

STAR SHOT – SÄDEHOITOKONEEN LAADUNVALVONTA FILMILLÄ

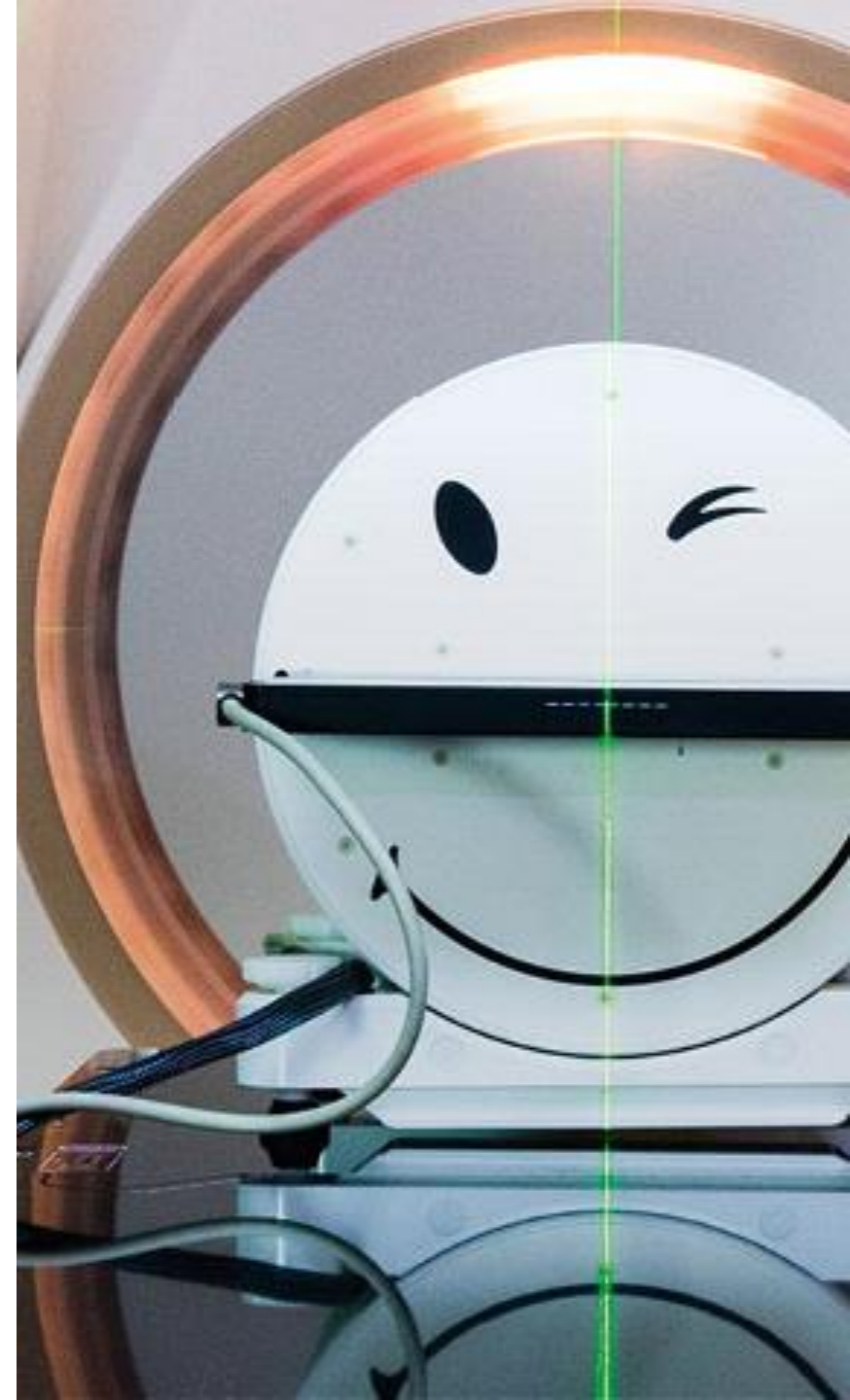
5.6.2025, Erikoistuva fyysikko Patrik Ikäheimonen

SISÄLTÖ

- Taustaa:
 - Laadunvalvonta
 - Star Shot testit
- Metodit: Meidän Star Shot testimme
- Tulokset:
 - Menetelmätestaus
 - Laitetestaus
- Tulevaisuuden ideoita

TAUSTAA: LAADUNVALVONTA

- Laadunvalvonnalla viitataan toimiin, joilla varmistetaan ulkoisen sädehoidon toteutumistarkkuus.
- Laadunvalvonnassa käytetään monia erilaisia fantomeita ja mittalaitteita.
- Laadunvalvontaa suoritetaan kullekin sädehoitolaitteelle säännöllisin väliajoin, uuden laitteen vastaanotossa tai tarpeen vaatiessa.
- Suorittajana toimii testistä riippuen röntgenhoitaja, fyysikko tai teknikko.
- Laitevalmistajilla ja käyttäjillä omat laadunvalvontametodit. Suomessa käyttäjien laadunvalvonnan toteutumista seuraa STUK.
- Laadunvalvonta voidaan jaotella säteilyntuoton ja laitteen mekaanisen suorituskyvyn laadunvalvontaan.



TAUSTAA: MEKAANINEN LAADUNVALVONTA

- Mekaanisessa laadunvalvonnassa keskitytään kiihdyttimen säteilyn laadun ja annoksen sijasta laitteen kohdistustarkkuuteen vaikuttaviin ominaisuuksiin.
- Mekaanisen laadunvalvonnan piiriin kuuluu esimerkiksi:
 - Kollimaattorien ja MLCiden liikkeet
 - Pöydän liikkeet
 - Isosentrin paikka
 - Kanturin liike ja huojunta
- HUSissa tyypillisesti isosentrin paikan tarkistamiseen käytetään Winston-Lutz -testiä ja kanturikulmien tarkistamiseen elektronista kulmamittaa.

TAUSTAA: STAR SHOT TESTIT

- Star Shot-termillä kirjallisuudessa viitataan testeihin, joissa esim. lineaarikiihdyttimen isosentrin kokoa mitataan analysoimalla kanturia pyörittämällä luotua tähtikuviota.
- Eri metodeja olemassa, mutta yleisin on kanturin pyörimistasossa olevan radiokromisen filmin sädettäminen.
- Isosentrin koko mitataan tyypillisesti etsimällä pienin säteiden keskiakselit sisältävä ympyrä.
- Myös pöydän ja kollimaattorin liikkeitä on mitattu Star Shot-testeillä.

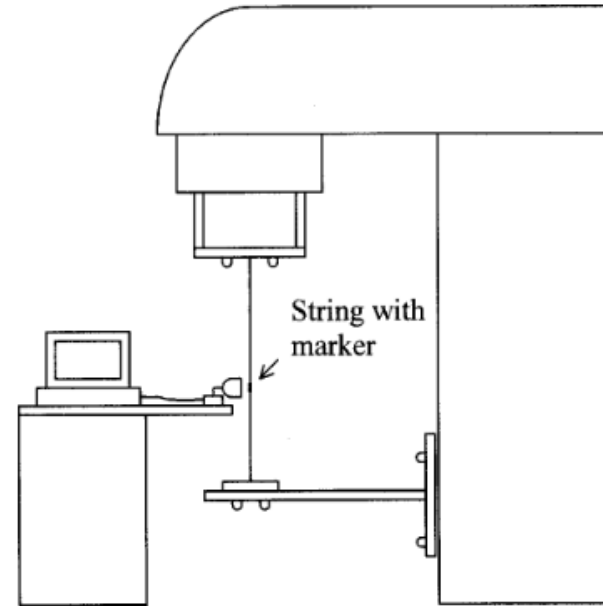


FIG. 2. The string system is mounted on a rigid aluminum arm attached to the gantry. The string is adjusted by an X-Y translator and a marker on the string is aligned to the room lasers and imaged by the webcam.

