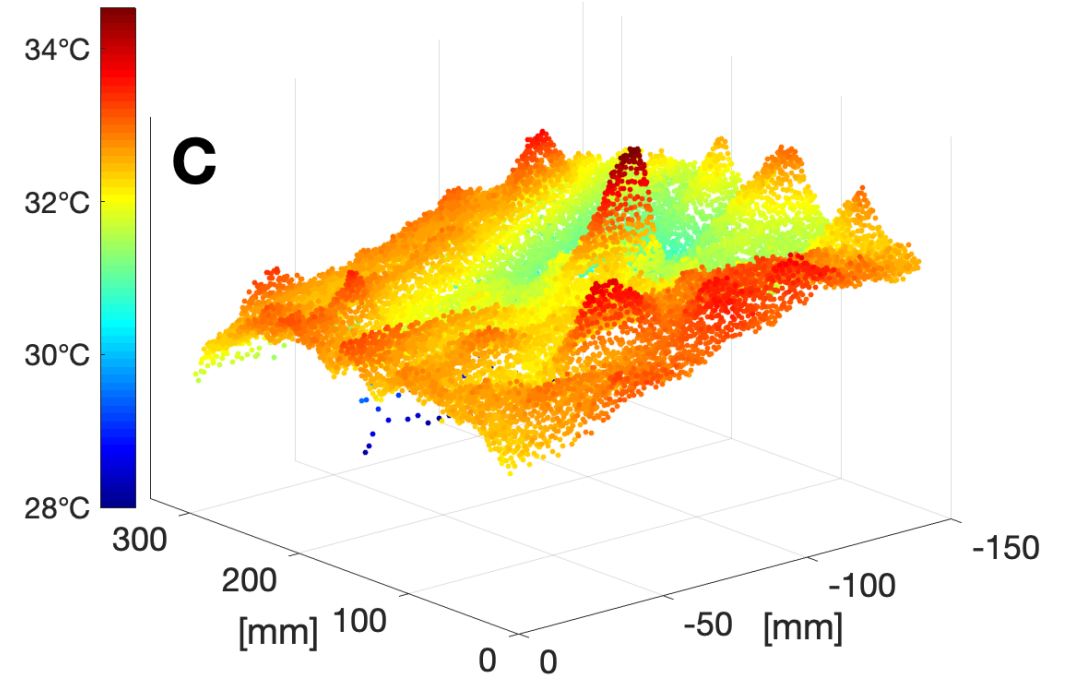
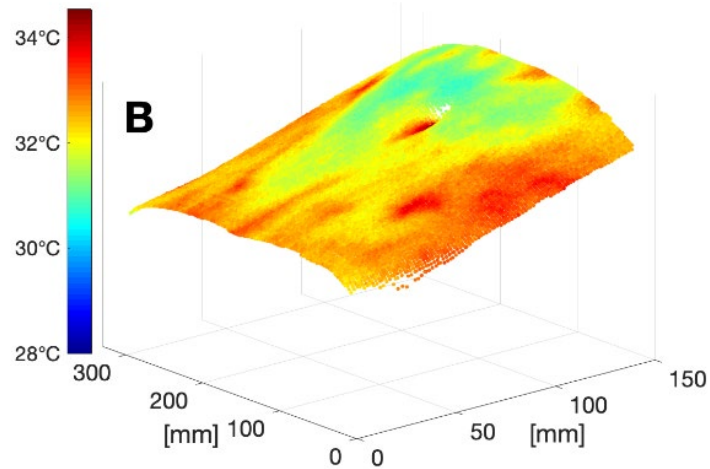
NEW TRACKING MODALITY

Inclusion of thermal information

Surface Data



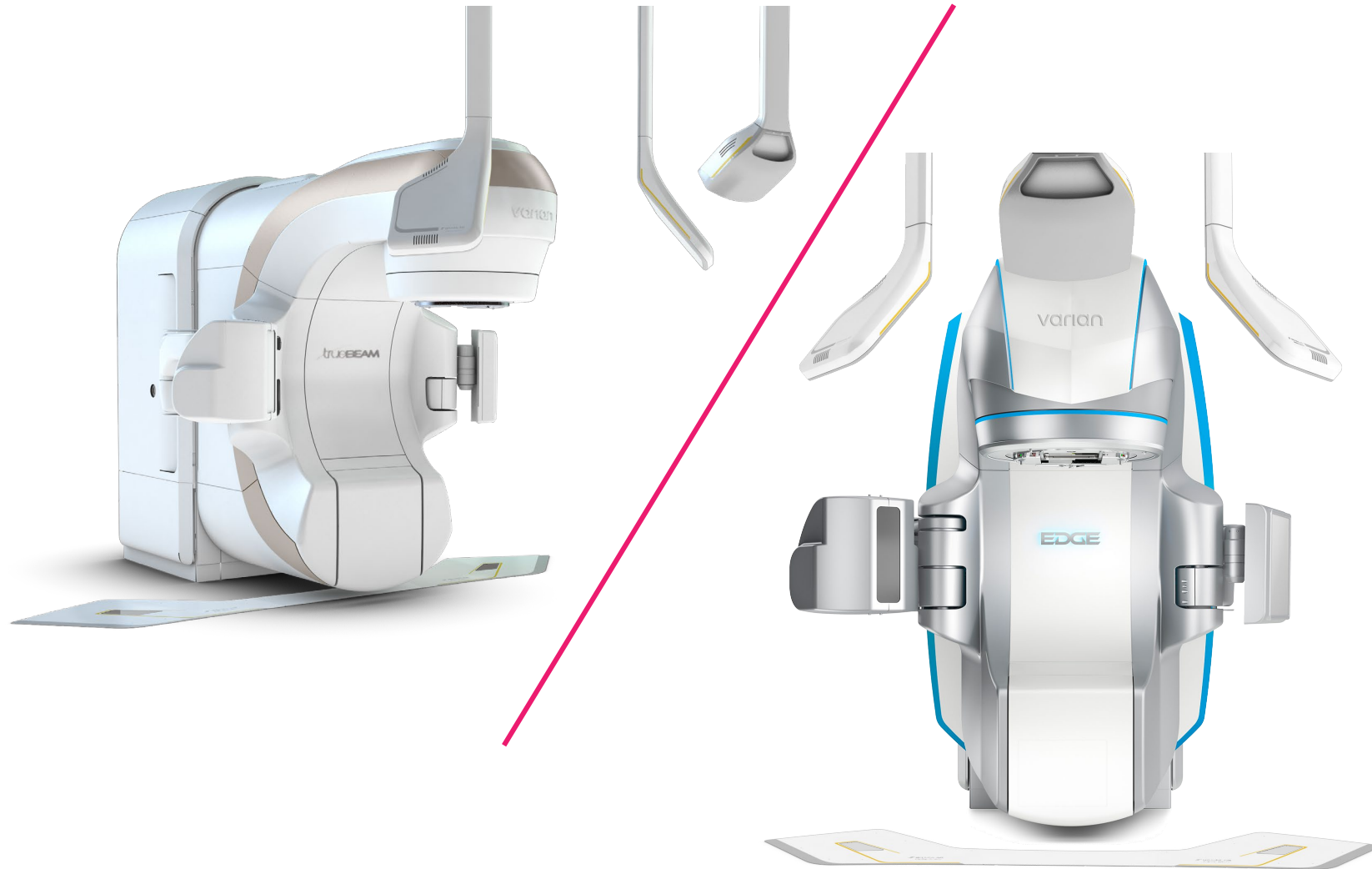
Thermal Data



ExacTrac Dynamic combines surface and thermal data to create surfaces with unique topography

DEEP INTEGRATION

With Varian medical linacs



Integration points:

- Automatic patient loading
- Surface pre-positioning
- Automatic couch control (shifts)
- 6DoF couch integration
- Automatic beam control
- Automatic table angle update
- MU- or gantry angle-triggered IGRT

DEEP INTEGRATION

With Varian on-floor solution



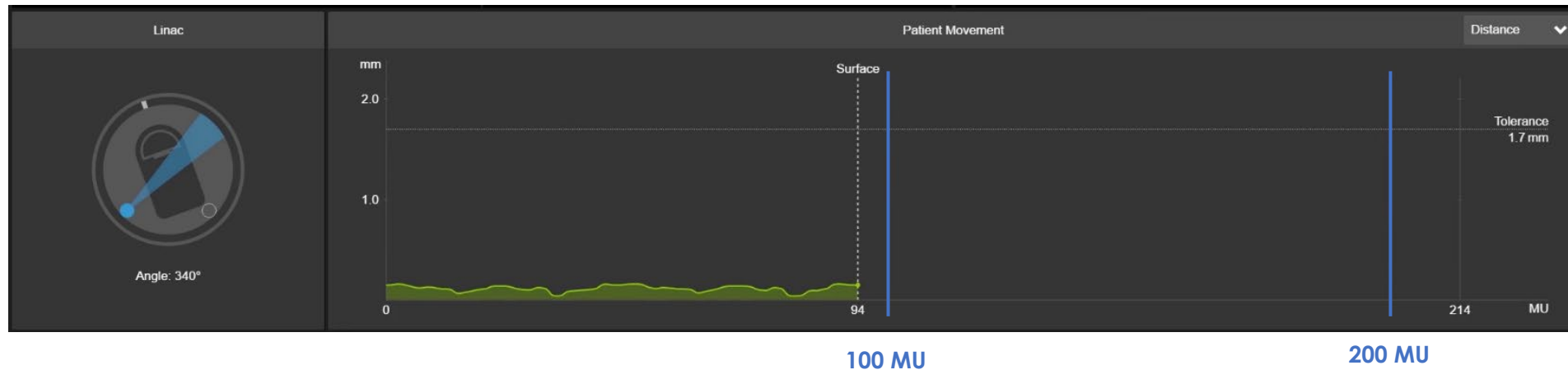
DEEP INTEGRATION

Advanced internal anatomy monitoring capabilities

Gantry angle-triggered X-Rays

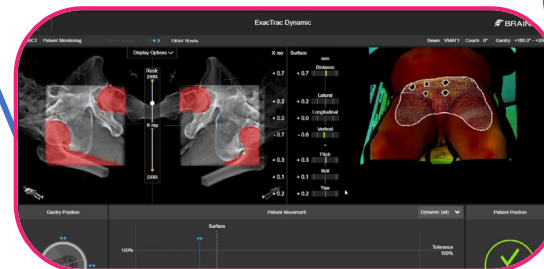
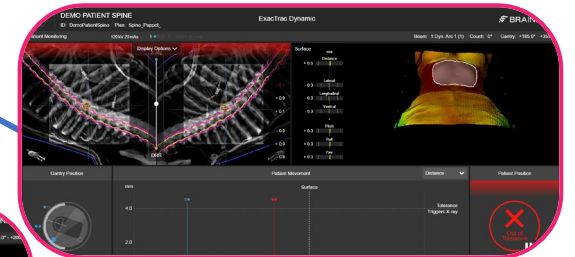
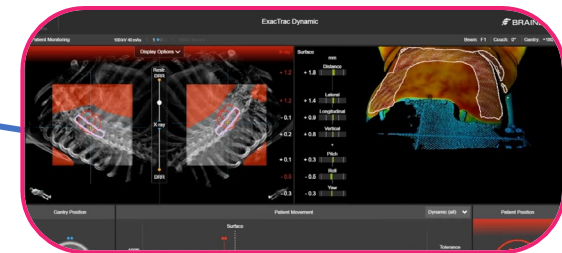
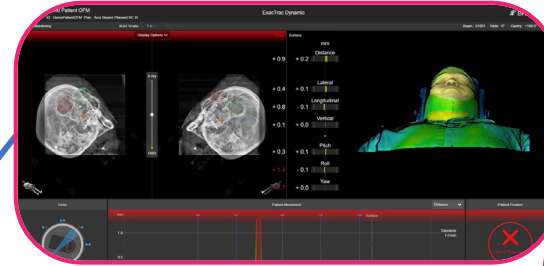
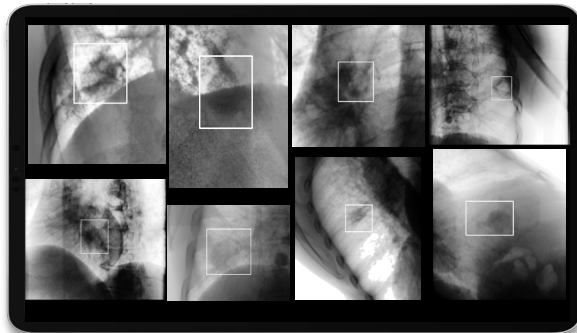
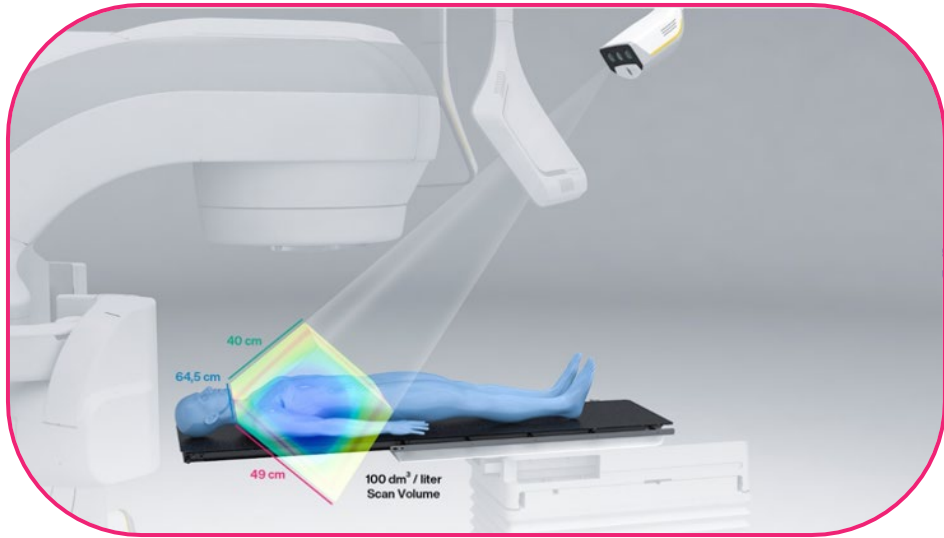


MU triggered X-Rays



EXACTRAC DYNAMIC

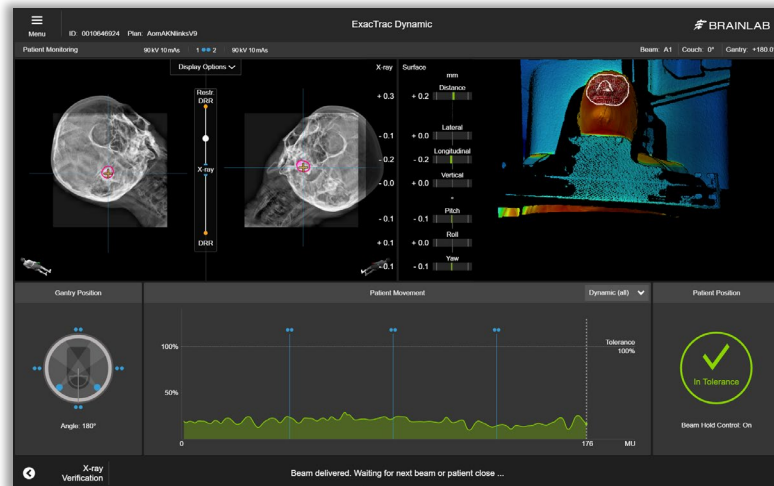
Full body IGRT & SGRT solution



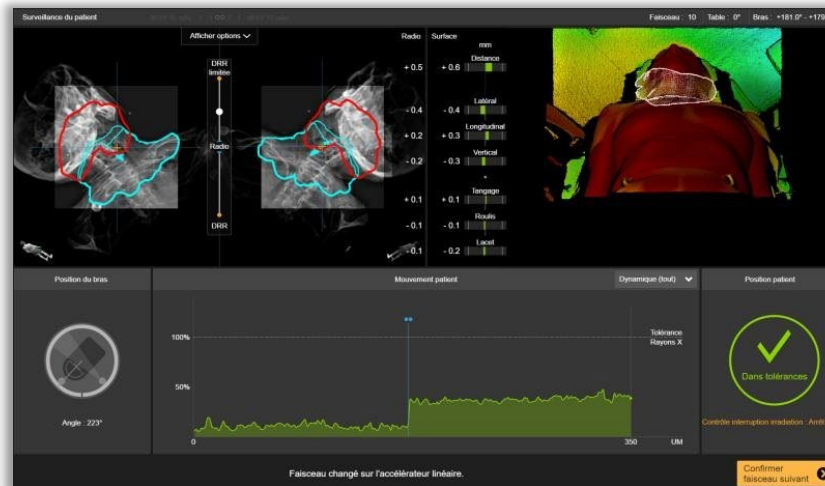
EXACTRAC DYNAMIC

Dedicated workflows for specific patient needs

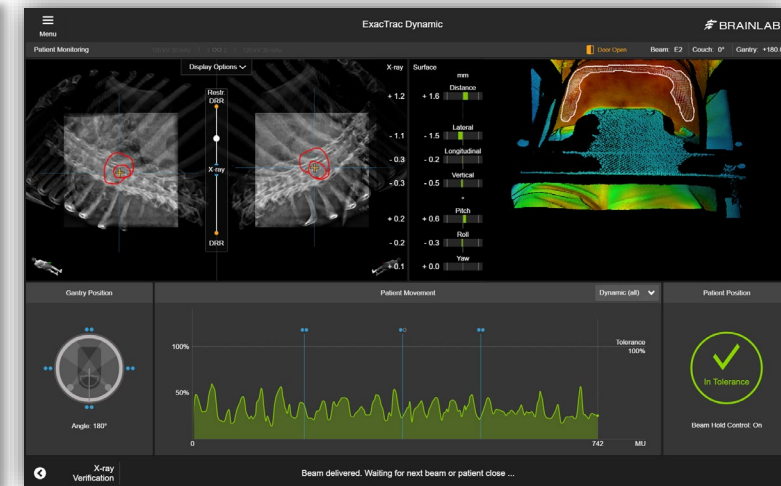
Standard ExacTrac X-Ray & Surface Positioning Workflow



