AI approaches in interventional radiotherapy

György Kovács

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- from the point of view of a clinician -

György Kovács

PREFACE

Artificial intelligence (AI) is the simulation of human qualities such as reasoning, learning, problem solving, understanding language and processing of visual information by machines.

#

As AI is still in its infancy, we are probably seeing two effects in the published literature. The Pareto Principle, also known as the 80/20 rule; in that 20% of effort has resulted in 80% of results. The last 20%, to get us effective clinical solutions will likely require a much larger and harder effort. Secondly, the lack of generalisability.

#

Currently published algorithms, especially in medical imaging, often underperform when removed from their carefully curated data environment.

#

There will always be a need for the clinician but AI has the potential to augment their skills to improve the uniformity of outcome for the patient.

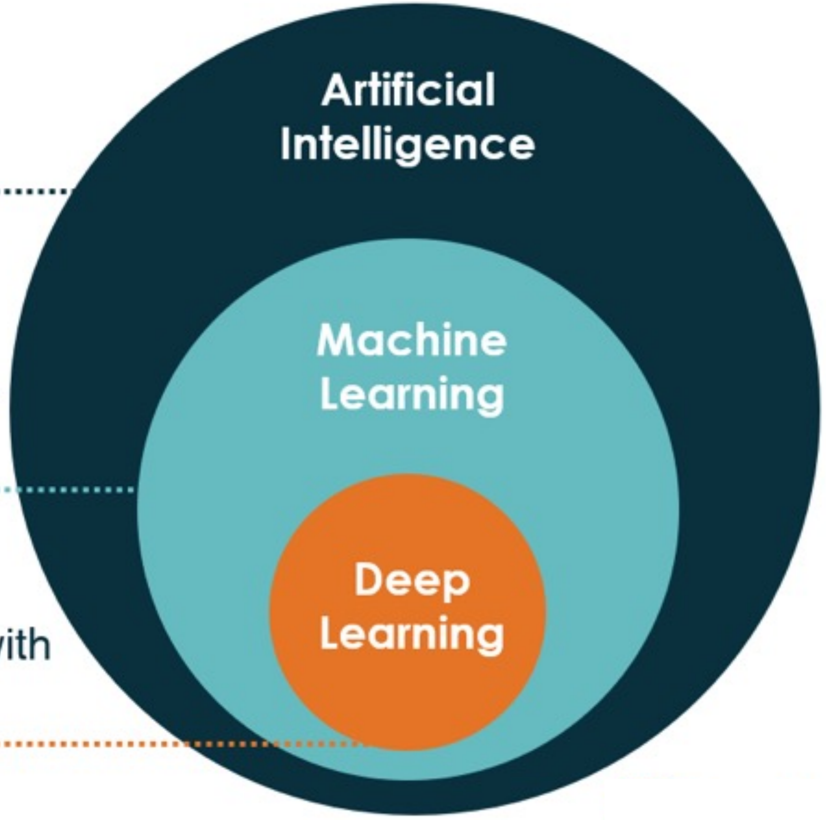
Rohan et al. Ir Med J; 2020, 113(3): p45

BASICS

ARTIFICIAL INTELLIGENCE (AI)
Programming systems to perform tasks which usually require human intelligence.

MACHINE LEARNING (ML)
Training algorithms to solve tasks by pattern recognition instead of specifically programming them how to solve the problem.

DEEP LEARNING (DL)
Training algorithms to solve tasks using neural networks with multiple layers



ARTIFICIAL INTELLIGENCE *versus* AUGMENTED INTELLIGENCE

Reputable, high-quality data alone could help ensure us a respectable position in frontline research of AI applications in health care.

#

One must remember that the introduction of new technologies in health care has not always been straightforward or without unintended adverse consequences.

Bhandari & Rebbiboina, Indian Journal of Urology, 2019; 35(2):89-91

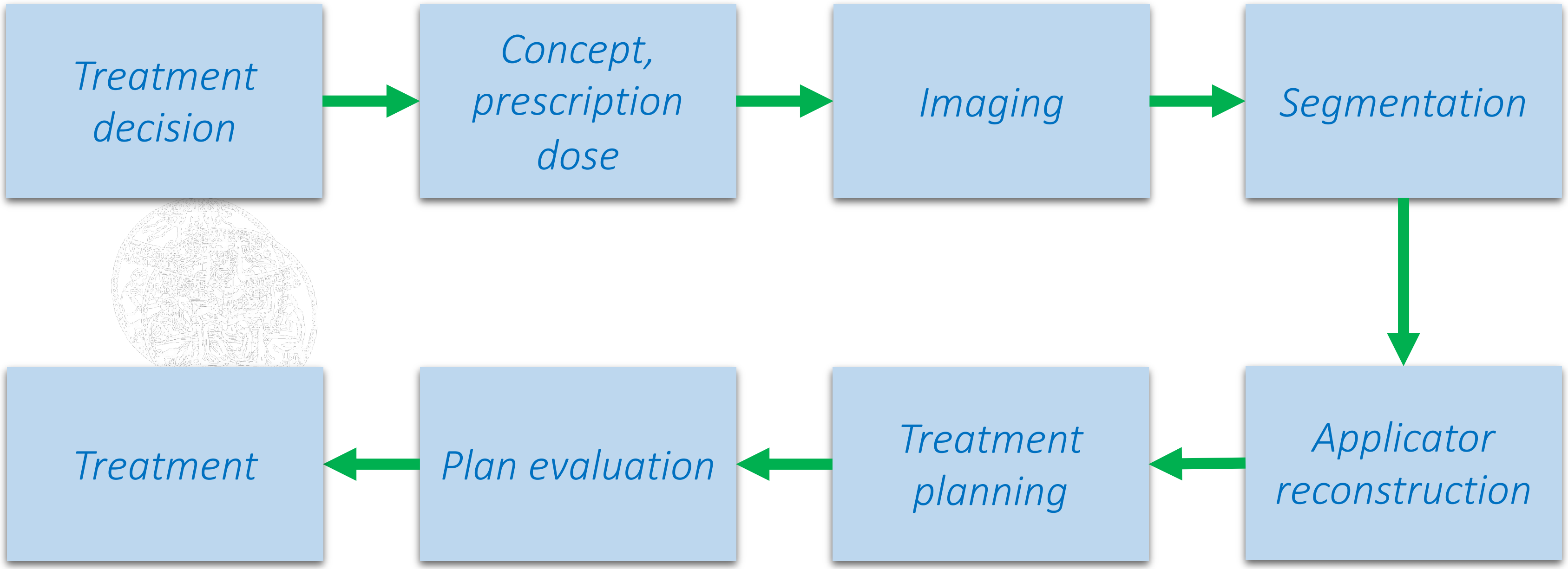
The *American Medical Association House of Delegates* uses the term augmented intelligence (AI) as a conceptualization of artificial intelligence that focuses on AI's assistive role, emphasizing that its design enhances human intelligence rather than replaces it.

https://www.ama-assn.org/practice-management/digital/augmented-intelligence-medicine

THE PROSTATE CANCER TREATMENT PATHWAY

First doctor's visit	Diagnosis e.g. through PSA testing, image-based diagnosis or biopsy	Treatment planning, e.g. for surgery or radiotherapy	The treatment itself	Tracking in between treatments	Follow-up after treatment trajectory is done
GP	Urologist, radiologist, pathologist, nuclear medicine physician, medical oncologist, oncology nurse	Urologist, radiation oncologist, nuclear medicine physician, medical oncologist *Medical Physicist?* *IT Expert?*	Urologist, radiation oncologist, nuclear medicine physician, medical oncologist *Medical Physicist?* *IT Expert?*	Urologist, radiation oncologist, nuclear medicine physician, medical oncologist	Urologist

INTERVENTIONAL RADIOTHERAPY FLOW CHART



Courtesy by F-A Siebert, 2022

AI & IRT TREATMENT DECISION

Large patient datasets and electronic medical records can be surveilled in a semi-automated manner to providing instantaneous predictive analytics that can be used to derive insights into a variety of diseases.

#

However, the prediction accuracy depends heavily on effective data integration acquired from various sources to allow it to be generalized.

#

Although these models will not replace the shared decision-making process, it may compliment the information that patients receive from traditional educational models.

#

While this is only the beginning and further validation is needed, the future application and possibilities of machine learning and artificial intelligence are endless.

Wong & Shageyan, Ann Transl Med 2019;7(Suppl 1):S1

AI & IRT TREATMENT DECISION

The PANDA – challenge: 1,290 developers and 10,616 digitalized prostate biopsies

It was found that a group of AI Gleason grading algorithms developed during a global competition generalized well to intercontinental and multinational cohorts with pathologist-level performance.

#

On all external validation sets, the algorithms achieved high agreement with uropathologists and high sensitivity for malignant biopsies.

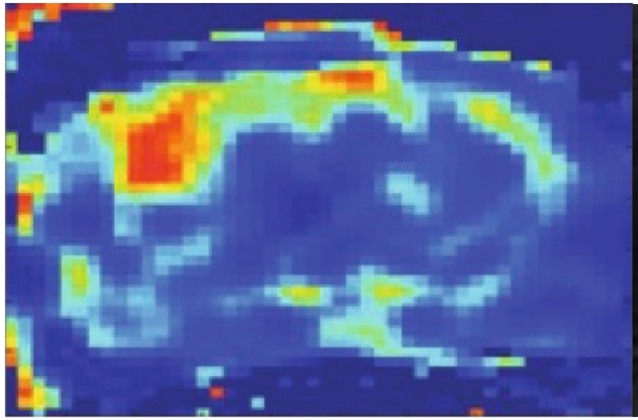
#

The performance exhibited by this group of algorithms adds evidence of the maturity of AI for this task and warrants evaluation of AI for prostate cancer diagnosis and grading in prospective clinical trials.