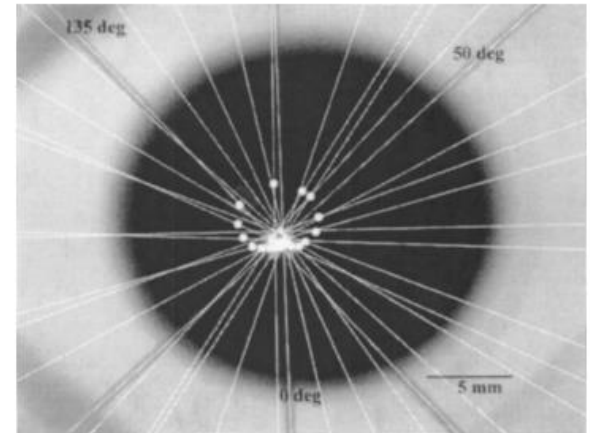


FIG. 4. Superimposed images of the string system showing the delineated optical axis for various gantry angles as well as the locus of the marker.

Star Shot webkameralla ja langalla (M. K. Woo (2002))

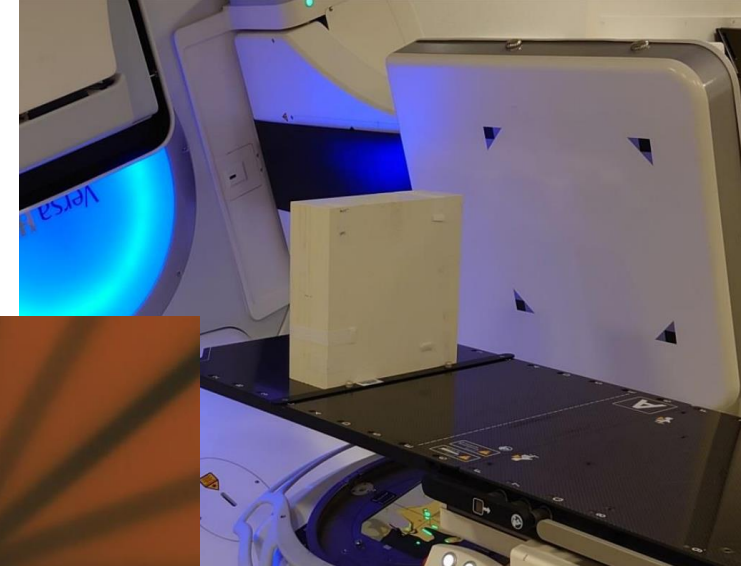
METODIT: MEIDÄN STAR SHOT-TESTIMME

- Mittaa kanturikulmat ja isosentrin koon kanturikulman funktiona.
- Kehitetty alunperin HUSin MRIdian-konetta varten.
 - O-ring kanturi, jonka kuorta ei saa irti -> kulmamitalla saa mitattua vain kun kanturi 90 asteessa.
- Nopea ja helppo tehdä klinikasta löytyvillä tarvikkeilla.
 - Vaatii palan filmiä ja kuivavesifantomia.
 - Fantomin asettelu, sädetys, filmin skannaaminen ja analyysi kestää yhteensä noin 15-30 minuuttia.
- Testi tarjoaa käyttäjälle vertailukelpoisia lukuja, verrattuna muihin, usein tulkinnanvaraisiin testeihin.

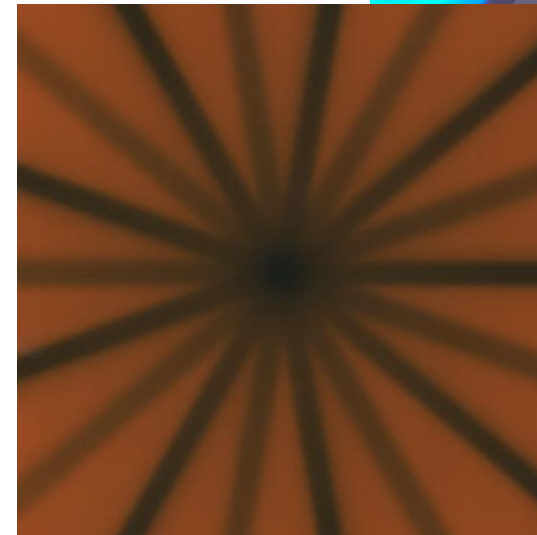


METODIT: TESTIN TOTEUTUS

- Koostuu Gafchromic-filmistä kahden kiinteävesifantomien (yht. 10 x 30 x 30 cm³) välissä.
- Fantomi asetellaan XZ-tasoon (laitekoordinaatistossa IEC61217:fixed).
- Filmi sädetetään 5, 9 tai 15 eri kulmasta 1 x 10 cm² kentällä.
- Saatua filmiä skannataan densitometrillä ja analysoidaan tarkoitukseen tehdyllä ohjelmalla.

