Respiratory Motion Management with Electromagnetic Beacons (Calypso)

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Seattle, WA

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Calypso Overview

History:
- 2000 – Calypso Medical incorporated
- 2006 – FDA cleared for prostate
- 2009 – Raised $50M in venture
- 2011 – Acquired for $10M by Varian

Beacon Transponder
- Copper coil + Fe core
- EM resonance circuit
- 1.9-mm diameter, 8-mm long
  (gold markers: 1.2 x 3 mm)
Calypso Overview

Array

Excitation Coils (4)

Sensor Coils (32)

Preampifiers

Receiver Circuits (32)

Algorithm

Transponder response signals

(x, y, z) coordinates w/ respect to Array

Sequential excitation at resonance frequencies

Transponders

Calypso Overview
Calypso for Prostate
Why Not Put Calypso on the Chest?
Surface Transponders for Breath Hold
**Workflow**

**SIM**
- Put surface beacons on sternum (ANT tattoo)
- Practice breath hold - comfortably deep
- Obtain CT with deep inspiration breath hold

**PLAN**
- Generate plan
- Enter beacon/iso coordinates into Calypso

**SETUP**
- Align 4-point setup and shift
- Place beacons on ANT tattoo

**CALYPSO**
- Place Calypso array and localize beacons
- Breath hold and set tracking trace to zero
- Verify zero BH position with portal imaging

**TREAT**
- Breath hold to zero position
- Verify on Calypso trace
- If within tolerance, beam on
Constraint 1

Array must be centered over the isocenter
Constraint 2: Transponders must be inside localization volume

Localization Volume

Array

Radius = 9 cm

Radius = 7 cm

8 cm

17 cm

21 cm
Out-of-Volume dialog box will appear if transponders are out of localization volume. Do the following:

1) Reposition the Array
2) Re-plan to reposition isocenter
Isocenter Placement for BH Plans

Deep inspiration breath hold
Isocenter Placement for BH Plans

Deep inspiration breath hold
Isocenter Placement for BH Plans

Deep inspiration breath hold
Set Zero and Track (Calypso v.3)

- Redefine tracking baseline for motion monitoring
- Capture vertical, lateral and longitudinal positions at any point in time
- Permit offset from plan
- Automated gating option available
Set Zero and Track
Non-coplanar Fields
- 15 patients completed treatment
- 14 patients within ±2 mm of baseline
- One required daily coaching
Array Interference with MVI

Array in Tracking Mode

Array Paused
Radiographic Fiducials

- Used nearly 40 years
- Not commonly used in lungs

- Percutaneous implantation
  - High pneumothorax rates
    - Georgetown: 33%
    - Stanford: 45%
    - UCSF: 40%(19g), 82%(18g)

- More recently
  - Bronchoscopic implantation
  - Low pneumothorax rates
    - Hokkaido: 1 out of 72 patients
Calypso for Real-time Lung Tumor Tracking

Real-Time Tumor Tracking in the Lung Using an Electromagnetic Tracking System

Amish P. Shah, PhD, Patrick A. Kupelian, MD, Benjamin J. Waghorn, PhD, Twyla R. Willoughby, MS, Justin M. Rineer, MD, Rafael R. Mañon, MD, Mark A. Vollenweider, MD, and Sanford L. Meeks, PhD

Department of Radiation Oncology, MD Anderson Cancer Center Orlando, Orlando, Florida

- “Implantation of the transponder proved to be possible but difficult. In 3 patients (out of 7) it was only possible to fixate 1 transponder.”

- “The most critical challenge was in the stability of the smooth-surfaced transponder within the lung.”
Calypso for Real-time Lung Tumor Tracking

Implanted 3 anchored transponders each in 5 patients
Implantation time: 15-20 minutes
No complications
All 15 anchored transponders had no migration
Successfully used for tumor localization and tracking

Calypso Anchored Beacon® for Lung is cleared for sale in the EU and Australia. It is not for sale in the U.S. and is an investigational device.
Calypso for Pancreas

UPenn Study (Metz et al, ASTRO 2013):
• Laparoscopic implantation w/o complications
• Transponders remained stable in pancreas
• 95 consecutive treatments with tumor tracking

Pancreas Motion Measured by Calypso

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• Real-time tumor tracking will allow margin reduction
• Poor correlation with Anzai belt
Calypso for Liver?

