Multivendor SBRT/IGRT
The Calypso 4D Localization and Tracking System / Elekta Synergy-S

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Objectives

• Understand operational and quality assurance aspects of Calypso combined with Synergy-S and Pinnacle TPS

• Understand the technical limitations of the hybrid system

• Describe clinical implementation of the system and typical cases treated
Objectives

• Understand the clinical rationale for localization and tracking

• Understand the necessity of hybrid technologies and systems

• Understand the physics behind the Calypso localization mechanism and its principles of operation
Introduction

- Dose escalation to the prostate increases local control

- Image guidance for accurate treatment delivery and intra-fraction motion monitoring is critical in this environment of dose escalation and hypo fractionation
Real Time Tracking
Prostate Motion During Treatment

C.A. Enke\textsuperscript{1}, T. Solberg\textsuperscript{1}, A. Mahadevan\textsuperscript{2}, T. Djemil\textsuperscript{2}, P. Kupelian\textsuperscript{3}, T. Willoughby\textsuperscript{3}, G. Weinstein\textsuperscript{4}, S. Jani\textsuperscript{4}, N. Flores\textsuperscript{5}, D. Liu\textsuperscript{5},

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<table>
<thead>
<tr>
<th>Patient ID</th>
<th># Fractions Analyzed</th>
<th>Fractions with &gt; 3mm excursion for &gt;30 seconds cumulative</th>
<th>Fractions with &gt; 5mm excursion for &gt;30 seconds cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>All (N=35)</td>
<td>1157</td>
<td>473 (40.88%)</td>
<td>179 (15.47%)</td>
</tr>
</tbody>
</table>

Percent of Fractions for All Patients

<table>
<thead>
<tr>
<th>Patients</th>
<th>No. fractions analyzed</th>
<th>Fractions with ≥3mm excursion</th>
<th>Fractions with ≥5mm excursion</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>1157</td>
<td>Study average: 41%</td>
<td>Study average: 15%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Individual: up to 87%</td>
<td>Individual: up to 56%</td>
</tr>
</tbody>
</table>
IGRT

• Transabdominal ultrasound, KV X-rays, and KV/MV CBCT

• Disadvantages:
  ➢ Snapshots of the prostate position
  ➢ Not available during radiation delivery
  ➢ Additional ionizing radiation exposure
  ➢ May be subjective and operator dependent in acquisition and interpretation

• Option: Hybrid system used for prostate EBRT (IMRT/SBRT)
Synergy-S/Calypso
The Calypso 4D Localization System

- New technology using non ionizing AC electromagnetic (EM) field for locating and tracking patient tumors: the Calypso system.

- An intermittent EM pulse excite implanted wireless circuits called Beacon transponders

- The Beacons echo a distinct signal determining their coordinates
The Calypso 4D Localization System

- The Beacons’ coordinates are used to determine the translational shifts in the X, Y, Z directions to register the target to linac isocenter.

- Rotation of the target around the three directions is also determined.

- After patient setup, the system continuously tracks the position of the target in real time.
Urologists consults the patient on treatment options

Decision to use EBRT and Implant Beacon® Transponders

Implant procedure

Referral and Implant Procedure Phase

Urologists consults the patient on treatment options

Decision to use EBRT and Implant Beacon® Transponders

Implant procedure

Treatment Planning Phase

Identify Beacon transponders in treatment planning 4—14 Days post implant

Enter treatment planning data into Calypso 4D Tracking Station

Calypso Calypso System Workflow

Plan check on Calypso 4D Console

Real-Time Setup with Calypso 4D Console

Objective, continuous monitoring during treatment

Treatment Delivery Phase
The Calypso 4D Localization System

- It consists of:
  - Beacon transponders
  - Console
  - Array
  - Optical cameras
  - Tracking station
Platform Overview

- Beacon® Transponders
- Tracking Station
- Optical System
- Infrared Cameras
- Optical Targets
- Electromagnetic Array™
- Console
Beacon Transponders

- Three Transponders Beacons are implanted under Ultrasound guidance
- 1.8mm x 8.5 mm (14 Gauge needle)
- When Excited with an EM pulse, they echo distinct signals used to determine their coordinates
- Coordinates used to locate target with respect to machine isocenter
The Calypso System - Beacon® Transponder

Actual size: ~8.5 mm

Wireless miniature Beacon® Electromagnetic Transponders
The Calypso System - Beacon®
Transponder
Implantation Procedure

