Published posters from tests and studies performed on the Micropos RayPilot® system 2007-2011

For high precision 4D RADIOTHERAPY™
Micropos has developed the electromagnetic RayPilot® system for high precision four dimensional radiotherapy, 4DRT. The system works as an add-on to existing linear accelerators and enables full control of a ROI* position throughout every radiotherapy session.

The system consists of the RayPilot® receiving system which is placed on any existing treatment table, the RayPilot® transmitter that is placed in the region to be tracked and the RayPilot® software. The system is CE certified to initially be used in the treatment of prostate cancer and in the future the system will be upgraded to include both tumor positioning and in-vivo dosimetry. The intention is also to widen the use of the system for both curative and palliative treatments in other tumor regions and in gating applications.

Micropos is also performing scientific collaborations e.g. on future applications where the RayPilot® system gives information to the linac collimator in order to let the beam follow the ROI in Real-Time. This is also known as Dynamic MultiLeaf Collimator tracking (DMLC tracking).

Micropos strive to make advanced radiotherapy faster, more precise and easier to work with. In other words it should be as easy as to just Plug & Treat®.

This brochure contains scientific posters that has been published in Europe and USA during 2007-2011.

* ROI = Region Of Interest
Electromagnetic positioning, real time positioning and four-dimensional radiotherapy using the Raypilot system
First human experience

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Introduction
Electromagnetic positioning (EMP) for radiotherapy (RT) was first described by Lennernäs & Nilsson 1995 in Uppsala. The background to the development of EMP for RT was the wide margin used for RT of prostate cancer and that the three-dimensional systems (3DRT) did not describe the correct dose distribution because they could not specify the target position in real time throughout the RT treatment chain. Therefore goals for a new system and technology were determined in 1995. The goals included (1) that the staff could be with the patient during positioning (no x-ray), (2) the system could be positioned in real time, (3) be independent and to be usable throughout the entire therapy chain for both photons and protons.

Material & Methods
The Raypilot system works as an add-on to existing linear accelerators, and with any table top including carbon fibre, and with any energy (Fig 1). The system consists of a receiving system, which is placed on the accelerator table top, an implanted transmitter that is placed in the ROI, and the RayPilot software. The transmitter is implanted using a modified Seldinger technique and a separate Chiba needle (Fig 2). A thin (w=1.3 mm) wire through the skin connects the transmitter to the rest of the system. The implant is fixed inside by pacemaker type staples and externally with a suture (optional). A transmitting antenna is located in the interior tip and a connector is located at the exterior end of implant (Fig 3). The position is calculated approximately 30 times per second. The accuracy in positioning of the system has a mean error of 0.45 mm (SD: 0.21 mm) (lab data).

Results
In the first patient studies, the transmitter was implanted during the final high dose rate brachytherapy. Patients had epidural analgesia and a two-day course antibiotic due to the brachytherapy. The transrectal ultrasound was used for the brachytherapy for the implantation, and the Chiba needle as a guide for the Seldinger instruments. The remaining external beam treatment took approximately 2.5 weeks. Further implantations have been performed in long term use fractionation (70Gy/2). Side effects were evaluated, and the implantation site was inspected daily. A transparent bandage was sometimes used over the skin exit. No infection occurred and the implants were well tolerated by the patients although some complained of local rigidity, possibly due to the wire or the bandage.

Discussion
Real time positioning (RTP), EMP and 4DRT will be important techniques for the radiotherapy of the future. RTP/4DRT will reduce the dose to organs at risk (OAR) by reducing the planning target volume (PTV) and it will make it possible to treat cancer with minimal risk of side effects even with high doses, i.e. hypofractionation for PC. The technique can be used for gating and in other tumorsites then PC. The ability to add other functions, such as patient identification and dose measurements, also makes the technology attractive for safety and quality improvement.
Evaluation of the localization accuracy and precision of the RayPilot® system compared to Cone-Beam CT

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Purpose
The Micropos Medical AB has developed the four-dimensional localization system RayPilot®. The system is designed to provide real-time prostate tumour localization before treatment and tracking during radiotherapy, without use of ionizing radiation. The aim of this investigation is to evaluate the localization accuracy of the RayPilot® system compared with Cone-Beam CT, Elekta's Synergy XVI.

Methods and materials
To investigate the accuracy of the RayPilot® and kV Cone-Beam CT a prostate phantom was made of tissue equivalent material with three gold markers placed similarly to the clinical practice. The RayPilot® transmitter was inserted between the gold markers. The phantom was mounted on a jig which could be moved in the x, y and z direction with the precision of 0.1 mm. This equipment was placed on the RayPilot® receiving sensor plate on the treatment table. Numerous controlled movements were executed on the phantom and the readout of the RayPilot® system and Cone Beam CT was detected simultaneously.