- Calypso beacons severely interfere with MRI
- Should not be used where follow-up MRI is indicated
- Select patient accordingly
Calypso for Respiratory Motion Management

Surface Transponders
- Surface transponders are useful for breath hold treatments
- CPT 0197T: Intrafraction tracking of target or patient motion
- Planning constraint: Localization volume (9-cm radius)

Anchored Transponders
- Awaiting FDA approval
- Preliminary studies regarding implantation are mixed
- More data needed to demonstrate safety of implantation process
- Calypso v.3 can track fast moving targets (25 Hz vs. 10 Hz)

Regular Transponders
- Regular transponders can be used to track Pancreatic tumors
- Real-time tumor tracking can help reduce PTV margin and treatment accuracy
North Cascades National Park: 3.5-hour drive + 5.5-hour hike from Seattle
Respiratory Gated Beam Delivery

David Shepard
Swedish Cancer Institute
Acknowledgments

- Astrid Morris, MD, SCI
- Guoqiang Cui, PhD, SCI
- Daliang Cao, PhD, SCI
- Roger Xie, PhD, SCI
- Susan Richardson, PhD, SCI
- Olga Green, PhD, Barnes Jewish
- Amy Readshaw, MS, D3 Radiation Planning
- Malin Kügele, PhD, Skåne University Hospital
Outline

• Techniques for hitting a moving target
• Gated beam delivery techniques:
  – Forced breath hold: Elekta ABC
  – Free breathing and coached breath hold: Varian RPM
  – Surface mapping: C-RAD Catalyst
Respiratory Motion

- Normal diaphragmatic excursion during uncontrolled breathing can cause tumors of the lung and liver to move up to 2 or 3 cm.
- Respiratory excursion during scan acquisition results in poorly defined tumor borders in a free-breathing scan.
The Impact of Respiratory Motion

Image Courtesy of UPMC
Photo  Static CT  CT with increasing motion ->

From Chen et al, Med Phys 2006

Courtesy Amy Readshaw
Image with breathing motion (free breathing CT)

Image without breathing motion (single phase 4DCT)

From Jiang, AAPM 2007
How To Hit a Moving Target?

- Aim wide
- Time your shot
- Stop the target
Aim Wide to Account for Respiratory Motion

- A 2cm diameter tumor could move 2 or 3 cm, requiring a PTV that stretches at least 6 or 7 cm in the superior-inferior direction.
Disadvantages of Aiming Wide

- Large volumes of non-target tissue are irradiated
- Increased toxicity
- Limits the dose that can be delivered to the tumor.
How To Hit a Moving Target?

- Aim wide
- **Time your shot**
- Stop the target
Time Your Shot:
Free Breathing Gated Delivery

- Delivery is timed to a patient’s breathing pattern
- RT is only delivered during a predetermined phase of the respiratory cycle
- Advantages of the “timed shot”
  - Tolerated by all patients
  - Smaller PTV than aiming wide
- Disadvantage of the “timed shot”
  - Can result in poor delivery efficiency
How To Hit a Moving Target?

- Aim wide
- Time your shot
- **Stop the target**
Stropping the Target: Breath Hold

- Margins can be reduced because the target is held in a stationary position during the beam delivery
- Results in significant sparing of healthy tissue
- Allows for dose escalation

Breath-hold

Free breathing
Stopping the Target: The Challenge

- Patient must hold breath in a position that is:
  - Predictable
  - Reproducible
  - Comfortable for the Patient
- Patient’s with compromised breathing are not good candidates for breath-hold techniques.
Generating the Gating Signal

- **External markers**
  - Varian: Real time position management (RPM)
  - Varian/Calypso: Surface transponders

- **Surface mapping**
  - VisionRT AlignRT
  - C-RAD Catalyst

- **Spirometry**
  - Elekta Active Breathing Coordinator (ABC)

- **Electromagnetic beacons**
  - Varian/Calypso
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Elekta - Active Breathing Coordinator (ABC)

- **Spirometer**: an instrument for measuring the air entering and leaving the lungs
- The ABC uses a specially modified spirometer to allow patients to repeatedly hold their breath at a precise point in the respiratory cycle.
- Radiation is delivered during a series of breath holds.
ABC in Treatment Planning

- Tumor is stationary.
- Eliminates motion induced CT artifacts (such as blurring)
- Increases accuracy of target delineation
The patient breathes through a mouthpiece that contains a turbine, which measures the breath volume. The balloon valve blocks the breathing tube during each breath hold.
Balloon Valve Inflation

