# ETTAC 2020

# 1st Workshop on Eye Tracking Techniques, Applications and Challenges

https://vision.unipv.it/ettac2020/

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In conjunction with

ICPR 2020

# Gaze stability during Ocular Proton Therapy: quantitative evaluation based on eye surface surveillance videos

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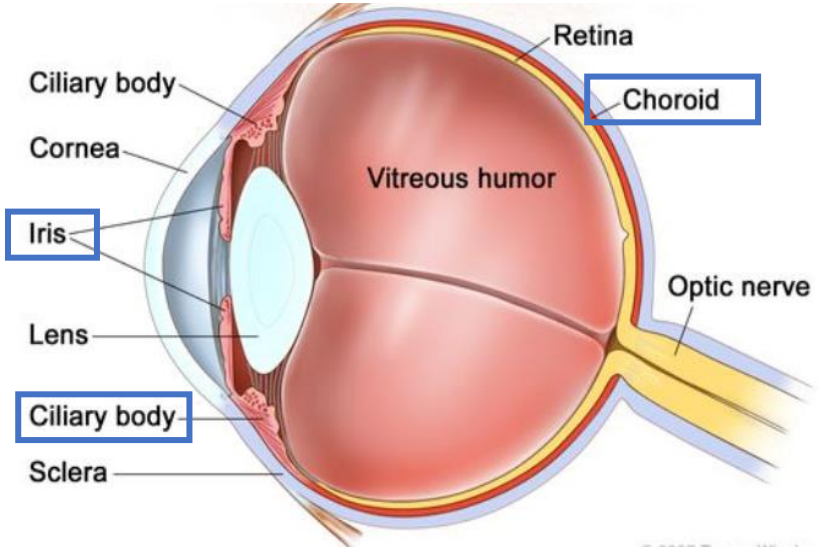
# Uveal Melanoma and Treatment Modalities




1. Choroidal melanoma (90%)
2. Iris melanoma (3%)
3. Ciliary body melanoma (7%)

Singh, M., et *al.* (2018) doi: 10.1007/s40487-018-0056-8.

## Treatment Modalities

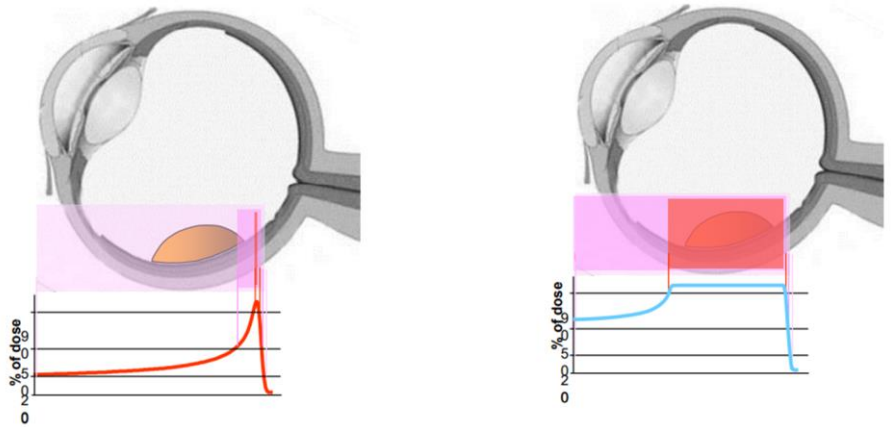
1970 — present

*Enucleation* — *Globe conserving therapies* — *Radiation Therapy*

Singh AD et al. (2011) doi: 10.1016/j.ophtha.2011.01.040.

Hrbacek J et al. (2016) doi: 10.1016/j.ijrobp.2016.01.040.

*Ocular Proton Therapy*

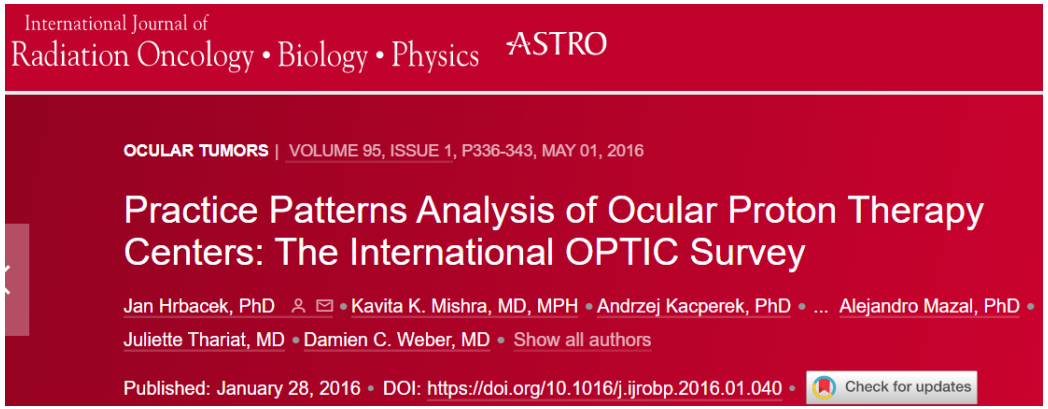



Highly conformal, hypo-fractionated, high dose irradiation

# Ocular Proton Therapy Centers

More than 30 000 eye patients worldwide have been treated with protons since treatments started at the Harvard Cyclotron Laboratory (HCL) in 1975
(Gragoudas et *al* (1977), doi: 10.1016/0002-9394(77)90133-7, Slopsema et al. (2018) doi: 10.1088/1361-6560/aaf9c9).

https://www.ptcog.ch/index.php/facilities-in-operation


International Journal of Radiation Oncology • Biology • Physics ASTRO

OCULAR TUMORS | VOLUME 95, ISSUE 1, P336-343, MAY 01, 2016

Practice Patterns Analysis of Ocular Proton Therapy Centers: The International OPTIC Survey

Jan Hrbacek, PhD • Kavita K. Mishra, MD, MPH • Andrzej Kacperek, PhD • ... Alejandro Mazal, PhD • Juliette Thariat, MD • Damien C. Weber, MD • Show all authors

Published: January 28, 2016 • DOI: https://doi.org/10.1016/j.ijrobp.2016.01.040 • Check for updates

In 2016 Particle Therapy Cooperative Oncology Group (PTCOG) listed worldwide **12 centers in 9 countries performing ocular proton therapy (OPT) using a dedicated fixed horizontal beam line.**

Hrbacek J et al. (2016) doi: 10.1016/j.ijrobp.2016.01.040.

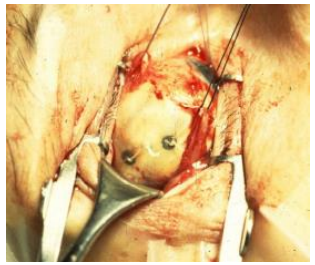
However, regardless the different clinical procedures and hardware/software equipment adopted by centers that currently offer OPT  some fundamentals are in common.

# Ocular Proton Therapy

**Accurate tumor localization and positioning** are mandatory to benefit from the advanced geometrical accuracy of protons

Clinical workflow is deeply based on **x-ray image guidance procedures**, both for treatment planning and patient setup verification purposes

## Surgery

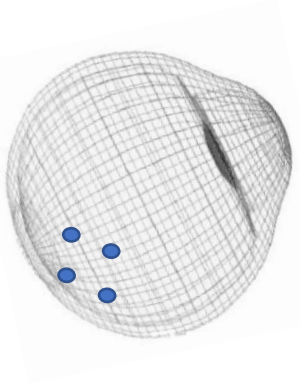


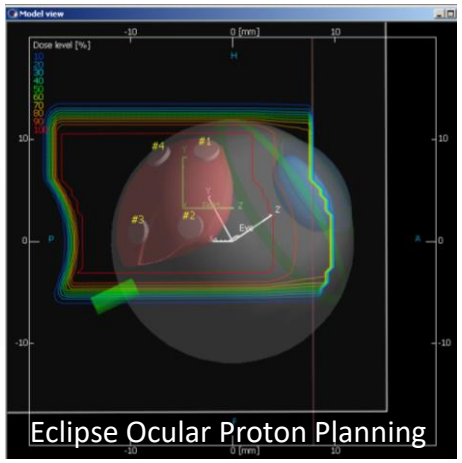
*Radiographic markers* for tumor localization