Cranial Radiosurgery for highest precision



Head & Neck treatments



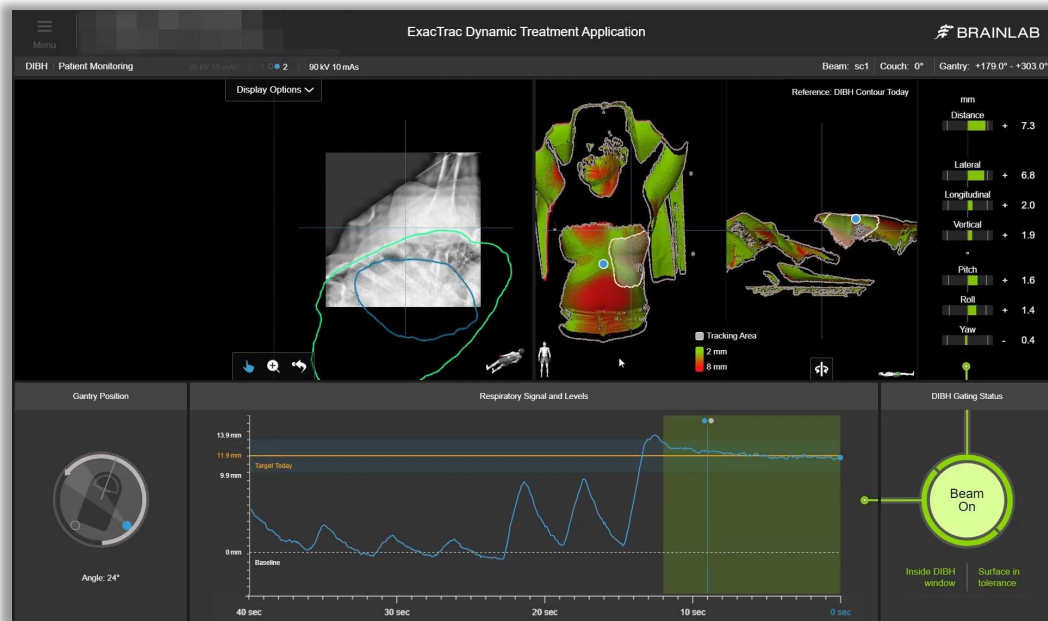
Spine SBRT treatments

Positioning, monitoring and repositioning at any couch angle

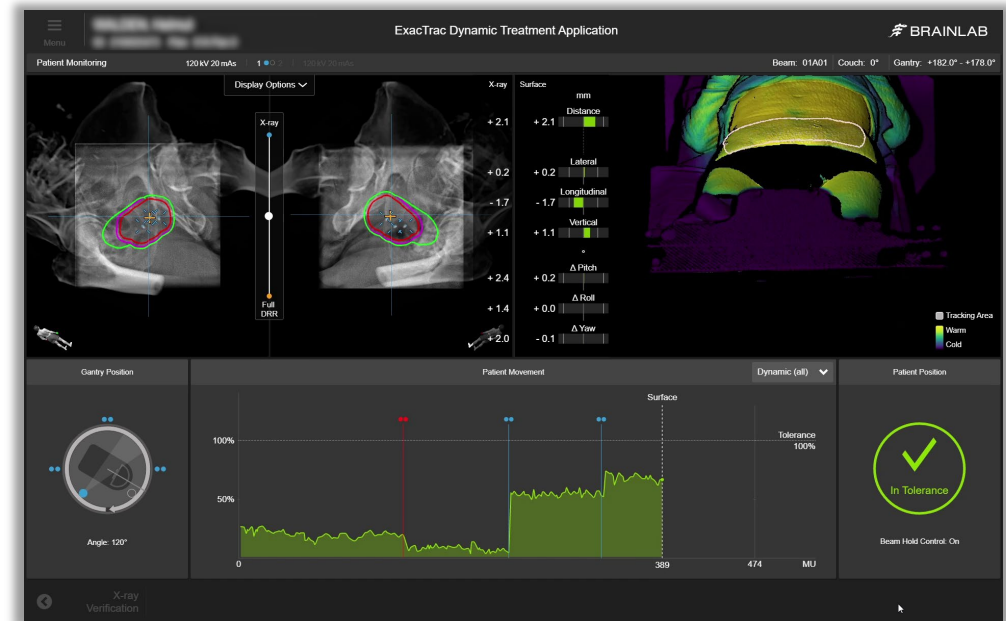
EXACTRAC DYNAMIC

Dedicated workflows for specific patient needs

Dedicated Workflows for Extra-Cranial Treatments



Breast treatments with the Deep Inspiration Breath Hold Workflow*

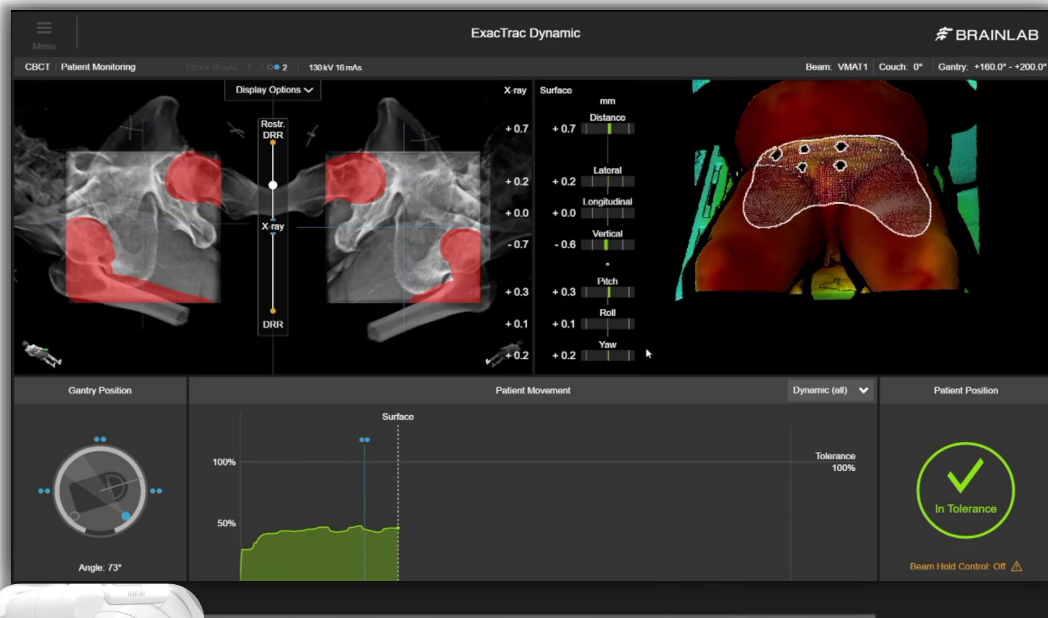


Prostate treatments with Implanted Marker Workflow

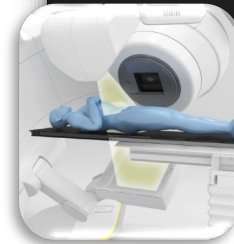
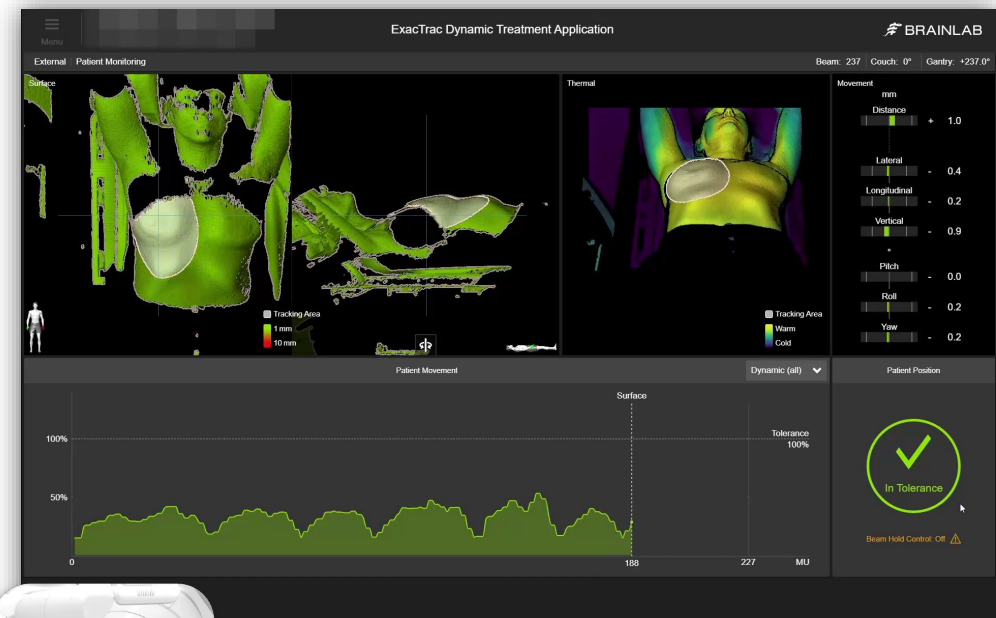
EXACTRAC DYNAMIC

Dedicated workflows for specific patient needs

Integrated CBCT Workflows for Soft Tissue Positioning



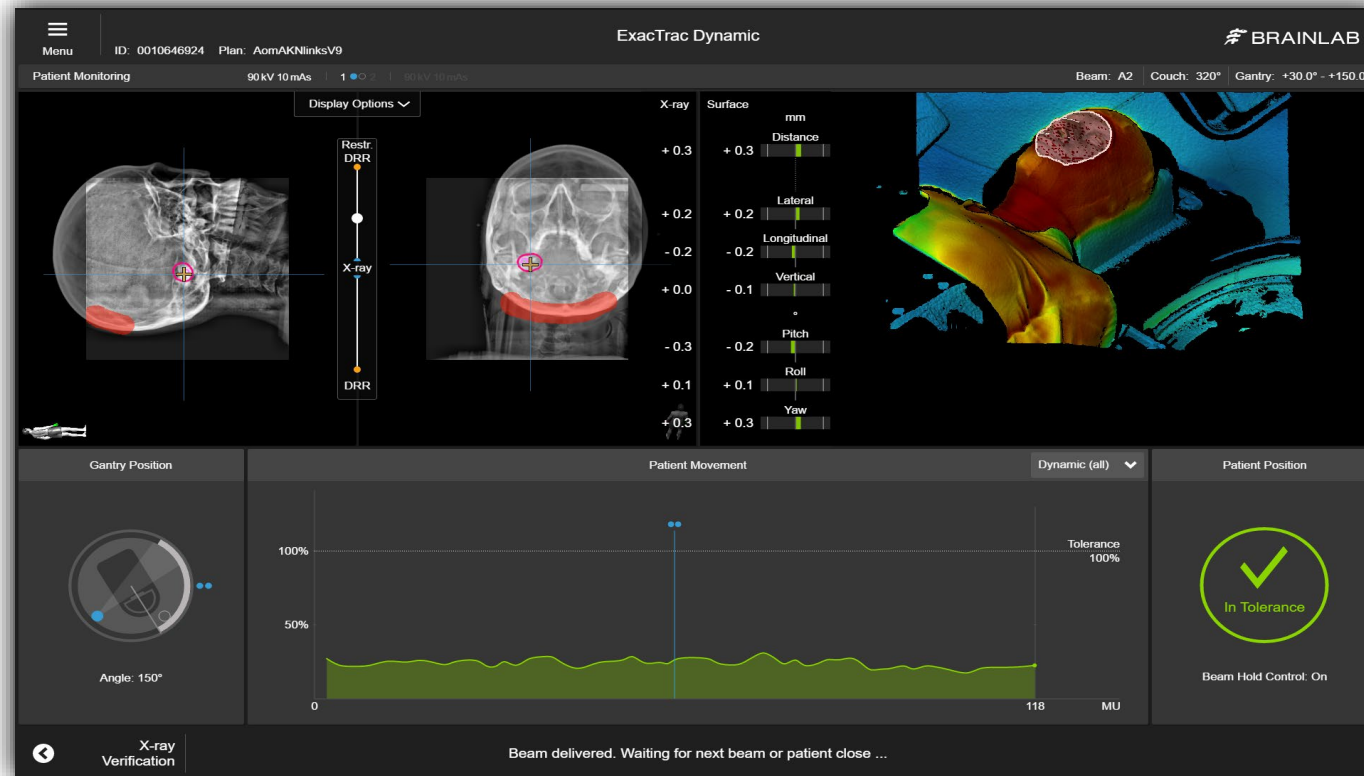
CBCT for positioning and ExacTrac for monitoring and repositioning



CBCT positioning and ExacTrac for surface-based monitoring*

EXACTRAC DYNAMIC STD. WORKFLOW

Internal anatomy verification at any couch angle



Setup

ExacTrac Automatic surface prepositioning

ExacTrac Positioning

Stereoscopic X-Ray images fused with DRRs from the treatment planning CT

Monitoring and Repositioning

ExacTrac continuous surface monitoring and automatic X-Ray imaging at coplanar and non-coplanar fields

- Triggered by monitor units, gantry angle, surface motion
- Quick correction if shifts detected, full 6DOF couch integration

CRANIAL SRS/SRT

4Pi hardware

February 7, 2023

CRANIAL 4Pi IMMOBILIZATION

New light-weight design and improved usability

- Dose optimized and minimalistic design*
- Compatible with multiple couch tops
- Light weight 4 Kg (current system: 9 Kg)
- Multiple mask types