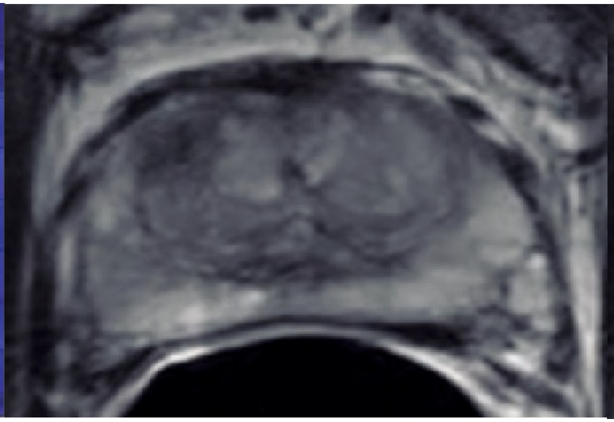
Bulten et al. Nature Medicine, 28, January 2022, pp 154–163

AI & IMAGING FOR IRT / DOSE PRESCRIPTION

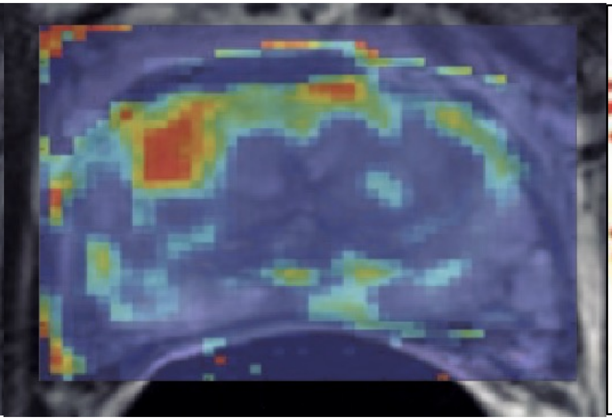
ML technique to detect prostate cancer and create a cancer probability map



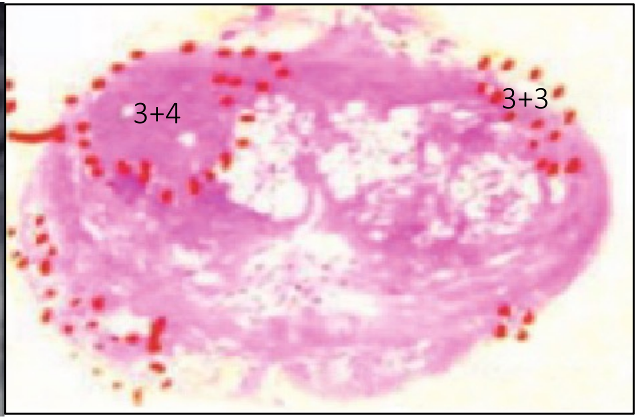
Hot colours show increased probability of cancer on a T2-weighted MRI image.



T2-weighted image of the mid-gland with a suspicious region in the anterior horn of the right peripheral zone.



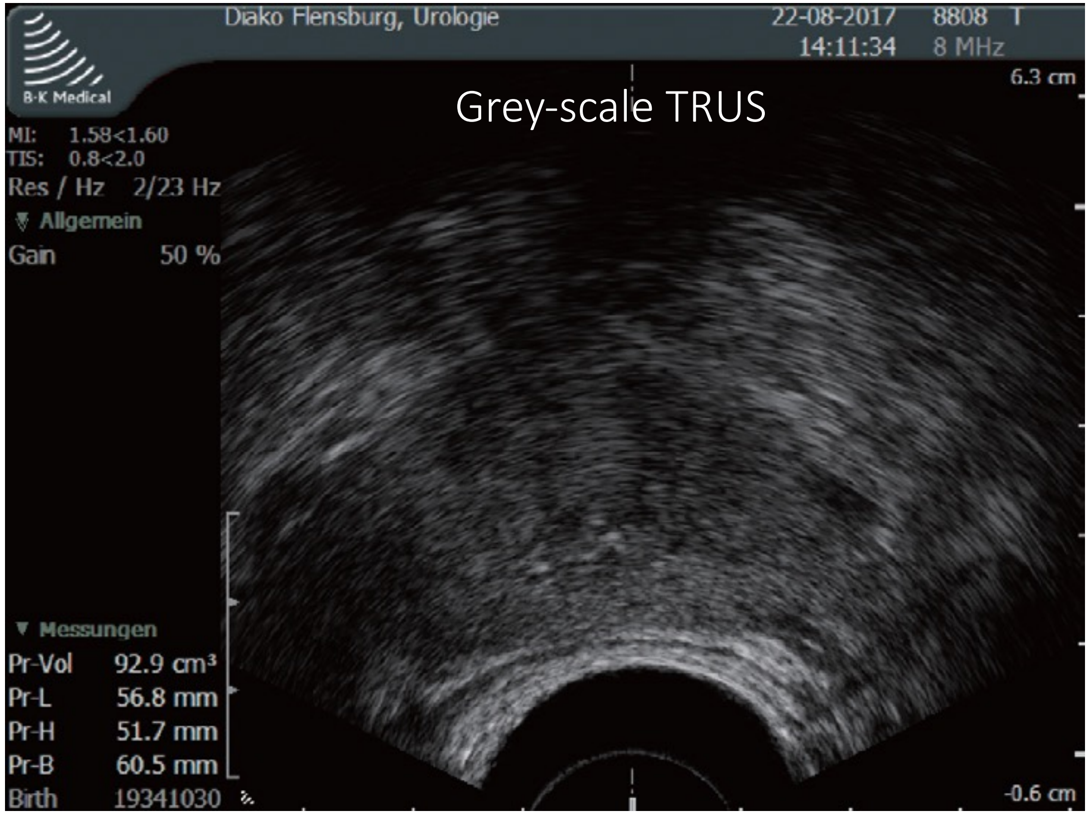
The T2-weighted image with the probability map shown as a transparent overlay

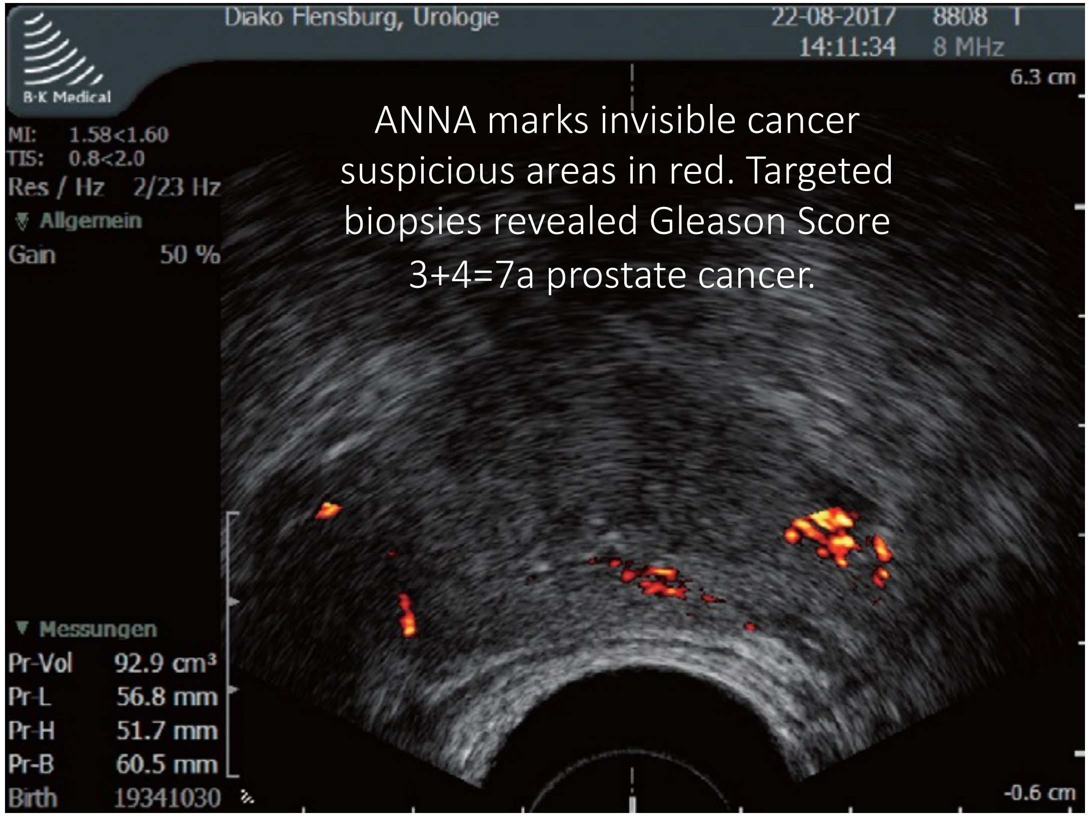


The corresponding histopathology whole-mount slide in which the main pathological finding is a Gl 3 + 4 tumour in the anterior horn of the right peripheral zone

Goldenberg at al. Nature Reviews/Urology, May 2019; https://doi.org/10.1038/s41585-019-0193-3
Moradi. et al. J. Magn. Reson. Imaging 35, 2012, pp1403–1413 .