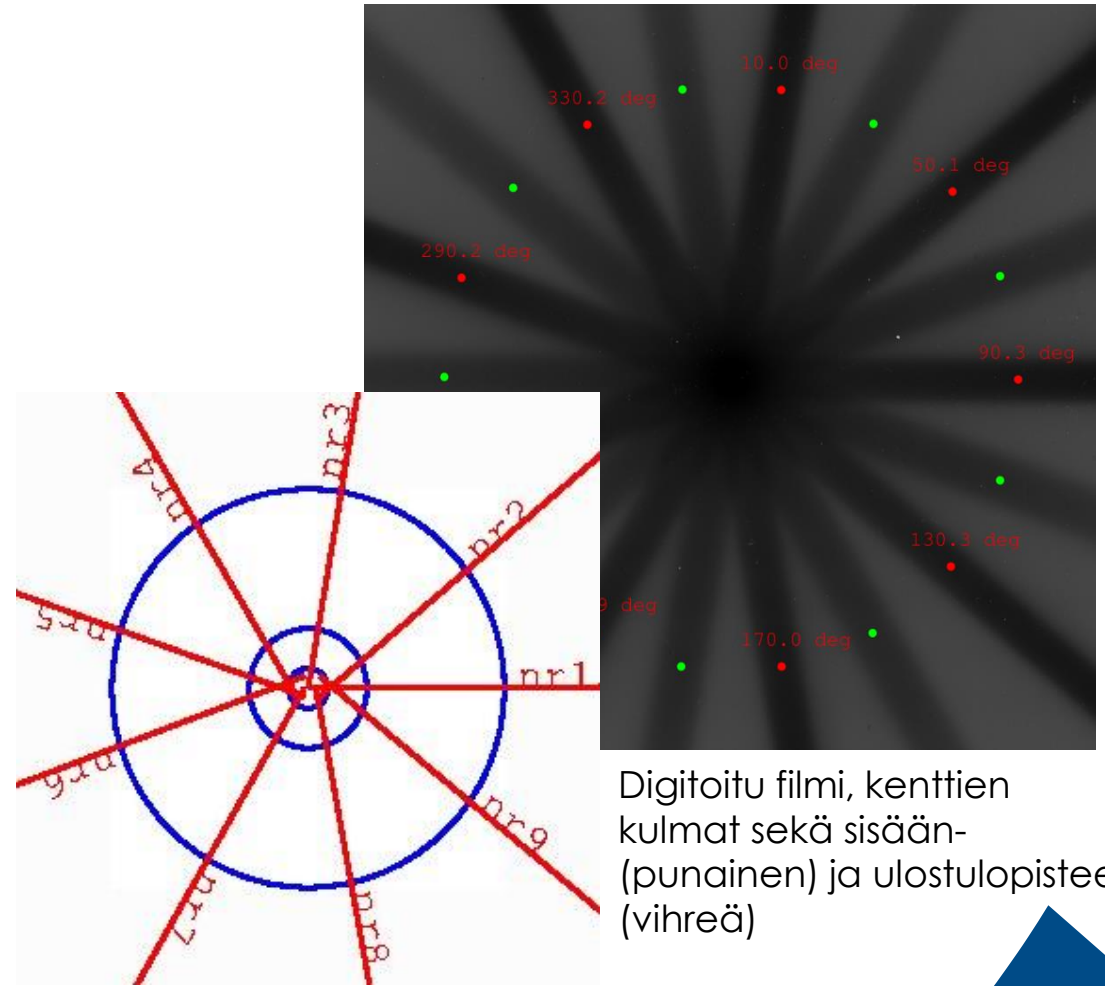


Kiinteävesifantomien asettelu



Star Shot-kuvio sädetetyllä filmillä

- Ohjelma tunnistaa kenttien keskilinjat filmistä ja laskee isosentrin paikan (piste, jossa keskilinjat lähimpänä toisiaan).
- Filmi mahdollisesti kiertynyt fantomin sisällä -> 90 asteen kenttä toimii referenssinä.
- Näistä voidaan määrittää kenttien etäisyys isosentristä (isosentrin koko) sekä kenttien kanturikulmat suhteessa referenssikenttään.
- Aiemmista Star Shot -testeistä eroten tulokset esitetään kanturikulman funktiona.



Digitoitu filmi, kenttien kulmat sekä sisään- (punainen) ja ulostulopisteet (vihreä)

Kenttien keskiakselit. Siniset ympyrät 1, 3 ja 10 mm säteellä isosentristä

TULOKSET

- Menetelmän luotettavuuden testaus
 - Testattu eri parametreilla: MU, energia, kollimaattorikulma, fantomin kierto, ym.
- Olemassa olevat julkaisut eri laitetypyeille:
 - Halcyon (Mikkola et al. ESTRO 2024)
 - MRIdian (Ikäheimonen et al. AAPM 2024)
 - TrueBeam, IX, Versa HD, Edge (Kulmala et al. ECMP 2024)
 - Säteilylähde offset (Paasonen et al. ESTRO 2025)

MENETELMÄTESTAUS: TOISTETTAVUUS

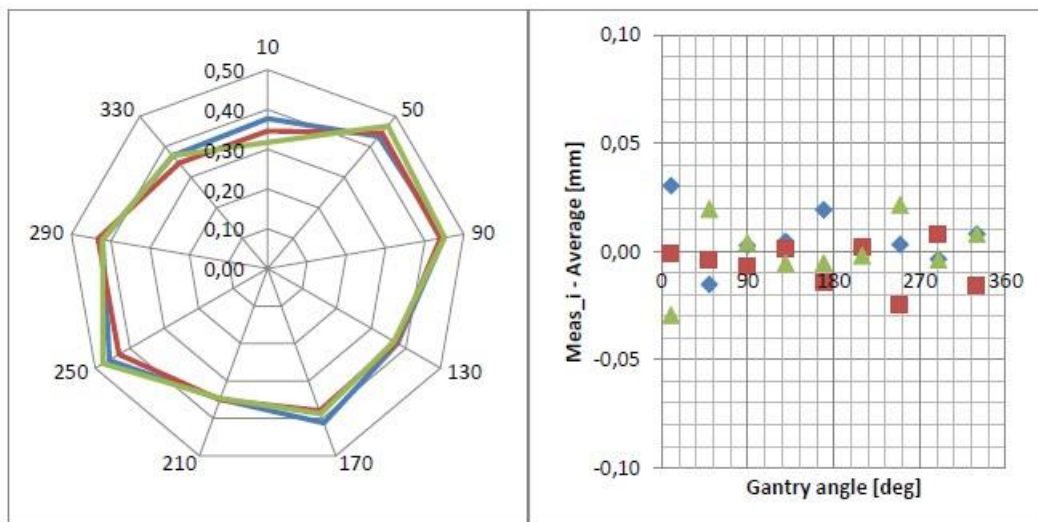


Figure 7. On the left is shown the "minimum distance between the beam CAX and isocenter on the XZ_{IEC61217} plane" as a function of gantry angle and monitor units: 600 MU, 300 MU and 150 MU. On the right is the absolute deviation between the individual result and the mean as a function of the gantry angle. The films were irradiated with TrueBeam(Säde2).

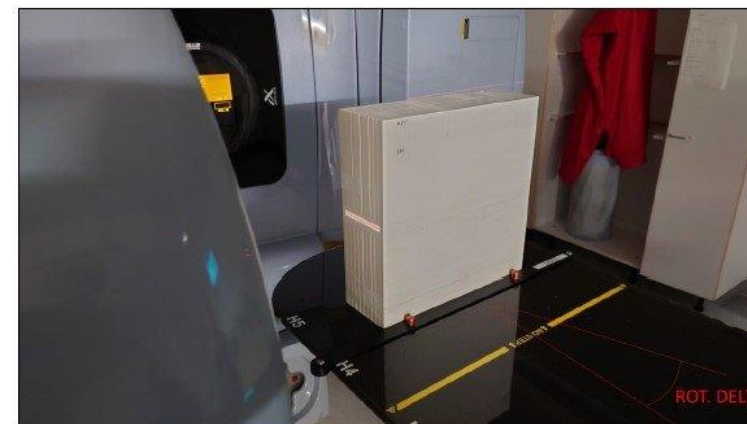


Figure 8A. RW3 phantom setup for StarShot at IX2300(Säde3). The red arc shows the phantom rotation axis.