- treatment planning

-daily setup image guidance

## Treatment Planning

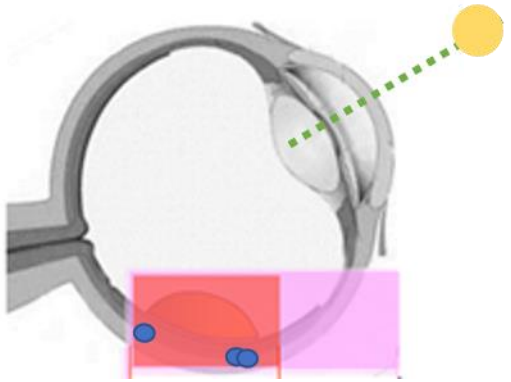





Definition of *optimal gaze direction*
Reference tantalum clip position

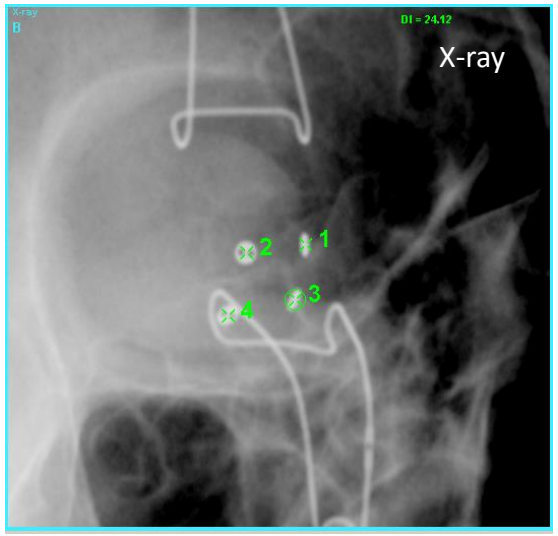
## Treatment Delivery and Setup Verification

*fixation light*

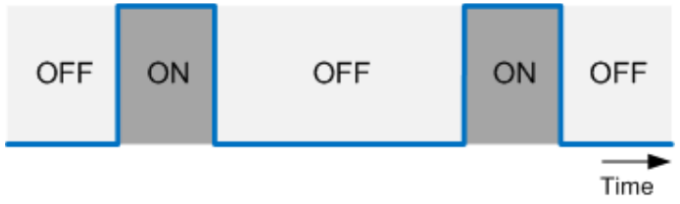


The patient *actively participates* during set-up and irradiation by looking at a fixation light.

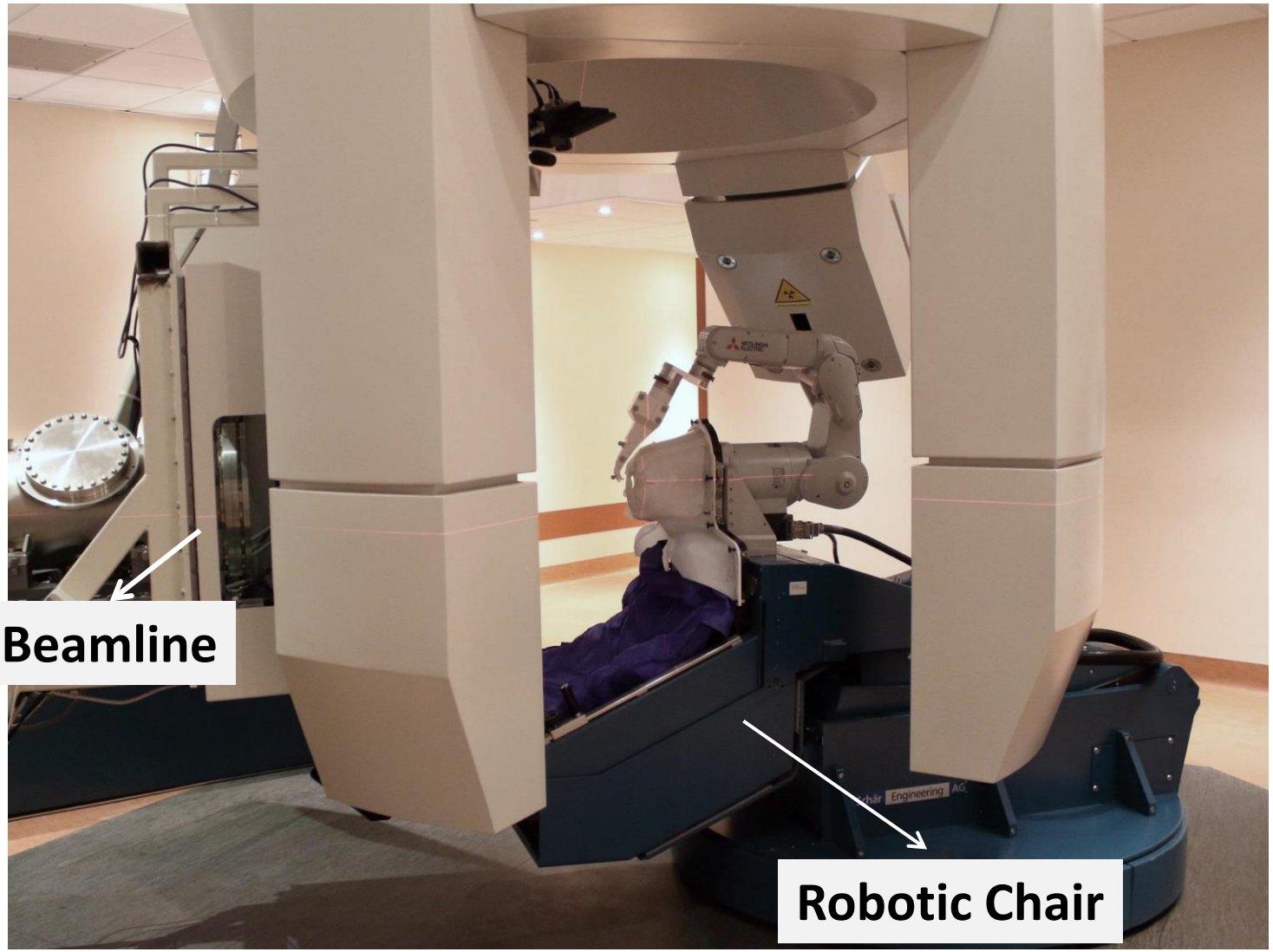
Proper eye alignment is verified using repeated *radiographic imaging* of the tantalum clips