AI & IMAGING FOR IRT / DOSE PRESCRIPTION





Grey et al, Transl Androl Urol 2020;9(3):1492-1500

AI & TREATMENT ECONOMY

There are multiple studies which reflect the potential of AI ANNs (***A**rtificial **N**euronal **N**etworks)* to allow the development of effective classification system for prostate cancer risk stratification.

#

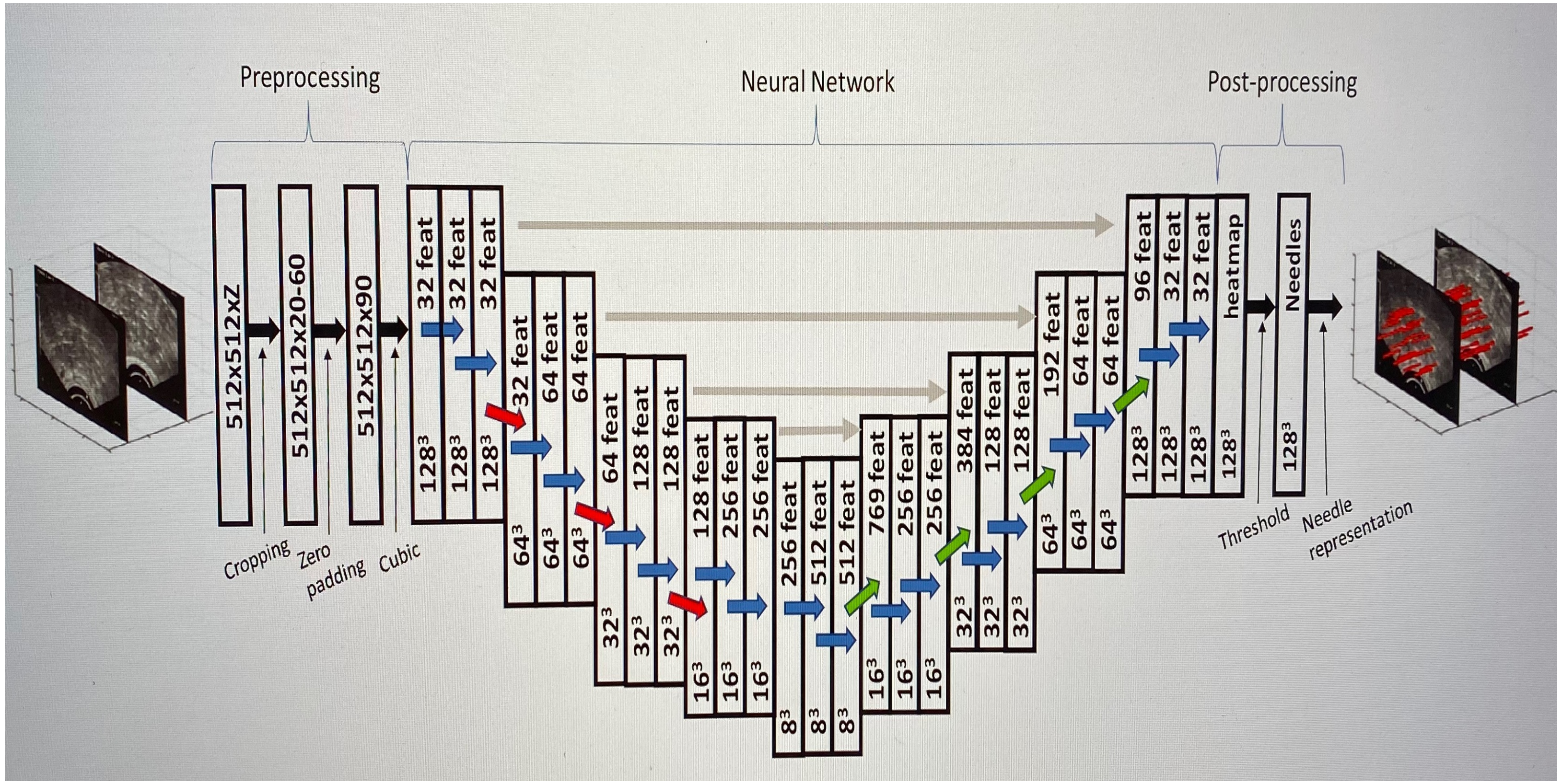
The 10-year costs of managing low-, and high-risk patients with prostate cancer have been estimated to be $45,957 and $188,928, respectively.

#

However, a broader incorporation of AI can certainly help in mitigating this burden.

Van Booven et al. Research and Reports in Urology 2021:13 31–39

AI & NEEDLE RECONSTRUCTION



A convolutional neural network via DL is developed to digitize needles in prostate HDR brachytherapy contexts.

#

The network demonstrated a precision that was higher than the interobserver variability.

Andersén et al. Medical Physics, 2020: 47(12):6414-6420

AI & TREATMENT PLANNING

AI-based segmentation algorithms can accurately delineate the treatment target, organs at risk, and brachytherapy applicators and seeds for commonly used imaging modalities in brachytherapy, such as CT, MRI, and ultrasound.

#

AI methods for dose calculations have also become available to enable calculations with tissue heterogeneity considered.

#

The biggest gains from AI when applied to problems that have a multitude of both input and output parameters, or have loosely correlated relationships between inputs and outputs.

This is true for contouring but is otherwise not a feature of the current challenges to brachytherapy treatment planning.