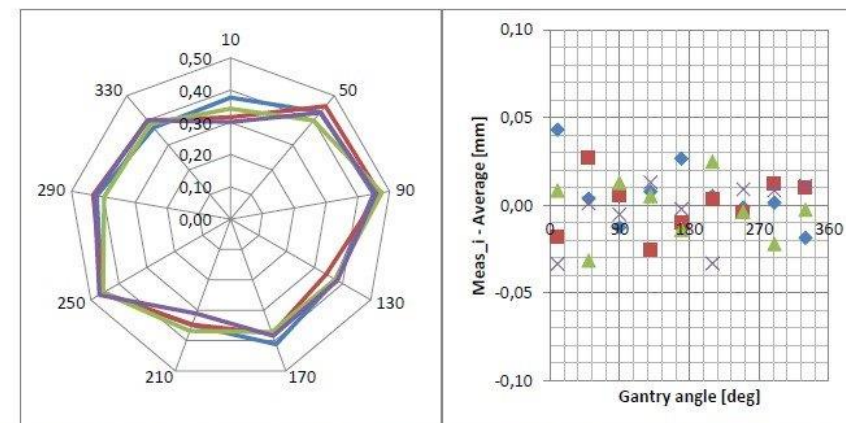
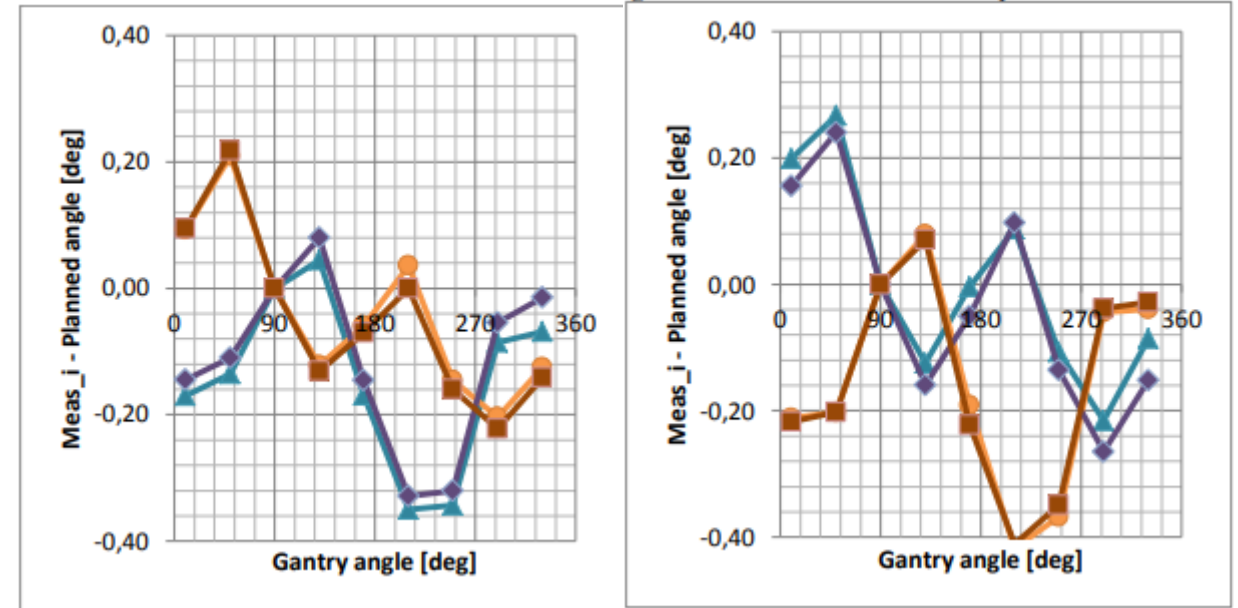
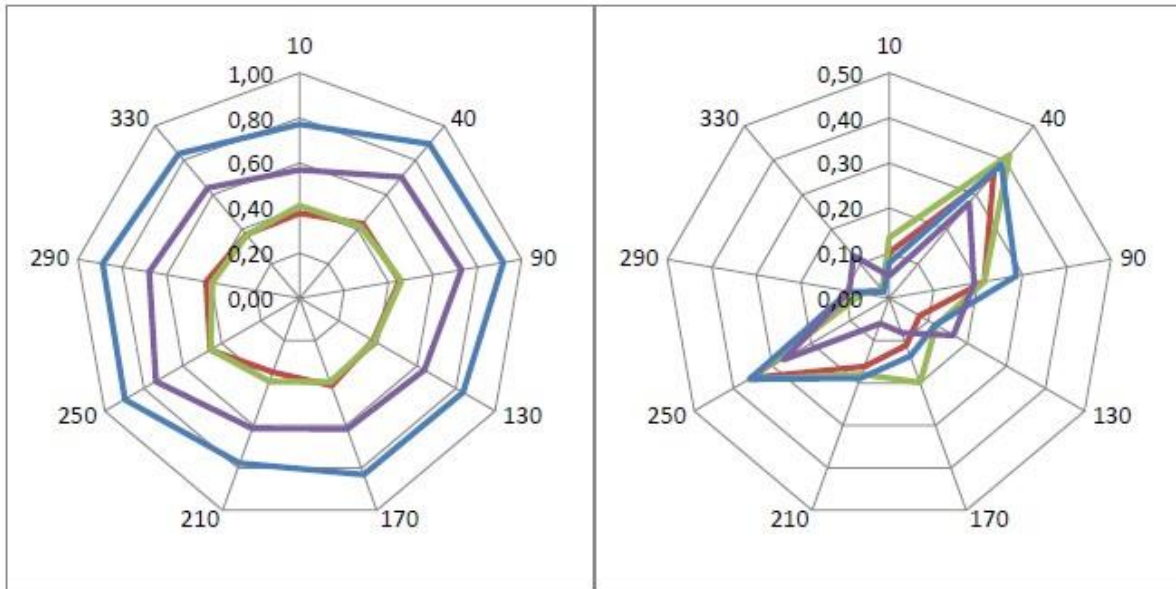


Figure 8B. On the left is shown the "minimum distance between the beam CAX and isocenter on the XZ_{IEC61217} plane" as a function of gantry angle and phantom rotation: (0, 1, 2 and 4) degrees. On the right is the absolute deviation between the individual result and the mean as a function of the gantry angle. The films were irradiated with TrueBeam(Säde2).

MENETELMÄTESTAUS: KOLLIMOINTI & DIGITOINTIVIRHE



Mitatun ja suunnitellun kanturikulman erotus kahdella eri densitometrillä ja eri filmin orientaatioilla: 0 astetta (sininen kolmio), 90 astetta (oranssi ympyrä), 180 astetta (liila timantti) ja 270 astetta (ruskea neliö).

MENETELMÄTESTAUS: YHTEENVETO

- Menetelmän tarkkuus näyttää olevan parempi kuin 0.1 mm riippumatta MU:ista, energiasta, fantomin kierrosta.
- Tulokseen kuitenkin vaikuttavat kollimaattorikulma ja erityisesti filmin digitointi.
 - Kollimaattorin kulma ja kanturin kiertosuunta voivat aiheuttaa jopa 0.4 mm virheen -> lopullinen testi suoritetaan kaksinkertaisella määrällä kulmia:
 1. kierros kollimaattorikulma 90 astetta, kanturin suunta myötäpäivään.
 2. kierros kollimaattorikulma 270 astetta, kanturin suunta vastapäivään.
 - Filmin digitointi aiheuttaa venymää digitoituun kuvaan -> digitointi 4 kertaa eri kierroilla, lopullinen tulos näiden keskiarvo.

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Introduction

In this work, gantry angle and isocenter radius is determined from a Star Shot pattern [1] on a Gafchromic film (Figure 1). Currently, the built-in Machine Performance Check (MPC) is used for Halcyon treatment units to determine the isocenter size at Helsinki University Central Hospital (HUCH). The enclosed O-ring structure of a Halcyon treatment unit makes direct angle measurement difficult, and as a result fewer angles are routinely checked. Additionally, the definition of isocenter size given by the MPC is not known.

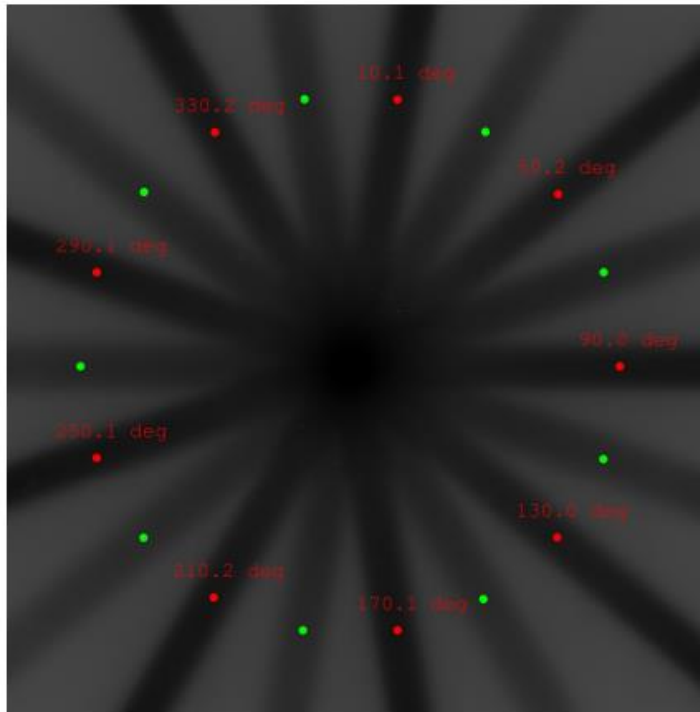


Figure 1. Gantry angles determined from a Gafchromic film.