Treatment delivery is *manually gated*

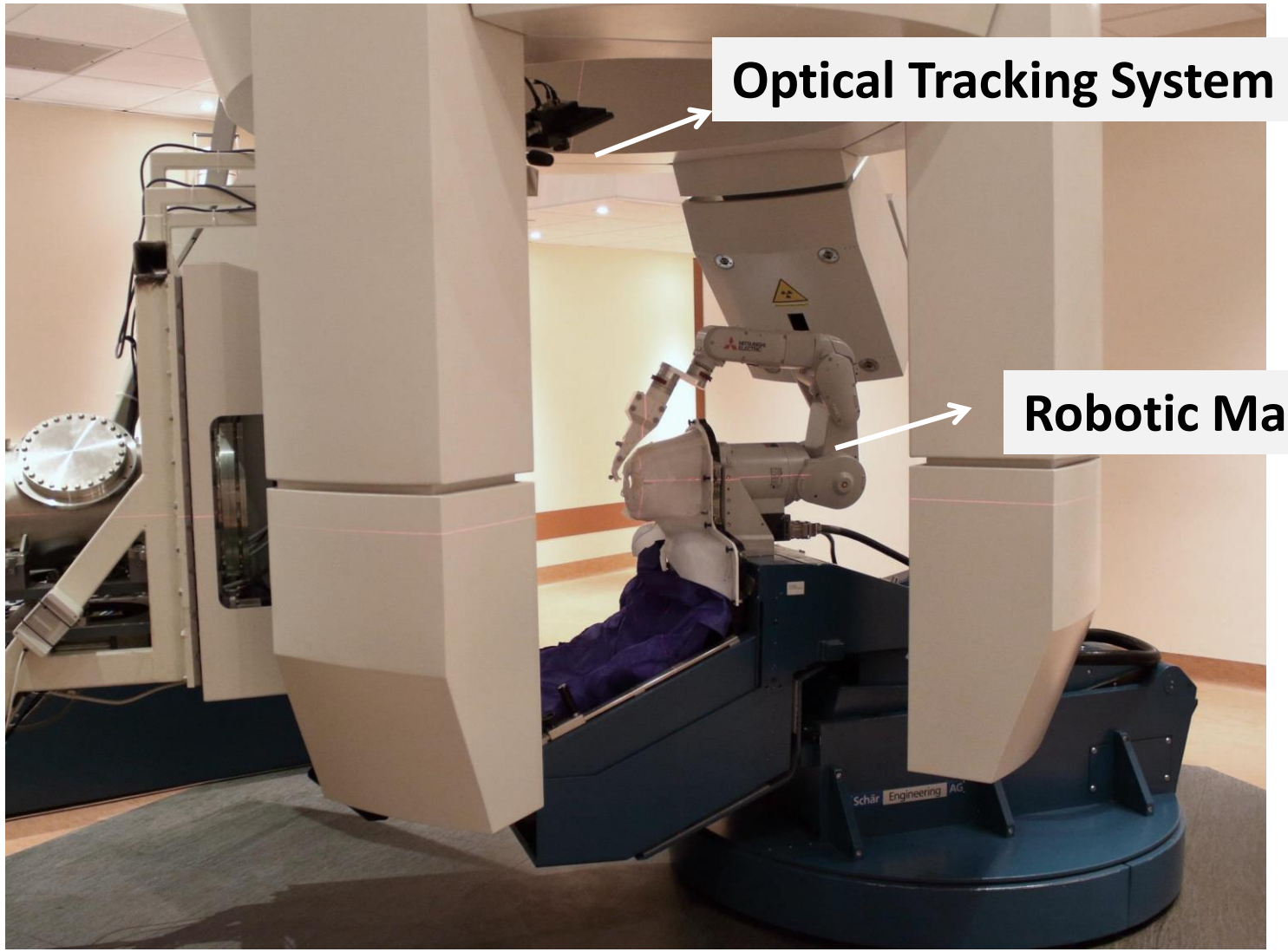


# Ocular Proton Therapy – Treatment Room @CNAO

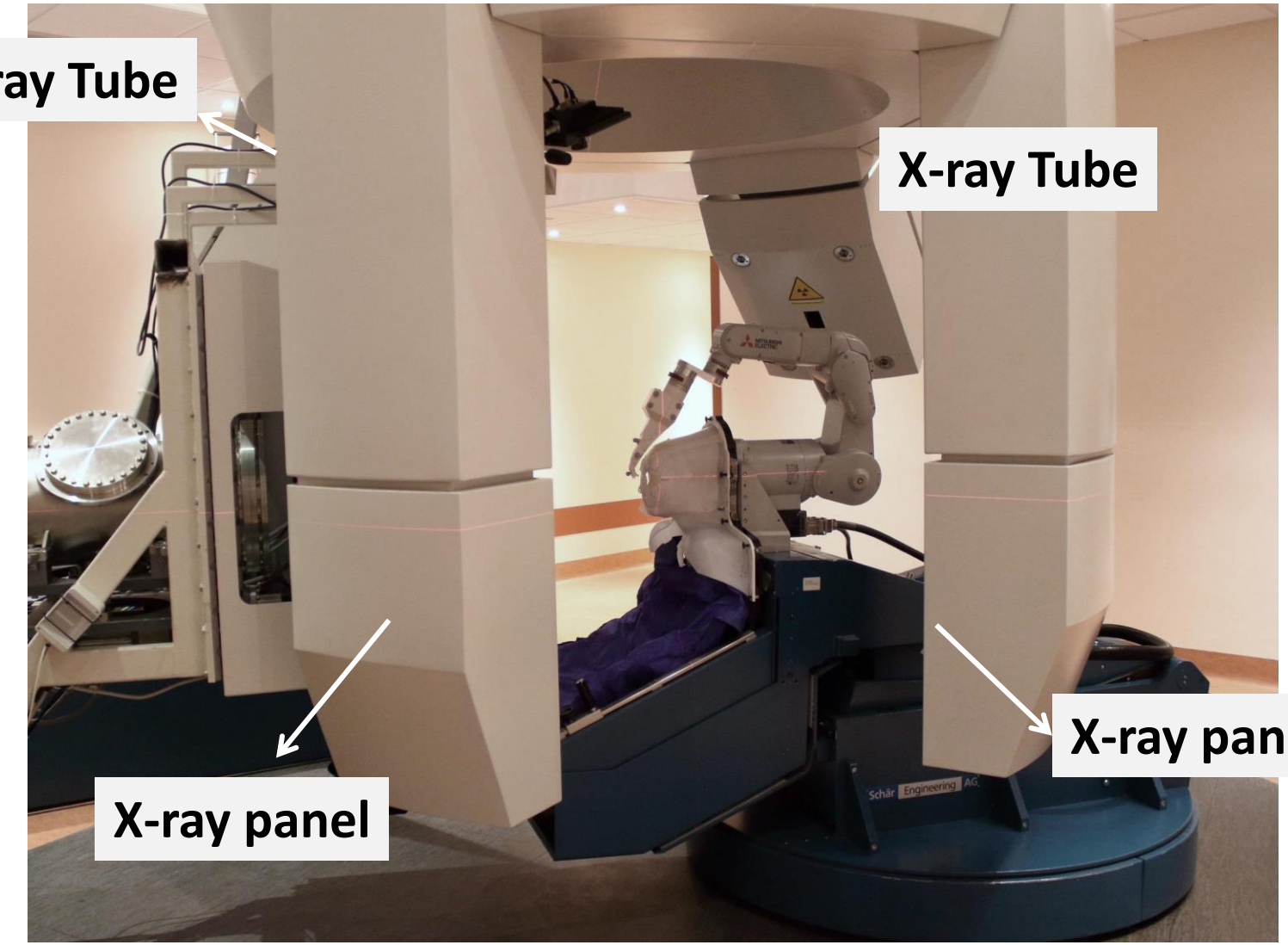



Ciocca M et *al*. doi: 10.1002/mp.13389

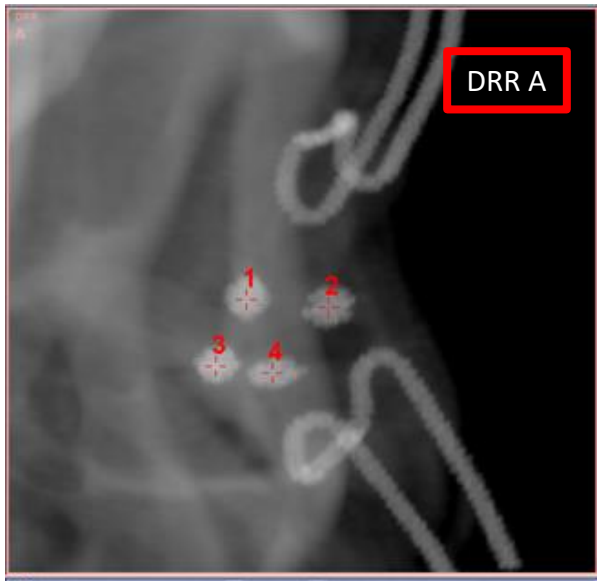
# Ocular Proton Therapy – Treatment Room @CNAO

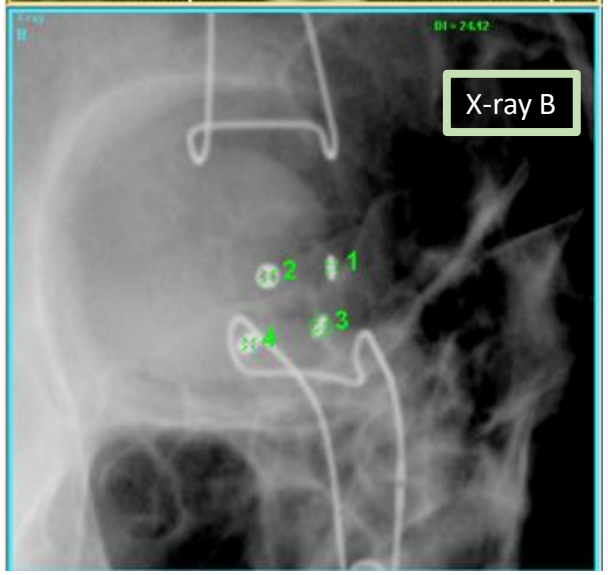


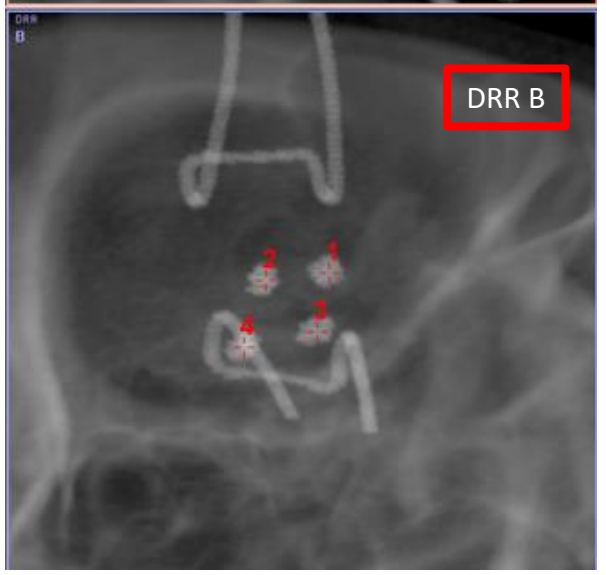
# Ocular Proton Therapy – Treatment Room @CNAO