Results
Both systems show sub millimetres accuracy but the Cone-Beam CT seems to overestimate the translation in the positive direction and underestimate it in the negative direction. The RayPilot® system had a higher precision than the Cone Beam CT with the lowest SD in all directions, 0.20 and 0.34 respectively.

<table>
<thead>
<tr>
<th>Translation</th>
<th>Movement</th>
<th>CBCT</th>
<th>RayPilot®</th>
</tr>
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<tbody>
<tr>
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<td>9.9mm</td>
</tr>
<tr>
<td>Vertical</td>
<td>10.0mm</td>
<td>9.8mm</td>
<td>10.0mm</td>
</tr>
<tr>
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<tr>
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<tr>
<td>Median</td>
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<td></td>
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</tbody>
</table>

Conclusion
The results indicate that the RayPilot® system is an accurate and precise tool to detect the prostate position during the course of radiotherapy and can be a beneficial tool to detect the prostate position during external beam delivering in real time.
How accurate could the RayPilot® system detect real time motion of the chest during breast radiotherapy?

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Purpose
During the course of radiotherapy for left side breast cancer the intrafractional movements, especially breathing motions, could imply a risk of increasing heart dose and the risk for late cardiac toxicity. By increasing the distance between the field edge and the heart by the use of gating, and thereby have control of the movements, it could be possible to reduce that risk. Aims of the study are to evaluate if Micropos RayPilot® system could be used to detect the intrafractional movement in real time (4D) and to evaluate the accuracy of the detected motion.

Materials and methods
Micropos RayPilot® system’s position transmitter was placed on the skin near the nipple of the breast for three of the female group members and the system continuous detects the 3D-position of the transmitter during breath. The detected transmitter translation is recorded. The range of translation is measured during normal and deep inspiration. The translation in vertical direction is exported to The QUASARTM respiratory motion QA phantom. To detect the possibility to track the motion by RayPilot® the position transmitter is placed on the phantom and the detected movements are compared. The detection was repeated four times.

Results
The results show relatively small movements of the chest wall during normal breathing but is relative large in deep inspiration particularly in the vertical direction. The detected movements of the respiratory motion phantom and the movements presented by the RayPilot® system has very good conformity.

Conclusion
The results show that Micropos RayPilot® system is a convenient and precise system to detect and track the chest wall motion during radiotherapy of breast cancer and it could be used in breathing adapted radiotherapy of left side breast cancer.
A new multi-functional implant for 4DRT, including positioning, dose measurement and patient identification.

**Introduction**

Organ positioning for radiotherapy using electromagnetic technology was first described by Lennernäs & Nilsson in 1995. The RayPilot™ system is a wire-based organ positioning system with the possibility to add other functions to an implantable transmitter.

**Purpose**

To investigate accuracy in dose and position measurements in an implantable transmitter for 4DRT.

**Materials & Methods**

An implantable RayPilot™ electromagnetic transmitter (Micropos Medical, Sweden) for real-time organ positioning was modified to include a dosimeter that was mounted near the positioning sensor in the tip of the transmitter.

The modified RayPilot™ transmitter was radiated at the Sahlgrenska University Hospital (Gothenburg, Sweden) using a Varian linear accelerator (Field 10x10cm; 2Gy= 120 MU at 100 cm, 15MeV) in 5 steps of 100 MU from 100 MU. Dose measurement was performed with the transmitter connected to a Hermes 5 electrometer (Mimator, Sweden). To evaluate changes in dose sensitivity due to the direction of radiation the transmitter was radiated with 100 MU from different gantry angles (45, 90, 135 and 180 degrees).

The same transmitter was evaluated regarding the accuracy in position using an automatic 3D moving device that moved the transmitter in 2000 random positions.

**Results**

The results of the dose measurements were nearly linear, as presented in the table and corresponding diagram, and independent of real-time positioning measurements (or vice versa). Measurement of dose using 100 MU at different gantry angles showed a mean of 53 nC (SD 1 nC).

The accuracy in positioning showed a mean error of 0.38 mm (SD: 0.18 mm).

**Conclusions**

This is the first report of a multifunctional transmitter measuring both dose and position in real-time. This study shows that neither the dose or the positioning components of the transmitter interfere with each other. The implantable transmitter seems to be well suited for real-time dosimetry and organ positioning measurements during radiotherapy.
Evaluation of positioning accuracy of the electromagnetic RayPilot® system with an in vivo dosimeter.