Methods

Star Shot film analysis is performed with four Halcyon treatment units at HUCH, with 9 gantry angles, and repeated on three films for each machine. A 30 x 30 x 10 cm³ water equivalent phantom is used (Figure 2), with a Gafchromic film in the middle along the lateral-vertical plane. The film is radiated with a 6X-FFF beam, with a 1 x 10 cm² MLC opening for 600 MU per gantry angle. The isocenter is determined along the horizontal and vertical axes [2], therefore the error in longitude direction is not known. The gantry angles come from maximum intensity peaks (Figure 1), and the isocenter radius is determined with an iterative algorithm that minimizes the average distance from all 9 gantry angles.

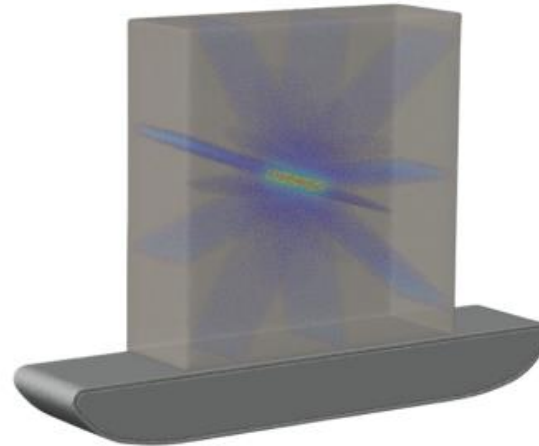


Figure 2. CT imaged phantom with simulated dose distribution.

Results

The average gantry angle deviation was 0.12 +/- 0.11° and the average isocenter radius was 0.20 +/- 0.14 mm. There is consistency in isocenter radius by gantry angle between the treatment units, however all results are within the department protocol limits (Figure 3).

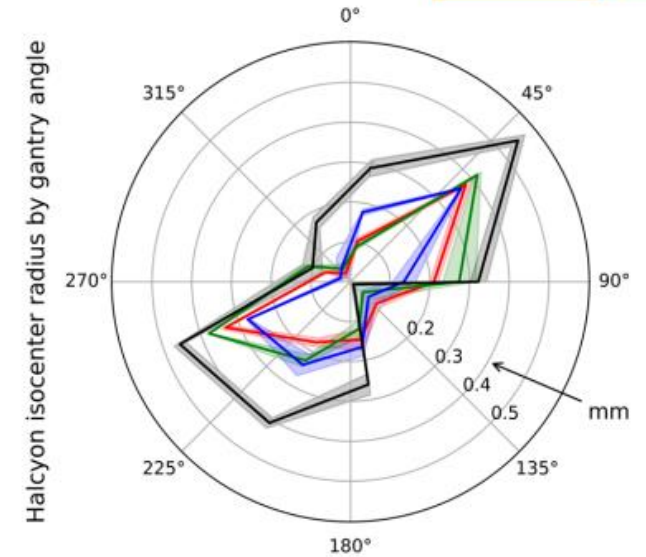


Figure 3. Red, green, blue and black are treatment units 1 to 4, shaded area is standard deviation.

Conclusion

We have demonstrated that Star Shot film analysis can accurately determine gantry angles and isocenter radius of a Halcyon treatment unit. The Star Shot film analysis can be used to determine both the gantry angles and the isocenter radius simultaneously, but the longitude direction is not considered without additional measurements. Film analysis is especially useful for enclosed O-ring treatment units, where other measurements are more difficult.

References

1. Woo MK. A personal-computer-based method to obtain "star-shots" of mechanical and optical isocenters for gantry rotation of linear accelerators. *Med Phys.* 2002 Dec;29(12):2753-5. doi: 10.1118/1.1521937. PMID: 12512707.
2. González A, Castro I, Martínez JA. A procedure to determine the radiation isocenter size in a linear accelerator. *Med Phys.* 2004 Jun;31(6):1489-93. doi: 10.1118/1.1755491. PMID: 15259652.

PO-GPV-T-210 Star Shot Film Analysis for the Accuracy of Gantry Angle and Isocenter Radius in the MRIdian Radiotherapy Device

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INTRODUCTION

A certain degree of mechanical freedom, or 'clearance', is left on the surface between the stand and the gantry to allow the gantry to rotate. If the weight distribution of the gantry is uneven, clearance can make the rotation of the gantry eccentric. The purpose of this study is to determine the radiation source position uncertainty of the MRIdian O-ring gantry in the lateral-vertical plane.

REFERENCES

1. Woo MK. A personal-computer-based method to obtain "star-shots" of mechanical and optical isocenters for gantry rotation of linear accelerators. *Med Phys.* 2002 Dec;29(12):2753-5. doi: 10.1118/1.1521937. PMID: 12512707
2. Mikkola K, Ikäheimonen P, Petrow P, Halkoaho J, Kulmala A. Star Shot film analysis for gantry angle and isocenter radius in Halcyon treatment units, ESTRO annual congress Glasgow 2024. Available from: <https://user-swndwfm.cld.bz/ESTRO-2024-Abstract-Book/4846/>

METHODS

The position of the radiation source as a function of the gantry angle is determined using a Star Shot test [1]. The beam pattern uses nine equidistant gantry angles from 210 to 170 degrees. The measurement is made with a film located on the central axial plane of a 30 cm x 30 cm x 10 cm plastic water phantom (Figure 1) [2].

The film is digitized and the image analyzed (Figure 2) to derive a difference between the planned and actual gantry angles, and the distance between radiation isocenter and beam centerlines. Each film is digitized four times, rotating it by 90 degrees each time to average out any image stretching caused by the scanner. The method is used to study the MRIdian (ViewRay Technologies Inc.) radiotherapy device. The measurement repeated six times over the course of six months.

RESULTS

The maximum distance between the isocenter and the beam centerline is 0.5 mm (Figure 3). The distance appears to be a function of gantry angle: the distance is close to 0.0 mm at certain angles, while at others it is almost 0.5 mm. The result remains extremely similar during the monitoring period.

The maximum difference between the planned and measured gantry angles is 0.25 degrees and seems to not be very dependent on gantry angle (Figure 4).

While the mean value across all measured angles stays roughly similar during the measurement period, the maximum difference increases linearly as a function of time. However, this trend evens out slightly at the end of the six-month period.

All results are within the department protocol limits.

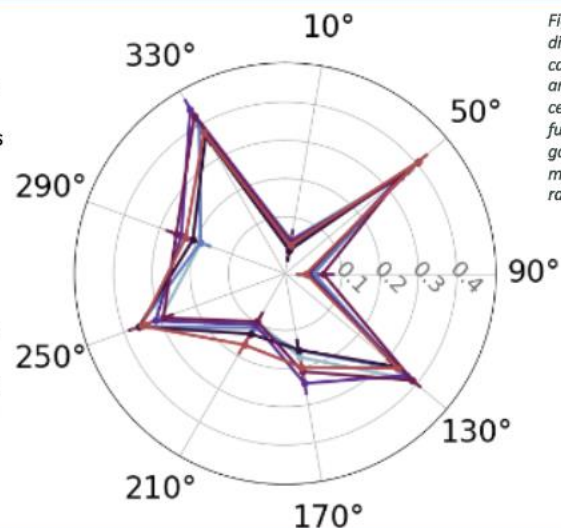


Figure 3 (on left): The distance between the isocenter and the beam centerlines as a function of planned gantry angle for all six measurements. The radial axis is in mm.

