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

1998
1998

2003
2003

2006
2006

2008
2008

2008
2008

2011
2011

2012
2012

2020
2020

2022
2022

Implanted Markers
Implanted Markers

Infrared Positioning
Infrared Positioning

X-ray Positioning
X-ray Positioning

Novalis
Novalis

Robotic Position Correction
Robotic Position Correction

Dynamic Tumor Tracking
Dynamic Tumor Tracking

Vero (w/o markers)
Vero (w/o markers)

Surface Tracking
Surface Tracking

ExacTrac Dynamic (surface tracking for all linacs)
ExacTrac Dynamic (surface tracking for all linacs)

Respiration Correlation
Respiration Correlation

ExacTrac Correlation
ExacTrac Correlation

Series of more technologically complex innovations.
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
Structure light emitter
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

In-Room Surface Matching

3D Model Reconstitution

Surrogate Model Check
NEW TRACKING MODALITY

Inclusion of thermal information

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
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
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
C-RAD Catalyst was found to generate false positional corrections for facial motion

- The average deviation observed due to changing facial expressions was $1.4 \pm 0.9$ mm and up to 8 mm
- Up to 1.1 mm 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
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

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

2/3 COUCH KICKS REQUIRED

Setup errors with and without ExacTrac
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
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.

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

- 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

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 >30s has been reported in 41% and 15% of fractions
- In individual patients, the number of fractions with displacements >3mm 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
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*
  › ± 2mm prostate positioning accuracy*
› Prostate intra-fraction can be verified (Snap Verification)
› Motion can be significant

Enmark et al.: IGRT of prostate cancer; is the margin reduction gained from daily IG time-dependent? Acta mm 2006; 45: 907-914
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

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Dedicated feature to handle large rotations of prostate

- Exclude rotations that have low relevance in round targets
- Surface tracking is based on partial shift
3DOF Positioning

- Fallback option if individual marker match causes issues
- Position implanted markers based on center of gravity
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
BREAST TREATMENTS
Breast DIBH
Deep Inspiration Breath Hold (DIBH)

Patient feedback system
Residual setup uncertainties for breast with SGRT has been reported to be $4.2 \text{mm} - 6 \text{mm}$

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

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

- 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, $5 \text{mm}$ was exceeded in $10\%$ of the fractions in the CC direction

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

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 1.51 cm while the heart setup errors ranged between -3.26 and 2.83 cm.

- 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

2 CT Outer Contours needed
at least 1 OAR needed
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
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 Navigation

Patient feedback system

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

Patient Feedback System

Patient feedback on display

DIBH window

Free breathing baseline
Thank you