CRANIAL 4Pi IMMOBILIZATION

Multiple mask types



Cranial 4Pi Stereotactic Mask



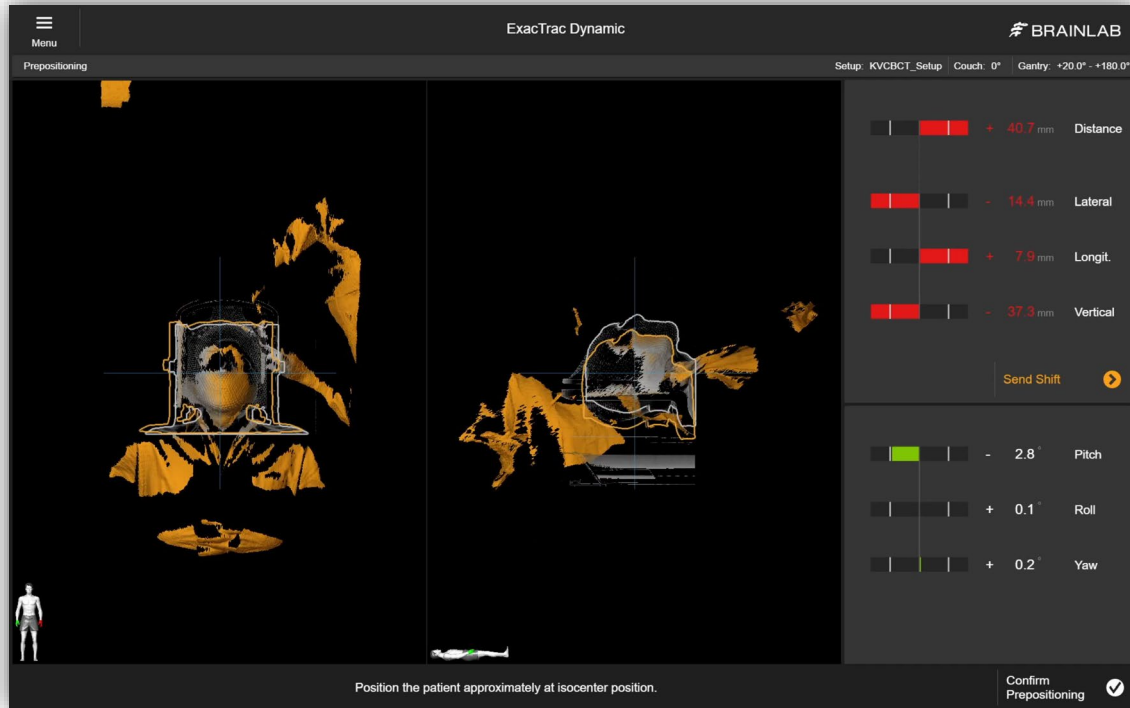
Cranial 4Pi Open Face Mask



Cranial 4Pi Basic Mask

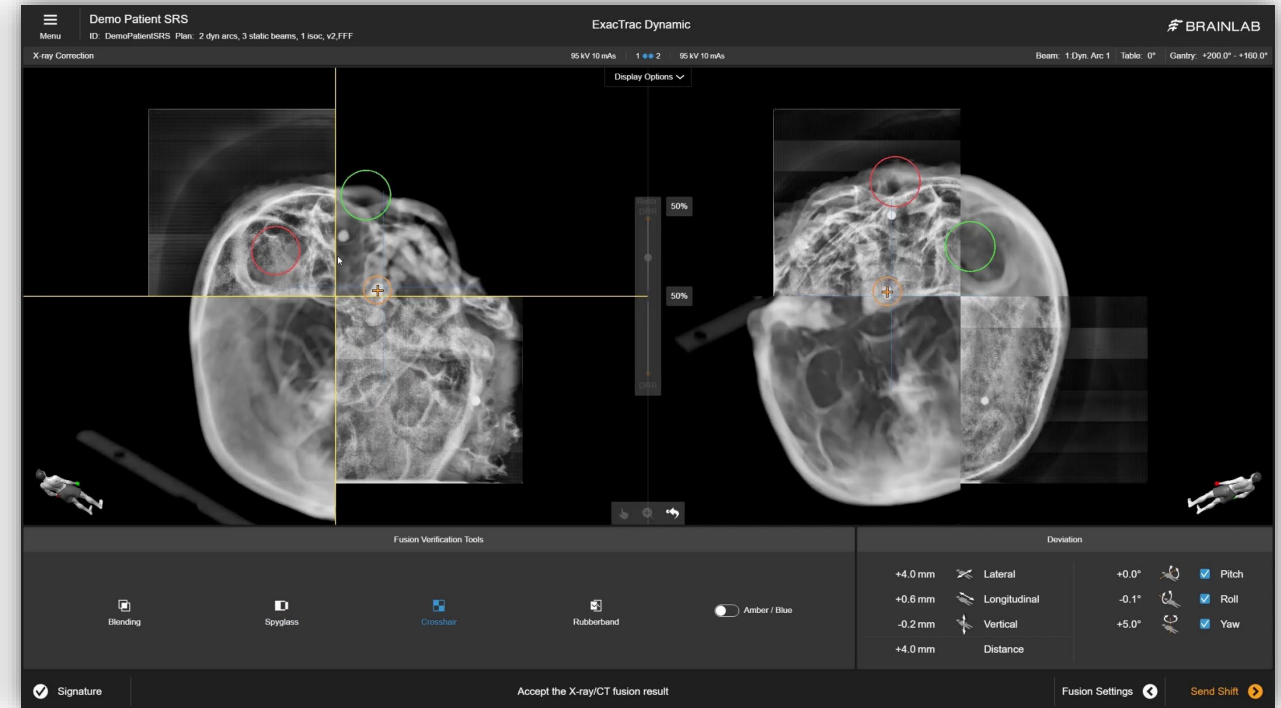
CRANIAL SRS POSITIONING

Quick setup with sub-millimeter position accuracy



Setup

ExacTrac Automatic surface prepositioning

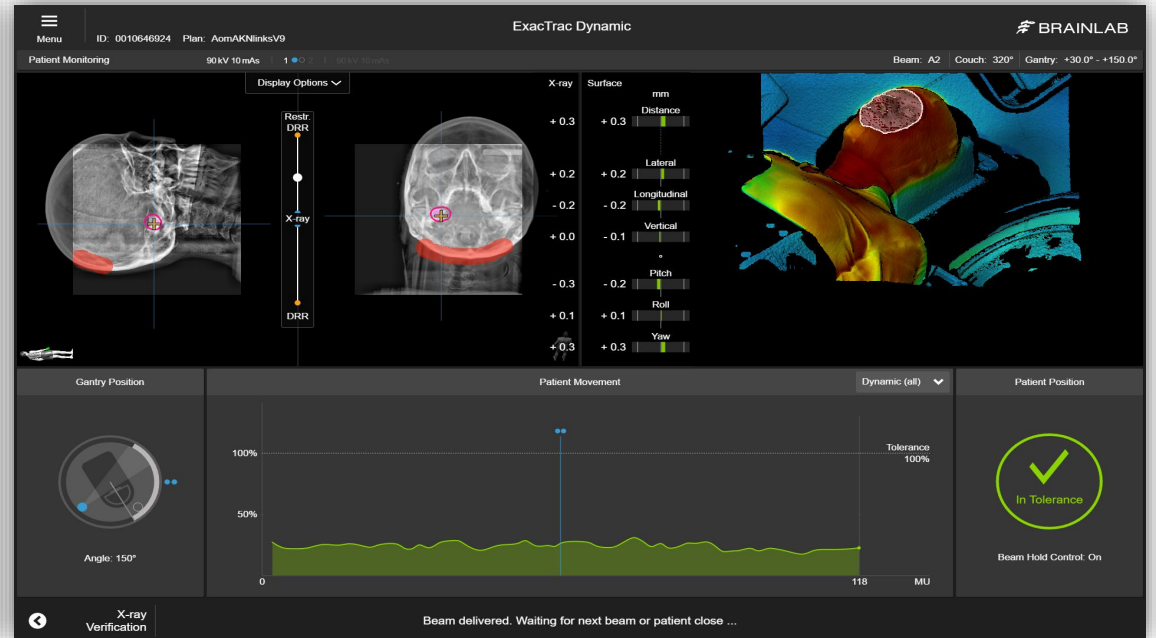
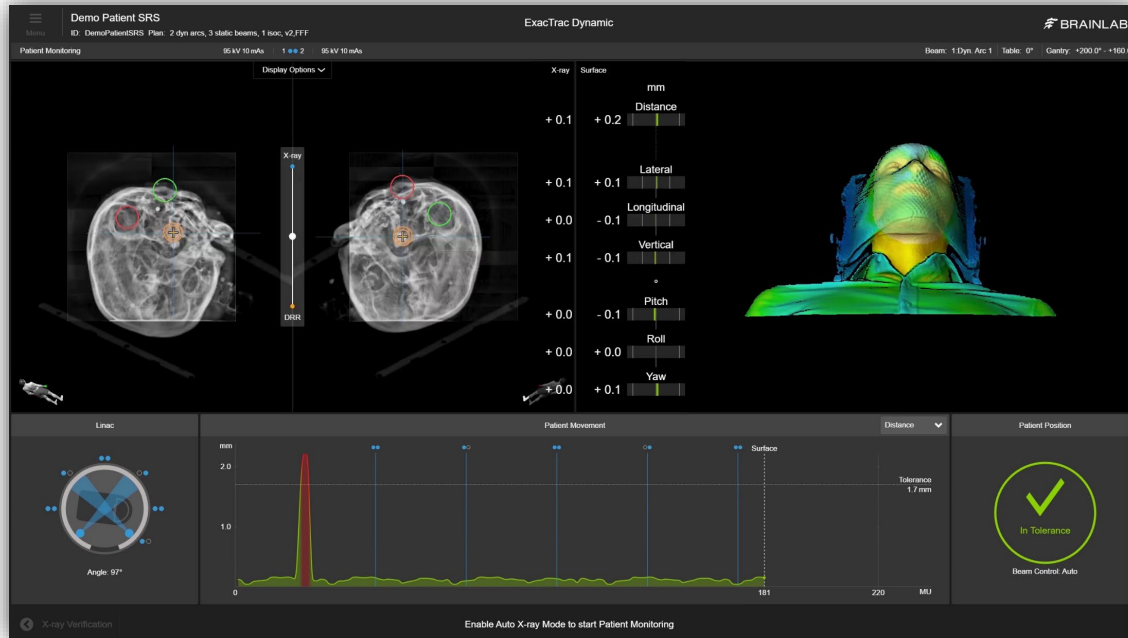


ExacTrac Positioning

Stereoscopic X-Ray images fused with DRRs from the treatment planning CT

CRANIAL SRS MONITORING

Internal anatomy verification & correction at any couch angle



Surface monitoring and automatic X-Ray imaging at coplanar and non-coplanar fields

- Triggered by monitor units, gantry angle, surface motion
- Quick correction if shifts detected with full 6DOF couch integration



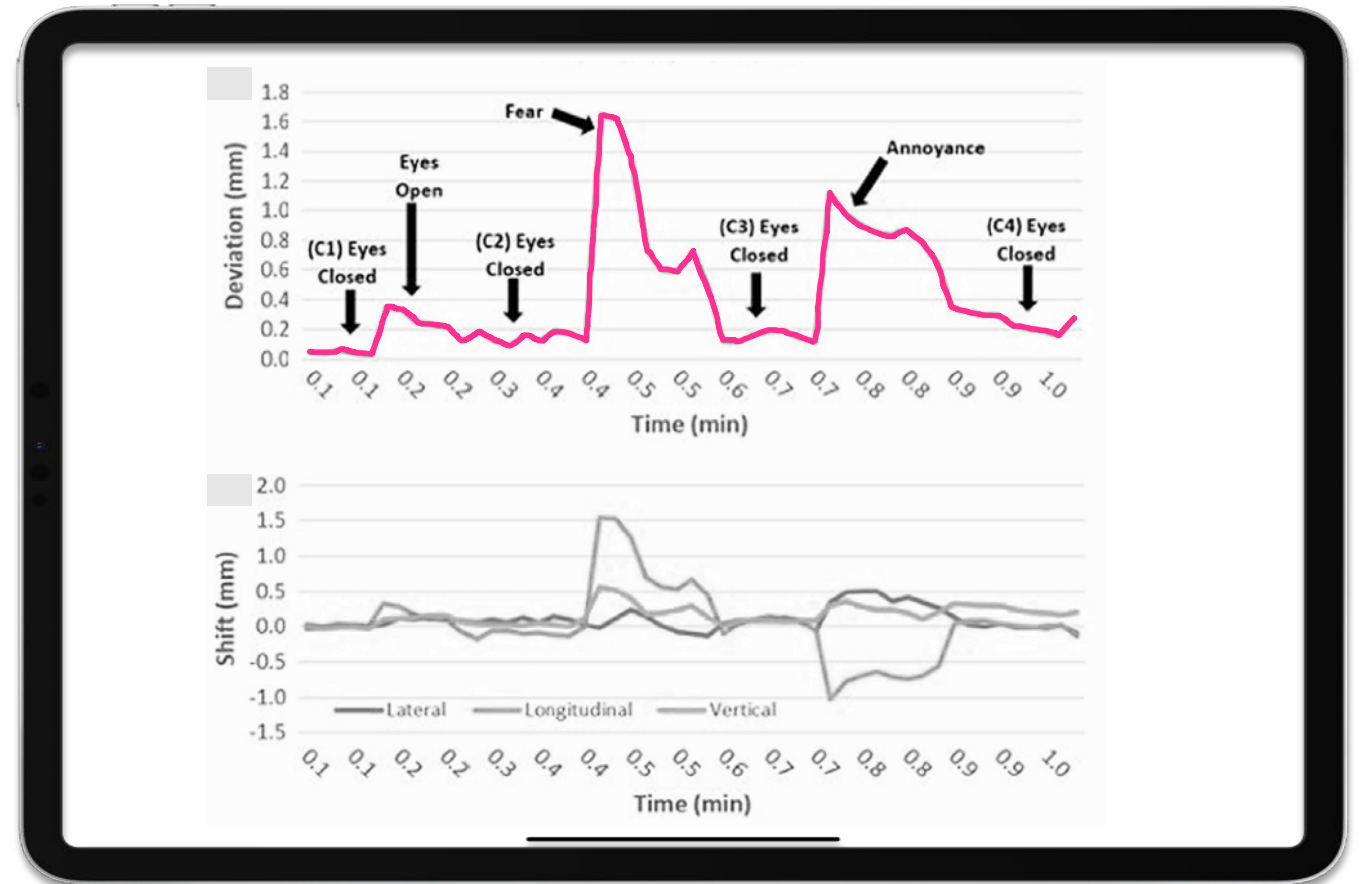
Back

Next

FALSE POSITIONAL CORRECTIONS

Due to facial motion, recorded deviation over 1 min interval

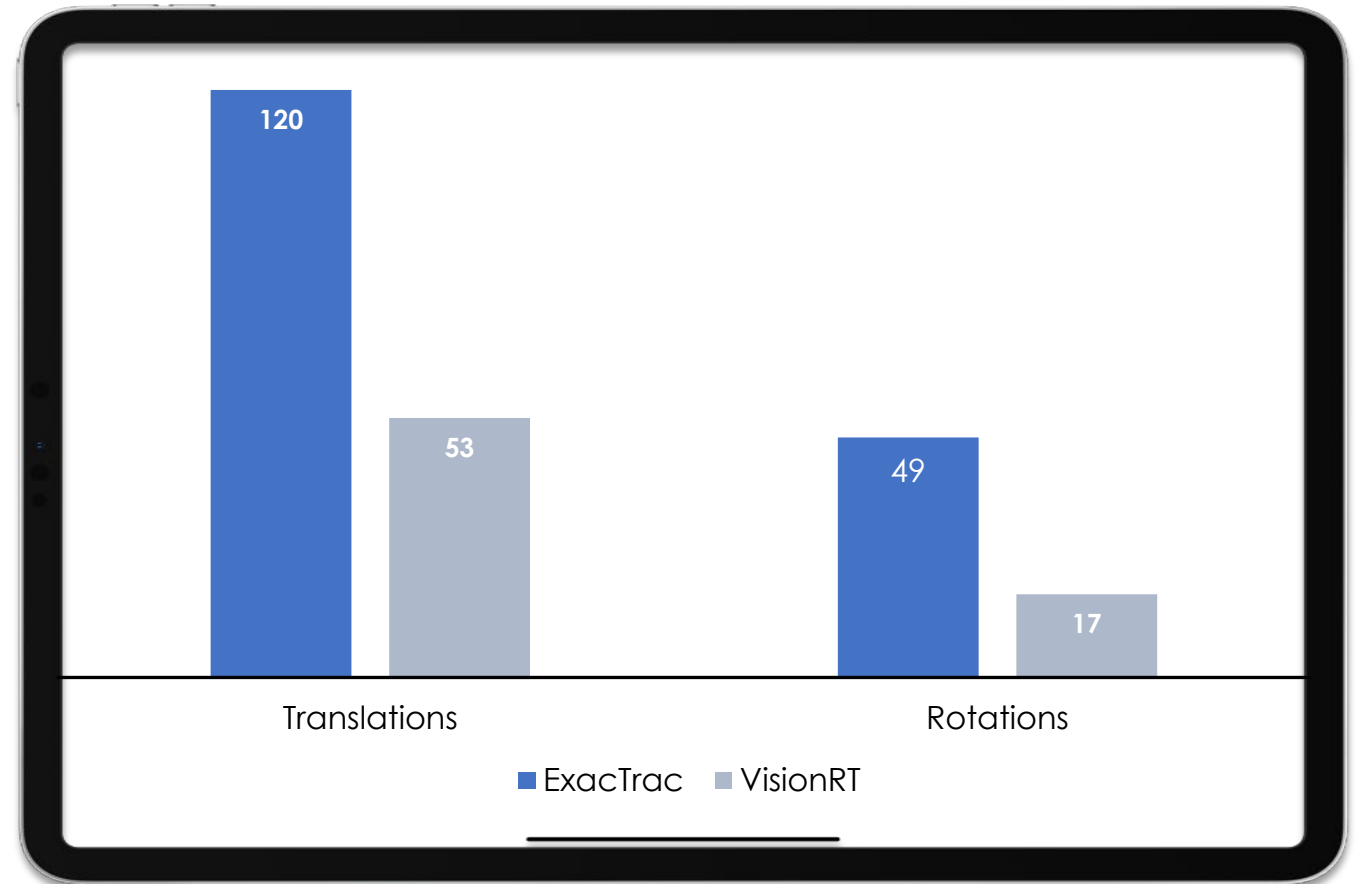
- C-RAD Catalyst was found to generate false positional corrections for facial motion
- The average deviation observed due to changing facial expressions was 1.4 ± 0.9 mm and up to 8 mm
- Up to 1.1mm isocenter shift was observed for a relaxed facial expression with eyes closed, for the two largest and most practical ROIs
- These errors may warrant additional radiographic imaging



OSMS LIMITATIONS IN DETECTING REAL SHIFTS

Out-of-tolerance detection sensitivity

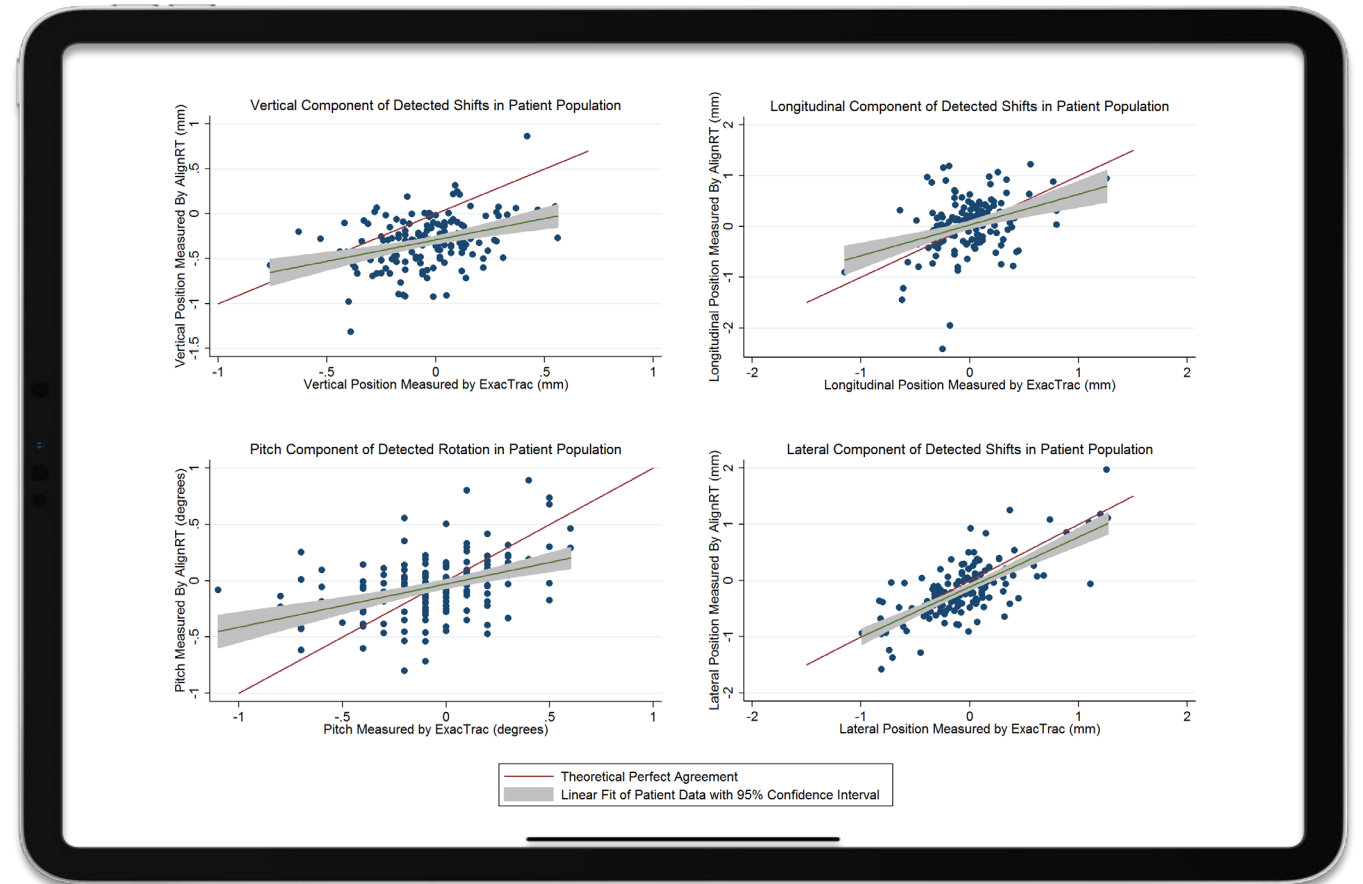
- 62 Cranial SRS patients evaluated (not phantoms)
- ExacTrac detected 120 translations and 49 rotations greater than a threshold of 0.7mm/°
- Only 44% and 35% of those were detected by VisionRT
- Despite improvements in software and calibration procedures, the accuracy for VisionRT was found to remain better when the table is not rotated



DISCREPANCY BETWEEN OSMS & IGRT IN PATIENTS

1:1 agreement between the systems was not found ($p < 0.05$)

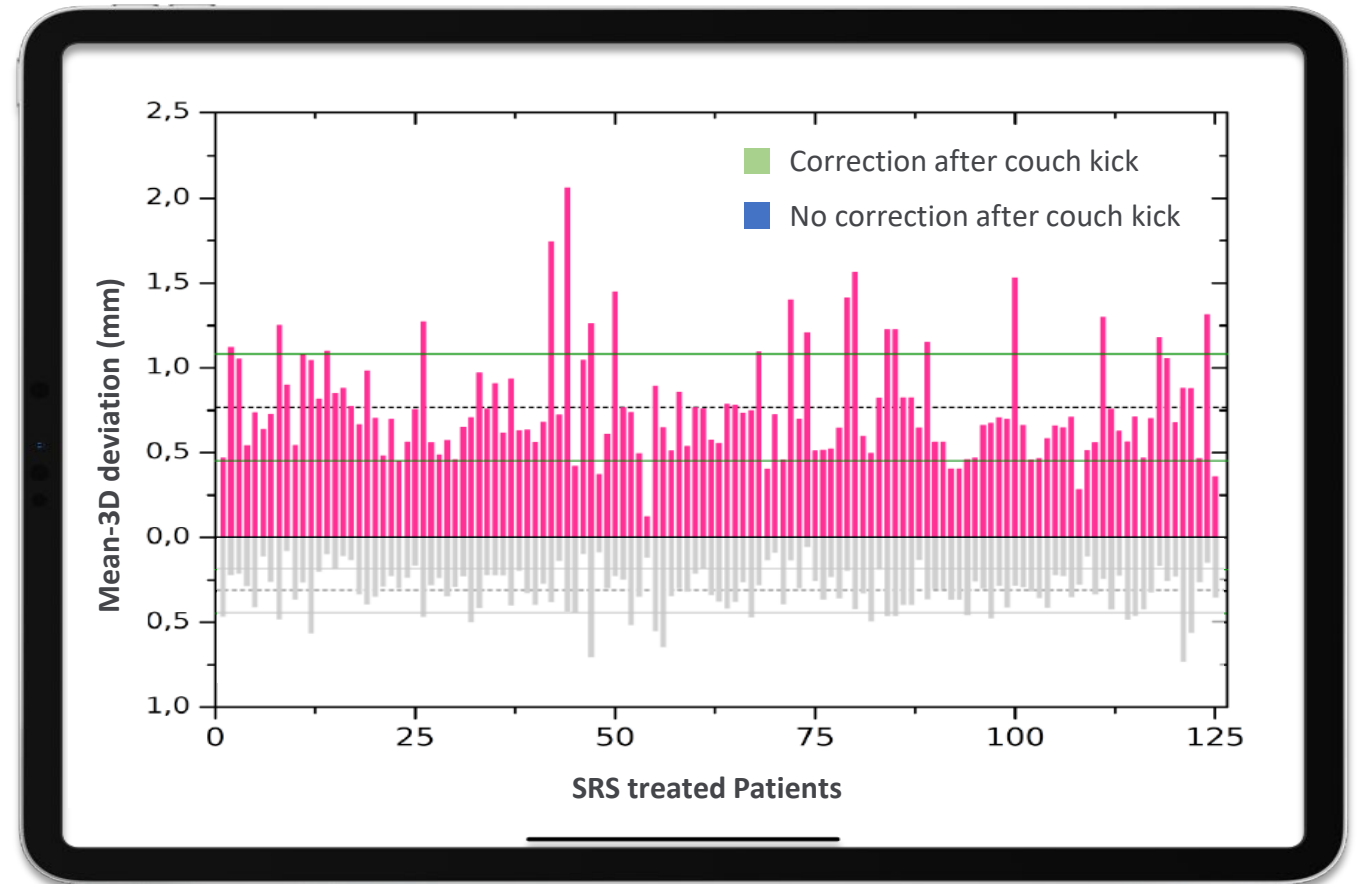
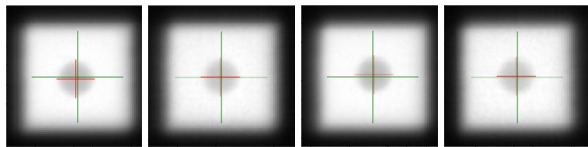
- ExacTrac and VisionRT agreed using phantoms, but not in real patients
- 156 treatment checks (blue dots) analyzed across 43 unique patients
- A shift of 1mm or 1° measured by ExacTrac would on average be measured as smaller by VisionRT
- The disagreement became larger as the systems measured larger shifts
- The two systems disagreed by more than 1mm and up to 2.4mm in 12.8% of the treatment checks