# Ocular Proton Therapy – Treatment Room @CNAO

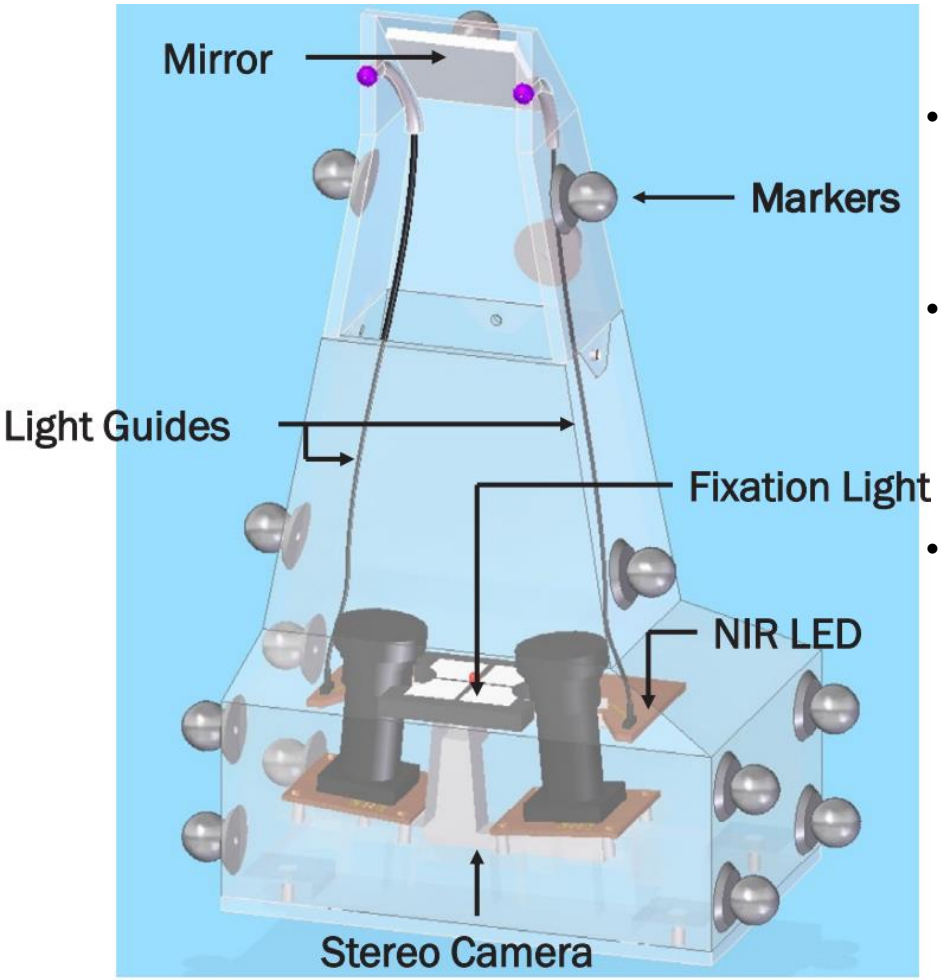



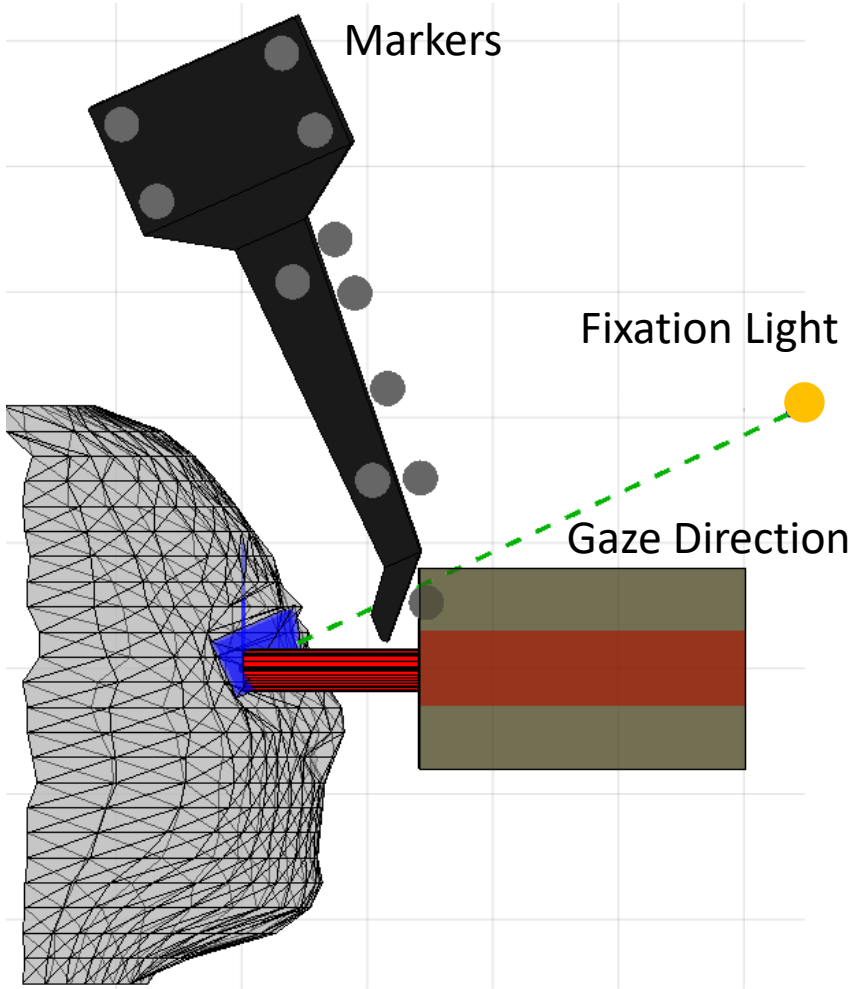



# Ocular Proton Therapy – Treatment Room @CNAO

# Ocular Proton Therapy @ CNAO – Eye Tracker System (ETS)




- ETS provides the **fixation light** for the stabilization of patient gaze direction.
- External markers geometry permit an **accurate positioning of fixation light** using industrial robots and optical tracking systems.
- ETS **monitors involuntary eye motion** by means of a stereo-camera system embedded in the same device providing real-time (25 Hz frame rate) optical imaging of the eye surface