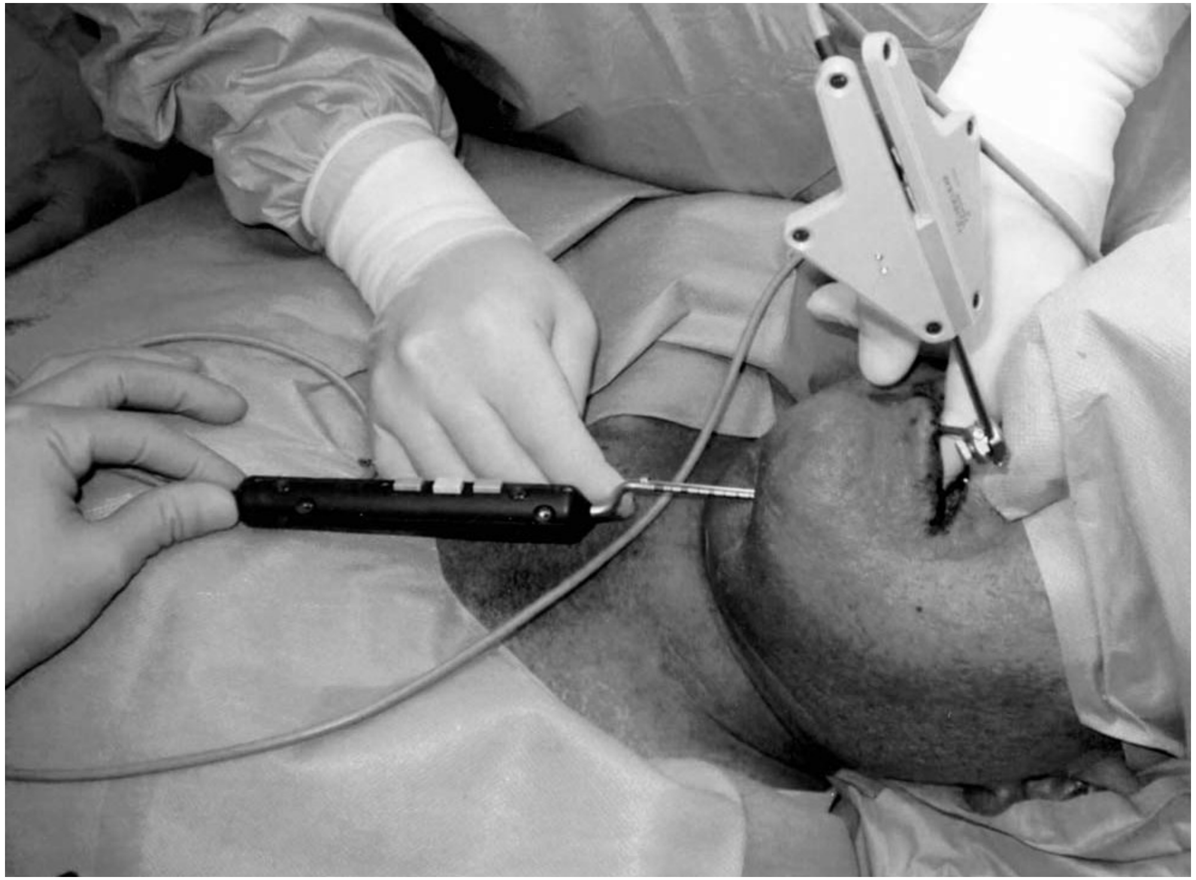
#

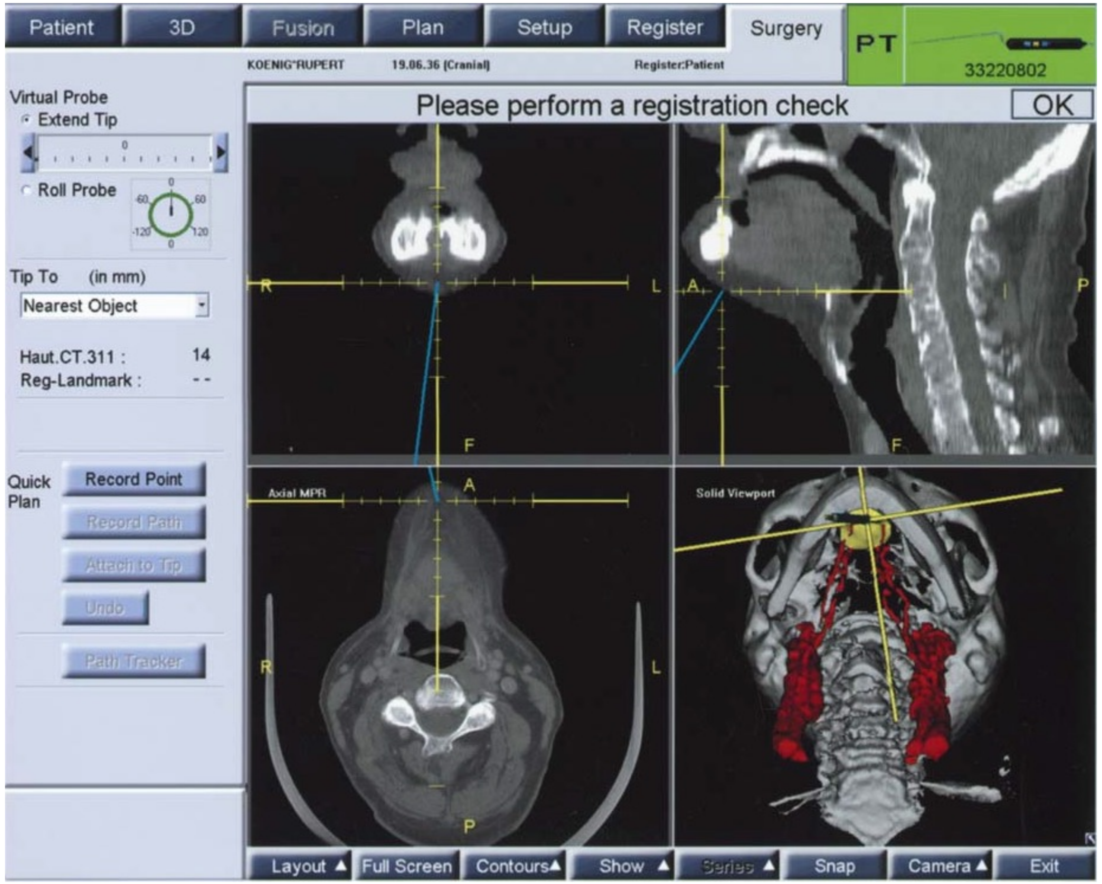
So, can AI overcome challenges in brachytherapy treatment planning? Possibly.

But quite often so can simpler, more absolute methods.

Xun Jia et al. J Appl Clin Med Phys. 2022;23:e13504.

NAVIGATION & GUIDED IRT NEEDLES





Krempien et al. Brachytherapy 4 (2005) 154–162

NAVIGATION & GUIDED IRT NEEDLES

Clinical data demonstrate already in 2005 that PDR brachytherapy in combination with sequential chemotherapy is effective and safe in re-irradiation of locally recurrent oropharyngeal carcinomas and can be offered to patients with curative intent.

#

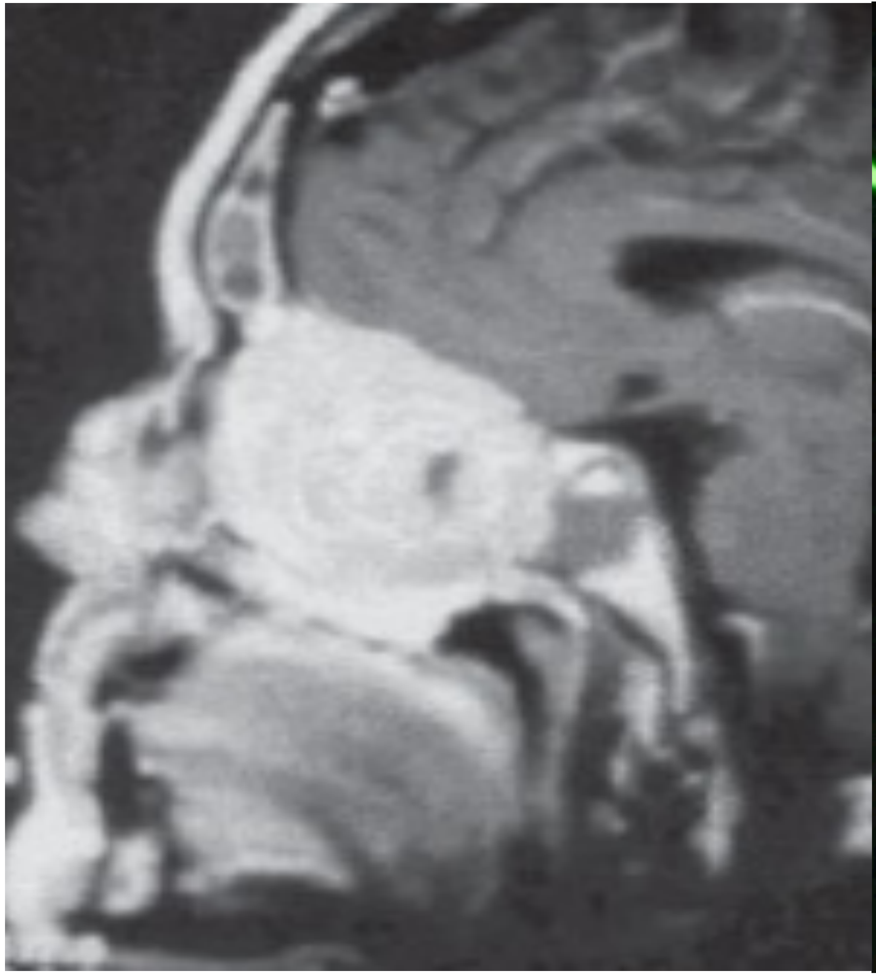
Image guidance allows virtual planning and navigated implantation of brachytherapy needles with regard to optimized needle distribution and risk structures.

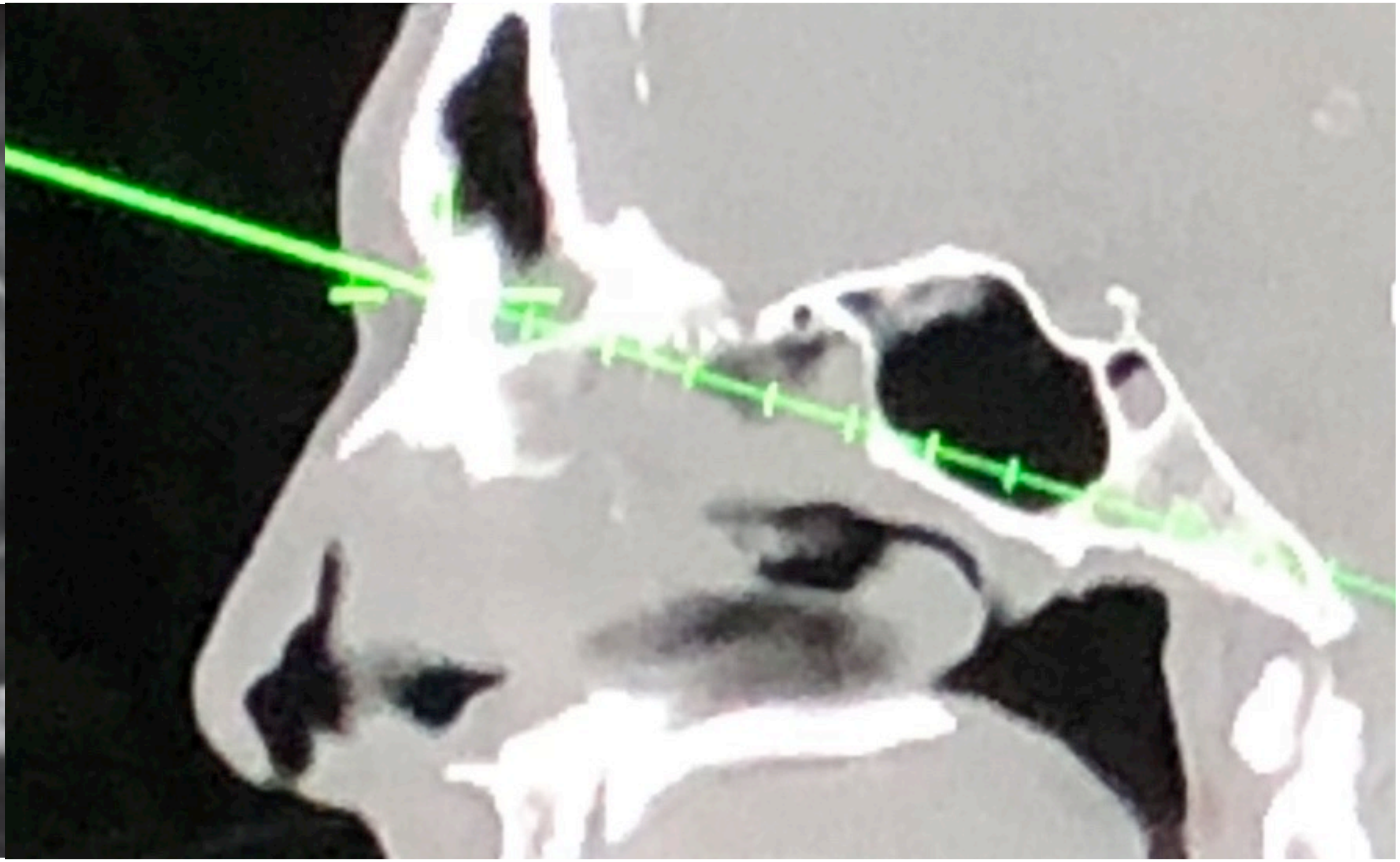
#

Mean deviation of image-guided needle implantation was 3.4 mm for each needle (SD, 1.9 mm; range, 0.5–14 mm). The mean deviation of all needles of an implant was 4.3 mm (range 2.3–8.6 mm).