- When the breath-hold volume is achieved, a balloon valve is activated to block airflow to the patient for a predetermined period of time.
- The end result is a repeatable breath-hold.
• Portable ABC-system
Pole Mounted Display Monitor and Portable ABC System in the Treatment Room
Visual display of breathing motion on the control monitor
ABC – Clinical Uses

• Left–sided breast cancer
• Any site in the thorax or abdomen which is subject to significant respiratory motion or benefits from anatomic changes during breath holding:
  1. Lung Cancer
  2. Liver Cancer
  3. Hodgkin’s disease
Why Use the ABC Assisted Breath-Hold For Left Side Breast Cancer?

• A breath-hold shifts the position of the heart away from the left breast and the left chest-wall
• Reduces breast motion
• Reduces motion of heart and lungs
Moderate Deep Inspiration Breath Hold (m-DIBH) increases separation between the left breast and the heart.

- Organs are shifted away from the high dose region
- Doses to normal tissue are reduced
CT-Fusion showing Heart Position *during* free Breathing and Breath Hold
Heart Position *during* Free Breathing and Breath Hold
Active Breathing Coordinator (ABC)
Swedish Cancer Institute

- At the SCI, we use ABC routinely for left-sided breast cancer patients
- We have a 5-step procedure for use of ABC
Step 1a: Patient Instruction

- A trained staff member explains to the patient how ABC works.
- The patient practices a relaxed breathing pattern and deep inspiration and learns to interpret the data on the ABC monitor.
Step 1b Patient Instruction

- The ABC mouthpiece is put in place and patient is given release button.
- Patient takes several deep breaths, in treatment planning position
Step 2: Determining the Threshold

- The maximum deep inspiration volume for the individual patient is determined.
- The threshold (breath-hold point at which ABC engages) is set at 75% of the maximum deep inspiration volume.
- Patient should be able to comfortably hold her breath for 12-15 seconds.
- This information is saved in the ABC system as a patient-specific file.
Step 3: Planning CT Acquisition during ABC assisted breath-hold

- As the breathing trace reaches the threshold, the operator tells the patient to hold her breath and closes the ABC’s balloon valve.
- The ABC freezes inspiration in tandem with the breath hold.
- Simultaneously, the operator acquires the planning CT images counting down the breath hold time for the patient.
Step 4: Treatment planning using ABC

- The breath-hold (mDIBH) CT images are used to develop a treatment plan.
- Medial and lateral tangent field with field-in-field technique.
- A single energy is used if possible.
Step 5: Radiation Treatment Set-Up and Delivery

• 20 min treatment slot
• Patient positioned during free breathing
• 5 – 10 sec of m-DIBH to set anterior SSD
• Segments of each tangent divided into 2 or 3 Breath-hold deliveries
Step 5: Radiation Treatment, Set-up, and Delivery

- Patient must have a clear line of sight to the in-room ABC monitor.
- When the patient reaches the predetermined breath hold point (threshold) the ABC is engaged and the accelerator beam is turned on by the therapist.
- Technicians supervise the process from the linac control room via patient video monitor and a laptop ABC display monitor.
- The beam will be switched on and off multiple times during the course of a single fraction.
New ABC Design and Capabilities

• In 2013, Elekta released a new ABC with a significant redesign.
• The new trolley has a more compact and ergonomic design.
• A key innovation is that they system now gates the linac in an automated manner resulting in a more efficient and safer delivery.
Generating the Gating Signal

• External markers
  – Varian: Real time position management (RPM)
  – Varian/Calypso: Surface transponders

• Surface mapping
  – VisionRT AlignRT
  – C-RAD Catalyst

• Spirometry
  – Elekta Active Breathing Coordinator (ABC)

• Electromagnetic beacons
  – Varian/Calypso
Varian’s Real-time Position Management (RPM) System

- A small box with infrared (IR) markers is positioned on patient’s abdomen or chest and serves as a surrogate for patient motion.
- IR camera is attached to foot of couch (if there are couch kicks) or to the ceiling of the room.
- Breathing motion tracked via the IR markers and the gating window set based on fluoroscopy.
- Can be used with free-breathing based gating or coached breath-hold.
Varian RPM - Respiratory Surrogate

Courtesy of Hua Li
Updated RPM System - TrueBeam

Courtesy Amy Readshaw
C-RAD Catalyst: Surface Mapping Solution

- Ceiling mounted projector-camera combination
- Three major functions: patient positioning, motion monitoring and respiration tracking/gating
C-RAD Catalyst: Under the Hood

- Projector-Camera Pair
- A sequence of patterns (structured light) is projected onto the surface measured.
- Software compares the projected and captured patterns to identify the coordinates of each pixel on the captured image.