2/3 COUCH KICKS REQUIRED

Setup errors with and without ExacTrac

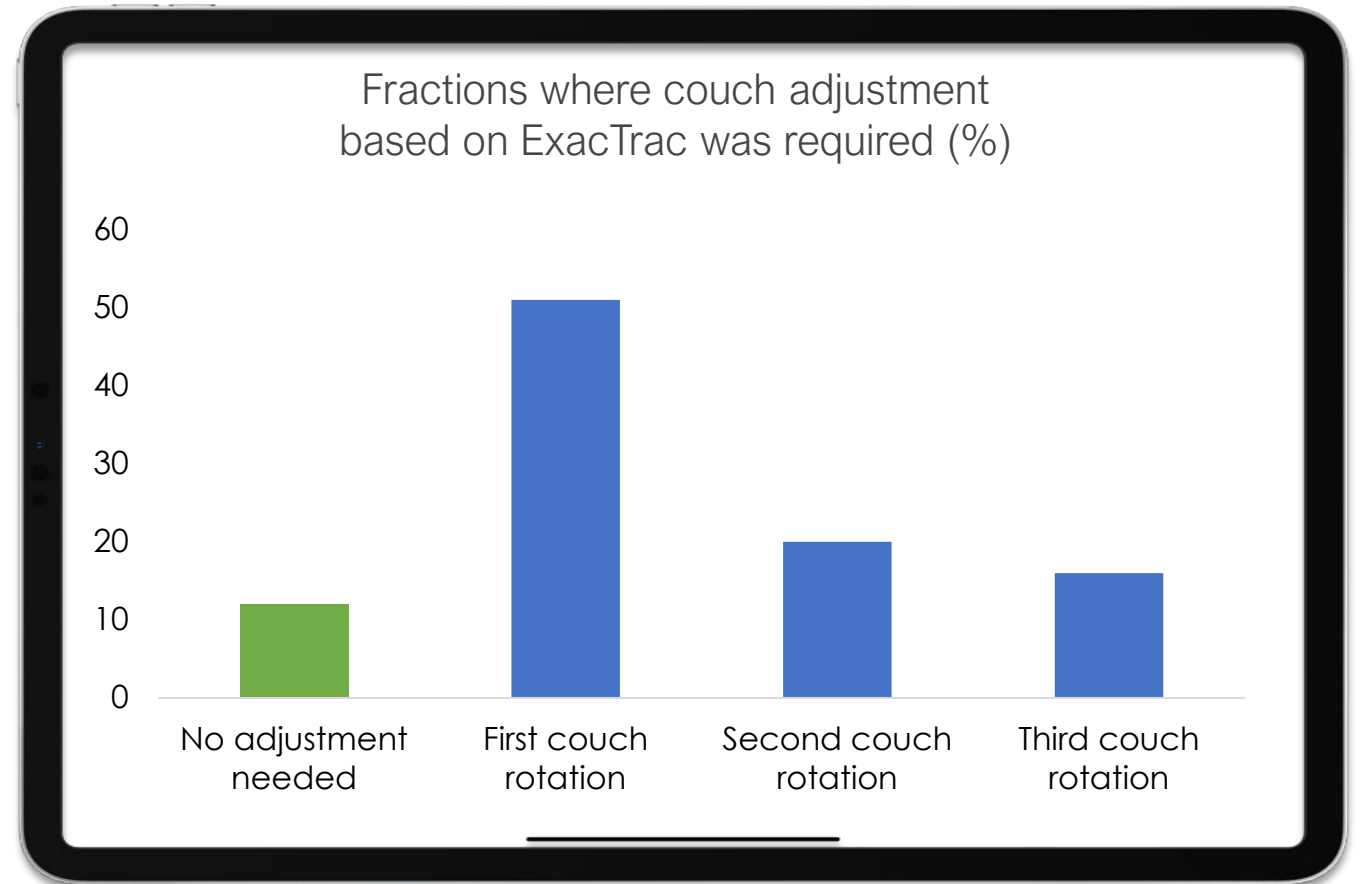
- Imaging with ExacTrac for all non-coplanar arcs of single-isocenter plans revealed intrafraction motion:
 - Deviations as large as 2mm
 - 66% of all couch kicks required repositioning to be within tolerance (0.5mm/0.5°)
- Deviations were not caused by couch inaccuracies



EXACTRAC WAS REQUIRED IN SPITE OF 2mm MARGIN

To ensure desired dose coverage

- Intrafraction motion with the Qfix mask system for 100 patients treated with HyperArc
- For brain metastases within 3cm from the plan isocenter, initial IGRT is sufficient to ensure brain metastases coverage when a 2mm margin is applied
- For brain metastases situated further than 3cm from the plan isocenter, dose coverage was only ensured by using ExacTrac – despite a 2mm margin





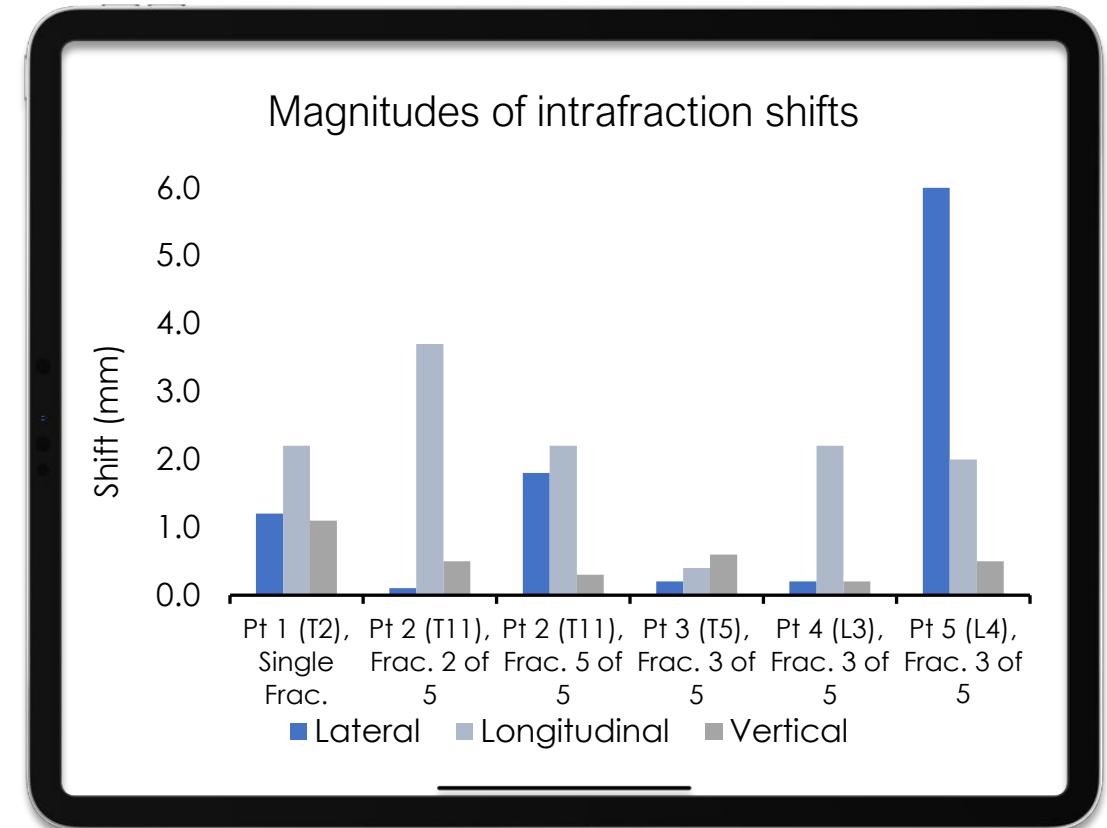
SPINE TREATMENTS

February 7, 2023

SPINE RADIOSURGERY

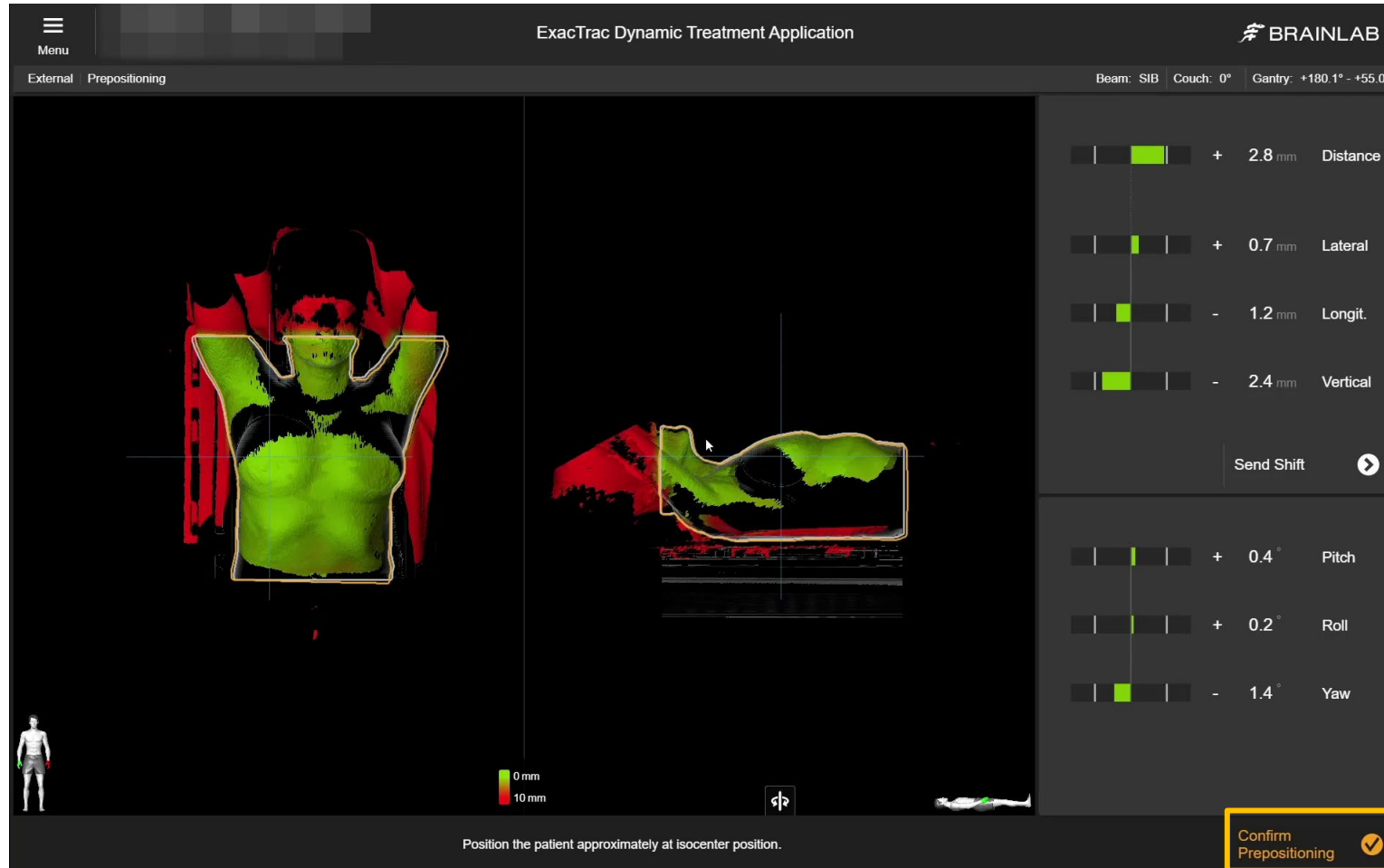
Intrafraction motion is not eliminated with immobilization systems

- Although immobilization devices are often used in spine SBRT, it is important to realize that **intrafraction motion in excess of 2–3mm can still occur** and that the importance of accurate and frequent verification is not reduced
- Occurrences of large shifts appear to be unpredictable and not correlating with the treatment site
- The frequency of large shifts cannot be estimated from small studies where the distributions are generally characterized by the mean and standard deviation
- Additionally, studies have reported that intrafraction displacements are not normally distributed, making estimates of outliers unreliable
- **The graph depicts six treatments where couch correction was required.** Patient 1 was immobilized using a head-and-shoulder thermoplastic mask. All others were immobilized in a full-body stereotactic immobilization system.