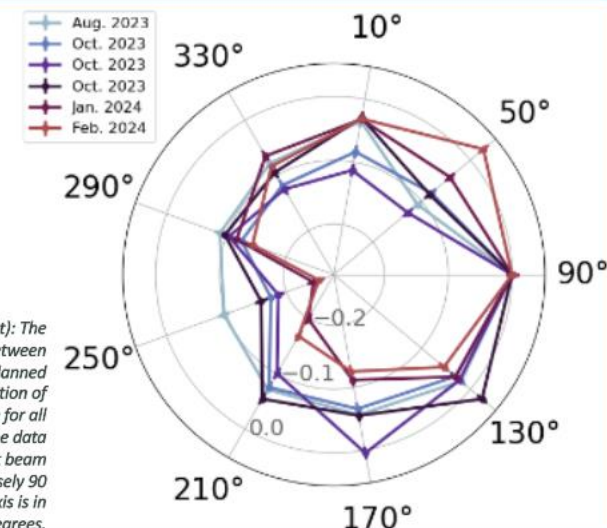


Figure 4 (on right): The difference between measured and planned angles as a function of planned gantry angle for all six measurements. The data is normalized so that beam number 1 is at precisely 90 degrees. The radial axis is in degrees.

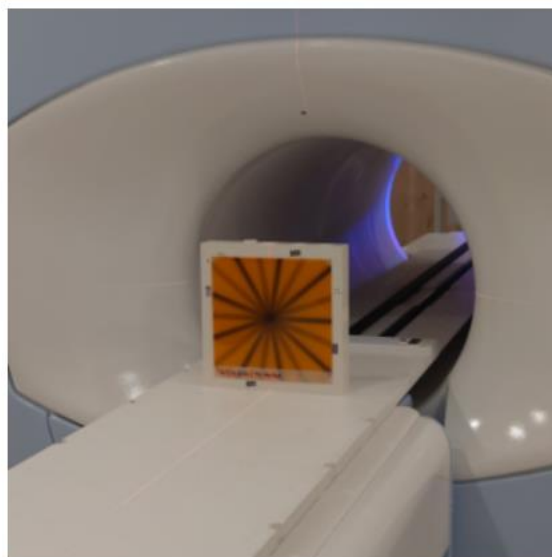


Figure 1 (on left): The measurement setup, showing the irradiated film, the other half of the plastic water phantom, and the MRIdian radiotherapy device.

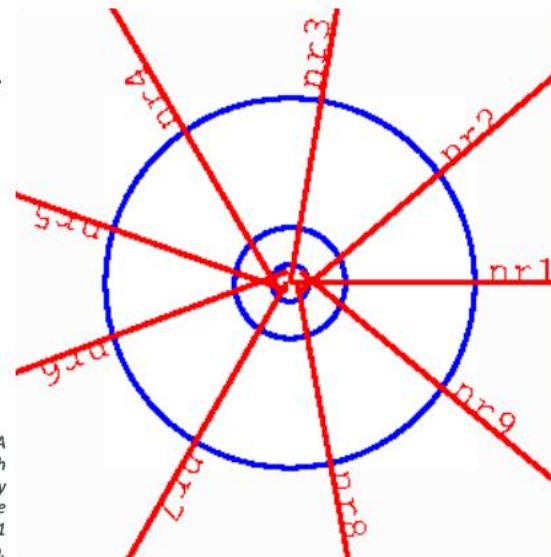


Figure 2 (on right): A visualization of each beam's path produced by the analysis software. The blue circles have radii of 1 mm, 3 mm and 10 mm.

CONCLUSIONS

The O-ring gantry of the MRIdian is shown to have a small, though highly angle dependent, source position uncertainty. While the isocenter size stays stable over six months, a noticeable increase in maximum angle deviation can be seen. The presented method is shown to give reliable and repeatable results.

In the future, there are plans to introduce this test into clinical use as a more convenient alternative to other isocenter size and gantry angle tests, as well as to expand the test to measure the source position uncertainty in three dimensions instead of two.

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As the precision of radiation treatments increases, mechanical imperfections are becoming more significant in terms of the validity of treatment delivery. The position of the radiation source is eccentric due to mechanical clearance in the gantry construction, uneven weight distribution and overall wear and tear. By developing methods to determine this uncertainty one can enable better treatment modeling.

In this work, we present an implementation of the Star Shot test, which determines the position of the radiation source in the vertical-lateral plane as a function of the gantry angle. The method is applied to four c-arm radiotherapy devices and the total displacements are reported.

Material & methods

The 2D distance between beam centreline and isocentre is determined with the Star Shot test using a field size of 1 x 10 cm², with nine equidistant gantry angles from 210 to 170 degrees (Figure 1).

The software calculates the beam entry and exit angles from the digitized (grayscale, 16-bit, 300 dpi) film: i) resamples the image as a function of radial distance and angle, ii) averages over the radial range: 6 cm to 8 cm, iii) and solves the beam angle by determining the 50 % edges of its intensity (Figure 2). The software plots the found beam angles (Figure 3A), beam CAXs (Figure 3B) and prints the detailed results to an ascii file.

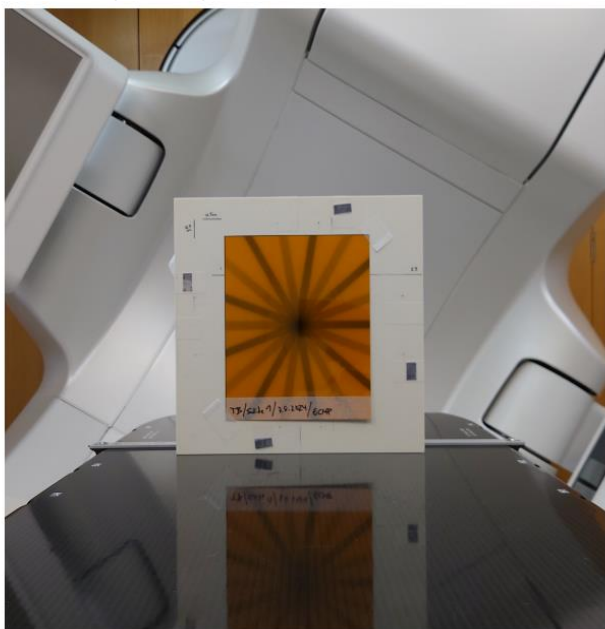


Figure 1: The measurement setup, showing the irradiated film, the other half of the plastic water phantom, and the radiotherapy device. The plastic water phantom (RW3, 10 x 30 x 30 cm³) (PTW Freiburg GmbH) and the RTQA2 film (Ashland Inc.) are aligned with the XZ_{IEC61217:FIXED} plane.

The accuracy of isocentre position in the vertical-lateral plane in clinical linear accelerators

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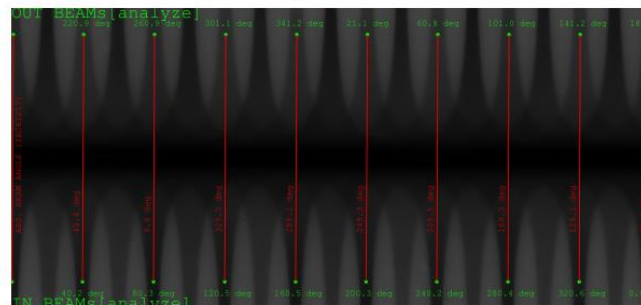


Figure 2: Radial representation of the Star Shot image. The horizontal axis shows the profile angle [0, 360 deg] and the vertical axis the radial position [-8.5, 8.5 cm]. The found beam entry and exit angles are shown in analysis coordinates (green dots and text) and the determined beam center axes and entry angles are shown in IEC61217 coordinates (red line and text).