Courtesy of C-RAD
Reference Image
Surface from CT Scan

Live Image
Patient on the coach

Images Matched
Shifts Calculated

Calculates shifts in Lat, Long, Vert, Pitch, Yaw, and Roll
Catalyst Modules

- **cPosition: Patient Setup**
  - Taking reference image for the first correct setup

- **cMotion: Intra-fraction Patient Motion Monitoring**
  - Live image compared to reference image taken earlier
  - Out-of-tolerance shifts will trigger visual/audio alarm and may interrupt beam if so set up

- **cRespiration: Breathing tracking**
  - Signal can be used for gated delivery
Catalyst: Surface Mapping Based Gating

- Patient can view breathing pattern on computer screen or using video display glasses.
- The patient breathes as instructed:
  - Audio
  - Video
- Coached to breathe with chest and not the stomach.
Gating Patterns:
Gating: Catalyst vs. RPM

Breathing amplitude for Catalyst and RPM.

From: Sofie Ceberg och Charlotte Thornberg
RPM vs Catalyst - Results [mm]

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<th>Catalyst</th>
<th>STD</th>
<th>RPM</th>
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RPM – Catalyst [mm]

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Från: Sofie Ceberg och Charlotte Thornberg
Considerations in Free-Breathing Gating

- Breathing surrogate may not perfectly correlate with the tumor motion.
- Trade-off between accuracy and efficiency
  - A tight gating window minimizes residual respiratory motion of tumor, but increases delivery time
  - Increasing the gating window decreases delivery time, but increases residual respiratory motion of the tumor and decreases accuracy
- Free-breathing gating still treats a target in motion
Free Breathing Gating
Planning and Delivery

- A 4DCT is performed at the time of simulation.
- A gating window is selected and the target is determined based on the extent of tumor motion during the gating window.
- Every day before treatment, the correlation between the breathing surrogate and the tumor position should be verified via imaging such as fluoroscopic kV images or a gated cone beam CT scan.
- Gating will generally add 5 to 10 minutes to the overall treatment time.
Summary

• Gated beam delivery can be used to mitigate the impact of respiratory motion in the delivery of radiation therapy.
• Gating makes it possible to shrink treatment margins and reduce the dose to critical structures.
• In some cases this makes dose escalation possible.
Respiratory Motion Management with Electromagnetic Beacons (Calypso)

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Array

- **Excitation Coils**: 4
- **Sensor Coils**: 32
- **Preamplifiers**: 32
- **Receiver Circuits**: 32
- **Algorithm**: Receives signals from transponders

Sequential excitation at resonance frequencies:
- $f_1$
- $f_2$
- $f_3$

Transponder response signals:
- $f_1$
- $f_2$
- $f_3$

Transponders:

$(x, y, z)$ coordinates with respect to the Array
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Constraint Violation

Calypso Manual

Out-of-Volume dialog box will appear if transponders are out of localization volume. Do the following:
1) Reposition the Array
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Deep inspiration breath hold
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9 cm
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Non-coplanar Fields

Couch Characterization
Nominal couch angle (Head-In): 1 degrees
Direction of positive rotation: CW - clockwise
(Viewed from above the patient)

Couch Angle 35°
Enter a couch angle: 0–360°
The entered couch angle must match the actual couch angle in order to track.
Press Enter when the couch is in position.

Couch Kick

Graph showing longitudinal cm with marked points at 189° and 188°.
• 15 patients completed treatment
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Radiographic Fiducials

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First Report Of Implantation Of Anchored Electromagnetic Fiducials In Human Lung Cancers For Real-time Tumor Localization And Tracking During Radiation Therapy

C. T. Bolliger¹, C. F. N. Koegelenberg², F. Von Groote-Bidlingmaier², M. Bernasconi², D. M. Steyn¹, M. Tamm³, F. Zimmerman⁴, A. Papachristofilou⁴, U. Schratzenstaller⁴, G. Paris⁵

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- No complications
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