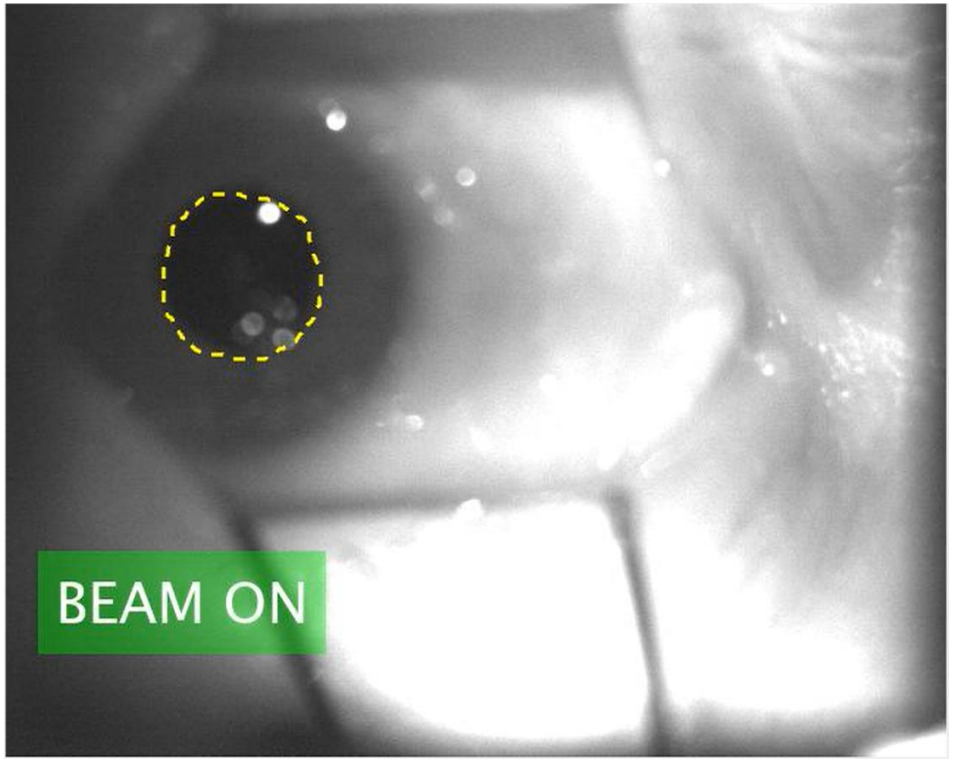


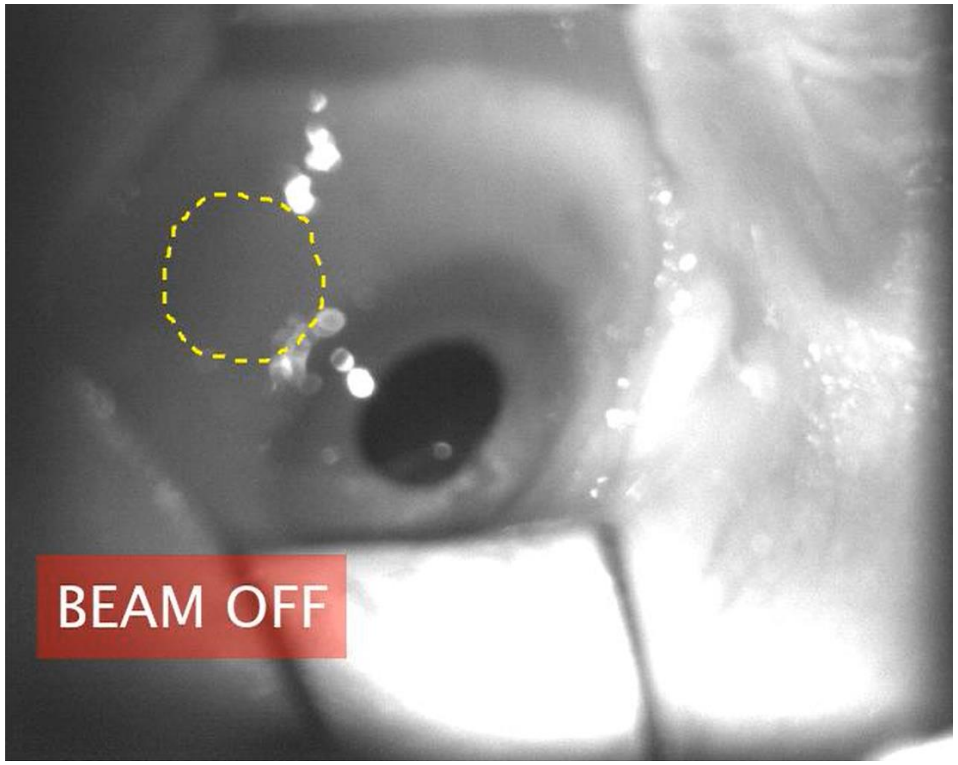


Fassi A et *al.* (2012) doi: 10.1364/AO.51.00244.
Via R, et *al.* (2015) doi: 10.1118/1.4915921.
Via R, et al. (2019) doi: 10.1016/j.ejmp.2019.02.020.
Elisei G, et *al. under review to Physica Medica*

# Ocular Proton Therapy @ CNAO – Eye Tracker System (ETS) clinical practice

While repeated x-ray images are acquired for quantitative setup evaluation purposes,
eye surface images acquired by the ETS embedded cameras allow for the **continuous qualitative monitoring gaze reproducibility**



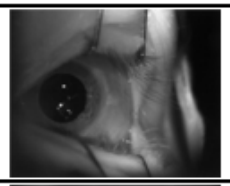
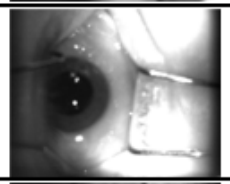
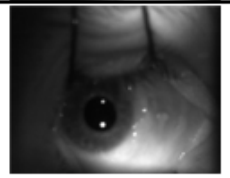

In clinical practice, **operators manually outline convenient ocular features** on a reference eye image to detect eventual eye misalignments or shifts during irradiation.
In case of eye misalignment during treatment, beam delivery is **manually gated off.**

# Purpose

Quantitative evaluation of patient gaze stability during ocular proton therapy at CNAO investigating the eye surface images recorded by Eye Tracking System.

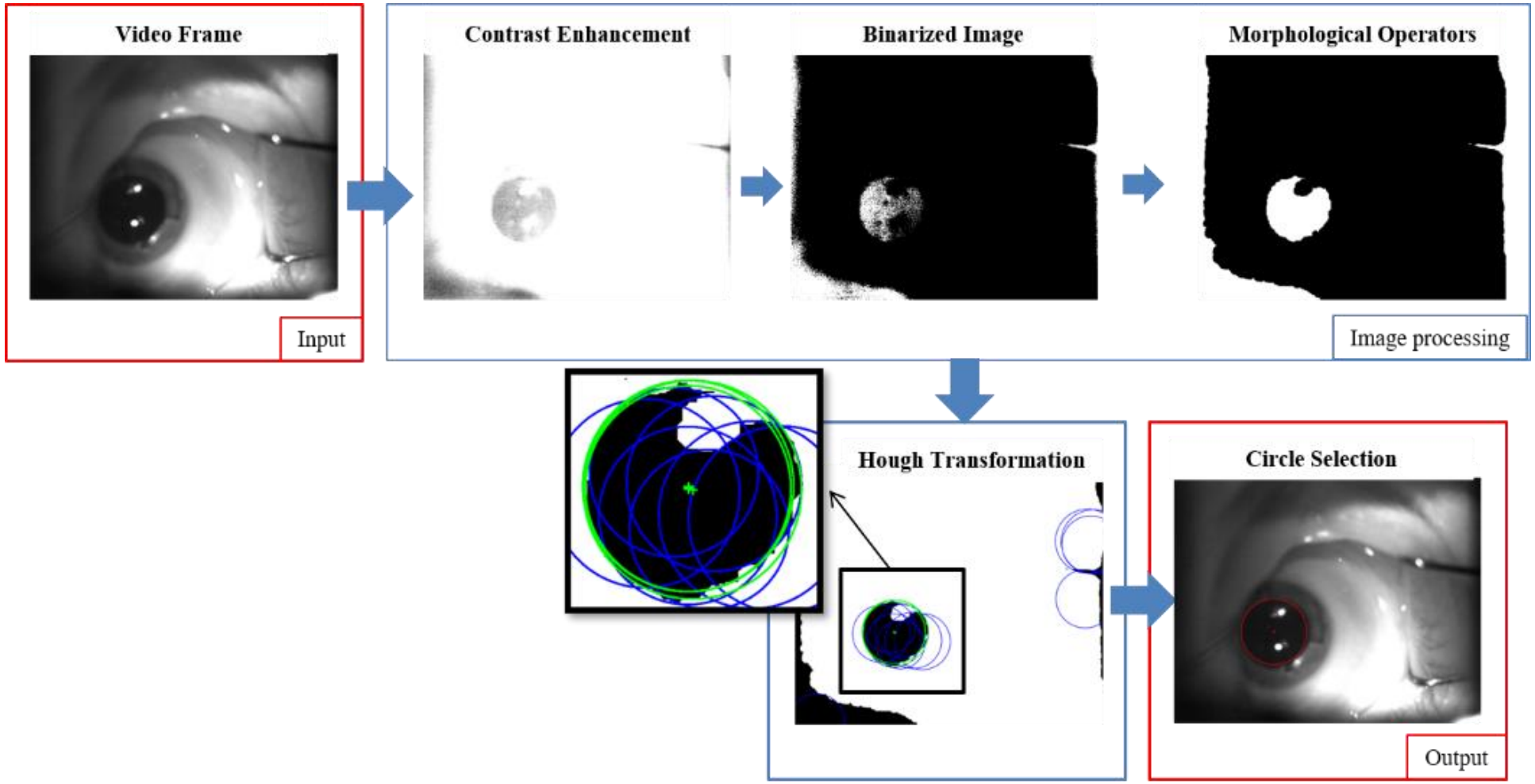
A fully automatic segmentation procedure of the pupil
in the collected eye surface images of one ETS stereo camera  is presented and validated in a clinical scenario

# Patient Data

| | Representative video frame | Diseased eye | Gaze direction (Polar/azimuth angles) [°] | Daily mean (std) delivery time[s] |
|---|---|---|---|---|
| P1 |  | Right | 28/0 | 193.8 (8.9) |
| P2 |  | Left | 28/110 | 163.8 (18.9) |
| P3 |  | Left | 28/0 | 184.6 (41.8) |
| P4 |  | Left | 30/90 | 226.7 (40.9) |
| P5 |  | Left | 29/0 | 123.1 (10.9) |