- Outpatient procedure — prep w antibiotics and same day enema

- Transrectal US and transperineal implantation by urology or radiation oncology

- Typically done w local anesthesia, @ 10 minutes

Transrectal ultrasound probe, needle guide and introducer for Beacon® electromagnetic transponder implant into prostate
Contraindications

- Anticoagulation/Antiplalet (Implantation)
- Allergy to local anesthetics (Implantation)
- Implanted signaling devices (Pacemaker, neurostimulator, certain infusion devices) - Interaction with electromagnetic signal unknown
- Prosthetic hip or large metal implantation (Vascular grafts) near transponders
- AP diameter restrictions
Implantation

- In pilot study with prototype system 58 of 60 implanted transponders were usable (1 voided, 1 unresponsive), a 3rd transponder moved 3cm from apex to superior SV (in venous plexus?) but was usable.

  Willoughby et al., IJROBP 2006;65(2):528-534

- Follow-up study 125 of 126 transponders usable (1 voided), one placed on prostate/rectal interface but usable.

  Kupelian et al., IJROBP 2007;67(4):1088-1098
Stability

• On second study of 42 patients (125 transponders) mean SD of intratransponder distances was 0.8 mm from day 4 to 80.

Kupelian et al., IJROBP 2007;67(4):1088-1098
The Flat Panel Array

- The array is an extendible flat panel
- Contains the source coils that generate the EM signal
- Source coils emit frequencies between 275 and 550 kHz
- 1 to 2% attenuation
Flat Panel Array

- Continuous, real-time monitoring of the prostate
- Objective guidance enables clinician to manage organ motion
- Accurate localization for maximum confidence
- Non-ionizing technology for quick patient setup
Transponder Signals

- Transponders excited sequentially at each of three unique resonant frequencies.
- Each transponder subsequently responds with a decaying magnetic field.
- Process of excitation and sensing is repeated several hundred times to improve signal/noise for each transponder localization.
Locate and Track Continuously

GPS for the Body®

**Step 1**
Beacon® Electromagnetic Transponders are excited by a pulse of electromagnetic energy.

**Step 2**
The Beacon transponders respond with an identifiable signature allowing the clinician to determine tumor location and motion (10 Hz update rate).
Unique Frequencies Identify Location
Table Overlay

- 3-Piece Kevlar Overlay
- No Standard couch, carbon fiber, tennis-racquet due to interference
Efficient Setup — Precise Positioning

Patient Alignment

Rapid shift to isocenter <35 seconds
Efficient Setup

Setup Time (seconds)

Sources:

Disclaimer: This content is informational only and represents no promise or guarantee by Calypso® Medical regarding coverage, coding, billing and payment levels.

Calypso v US 1.6 v 3.7 min @ CCF, Warman et al., IJROBP 2007 69(2):S661
During Radiation Prostate is Constantly Monitored

From outside the treatment room, RTT can watch for “Out Of Tolerance” indicator.
Cleveland Clinic Prostate EBRT

- **Dose**:  
  - Low-risk 76 Gy, 2 Gy per fraction  
  - Int & High-risk 78 Gy (66 Gy to proximal SV)

- **PTV**:  
  - Clarity or CBCT = CTV + 5 mm post, 8 mm lat/ant/sup/inf  
  - Calypso = CTV + 4 mm post, 6 mm lat/ant/sup/inf

- **Sim**:  
  Supine, empty rectum, full bladder, no specific immobilization, urethrogram, no intra-rectal devices
• 1,765 EBRT treatments @ CCF from 1996-2003
• All fractionations included (2Gy, 1.8Gy, 2.5Gy)
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• All fractionations included (2Gy, 1.8Gy, 2.5Gy)
IGRT/Calypso: Patient Setup

- Initial offset corrections often systematic
- Relatively stable with significant outliers

*Alignment relative to laser/skin mark setup (1524 fractions) showed initial offset shift >5 mm in vector length in >75% of fractions

Kupelian et al., IJROBP 2007;67(4):1088-1098
Clinical Results – Patient Tracking

Clinically relevant prostate motion observed

- In 97% of patients motion exceeded pre-set thresholds
- Motion was unpredictable and variable day-to-day and patient-to-patient

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Kupelian et al., IJROBP 2007;67(4):1088-1098
3D Variable Motion

- **Isocenter Offset (mm)**
  - Lateral
  - Longitudinal
  - Vertical

- **Time (sec)**
  - 60
  - 120
  - 180
  - 240
  - 300
  - 360
  - 420
  - 480
  - 540

Graph showing variations in isocenter offset over time for different directions.
Clinical Results – Patient Tracking

- Transient Excursion
- Continuous Drift
- Persistent Excursion
- Stable
- Erratic Behavior
- High-Frequency Excursion

Kupelian et al., IJROBP 2007;67(4):1088-1098
How Much Interruption?