SURFACE ONLY WORKFLOW

Prepositioning

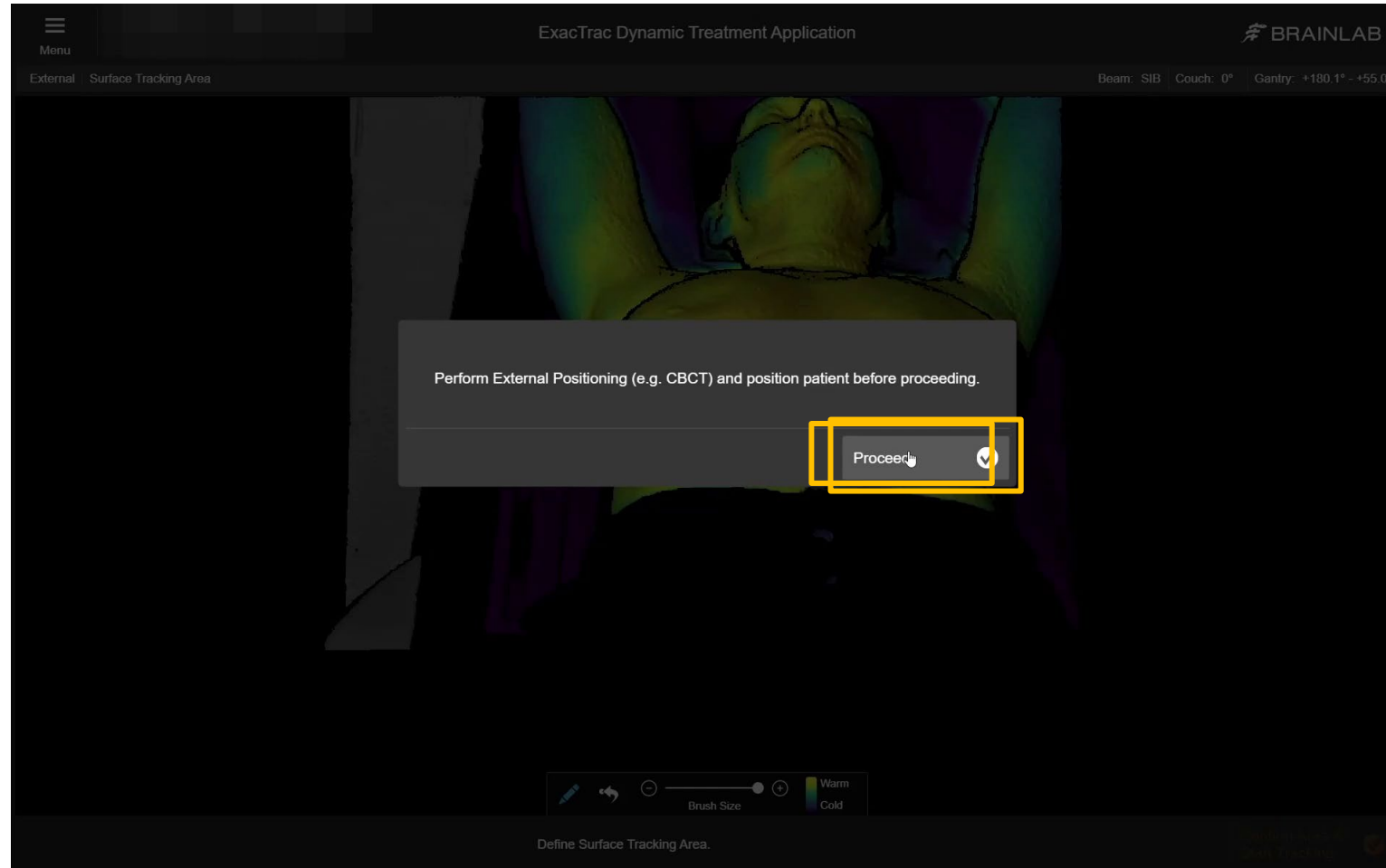


Prepositioning

- Based on CT outer contour
- Color coding for postural alignment

SURFACE ONLY WORKFLOW

External CBCT positioning

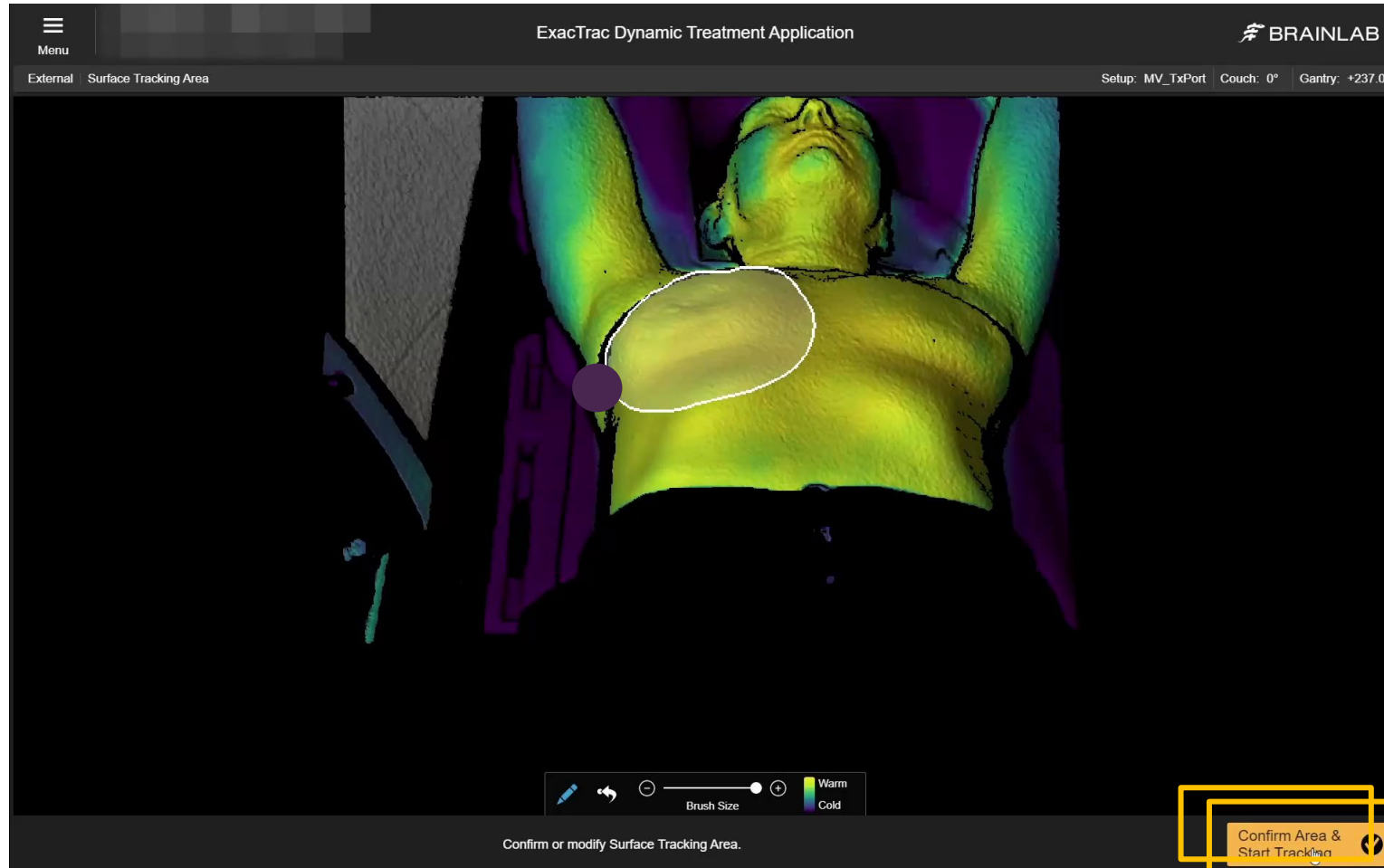


External positioning

- Only applicable at couch angle 0°

SURFACE ONLY WORKFLOW

Surface tracking area selection

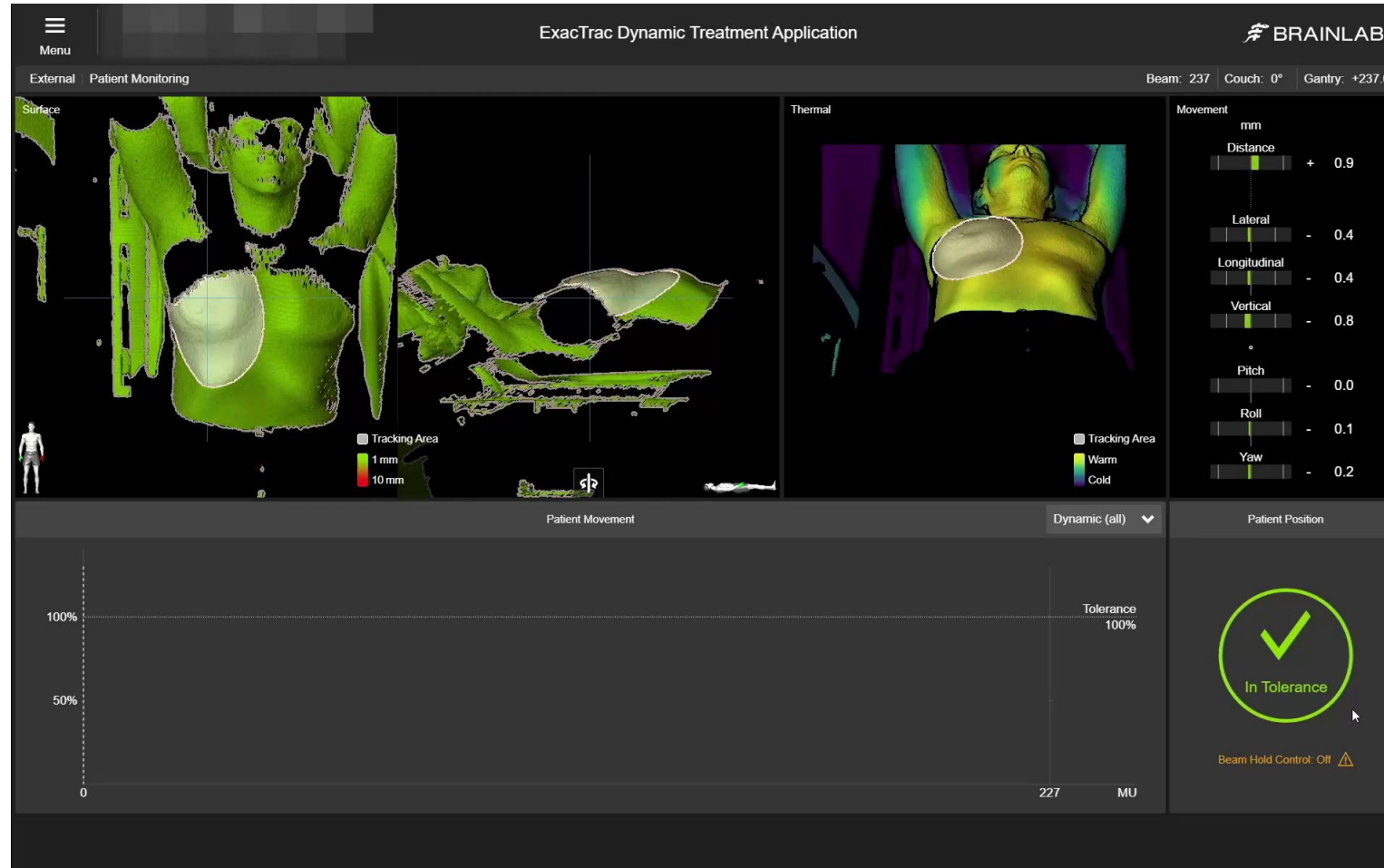


Surface tracking area selection

- Selected area is saved for monitoring

SURFACE ONLY WORKFLOW

Patient monitoring



Patient within tolerance

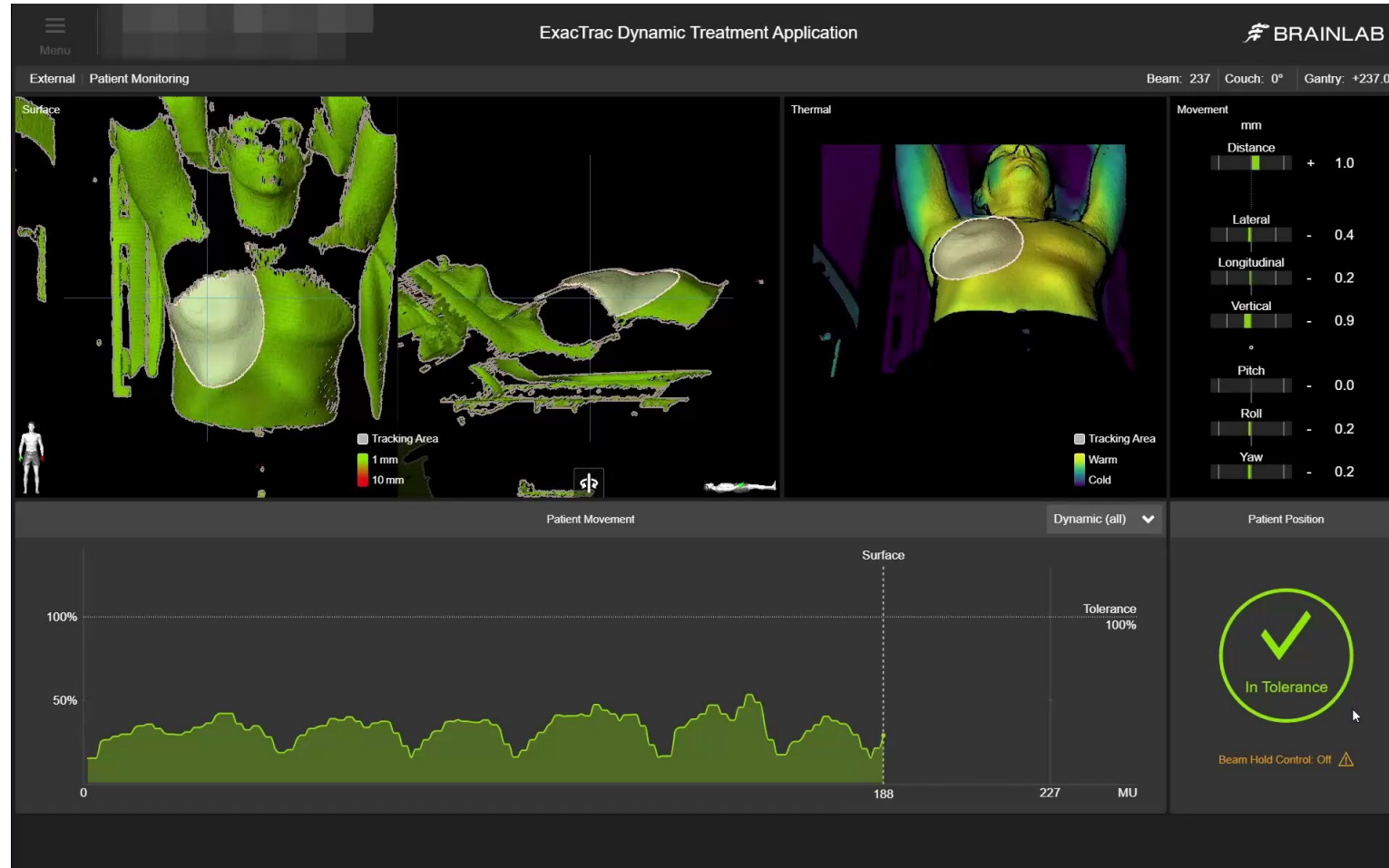
Green color-coding shows patient's live surface is within tolerance. Also indicated by:

- Deviation bars
- Patient position indicator (check mark)

Treatment is ready to begin

SURFACE ONLY WORKFLOW

Patient monitoring



Motion within tolerance

- Set tolerances allow for breathing motion

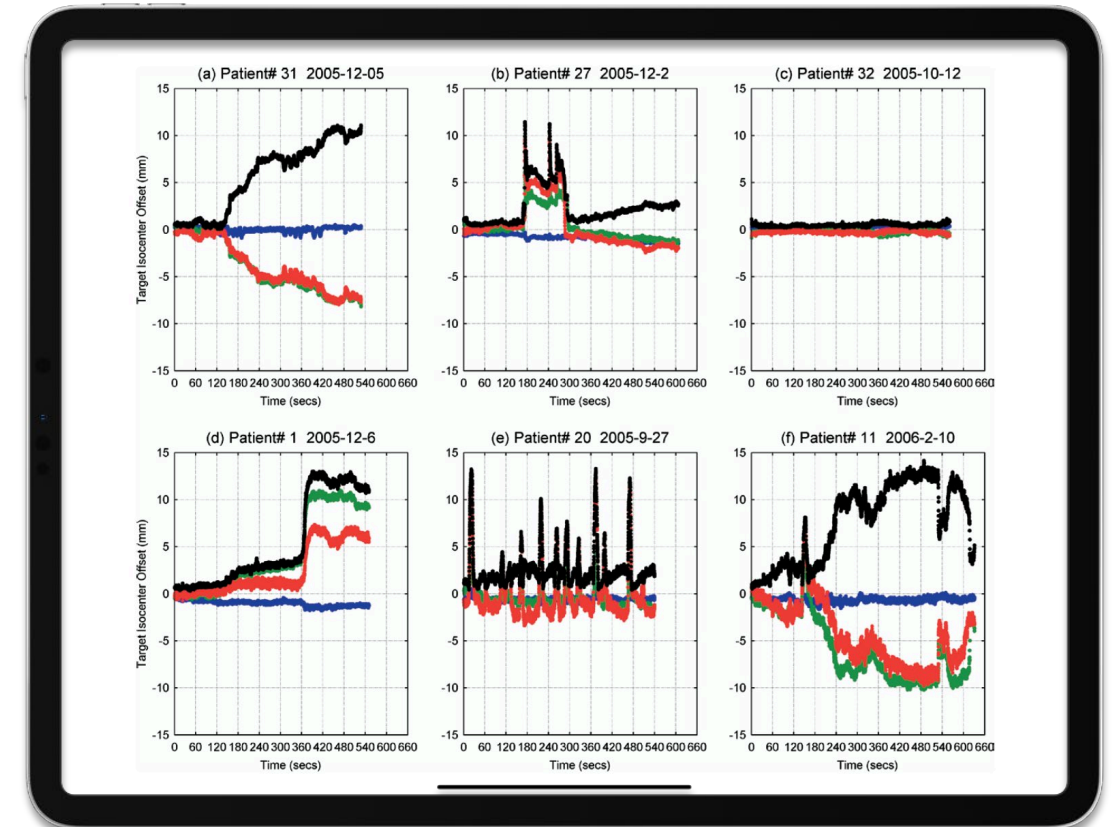
PROSTATE SBRT

February 7, 2023

PROSTATE SBRT

The frequency and extent of intrafraction motion can be significant

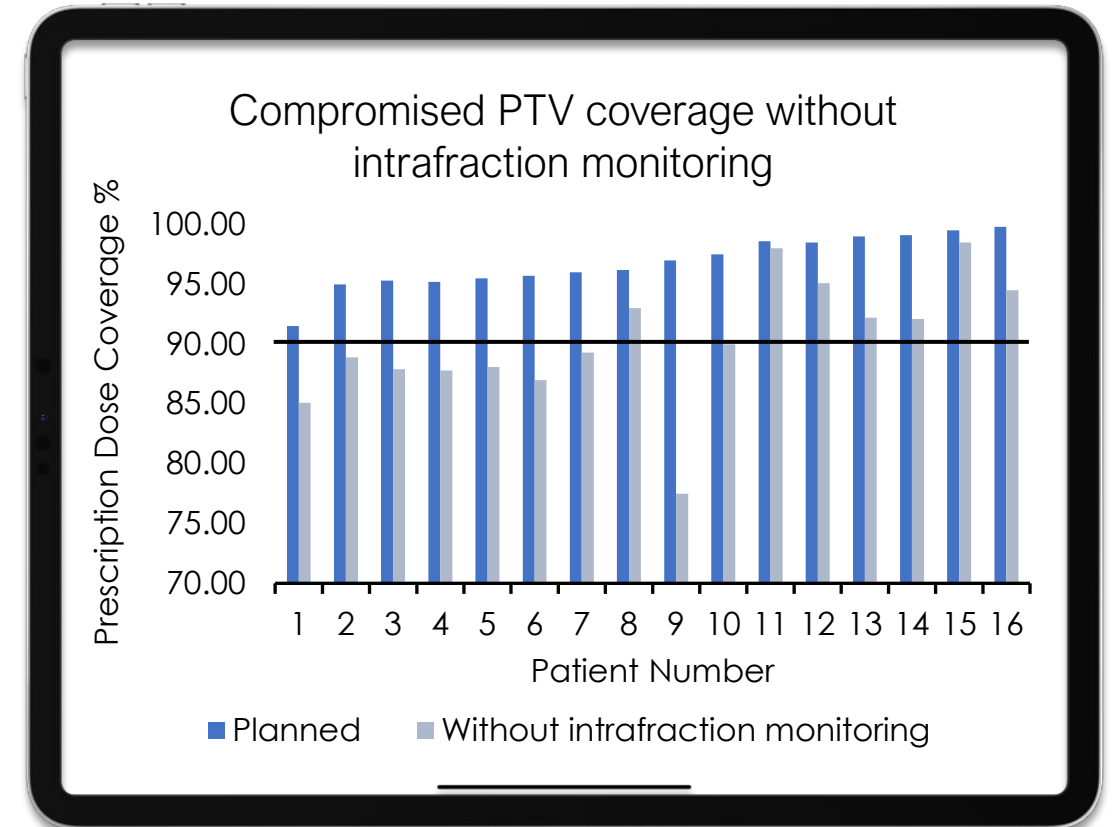
- Prostate motion can vary from persistent drift to transient rapid movements
- Displacements of ≥ 3 or ≥ 5 mm for cumulative durations >30 s has been reported in 41% and 15% of fractions
- In individual patients, the number of fractions with displacements >3 mm can range from 3% to 87%
- Up to 56% of fractions in any given patient can show displacements ≥ 5 mm
- The graphs depicts examples of behaviors observed: (a) continuous target drift; (b) transient excursion; (c) stable target at baseline; (d) persistent excursion; (e) high-frequency excursions; (f) erratic behavior. Red: vertical, green: longitudinal, blue: lateral, black: vector length