# Proposed strategy

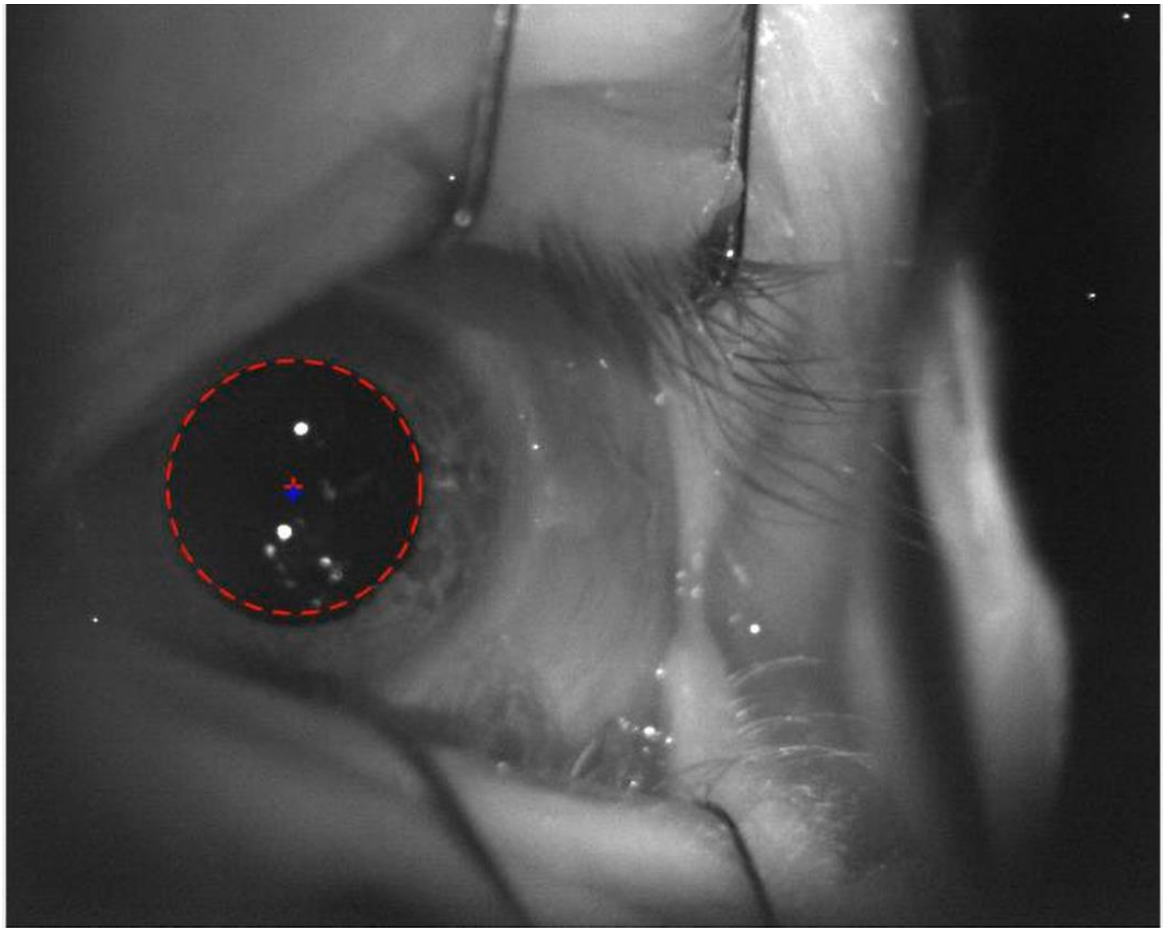
A custom routine for video analysis was developed in MATLAB (MatWorks, Natick, MA, USA - Image Processing Toolbox: Version 9.5)



# Evaluation of Pupil Position Stability

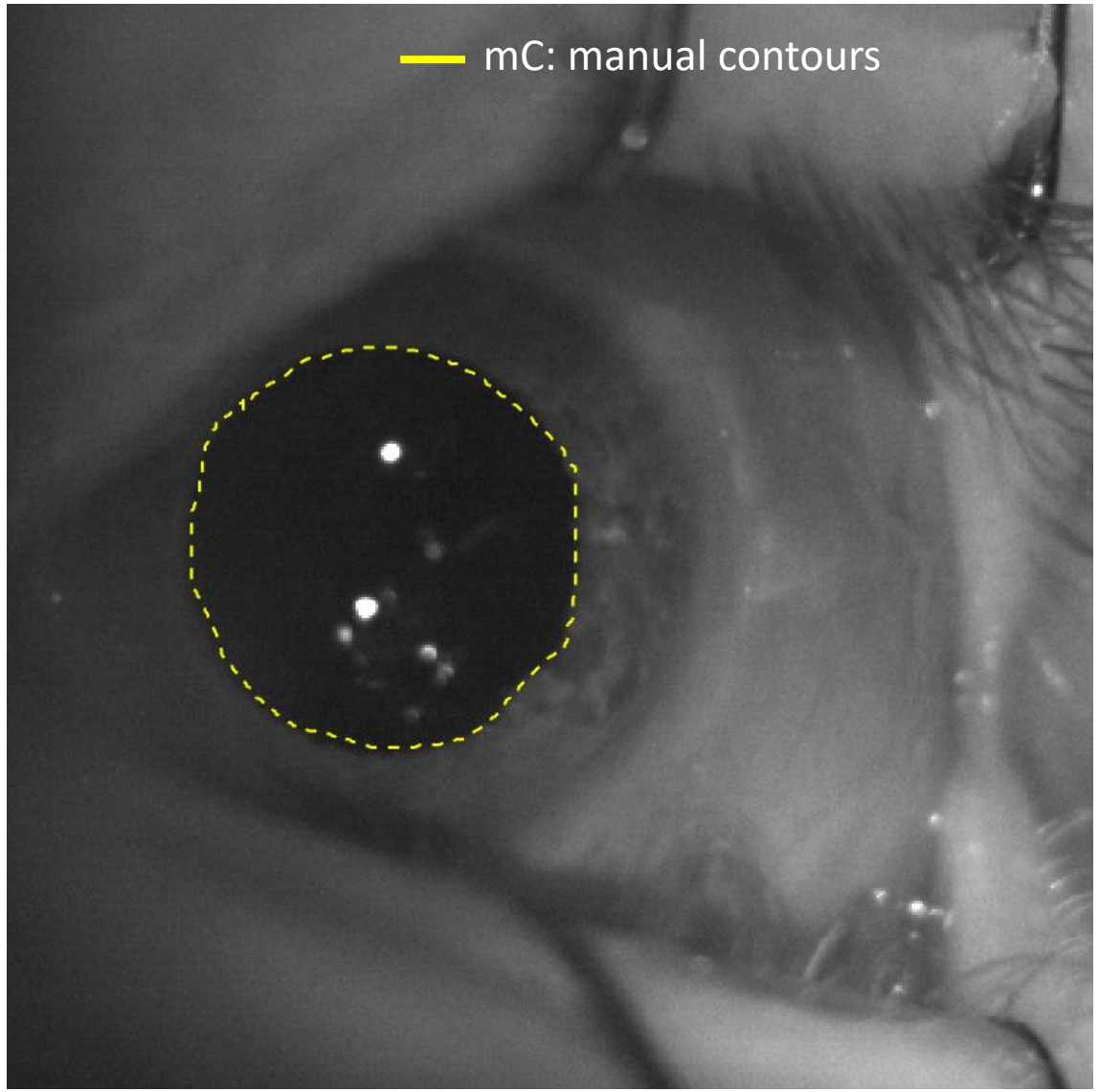
The first available frame after the start of irradiation was selected to automatically define the **reference position of the pupil**.

Throughout the treatment fraction, the **center of the circle** fitting the pupil was automatically extracted every 10 frames (0.8s)



Stability of gaze direction was measured as the 2D distance between the center of the circle at reference position and the center of the circles automatically detected in the remaining frames. 2D distances were expressed as the percentage of the radius of the reference circle pupil