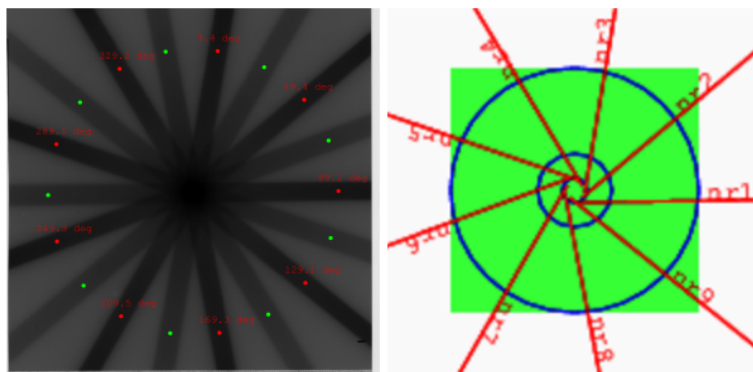


Figure 3: The left image shows the beam entry (red circle) and exit (green) directions and beam angles (red font) according to the IEC61217 scale. The right image shows the central axis of the detected beams near the isocentre, centered on the blue circles (diameters: 1, 3 and 10 mm). Data from TrueBeam.

The method is used on IX*, TrueBeam*, Edge* (*Varian Medical Systems Inc.) and VersaHD (Elekta Instrument AB) radiotherapy machines at HUCH.

Results

The average distance between isocentre and beam centreline on the vertical-lateral plane is found to be 0.9 mm for VersaHD, 0.4 mm for TrueBeam, 0.3 mm for IX and 0.1 mm for Edge (Figure 4).

The measurements were repeated three times. The random uncertainty (due to the film, digitizer, and phantom) in determining the beam displacement is found to be less than 0.1 mm.

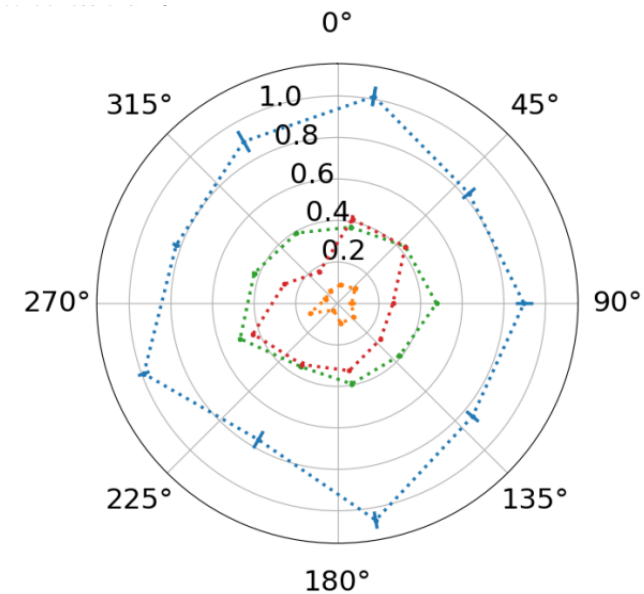


Figure 4: The distance between the isocentre and the beam centerline as a function of the gantry angle and the examined device: VersaHD (blue dot), TrueBeam (green), IX (red) and Edge (orange). Error bars show standard deviation. The radial axis is in millimeters.

Conclusion

We have demonstrated that our implementation of the Star Shot test can be used to determine beam centerline displacements with a small uncertainty. The found displacements seem to be device-specific and almost independent of the gantry angle.

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Introduction

In a linear accelerator, photon radiation is produced by colliding accelerated electrons with a target. Due to collimator design, if the collision position is not ideal, the radiotherapy beam exiting the device can become eccentric. The purpose of this study is to evaluate the suitability of the Star Shot test for quantifying offsets in the radiation source position.

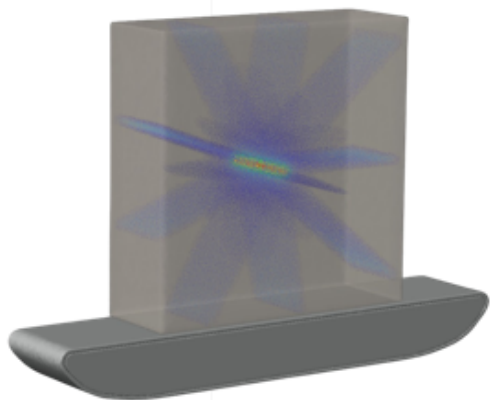


Figure 1. StarShot phantom with planned (15 angularly equally spaced radiation fields) dose distribution.

Materials/Methods

In this work, the position of the radiation source as a function of the gantry angle is determined using a Star Shot test¹⁻³. A 30 x 30 x 10 cm³ water equivalent phantom is used (Figure 1), with a Gafchromic film in the middle along the lateral-vertical plane. The method is used to study the source position i) as a function of treatment device and beam energy, without disturbing the system under investigation, and ii) as function of a transversal electron beam steering with four intentional electron beam position shifts. The study includes three TrueBeam (Varian Medical Systems Inc., Palo Alto) radiotherapy devices in clinical use at Cancer Center (Helsinki).

Results

At least one photon energy can be found in every device where the radiation isocentre radius is smaller than 0.2 mm. With the newest device, the radiation isocentre radius of all four photon energies is found to be smaller than 0.2 mm. The largest radiation isocentre radius (0.7 mm) was found in one of the energies of an older device.

For intentional source position shifts, the maximum distance between the isocentre and the beam centerline (1.4 mm) was determined with a transverse electron beam steering of -1.7 A and the smallest distance (0.1 mm) with a steering of -0.8 A. The distance between the beam centerline and the isocentre as a function of the gantry angle and beam steering: present value, +/-0.3 A and +/-0.6 A, is shown in figure 2. The radiation isocentre radius as a function of the beam steering is presented in figure 3.

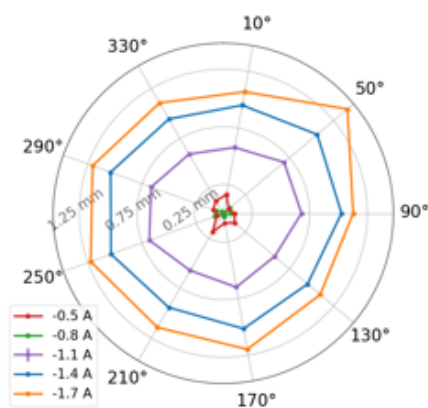


Figure 2. Distance between beam centerline and isocentre as a function of gantry angle and transversal source position [A]. Data from TrueBeam(sn:2398) FFF6 beam.

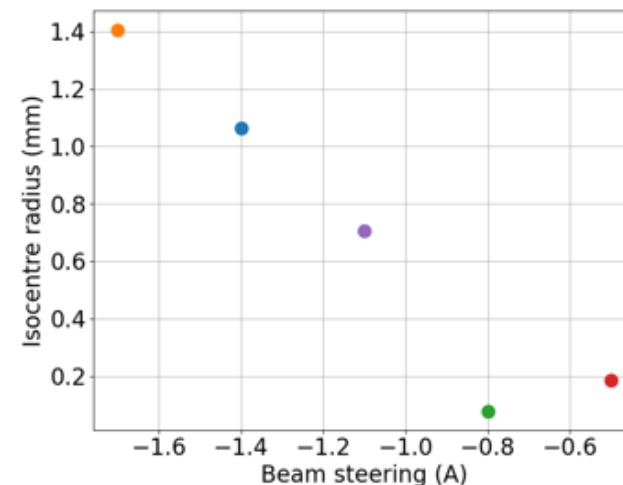


Figure 3. The average isocentre radius as a function of the transverse position of the electron beam at the target [A]. Data from TrueBeam(sn:2398) 6FFF beam.