PROSTATE SBRT

Clinical impact of intrafraction monitoring

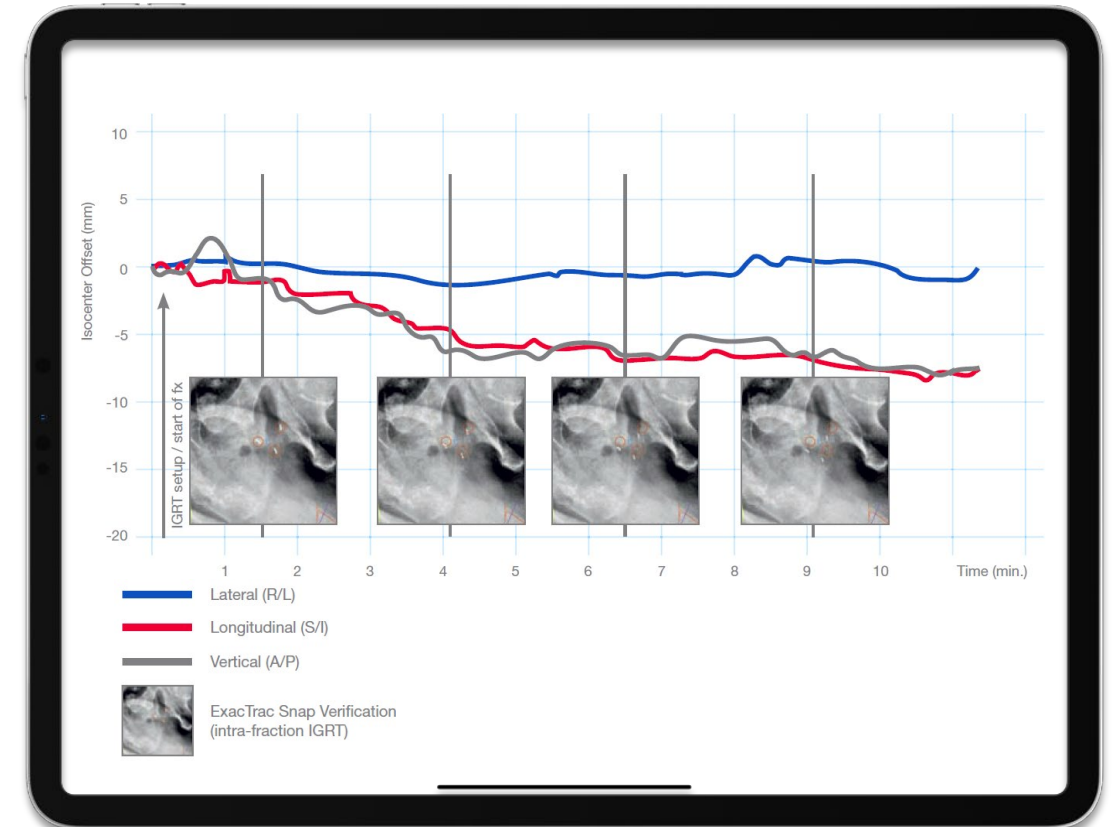
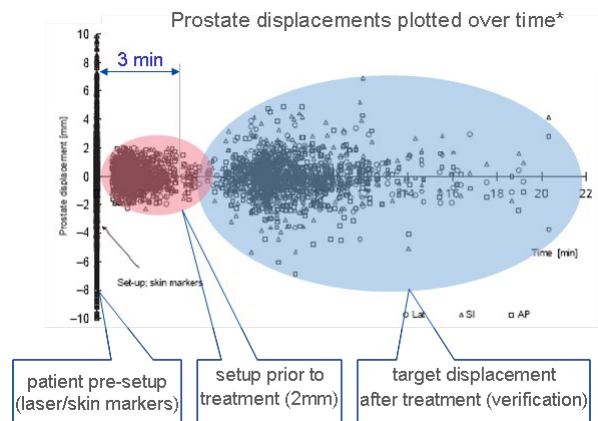
- The role of IGRT has increased in importance as studies have shown a benefit in dose escalation while balancing the toxicity profile is just as crucial in clinical practice
- The graph depicts 16 SBRT patients exhibiting frequent posterior shifts during treatment
 - 56% of these patients would not meet PTV coverage requirements without intrafraction monitoring for prostatic drift
- Intrafraction motion can result in approximately 10% of patients having a delivered dose that does not meet clinical coverage requirements for SBRT



PROSTATE DRIFT

Daily prostate drift detected by ExacTrac implanted markers

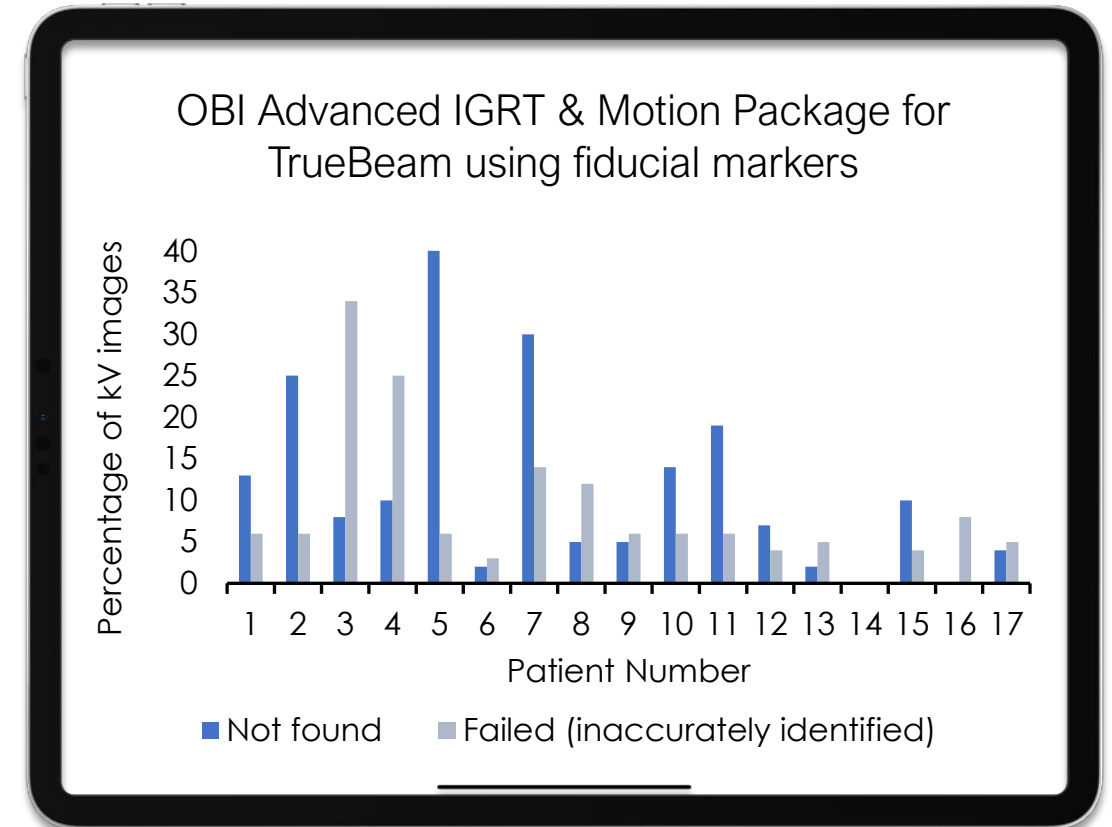
- › Possible prostate drift from the isocenter in 3 dimensions over a 10 min treatment fraction
- › 9.0 min mean treatment time (patient setup to beam-off)*
- › Majority of IGRT setups completed within 3 min*
 - › $\pm 2\text{mm}$ prostate positioning accuracy*
- › Prostate intra-fraction can be verified (Snap Verification)
- › Motion can be significant



PROSTATE SBRT

Motion management limitations of various IGRT technologies

- Intrafraction prostate motion appears to be driven primarily by rectal peristalsis and less with respiratory patterns and variation in pelvic muscular tension
 - Optical surface monitoring is of limited value
- Limitations for the OBI to evaluate prostate motion with periodic kV imaging at certain angles
 - OBI limitations at 0° and 180° for the AP direction
 - Prostate motion is common in the AP direction due to bladder and rectum motion
- Limitations for electromagnetic tracking in patients with large body habitus
- These limitations can be avoided with a room-based kV system such as ExacTrac Dynamic



PROSTATE SBRT

Large rotations

Dedicated feature to handle large rotations of prostate

- Exclude rotations that have low relevance in round targets
- Surface tracking is based on partial shift

The screenshot displays the ExacTrac Dynamic Treatment Application interface. At the top, it shows the patient ID 'ANON_2021_6_7_10_37_30_285' and the plan 'PTV1'. The main area features two X-ray images of a prostate target, with a central overlay indicating rotation settings: 'Setting excluded rotation deviation to 0.00° for Surface Monitoring', 'Pitch: 0.00° instead of -15.33°', and 'Roll: 0.00° instead of -2.32°'. Below the images, a 'Deviation' panel is highlighted in yellow, showing settings for Pitch (-15.3°), Roll (-2.3°), and Yaw (+1.9°), with a checkbox for 'Set deviation rotation as reference position for surface' which is checked. The interface also includes a 'Fusion Verification Tools' section with options like Blending, Spyglass, Crosshair, and Rubberband, and a 'Review Compromise' button at the bottom right.

PROSTATE SBRT

Marker pattern

3DOF Positioning

- Fallback option if individual marker match causes issues
- Position implanted markers based on center of gravity

The screenshot displays the ExacTrac Dynamic Treatment Application interface. At the top, the patient ID is ANON_2021_6_7_10_37_30_285 and the plan is PTV1. The interface shows two side-by-side X-ray images of the prostate area. In the center of each image, a blue dashed box indicates the detected marker pattern, with a blue dot representing the center of gravity. An orange circle highlights the area around the markers. Below the images, there is a control panel with several sections:

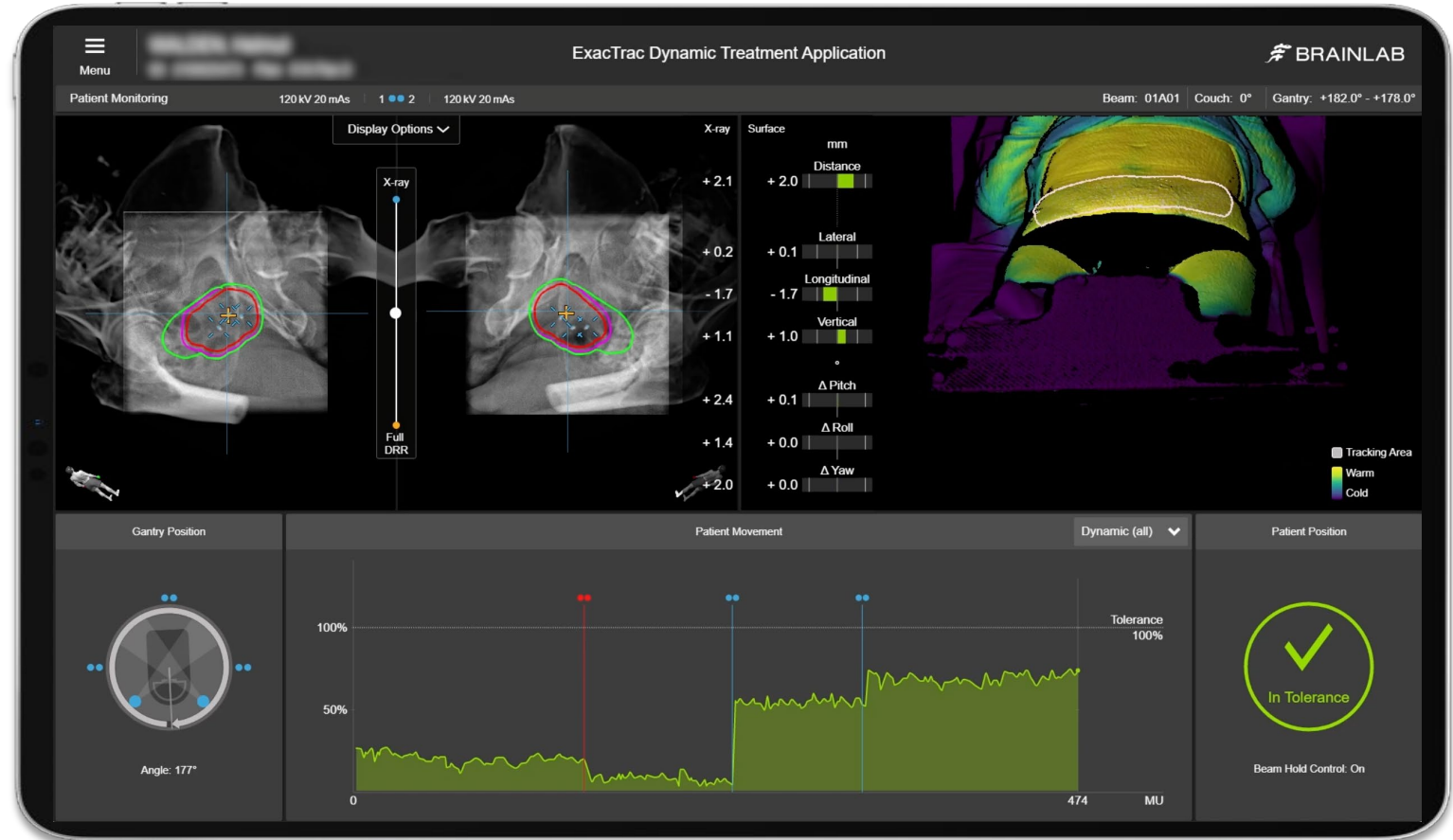
- Description:** Lists 'Detected Marker' (blue dashed box), 'Planned Marker (active)' (orange circle), 'Planned Marker (excluded)' (grey circle), and 'Center of Gravity' (blue dot).
- Detection Mode:** Shows 'Individual Markers' (radio button) and 'Marker Pattern' (radio button, highlighted with a yellow box). A note below reads 'X-ray monitoring not possible for this mode'.
- Detected Marker Tools:** Includes 'Move Pattern' (blue arrow) and 'Re-Detect' (refresh icon).
- Planned Marker Tools:** Includes 'Show Planned Marker' (toggle switch), 'Short Marker 1 (of 4)' (dropdown menu), 'Exclude' (minus icon), and 'Center' (plus icon).
- Viewing Tools:** Includes 'Center on Isocenter' (crosshair icon).

At the bottom of the interface, there is a status bar with the text 'Verify compromise fused marker positions.' and a 'Confirm Marker Position' button with a checkmark icon.

PROSTATE SETUP AND MONITORING

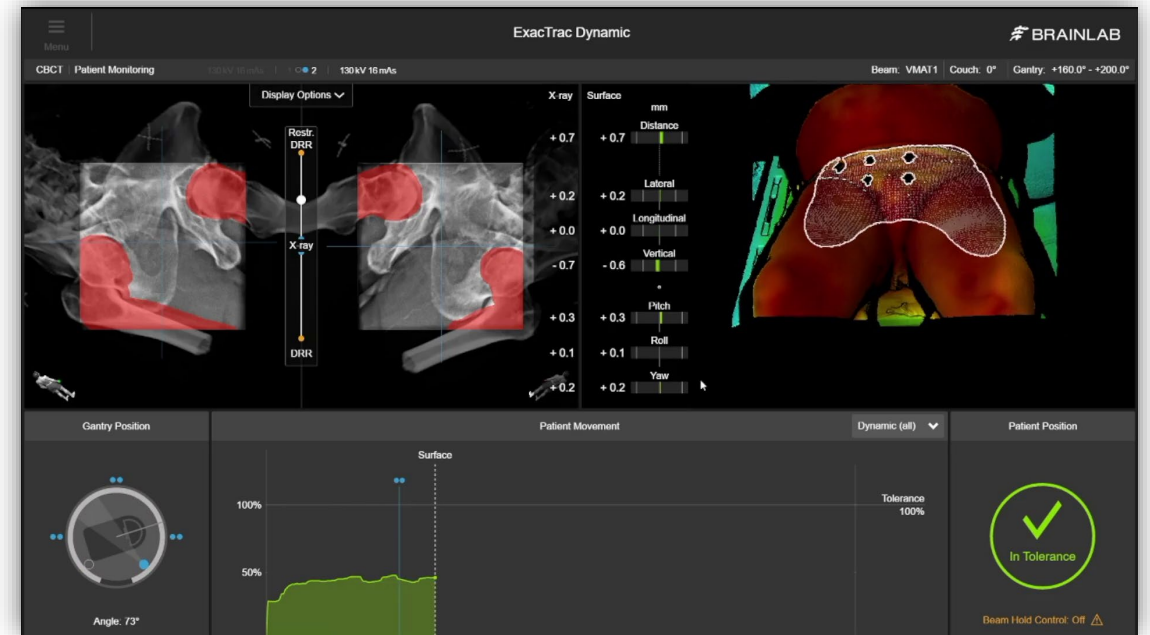
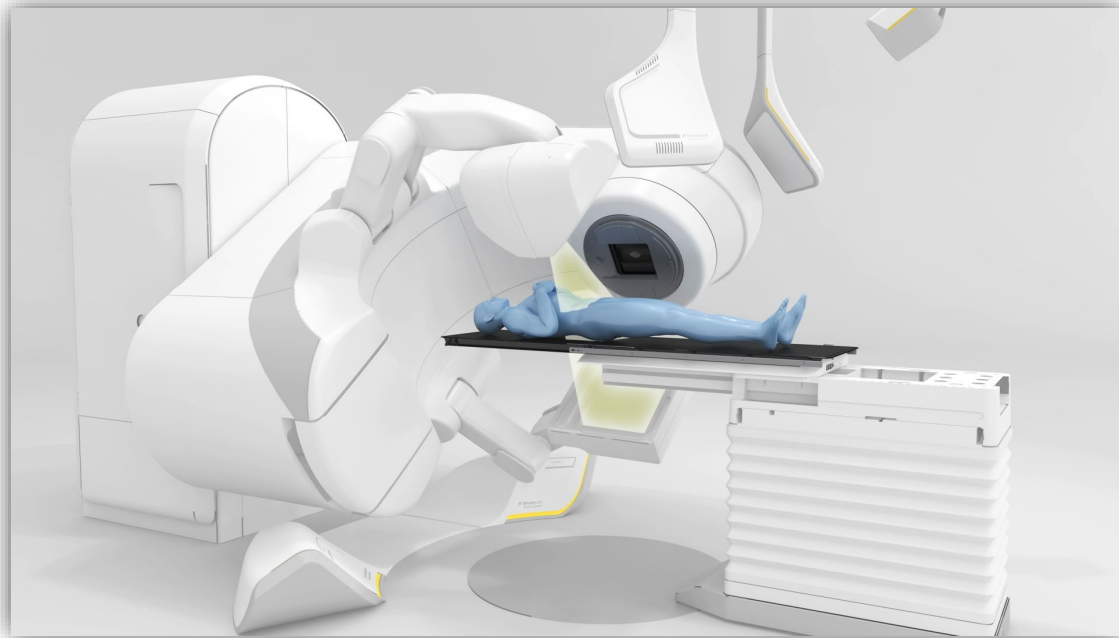
The implanted markers workflow

- SGRT setup without the need of simulation tattoos
- 4D tracking
- Automatic marker detection
- 6D Fusion
- Exclusion of large rotations
- DRR recalculation for restricted angles
- 3D Fusion to restricted DRRs
- Automatic couch correction for detected shifts
- SGRT intra-arc monitoring
- Automatic IGRT trigger for outside of tolerance motion



EXACTRAC DYNAMIC

CBCT workflow



Setup

ExacTrac **Automatic surface pre-positioning**

CBCT Positioning

CBCT is used to bring the patient to treatment position

Referencing

ExacTrac automatic acquisition of a **reference surface and reference X-Ray** at CBCT position

Monitoring & Re-Positioning

ExacTrac **continuous surface monitoring and automatic X-Ray imaging**

- Triggered by monitor units, gantry angle, surface motion
- Quick correction if shifts detected, full 6DOF couch integration

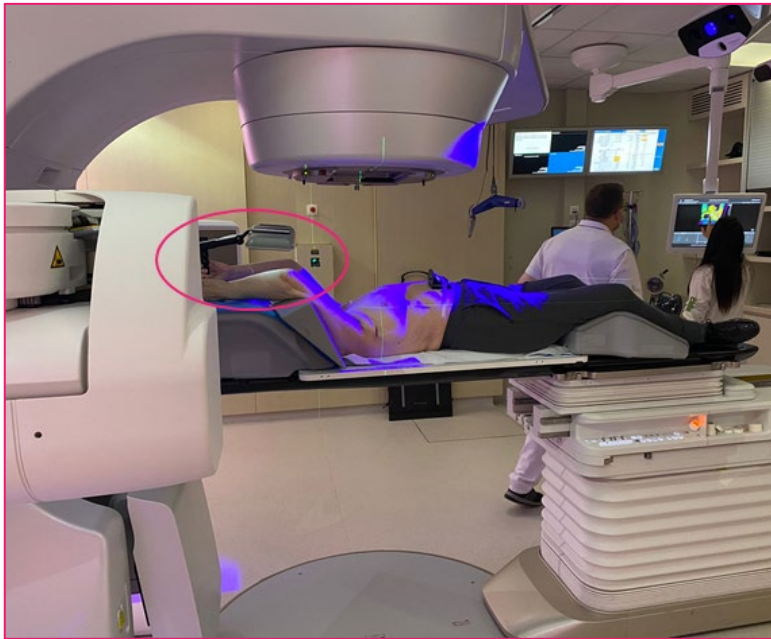


BREAST TREATMENTS

February 7, 2023

BREAST TREATMENTS

Breast DIBH



Deep Inspiration Breath Hold (DIBH)