# Strategy Validation



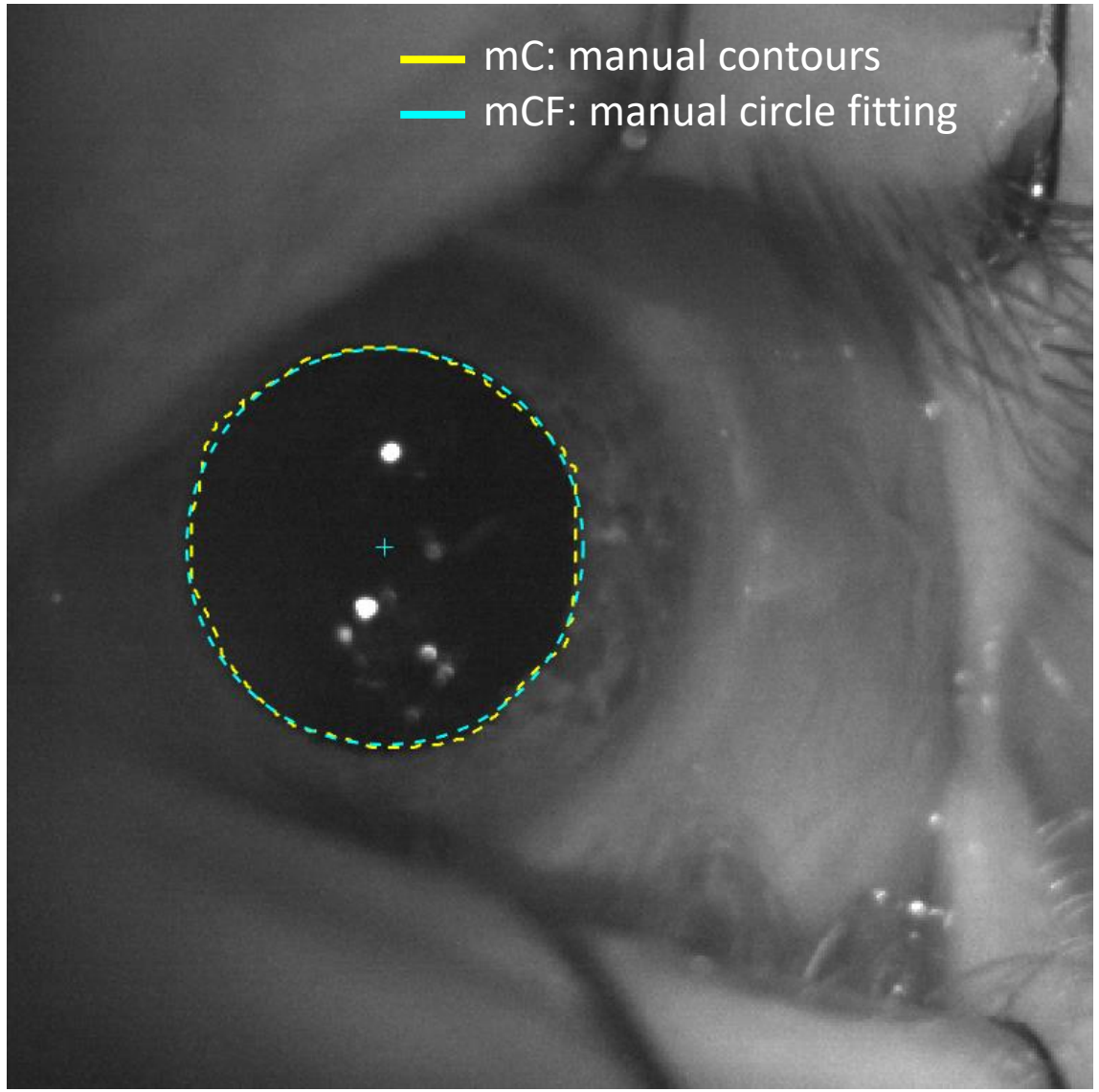

In clinical routine, **manual contour** is used as a reference to refine the setup.

We selected a single frame extracted from the setup video recorded for P1 to P5.

To highlight any potential **inter-operator contouring variability**, we asked 4 different operators to trace the pupil at the best of their capabilities.

A total of 80 manual contours (mC: manual contours) referring to 5 patients, 4 setup fractions and 4 different operators were tested.

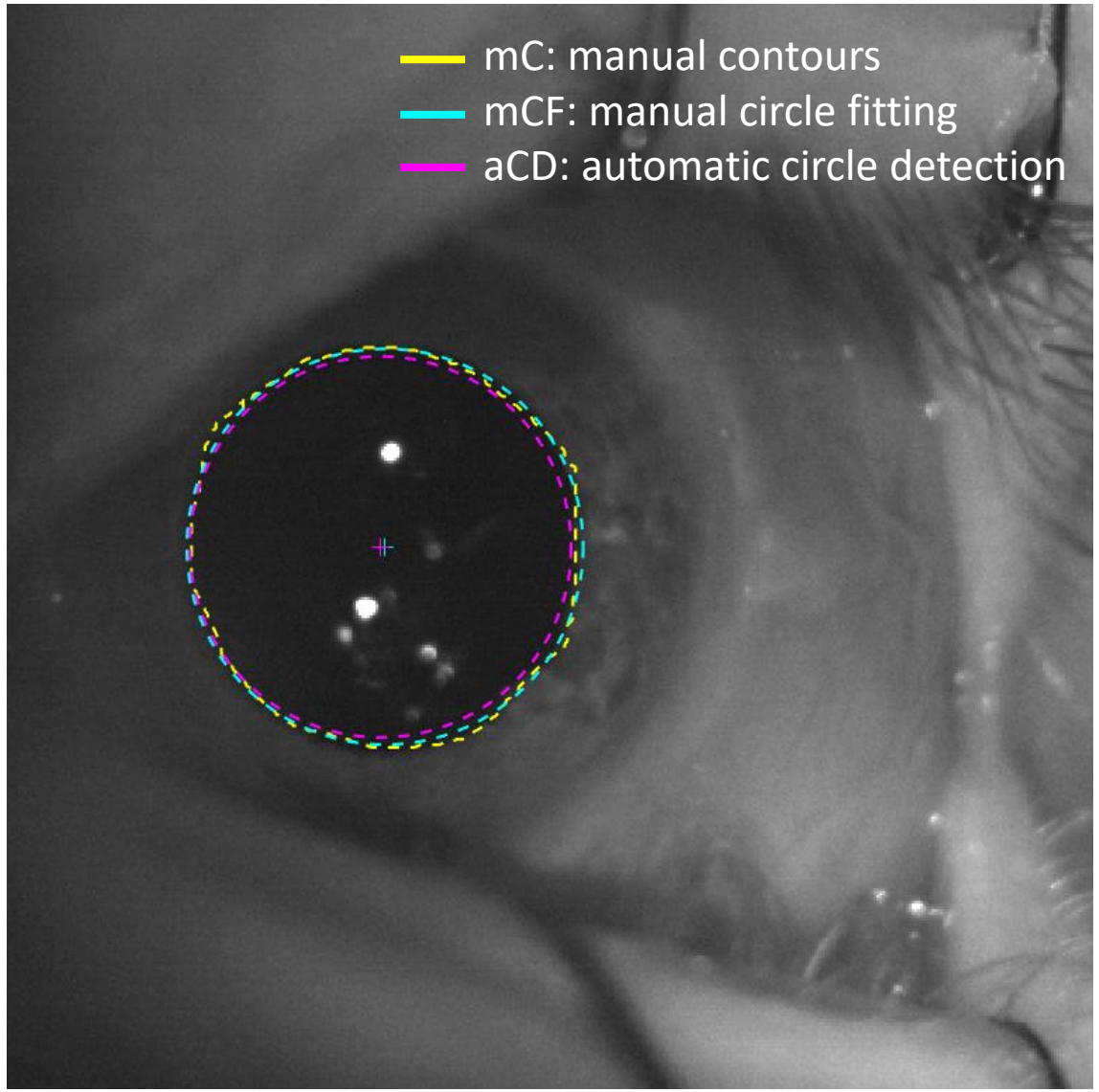
# Strategy Validation




Each manual contour was fitted by a **circular regression (mCF: manual circle fitting)** and the corresponding coefficient of determination (R-squared) was calculated.

We quantified the goodness-of-fit of manual pupil contours to a circle as an indicator of the **applicability of the proposed method** since it is based on circular features detection.

# Strategy Validation



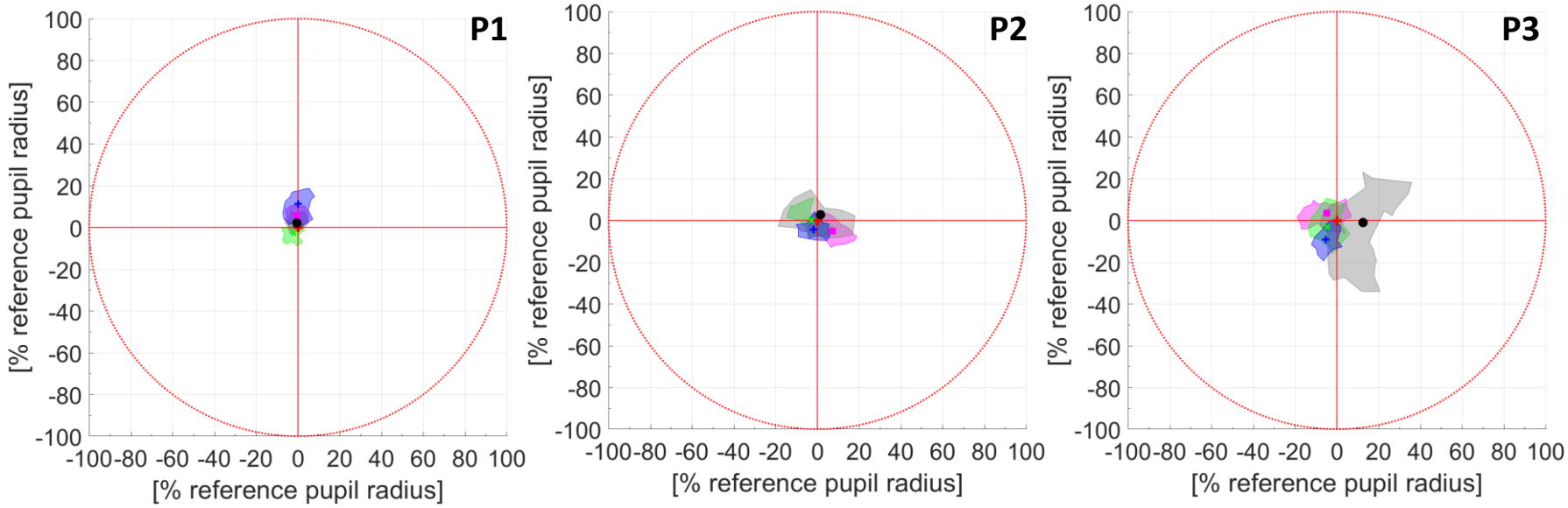

Evaluate the **performance** of the proposed method calculating the 2D distance between the center of each manual circle fitting and the center of the circle automatically detected by the described algorithm (aCD: automatic circle detection).