- Review of actions taken at 5 centers on multi-institutional study (35 patients)
  - Four used 5mm action threshold (998 fx)
  - One used 3mm action threshold (159 fx)

- Interventions in 36.2% of cases exceeding threshold, avg delay 35-120 seconds (interruption – realignment).

Enke et al., IJROBP 2006 66(3):S363
How Much Margin Do We Need?

- Patients on Calypso intra-institutional protocol reviewed

Litzenberg et al., IJROBP 2007
69(3):S363-S364
Margins forecasted by method of Van-Herck
Assessing the Impact of Margins (AIM) Outcomes Study Publication

- Published in *Urology* in May 2010

- Assessed effect of reduced treatment margins and real-time tracking on patient-reported quality of life (QOL), using previously published comparator cohort (Sanda et al, NEJM, 2008)

- Conclusion: AIM patients had significantly reduced acute GI, GU and some sexual symptoms compared to comparator cohort
## Treatment Planning

### Patient Selection

<table>
<thead>
<tr>
<th>Prostate position from anterior surface</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 17 cm</td>
<td>Localize and track</td>
</tr>
<tr>
<td>17-23 cm</td>
<td>Localize only</td>
</tr>
<tr>
<td>&gt;23 cm</td>
<td>Not a candidate for the Calypso System</td>
</tr>
</tbody>
</table>
Treatment Planning

Calypso® 4D Localization System
Localization Designation Worksheet
After Implantation

Determine a patient's localization designation from information:
1. Use the treatment planning system's distance measuring tool to measure the patient's maximum anterior skin to table surface distance (A) from the isocenter (in centimeters). Record this distance in centimeters on the worksheet below.
2. After selecting the isocenter position, measure the distance between the isocenter and the table surface (B). Record that distance in centimeters on the worksheet below.
3. Measure the distance from the most posterior transponder to the table surface (C). Record that distance in centimeters on the worksheet below.

Localization Designation Determination Worksheet

Patients Name: Mc Givney, La Dec: #11385577

Anterior Skin Distance to Table Surface Distance (A):

Isocenter to Prostate Center to Table Surface Distance (B):

Posterior Transponder to Table Surface Distance (C):

Skin Surface to Prostate Center or Isocenter Distance (A minus B):

Skin Surface to Posterior Transponder Distance (A minus C):

Localization Designation:
- Location and Track
- Location Only
- Not a Candidate

Calypso® 4D Localization System
Treatment Planning Data Worksheet

TREATMENT PLANNING INPUTS: CR

Philips Pinnacle

Input Units:
- Centimeters

Coordinates:

Apex Transponder Coordinates: X: ** Y: ** Z: **

Left Base Transponder Coordinates: X: ** Y: ** Z: **

Right Base Transponder Coordinates: X: ** Y: ** Z: **

Document completed by:
## Treatment Planning

![Treatment Planning Image](image)

### Points Of Interest

<table>
<thead>
<tr>
<th>Current</th>
<th>Name</th>
<th>Coord Sys</th>
<th>Lateral</th>
<th>Ant-Post</th>
<th>Sup-Inf</th>
<th>Diameter</th>
<th>2D Mode</th>
<th>3D Mode</th>
<th>Color</th>
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<td></td>
<td>iso</td>
<td>CT</td>
<td>-0.84</td>
<td>-48.58</td>
<td>116.40</td>
<td>1 cm</td>
<td>On</td>
<td>Off</td>
<td>inverse_gr-</td>
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<td>On</td>
<td>Wireframe</td>
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<tr>
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<td>Rt base</td>
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<td>-48.20</td>
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<td>1 cm</td>
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<td>Wireframe</td>
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<tr>
<td></td>
<td>Lt base</td>
<td>CT</td>
<td>0.49</td>
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<td>116.40</td>
<td>1 cm</td>
<td>On</td>
<td>Wireframe</td>
<td>skyblue</td>
</tr>
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Generated Reports

Trend Report
Localization Summary

Initial Shift (Shading = No Localization Data)