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² Micropos Medical AB (publ), Gothenburg, Sweden

Introduction
Electromagnetic organ positioning for radiotherapy was first described by Lennernäs & Nilsson in 1995. The RayPilot® system is a wire based positioning system with the possibility to add other functions to the implantable transmitter. However, adding a dosimeter might interfere with the positioning function. In this study the accuracy of a new implant with positioning, patient identification and an in vivo dosimeter is evaluated.

Materials
For testing RayPilot system accuracy the transmitter is modified and has a dosimeter (a commercially used diode for patient dosimetry in radiotherapy) connected in addition to the positioning components. The transmitter was mounted in an apparatus that moved the transmitter in 2000 random positions. The apparatus was placed on the RayPilot receiving system on a carbon fibre table top (iBeam from Medical Intelligence).

Results & Conclusions
The accuracy of the RayPilot positioning system with a dosimeter added was 0.38 mm ± 0.18 mm (radial mean ± SD). Maximum radial error was 1.57 mm. This corresponds to the precision of a non modified RayPilot system.

The tests shows that the RayPilot system is unaffected when an in vivo dosimeter is added in the transmitter and the system shows to be well suited for combined measurement of real-time position and delivered dose to a target in radiotherapy.

References:
A new patient positioning system using magnetic implants and magnetic field sensors.
Stochastic Pattern of Motion In the Prostate

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¹ Dept. of Oncology, Gothenburg University, Sweden  ² Micropos Medical, Sweden

Introduction
The Micropos 4DRT is an electromagnetic positioning system being developed to provide accurate, precise, objective, and continuous target localization throughout the course of clinical radiotherapy. Here we present the first in vivo test of continuous system tracking capability with the goal of evaluating possible patterns of motion in prostate movement.

Results
Continuous monitoring of transponder motion using the Micropos system was successfully performed in all study patients for a time period of ten to twenty minutes. All study patients displayed movements of the target (range 1 – 15 mm). Real-time tracking demonstrated unpredictable transponder motion patterns in several patients, ranging from a persistent drift to transient rapid motion in the range of 0-15mm. Examples of transponder motion pattern recorded in two separate sessions are given (pat #9 and #10) in figure 2.

Materials & Methods
The Micropos Medical 4 dimensional (4D) localization system was recently used in a pilot in vivo technical feasibility study (ref. 1). An electromagnetic positioning marker was temporarily inserted in the prostatic urethra (Fig.1B) of 13 patients scheduled to receive external radiotherapy for localized prostate cancer. A receiving sensor plate (antenna system) was placed at a known position in the treatment tabletop (Fig.1A). After initial system calibrations were performed, 10 patients were included in a descriptive feasibility study that compared radiographic transponder location to radiotransponder location. In this study, transponder position was determined with a 3-D resolution (±SD) of 1.7mm (as compared to 2 orthogonal 2-D radiographic positioning). In addition to simultaneous acquisition of Micropos system data and orthogonal X-ray images, continuous positioning data was recorded during a 10-20 minute study session in the last 5 patients.

Aim of Study
To evaluate in vivo the real-time prostate target localization functionality of the Micropos 4DRT system.

Conclusions
• The Micropos 4DRT positioning system demonstrates real-time tracking functionality in vivo.
• Prostate target motion is of a stochastic nature and individual patients could display significant target displacement during treatment sessions.

References:
Technical description of the next generation electromagnetic positioning device for 4DRT.

B Lennernäs M.D. Ph.D.1, S Levitt M.D. Ph.D. 2, B Rosengren M.D. Ph.D.3, H Syrén MSc.3, R Iustin MSc.3, S Nilsson M.D. Ph.D.2

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Introduction

Electromagnetic positioning was first described by Lennernäs & Nilsson 1995. In this technical note we describe the latest development of the Micropos 4DRT RayPilot system. It is an electromagnetic positioning system being developed to provide accurate, precise, objective, and continuous target localization throughout the course of clinical radiotherapy (Fig.1). It is not X-ray dependent and can be used with or without IGRT techniques. The system uses a non-permanent implant and can be used on existing treatment table tops.

Materials & Methods

The Micropos Medical RayPilot 4D localization system generation 1 has earlier been used in a pilot in vivo technical feasibility study (ref. 2, poster P-1077 ESTRO 2008). In this study an electromagnetic positioning marker was temporarily inserted in urethra, and the transponder position was determined with a 3D resolution of 1.7 ± 1.0 mm (as compared to 2 orthogonal 2-D radiographic positioning). The system has now been further developed with a reduced transmitting implant diameter, a significantly improved positioning algorithm, an optimized antennae system with e.g. 33% increase of the number of receiving antennae. The system has been evaluated in vitro using an automatic 3D-moving device in order to test a large number of random positions (Fig.2).