To guarantee comparability of data, results are presented as percentage of the radius of the circle automatically detected by the proposed algorithm.

# Strategy Validation - Results

| | Method applicability | Inter-operator variability | Method performance | Reference pupil radius Median [min-max][pixel] |
|---|---|---|---|---|
| | *mCF R-squared median(min-max)* | *mCF centers distances Median (iqr) [min-max] [%radius]* | *mCF-aCD centers distances Median (iqr) [min-max] [%radius]* | |
| **P1** | 0.98 (0.70 – 1.00) | 1.4 (1.3) [0.4 – 6.0] | 2.4 (2.3) [0.3 – 4.7] | 71.9 [70.0 – 73.1] |
| **P2** | 0.99 (0.62 – 1.00) | 3.8 (3.0) [0.9 – 9.2] | 4.7 (3.0) [1.1 – 8.6] | 68.4 [67.2 – 68.5] |
| **P3** | 0.98 (0.77 – 1.00) | 3.7 (3.0) [0.6 – 7.0] | 8.2 (3.3) [3.5 – 10.7] | 56.8 [55.2 – 58.3] |
| **P4** | 0.95 (0.74 – 1.00) | 4.3 (4.0) [1.9 – 9.4] | 9.6 (6.5) [1.8 – 13.3] | 67.1 [66.4 – 67.3] |
| **P5** | 0.95 (0.65 – 1.00) | 3.5 (3.9) [0.5 – 10.7] | 6.4 (3.3) [1.5 – 10.4] | 52.8 [51.9 – 54.1] |
| **ALL** | **0.97 (0.62 – 1.00)** | **3.3 (3.6) [0.4 – 10.7]** | **5 (5.3) [0.3 – 13.3]** | |

# Evaluation of Pupil Position Stability - Results



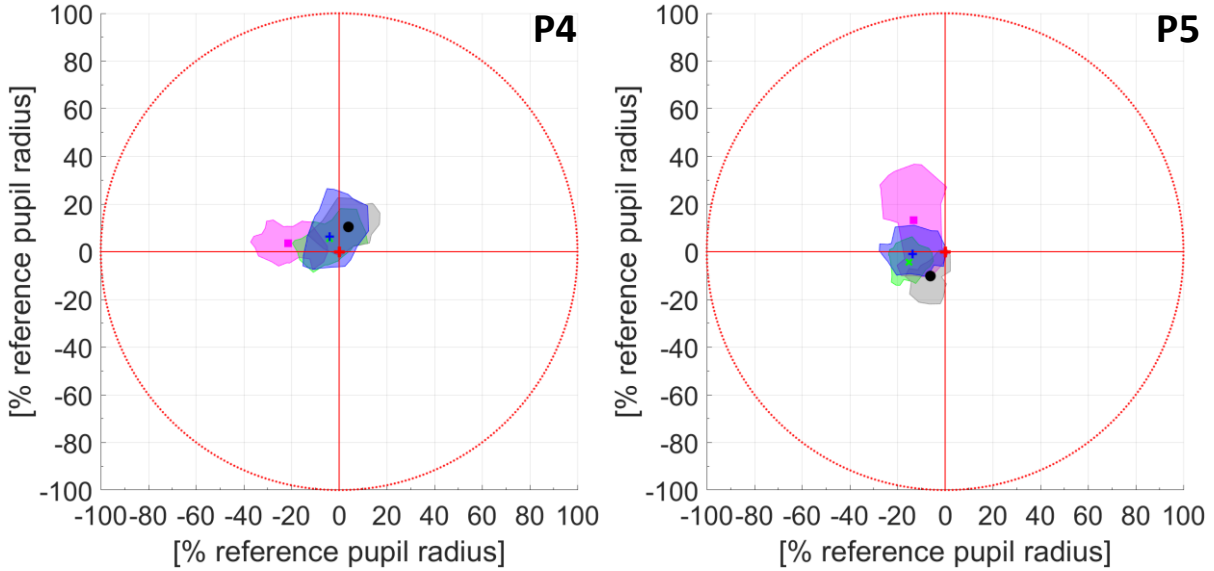

reference setup pupil

**Mean fractional pupil position**

- Treatment Fraction 1
- Treatment Fraction 2
- Treatment Fraction 3
- Treatment Fraction 4

**95th percentile of pupil positions from mean fractional position**

- Treatment Fraction 1
- Treatment Fraction 2
- Treatment Fraction 3
- Treatment Fraction 4




| | 2D distance [% reference pupil radius] Median (IQR) |
|---|---|
| **P1** | 6.6 (5.5) |
| **P2** | 7.0 (6.5) |
| **P3** | 11.4 (9.9) |
| **P4** | 13.1 (11.6) |
| **P5** | 16.5 (10.0) |

# Conclusion and Future Perspective

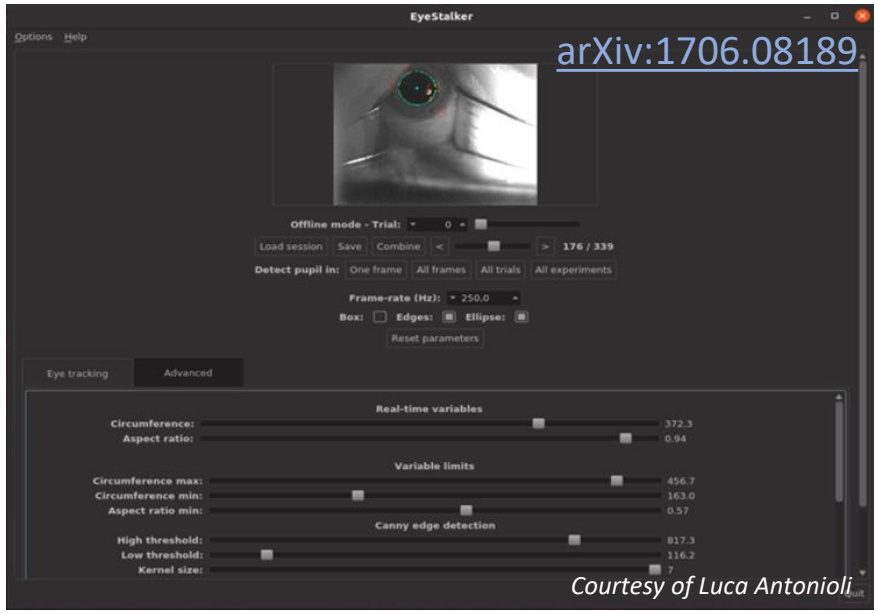
Preliminary approach to quantitatively evaluate the stability of gaze direction over an entire OPT treatment course relying on an automatic segmentation procedure of the pupil.

**Gaze stability was clinically acceptable in the evaluated patient cohort.** Good patient collaboration : median 2D pupil deviation from the reference was <1mm

**Image quality dependance: >**blurred/non uniformly illuminated; >inter-operator variability; < strategy performance

Investigation of more robust and sophisticated features extraction approaches

**Robust Video-Based Eye Tracking Using Recursive Estimation of Pupil Characteristics (Terence Brouns)**



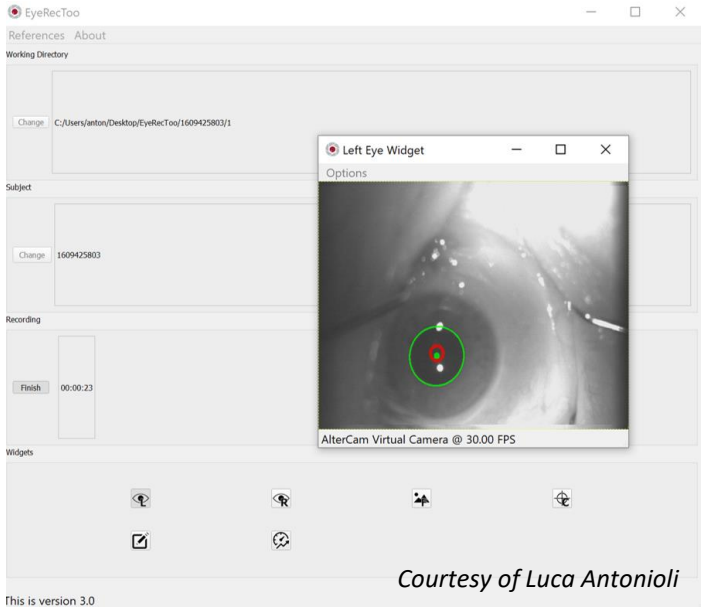
*Courtesy of Luca Antonioli*

Conference Paper

EyeRecToo: Open-source Software for Real-time Pervasive Head-mounted Eye Tracking

January 2017
DOI: 10.5220/0006224700960101
Conference: International Conference on Computer Vision Theory and Applications

Thiago Santini · Wolfgang Fuhl · David Geisler · Enkelejda Kasneci



*Courtesy of Luca Antonioli*

# Thank you for your attention

## Gaze stability during Ocular Proton Therapy: quantitative evaluation based on eye surface surveillance videos

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