Right Lateral Offset (cm)
Left Lateral Offset (cm)
Inf. Longitudinal Offset (cm)
Sup. Longitudinal Offset (cm)
Post. Vertical Offset (cm)
Ant. Vertical Offset (cm)

Sessions
Generated Reports
QA

- Camera Calibration
  - Quarterly
  - L-Frame fixture
  - T-Frame fixture

- System Calibration
  - Daily and Monthly
  - Isocenter fixture
Camera Calibration
System Calibration

Calibrate Calypso coordinate reference frame to Machine isocenter (treatment room laser positions).
Panel
Calibration
Horizons

- Dynamic Dose Reconstruction
- Post-prostatectomy
- Hypo-fractionated prostate SBRT
- Lung Cancer
- Breast Cancer
- Pancreatic Cancer
- Spine SBRT
Prostate SBRT

RTOG 0938

• 36.25 Gy in 5 Fx
• 2 Fx / week, 3 to 4 days apart
• 5 or more IMRT non-coplanar beams or VMAT
• 6 or 10 MV
• Fiducials, and possibly rectal balloon to immobilize the prostate
• GTV = CTV = Prostate
• PTV = CTV + 5 mm (3 mm Post)
• Prescription dose (PD) to at least 99% of prostate and 95% of PTV
• Max dose within PTV \leq 7\% above PD
• Urethra visualization required if max dose > 38.78 Gy
• If Tx time > 7 min, need tracking or repeat IGRT
**Prostate SBRT Dose-Escalation Study (Timmerman)**

- 45, 47.5, and 50 Gy in 5 Fx
- Min 36 h between fractions
- 6 to 15 MV Tomotherapy or Trilogy
- IMRT with Tissue Heterogeneity on
- Markers (gold seeds or Calypso) implanted 1 week before sim
- 60-100 cc rectal balloon
- Urethra delineated with flexible catheter in sim
- CBCT before each fraction to confirm fiducials, ballon, and filling of bladder
- PTV = Prostate + 3 mm
- Prescription dose (PD) to at least 95% of PTV
- Urethra, Bladder wall and Ant Rectal Wall Max Dose ≤ 105% of PD
Prostate SBRT
CCF Experience

- Combination of both protocols: Prostate and SV to 36.25 Gy and part of the Prostate to 50 Gy.
- Mimic highly conformal brachytherapy dose distributions
- 5 Fx every other day
- 6 or 10 MV Novalis TX
- IMRT VMAT or HybridArc with Tissue Heterogeneity on
- Markers (Calypso) implanted 1 week before sim
- 100 cc rectal balloon
- Urethra delineated with flexible catheter and contrast in sim
- PTV = Prostate + 5 mm (3 mm post limited by rectum)
- PTV SV = SV + 4 mm (3 mm post limited by rectum)
- Expanded Urethra: 7 mm lat and ant, 2 cm post
- CBCT before each fraction to confirm fiducials, ballon, and filling of bladder
- Tracking using Calypso
Prostate

- Prostate implanted with calypso transponders
- Balloon inserted during the sim
- High risk area delineated
- 36.5 Gy in 5 fx QED
- 50 Gy HRA
- Use VMAT or Hybrid arcs
Prostate
Spine SBRT (with instrumentation)

- Tested in acrylic phantom with up to 6 cm of medium density bone slabs (1.6g/cm$^3$) or up to 2 cm bone cement.

- Tracking accuracy $<0.5$ mm for 30 second tracking demos.

Djemil et al., IJROBP 2007 69(3):S2105
Lung and Spine (Clinical Phase I)

- Calypso transponders successfully implanted into 4 spine and 2 lung SBRT patients
- Position of transponders verified by kV X-ray prior to treatment
  - All 4 spine cases remained stable
  - One lung case stable, other pt evacuated transponder
- All 6 patients tracked successfully. Spine transponders approached maximum distance for tracking (25 cm).

Willoughby et al., IJROBP 2008 72(1):S642-S643
Breast Cancer

Use Surface Transponder For Motion Monitoring During Treatment

- Single patient, multiple use
- Place on skin mark and align with lasers
- Use orientation indicator + setup notes to ensure correct device orientation
- Confirm patient set-up with alternate alignment method (lasers and tattoos, SSD measurements or imaging)
Breast Cancer

Utilize Calypso Surface Transponder with left-sided breast patients to monitor breath hold position during radiation delivery and reduce cardiac exposure.
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• Kevin Stephens, M.D.
• Arul Mahadevan, M.D.
• Patrick Kupelian, M.D.
• Lisa Levine/Calypso