Patient feedback system



BREAST SETUP

The addition of IGRT to SGRT can reduce random errors

Residual setup uncertainties for breast with SGRT has been reported to be $4.2\text{mm}^1 - 6\text{mm}^2$

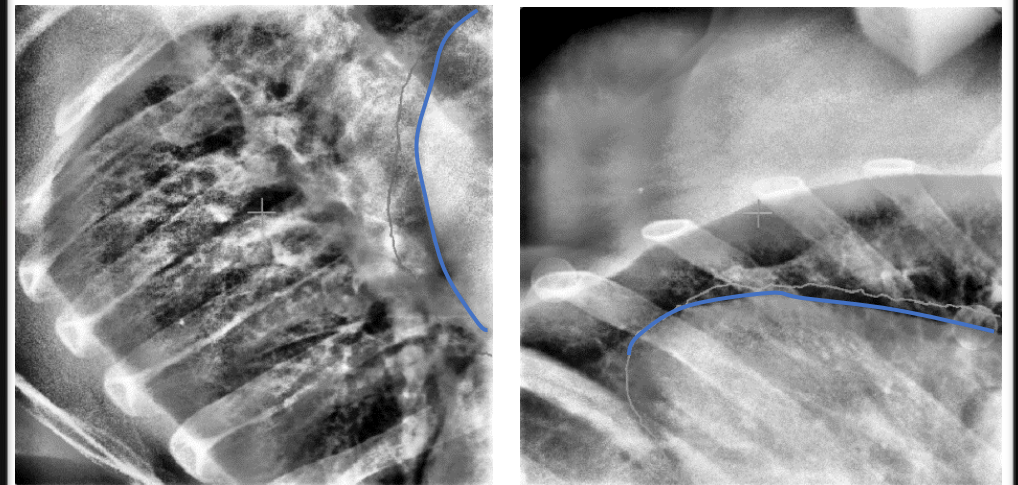
- SGRT did not prove accurate enough to replace the daily orthogonal kV images aligned to bony anatomy

Systematic residual uncertainties can be reduced from 3mm with SGRT only to $\leq 2\text{mm}$ with SGRT + IGRT³

- The clinical importance of this reduction may be questionable; however, also random errors were found to be reduced with the addition of IGRT
- With SGRT only, 5mm was exceeded in 10% of the fractions in the CC direction³

While the breath-hold level can be accurate within 2 mm, heart planning margin of up to 3–7mm may still be needed due to errors in pitch and CC movement

Verification of Heart Position with ExacTrac



¹⁾ Hattel et al. JACMP. 2019 Jun; 20(6): 39–44. doi: 10.1002/acm2.12599.

²⁾ Stanley et al. JACMP. 2017 Nov; 18(6): 58–61. doi: 10.1002/acm2.12183.

³⁾ Laaksomaa et al. JACMP. 2019 Mar; 20(3): 97–104. doi: 10.1002/acm2.12553.

BREAST DIBH

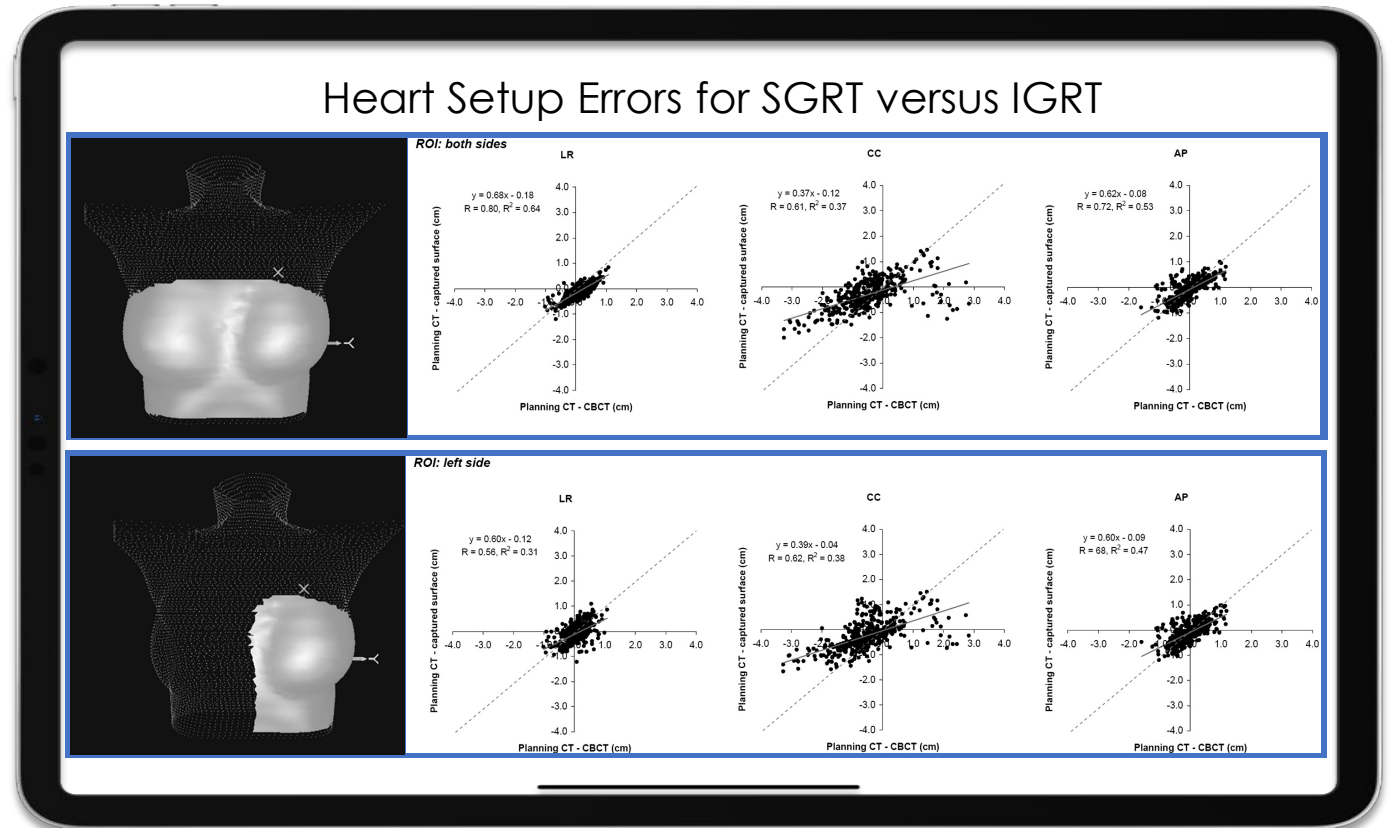
Potential variability in heart position relative to the breast surface

Surface setup data were compared with heart setup data

The results indicate **considerable geometric uncertainties of the heart relative to the breast surface**

For the CC direction, the surface setup errors ranged between -2.00 and 1.51cm while the heart setup errors ranged between -3.26 and 2.83cm

- A shift of the heart in CC direction can have at least the same impact on the dose distribution as a shift in LR direction

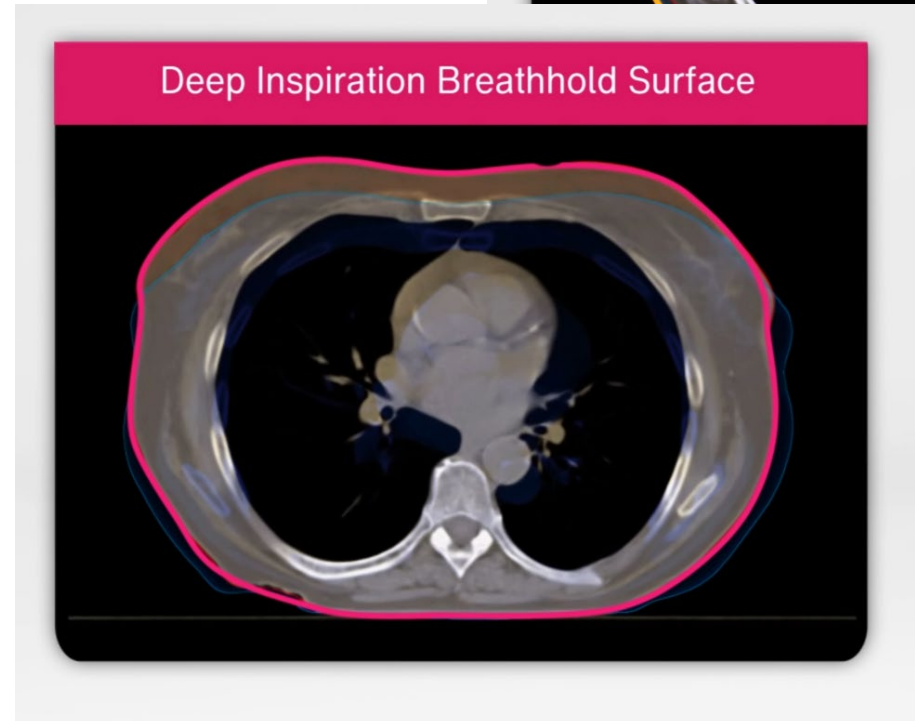
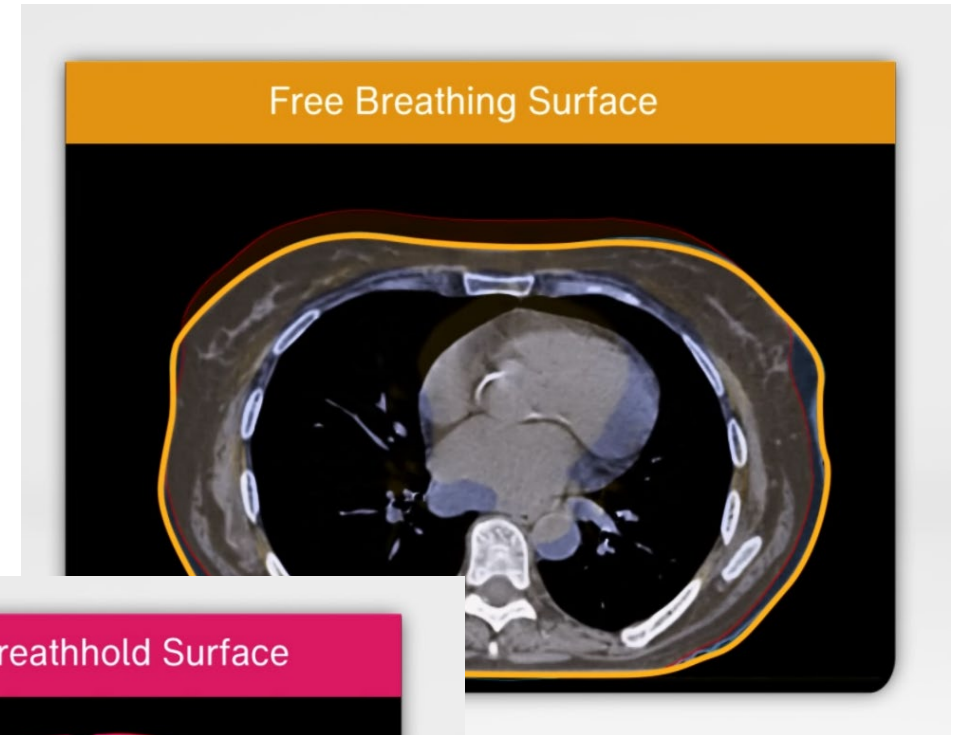


BREAST DIBH

Before treatment

Outer Contour Generation

- Free Breathing and DIBH CT
- Breathing amplitude calculation based on difference between FB and DIBH contour