Results

The system precision for 5000 random positions in generation 2 was 0.37 mm, 0.19 mm, and 3.1 mm for 3D error, 3D and max error. The submillimeter precision is demonstrated in Figure 3. Generation 1 system (used in clinical study) showed a corresponding resolution of 0.77 mm, 0.58 mm, 6.6 mm.

Figure 3. Histogram showing the distribution of in vitro errors in generation 2.

The 3D in vivo study of generation 1 showed a resolution of 1.7 mm (compared to 0.77 mm in vitro). With all technical upgrades the precision has increased significantly in vitro indicating that generation 2 will give a submillimeter precision in vivo.

Conclusions

- 4DRT electromagnetic positioning systems demonstrates high precision both in vivo and in vitro.
- Generation 2 shows submillimeter precision in vitro and indicates use in vivo with high precision.
- The system shows promising results for use in positioning and continuous supervision of organ movement during radiotherapy.

References:

Figure 1. Illustration of the Micropos 4DRT system on a linear accelerator table.

Figure 2. Automatic 3D-moving device for testing random positions.
Target localization using a novel electromagnetic high precision positioning system in patients with localized prostate cancer

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¹ Dept. of Oncology, Gothenburg University, Sweden  ² Micropos Medical, Sweden

Introduction
Image-guided radiotherapy (IGRT) techniques are being increasingly implemented. An important issue in IGRT is intrafraction and interfraction organ motion. The Micropos 4DRT system is being developed to provide accurate, precise, objective, and continuous target localization throughout the course of clinical radiotherapy. This study presents the first in vivo use of the system.

Results
All temporary transponder insertion and localization procedures were successful and without any patient complications. Comparison of the patient localization on the basis of the transponder location as per the Micropos 4DRT system with the radiographic transponder localization showed an average (±SD) absolute and relative 3D difference of 2.7 ± 1.2 and 1.7±1.0 mm respectively (Table 1). The absolute measurement was made by comparing the 3 dimensional position from the Micropos positioning system to the X-ray images relative to the reference markers in the receiving sensor plate. For each patient the implant was placed in three different positions (A1-3). The relative measurement was made by comparing the movement of the implant from the middle position to the end positions from the system to the X-ray images. Two comparable movements were thus obtained for each patient (R1-2/R2-3). System real-time tracking demonstrating organ motion was also successfully performed (data not shown).

Materials & Methods
An active positioning marker was temporarily inserted in the prostatic urethra (Fig.1A) of 13 patients scheduled to receive external radiotherapy for localized prostate cancer. A receiving sensor plate (antenna system) was placed at a known position in the treatment tabletop (Fig.1B). After 3 initial patients, system calibrations were performed. 10 additional patients were then included in a descriptive feasibility study that compared radiographic transponder location to radiotransponder location. With three registered positions per patient, a total of thirty positions were available for comparison. For every position a frontal and side 2D kilovoltage radiograph was obtained using a commercial virtual simulation system (Ximatron radiotherapy simulator, Varian). Each pair of 2D radiographs allows calculation of a 3D position for comparison with the Micropos system position data. Points of reference (radiopaque markers) were located in the receiving plate to allow comparison of radiographic localisation data with Micropos data. Synchronous registration of positioning data from the Micropos system was made at each of the radiographic localizations.

Aim of Study
To evaluate in vivo the target localization accuracy of a novel electromagnetic positioning technique and to assess its real-time tracking ability.

Table 1 The three-dimensional shift in mm between the Micropos 4DRT positioning system and the corresponding X-ray images. Absolute (A) and relative (R) mean 3D (±SD) differences given.

<table>
<thead>
<tr>
<th>Patient</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>R1-2</th>
<th>R1-3</th>
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</table>

Conclusions
• In vivo use of the Micropos 4DRT system allows for high-precision target localization (<3mm 3D difference)
• This novel non-ionizing technique appears well suited for real-time organ motion tracking
Micropos Medical was founded in 2003 by four physicians with long clinical experience in the field of radiation oncology. The founders are pioneers in both passive (gold) and electromagnetic fiducial markers in radiotherapy. The company has received several awards and grants from among others The Swedish Agency for Innovation Systems (Vinnova), the Swedish Business Development Agency (Nutek), the Venture Cup and the Innovation Cup.


The RayPilot® system is in clinical use at European University Hospitals.

In cooperation with:

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