Krempien et al. Brachytherapy 4 (2005) 154–162

AUGMENTED REALITY & INTRAOPERATIVE GUIDANCE





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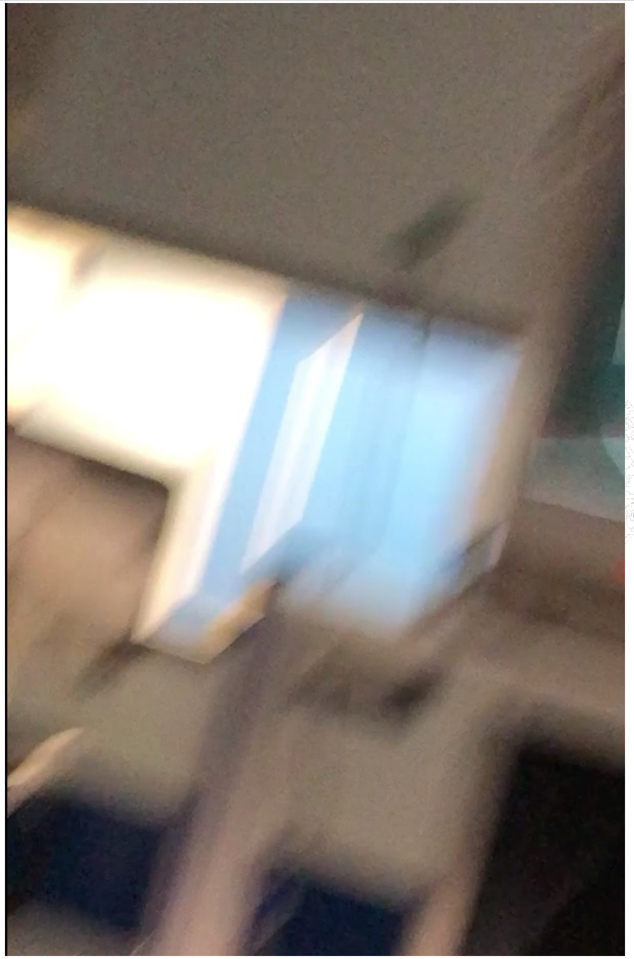
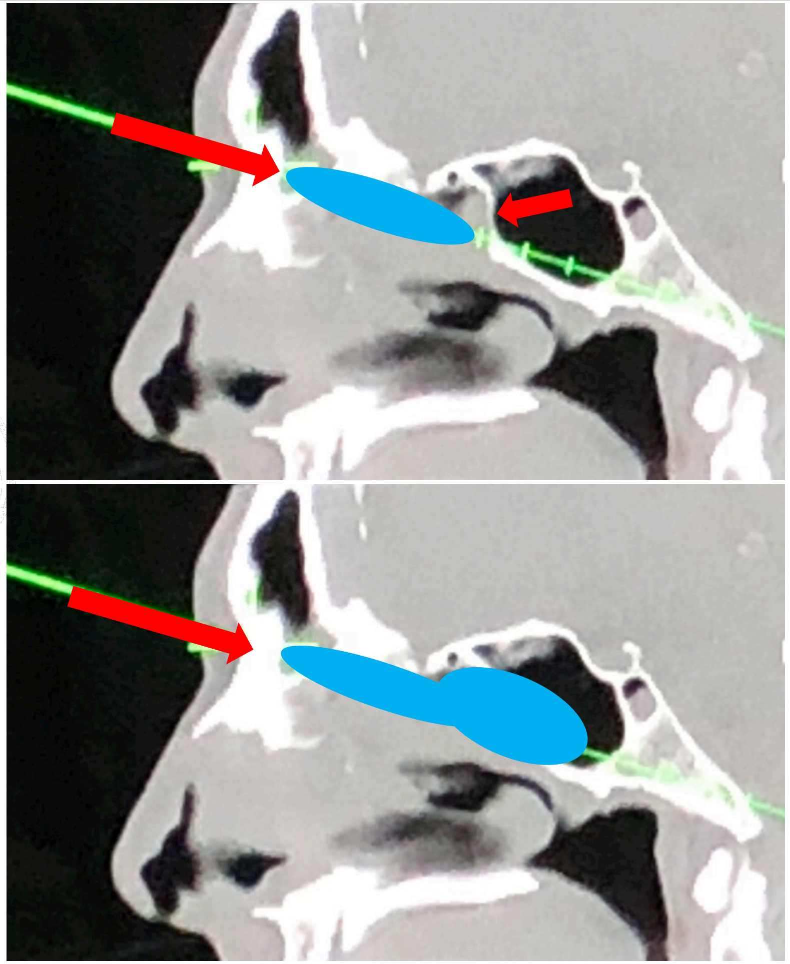
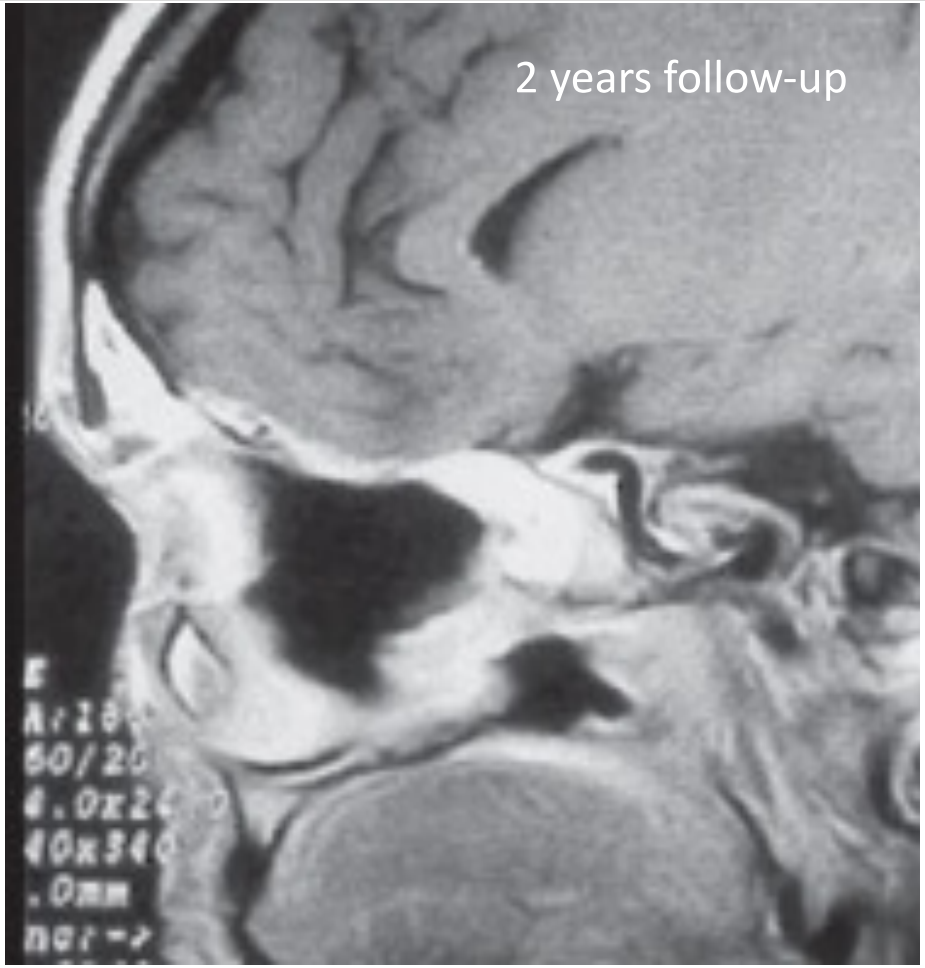
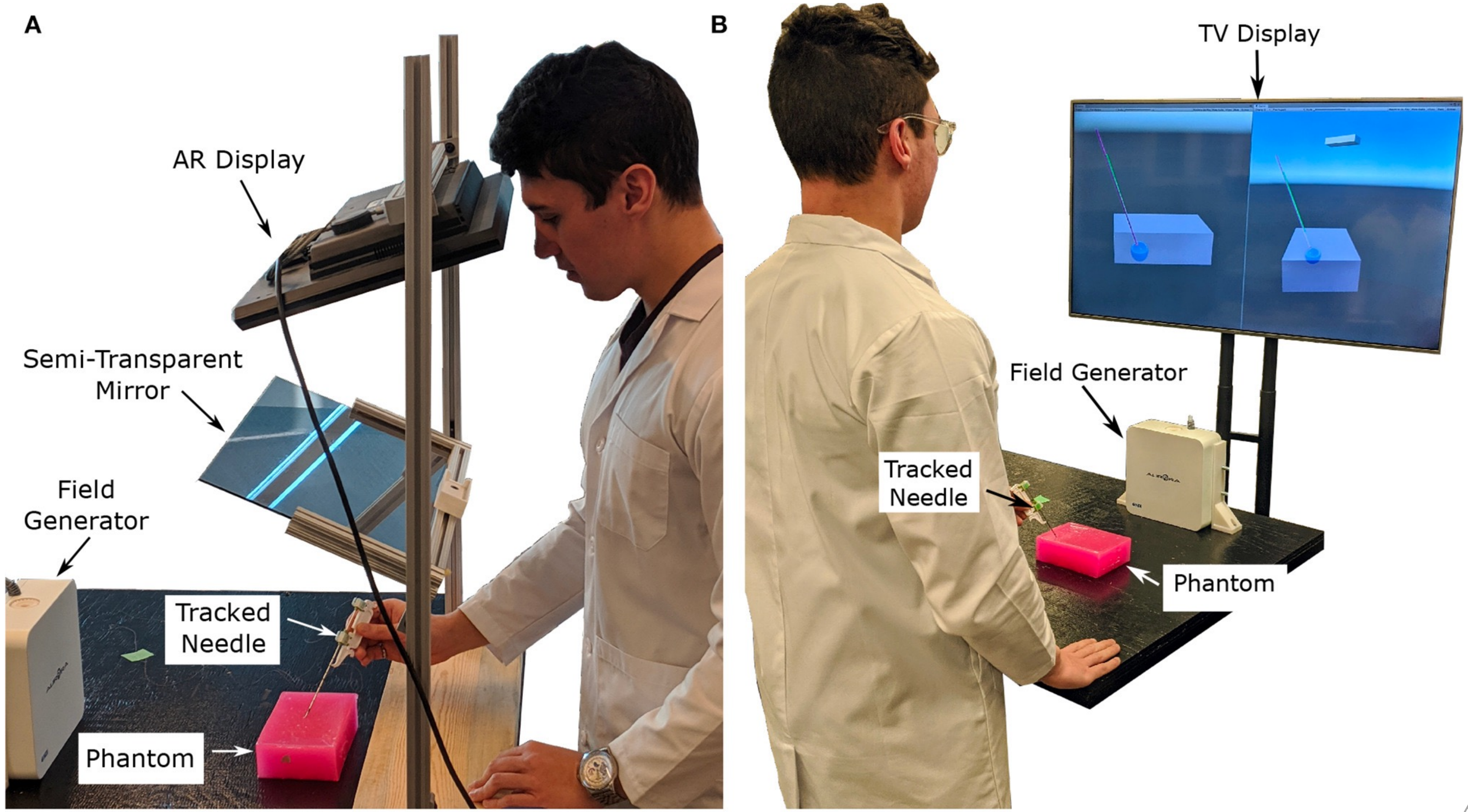
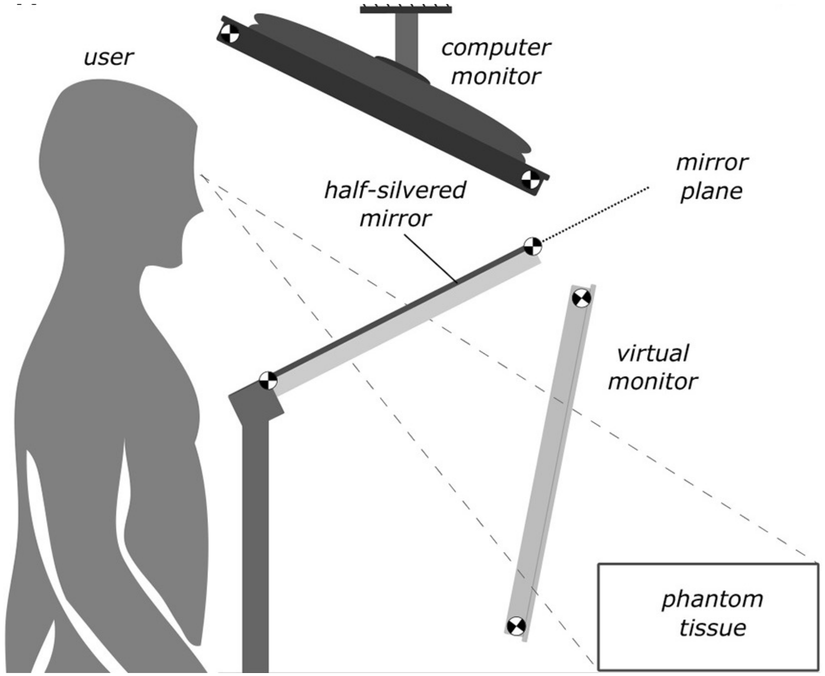