DIBH WORKFLOW

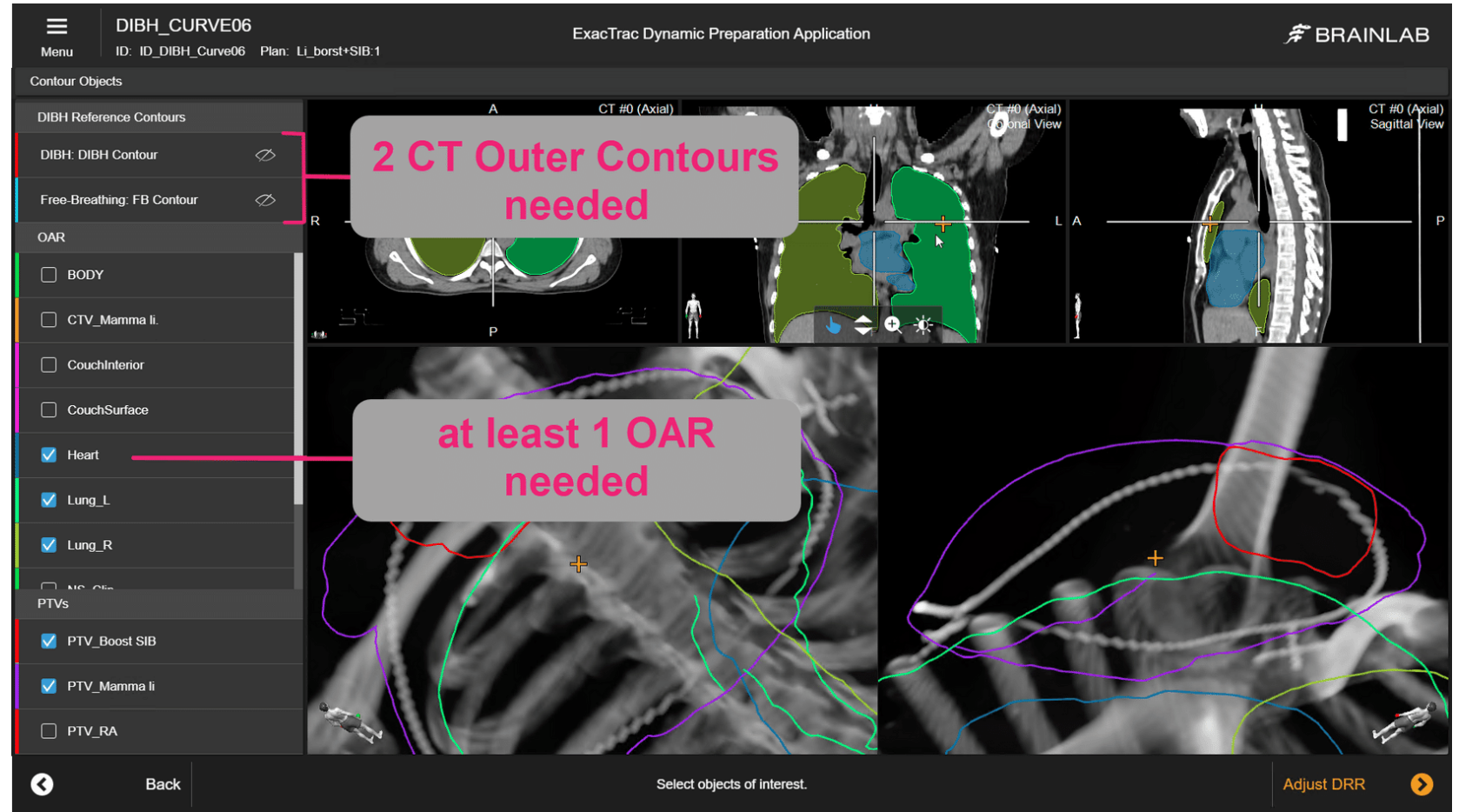
Data requirement

2 CT Reference Outer Contours

- Free breathing
- DIBH

1 OAR in DIBH Position

- Monitoring and DIBH Level Validation

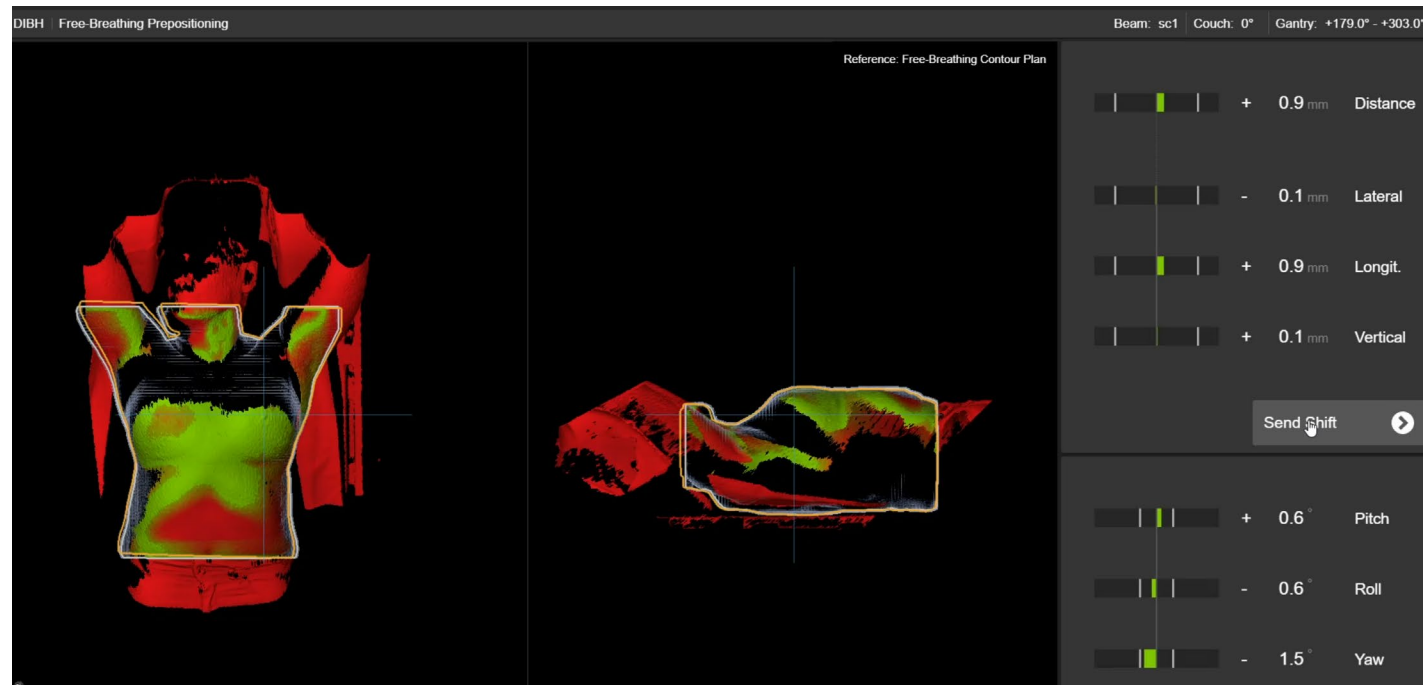
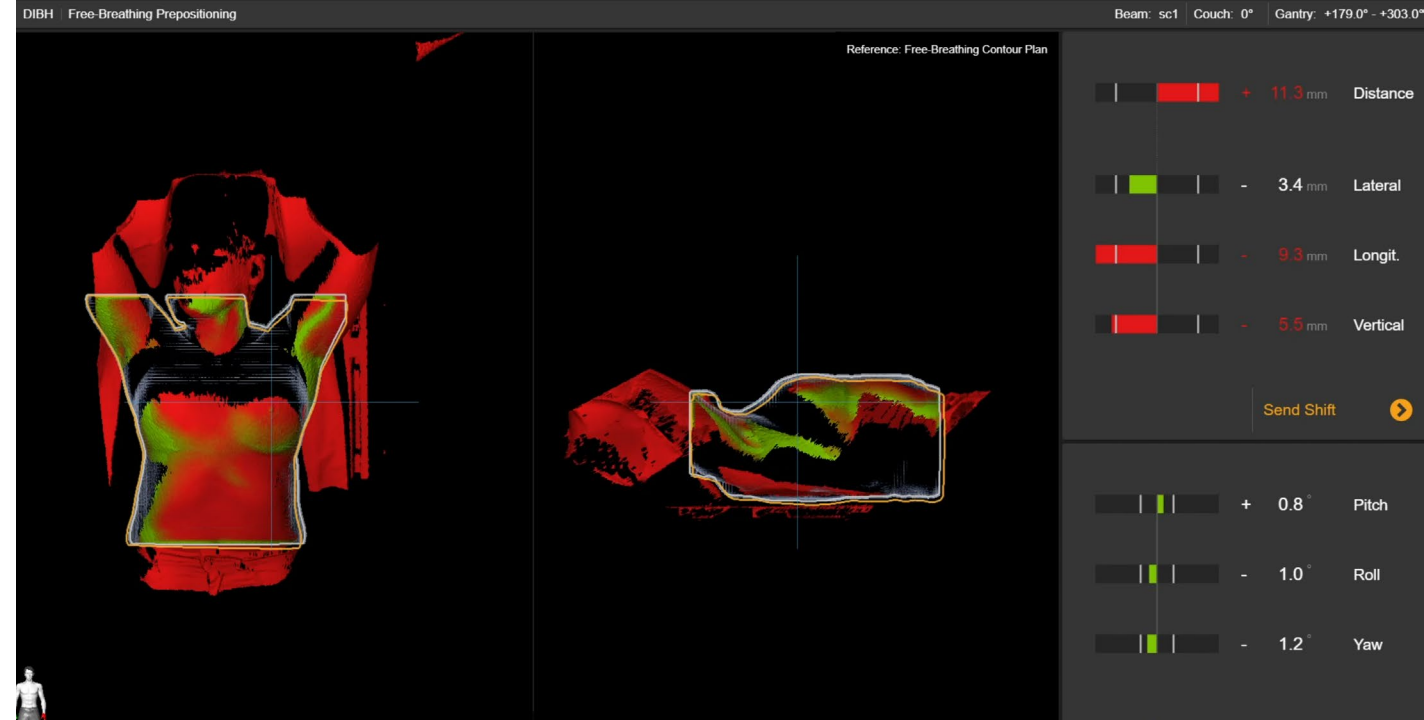


DIBH WORKFLOW

Prepositioning

Automatic pre-positioning using live surface information

- Based on free-breathing outer contour
- Highlights for posture correction (new color-coding)



DIBH WORKFLOW

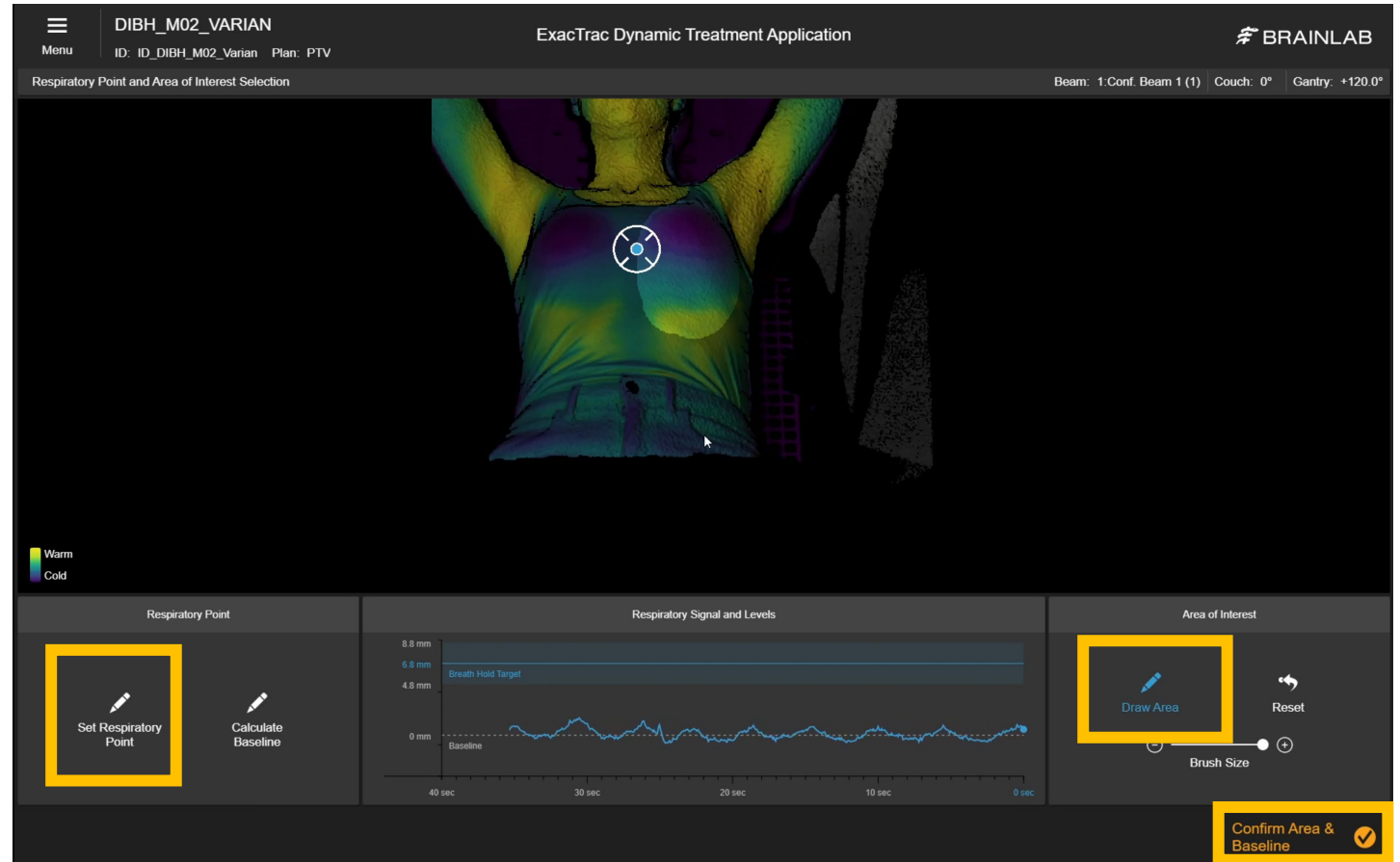
Surface selection

Respiratory point selection

- Breath hold amplitude based on difference between free-breathing and DIBH contour

Surface tracking area selection

- Enables patient surface monitoring

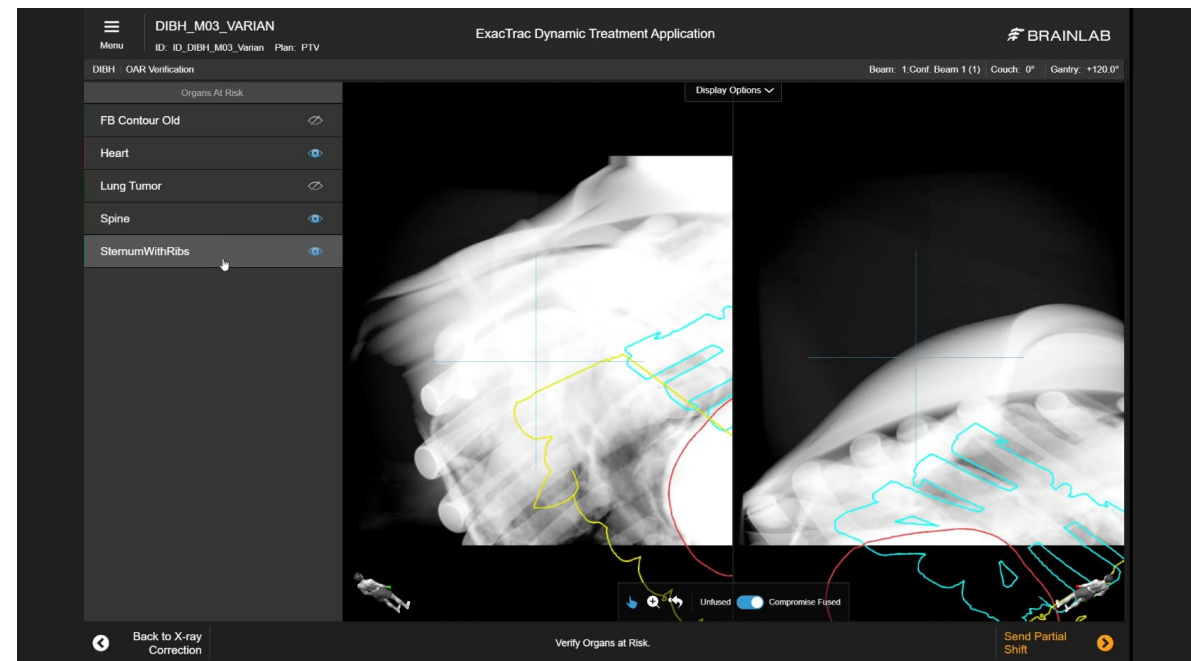


DIBH WORKFLOW

Positioning

Stereoscopic X-Ray images at breath hold

- Accurate fusion to the DIBH CT (DRR)
- Verify position of the patient and organs at risk

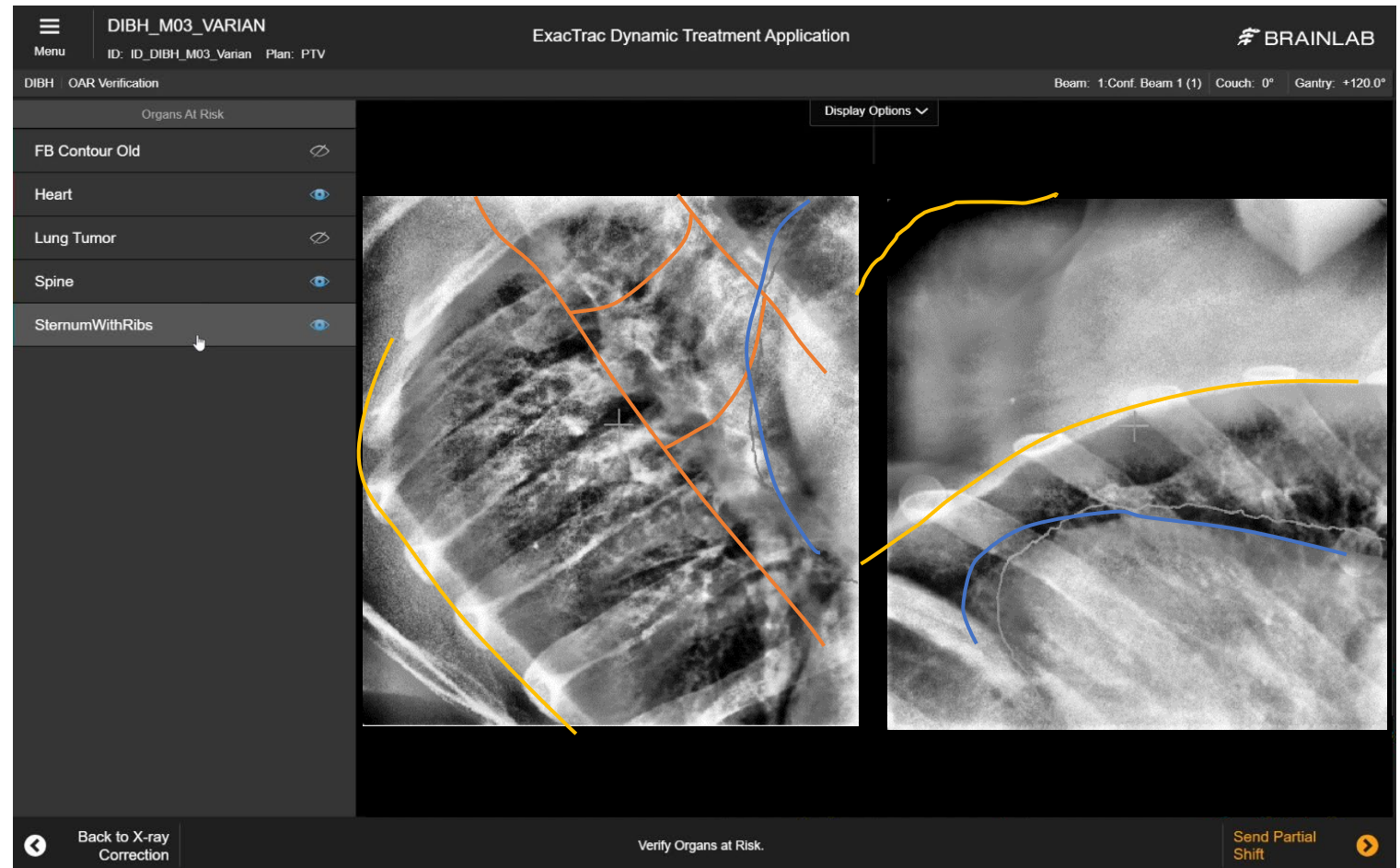


DIBH WORKFLOW

Positioning

Stereoscopic X-Ray images at breath hold

- Accurate fusion to the DIBH CT (DRR)
- Verify position of the patient and organs at risk



Heart 

Breast Outline 

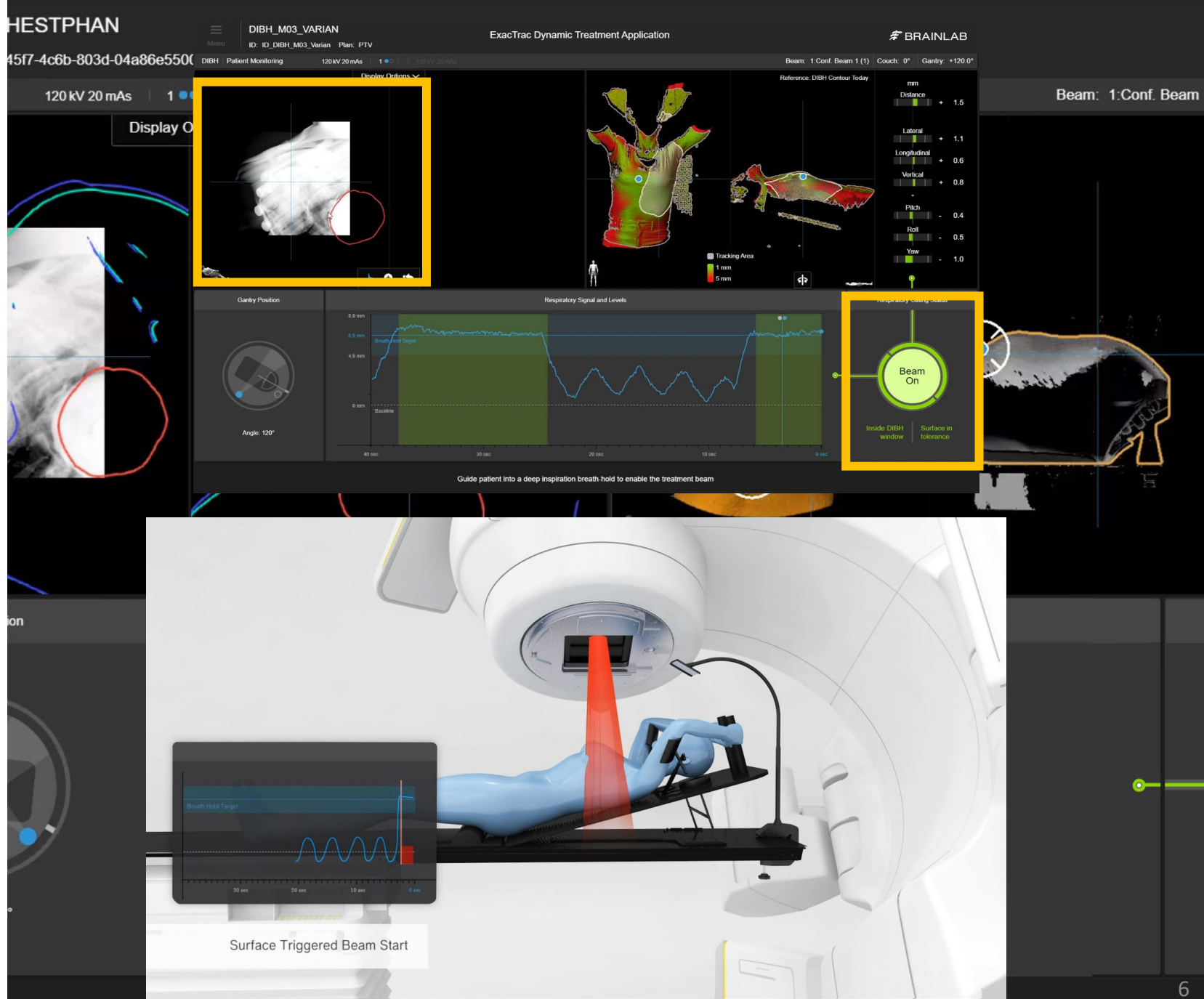
Spine 

DIBH WORKFLOW

Treatment

Real-time surface and breathing curve monitoring

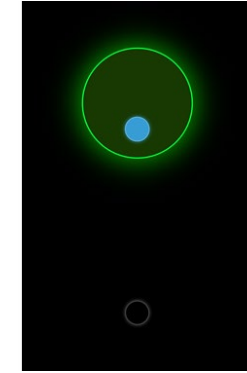
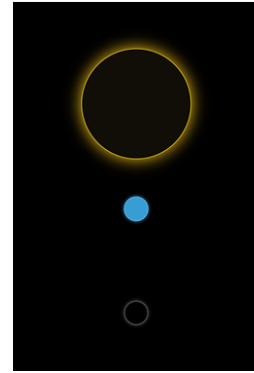
- Automatic beam hold if AOI or respiratory level is out of tolerance
- Visual verification of internal anatomy by X-Rays



DIBH Navigatoin

Patient feedback system

Patient feedback on display



DIBH window

Free breathing baseline

Patient Feedback System

- Guided navigation to breath hold target level
- Flexible ceiling mounted in-room monitor and intuitive display for patient







Thank you