Conclusion

The transversal radiation source position offsets can be detected using Star Shot test and the results can be used to guide transversal source position corrections.

References

1. Kulmala A., Ikäheimonen P., Petrow P., Mikkola K. and Halkoaho J. 2024 The accuracy of isocentre position in the vertical-lateral plane in clinical linear accelerators, ECMP congress, Munich
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3. Mikkola K., Ikäheimonen P., Petrow P., Halkoaho J. and Kulmala A. 2024 Star Shot film analysis for gantry angle and isocenter radius in Halcyon treatment units, ESTRO annual congress, Glasgow

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LAITETESTAUS: YHTEENVETO

- Kaikilla kliinisessä käytössä olevilla laitteilla isosentrin koko on ≤ 0.9 mm, useimmilla ≤ 0.5 mm.
- Kentän etäisyys isosentristä riippuu kanturikulmasta Halcyon-, ja MRIdian-koneissa, vaihdellen jopa alle 0.1 mm:stä yli 0.5 mm:iin.
- Keskimääräinen ero mitattujen ja asetettujen kanturikulmien välillä pysyi laitteilla noin 0.2 asteessa.
- Isosentrin koko riippuu säteilylähteen paikasta.
- Metodia verrattu laitevalmistajan omaan isosentrin huojuntatestiin; havaittu, että tulokset yhtenevät.

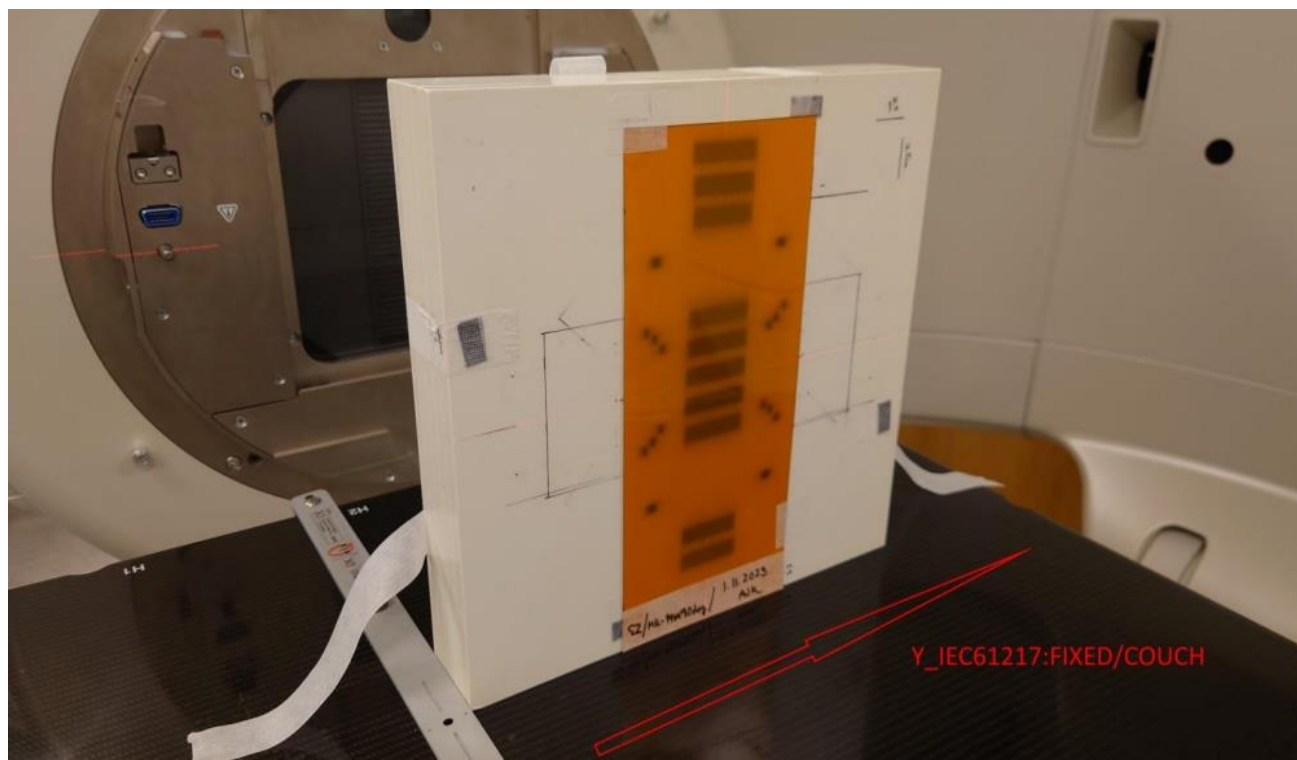
TULEVAISUUDESSA: LONG SHOT-TESTI

- Soveltuu longitudisuuntaisen isosentrin koon ja kanturikulmien huojunnan mittaamiseen.
- Samat materiaalit kuin Star Shot testissä, mutta filmit sädetetään XY- ja ZY-tasoissa.
- 15 kenttää sekä filmin orientaation määrittämiseksi käytetyt filmiä kohtisuoraan sädetetyt beacon-kentät.



HUS⁺

Fantomien
asettelu



YZ-tasossa
sädetetty
filmi

TULEVAISUUDESSA: COUCH- /COLLSHOT

- Soveltuu kollimaattori/pöytähuojunnan mittaamiseen.
- Samat materiaalit kuin Star Shot testissä, filmit sädetetään XY-tasossa, kanturi staattinen 0 astetta.
- 9 MLC & 5 JAW kenttää sekä filmin orientaation määrittämiseksi käytetyt filmiä kohtisuoraan sädetetyt beaconkentät.



Couch-/Collshot-testin filmikuvio

YHTEENVETO

- Star Shot filmitesti nopea ja helppo testi sädehoitokoneiden kanturikulmien ja isosentrin koon tarkistamiseen.
- Testin tulokset riippumattomia esim. MUista, energiasta ja fantomin kierrosta.
- Kollimaattorin kierto ja digitointi vaikuttavat tuloksiin -> ekstra sädetykset ja skannaukset korjaavat.
- Metodilla testattu HUSin Halcyon, MRIdian, TrueBeam, Edge, IX ja VersaHD koneita, sekä säteilylähteen paikan muuttamisen vaikutusta tuloksiin.
- Tulevaisuudessa testi laajennetaan mittaamaan longitudisuuntaista huojuuntaa, ja kollimaattorin sekä pöydän liikettä.

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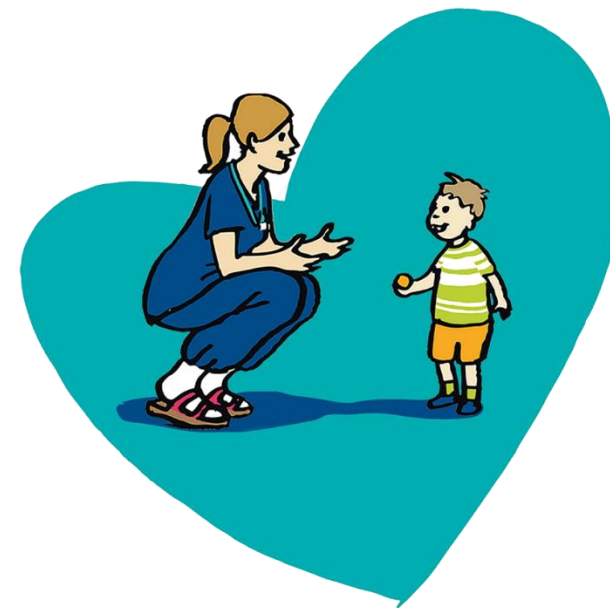
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KIITOS! KYSYMYKSIÄ?

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**Kohtaaminen
Edelläkävijyys
Yhdenvertaisuus**