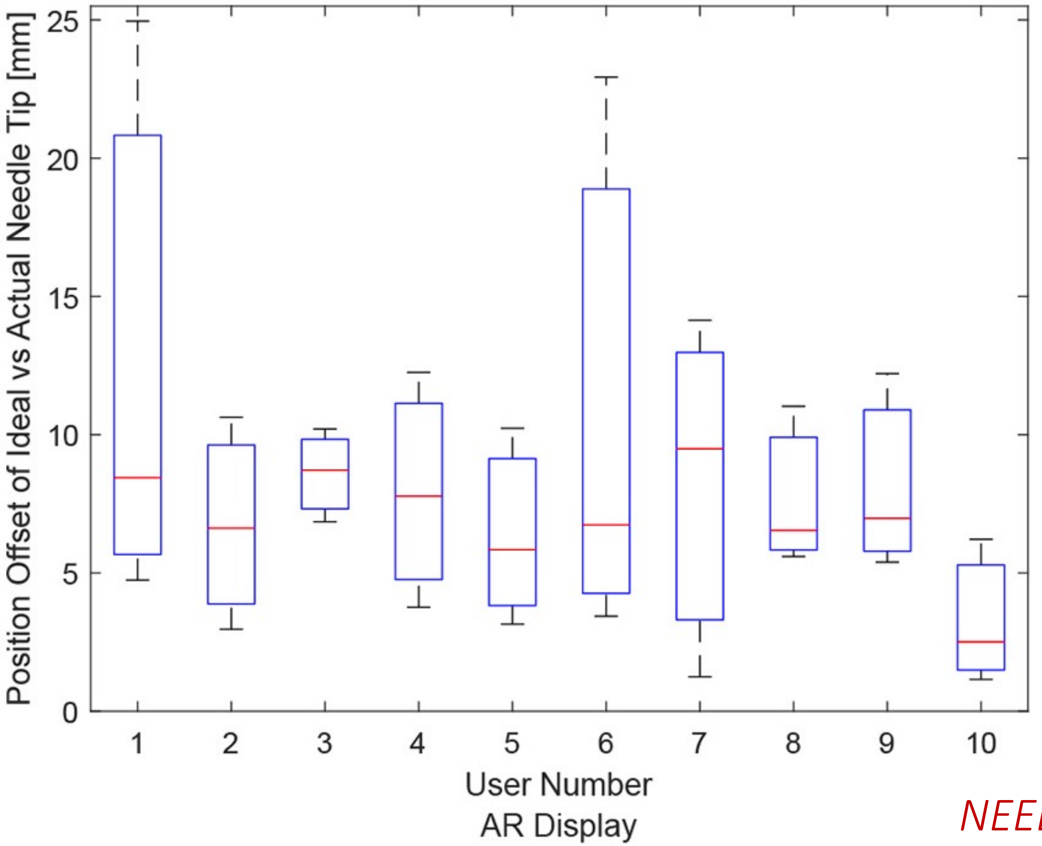
AUGMENTED REALITY & MANUALLY GUIDED NEEDLES



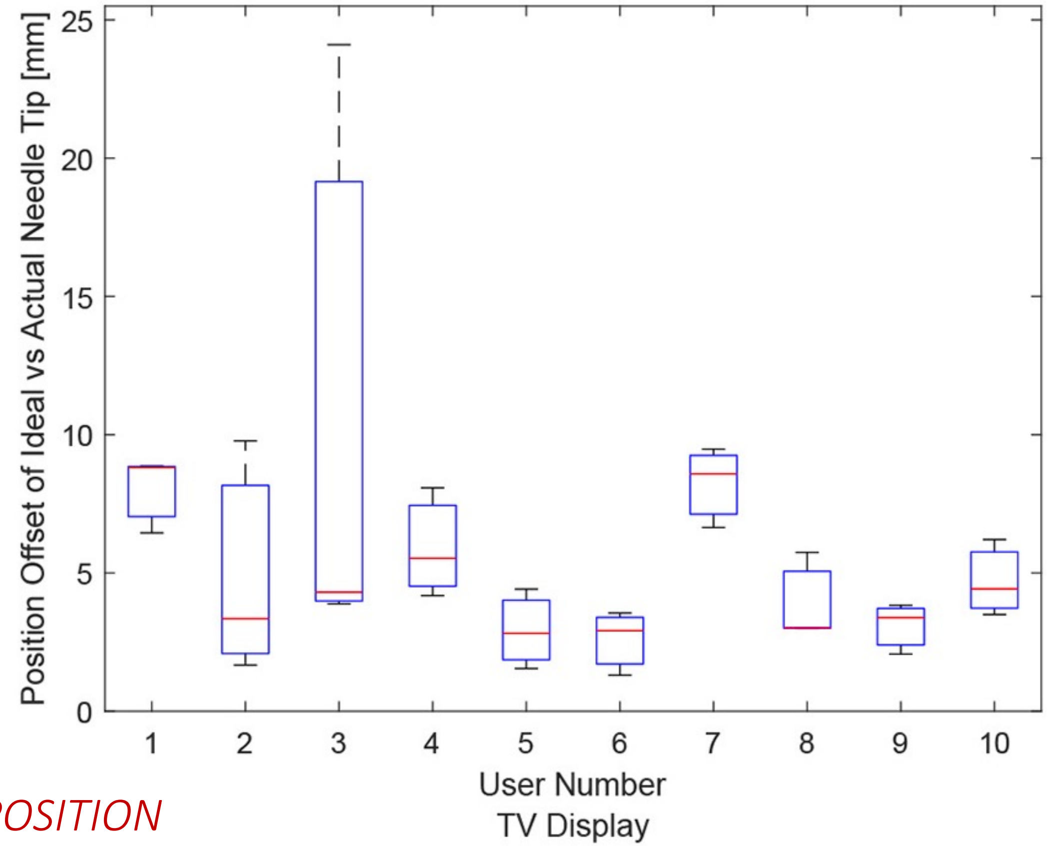


Asgar-Deen et al. Front. Robot. AI 7:72.; doi: 10.3389/frobt.2020.00072

AUGMENTED REALITY & MANUALLY GUIDED NEEDLES



NEEDLE POSITION



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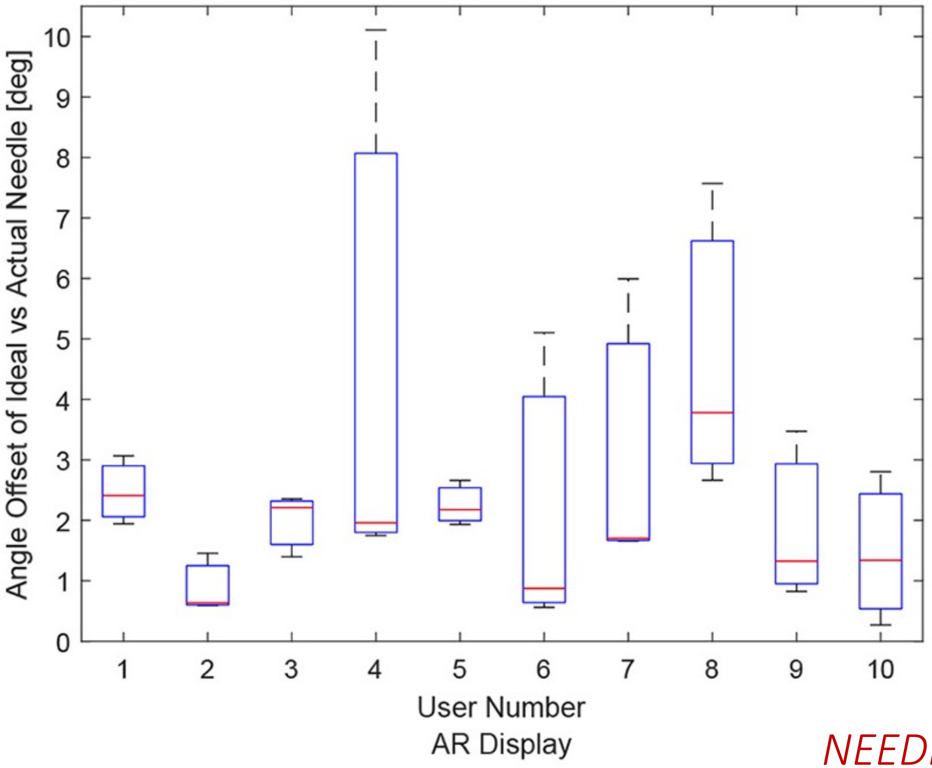
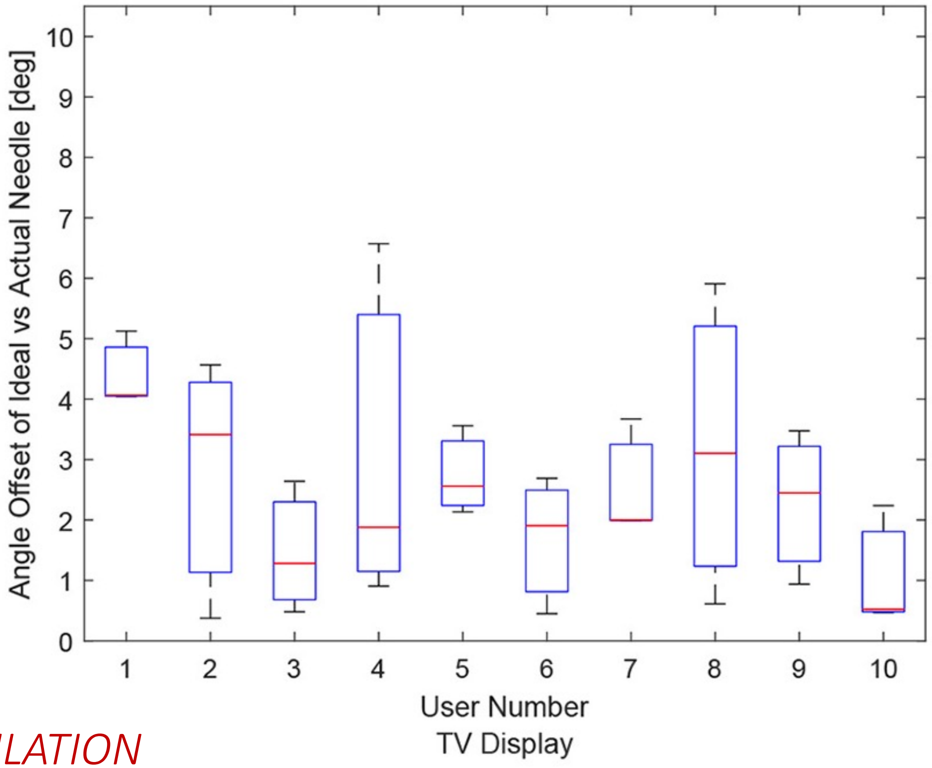




NEEDLE ANGULATION

Asgar-Deen et al. Front. Robot. AI 7:72.; doi: 10.3389/frobt.2020.00072

AUGMENTED REALITY & MANUALLY GUIDED NEEDLES

The system aims to provide physicians with an alternative method to visualize ideal and actual needle trajectories for their needles in an intuitive and impactful way.

#

It has allowed inexperienced users the ability to localize needles given complex angles with sub-centimeter and sub-degree precision.

#

It was found that an AR setup is non-inferior to a TV setup for a static targeting task.

Further research will have to be conducted to see if this is also true for more dynamic targeting tasks.

Asgar-Deen et al. Front. Robot. AI 7:72.; doi: 10.3389/frobt.2020.00072

AUGMENTED REALITY MEETS ARTIFICIAL INTELLIGENCE IN ROBOTICS

AR Supports AI (*18 Papers*)

This cluster groups papers in which a certain augmented reality visualization facilitates the integration of artificial intelligence in robotics. An example is an augmented reality application which provides visual feedback that aids in AI robot performance testing.

AI Supports AR (*11 Papers*)

Papers in which the output of AI algorithms and neural networks support an accurate display of augmented reality markers and visualizations.

Bassyouni & Elahjj, Front. Robot. AI 8:724798; doi: 10.3389/frobt.2021.724798

AUGMENTED REALITY MEETS ARTIFICIAL INTELLIGENCE IN ROBOTICS

Learning (*12 Papers*)

A robot learns to achieve a certain task, and the task is visualized to the human using AR. This category combines papers on learning from demonstration (LFD) and learning to augment human performance.

Planning (*8 Papers*)

A robot intelligently plans a certain path, task, or grasp, and the user can visualize robot information and feedback through AR.

Perception (*9 Papers*)

A robot depends on AI vision algorithms to localize itself or uses object detection and recognition to perceive the environment. AR serves here in identifying the robot's intent.

Bassyouni & Elahjj, Front. Robot. AI 8:724798; doi: 10.3389/frobt.2021.724798

AUGMENTED REALITY MEETS ARTIFICIAL INTELLIGENCE IN ROBOTICS

Published results also explain how AR and AI can be combined to solve the model-mismatch paradigm

by creating a closed feedback loop between the user and the robot.

#

This forms a solid base for increasing the efficiency of the robotic application and enhancing the user's

situational awareness, safety, and acceptance of AI robots.

Bassyouni & Elahjj, Front. Robot. AI 8:724798; doi: 10.3389/frobt.2021.724798

ROBOTS in PROSTATE LDR INTERVENTIONAL RADIOTHERAPY

A review of LDR prostate BT robots guided by US, CT, MRI, MRI-US fusion and CT-US fusion

identified 26 robotic systems;

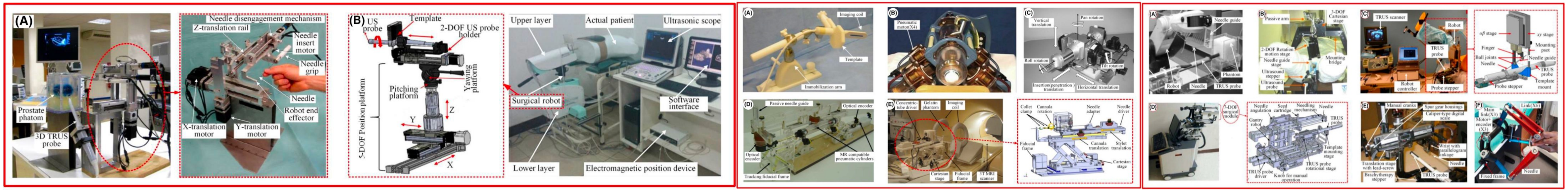
however, they differ in terms of available features, functions and degree of automation.

#

Excluding the real-time seed treatment (FIRST™) system,

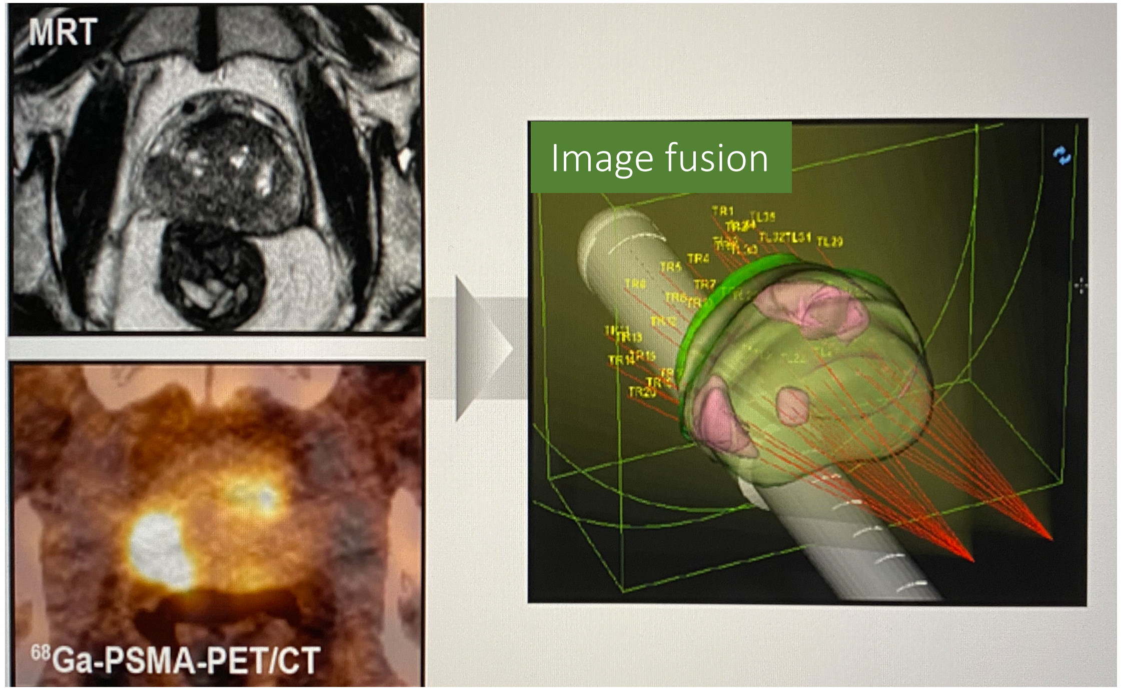
all other robotic systems were developed in universities and hospitals and have not yet been commercialized.

Dai et al. Int J Med Robot. 2021;17:e2239.



POTENTIAL ROBOTS in HDR INTERVENTIONAL RADIOTHERAPY

Prostate Biopsy Robot “Mona Lisa”



https://www.uniklinik-freiburg.de/urologie/aktuelles/roboterassistierte-bildgestuetzte-mrt-psma-petct-prostatafusionsbiopsie-isrobottm-mona-lisa.html

Puncture needles can only be used once in the process of robotic radioactive seed implantation.

#

Master-slave type robots allow additional time to change the needle, thereby increasing surgical efficiency.

#

Future BT robots should take advantage of this benefit.

Dai et al. Int J Med Robot. 2021;17:e2239.

POTENTIAL ROBOTS in HDR INTERVENTIONAL RADIOTHERAPY

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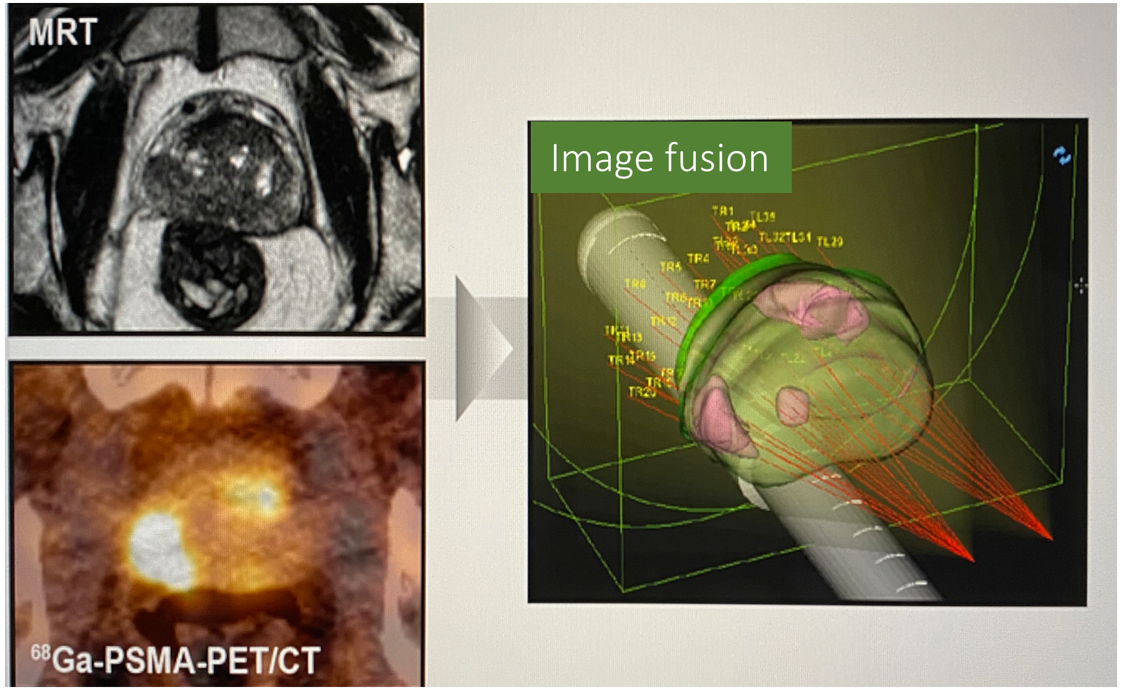

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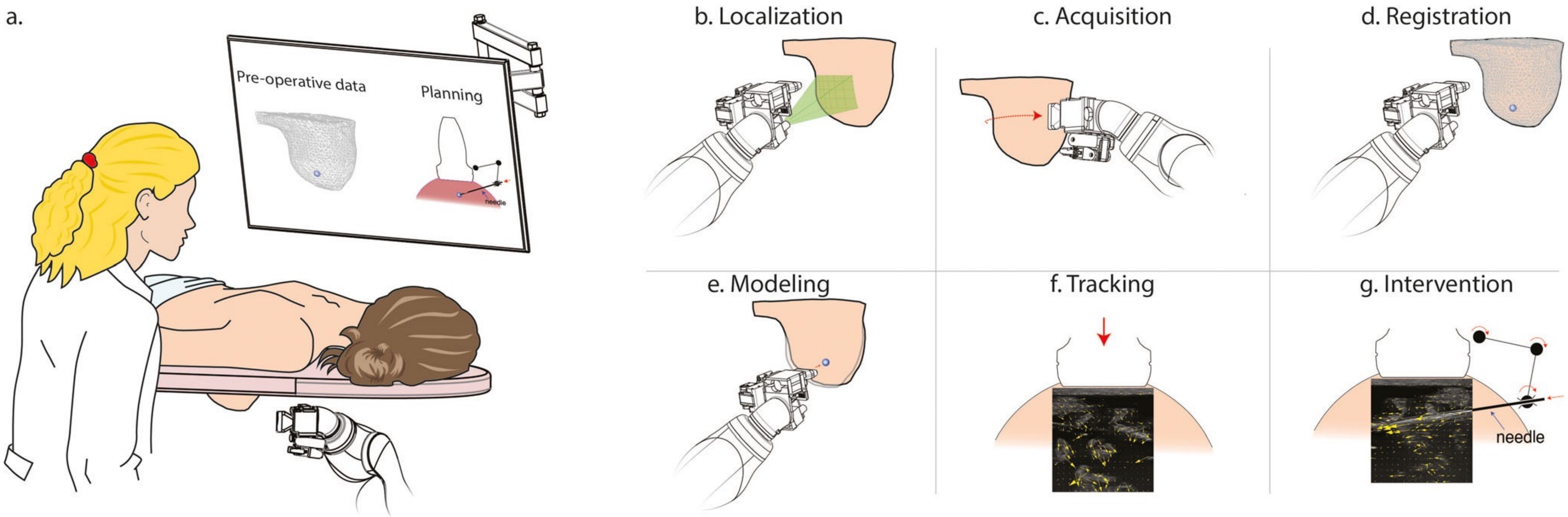
FUTURE POTENTIAL OF ROBOTIC IRT

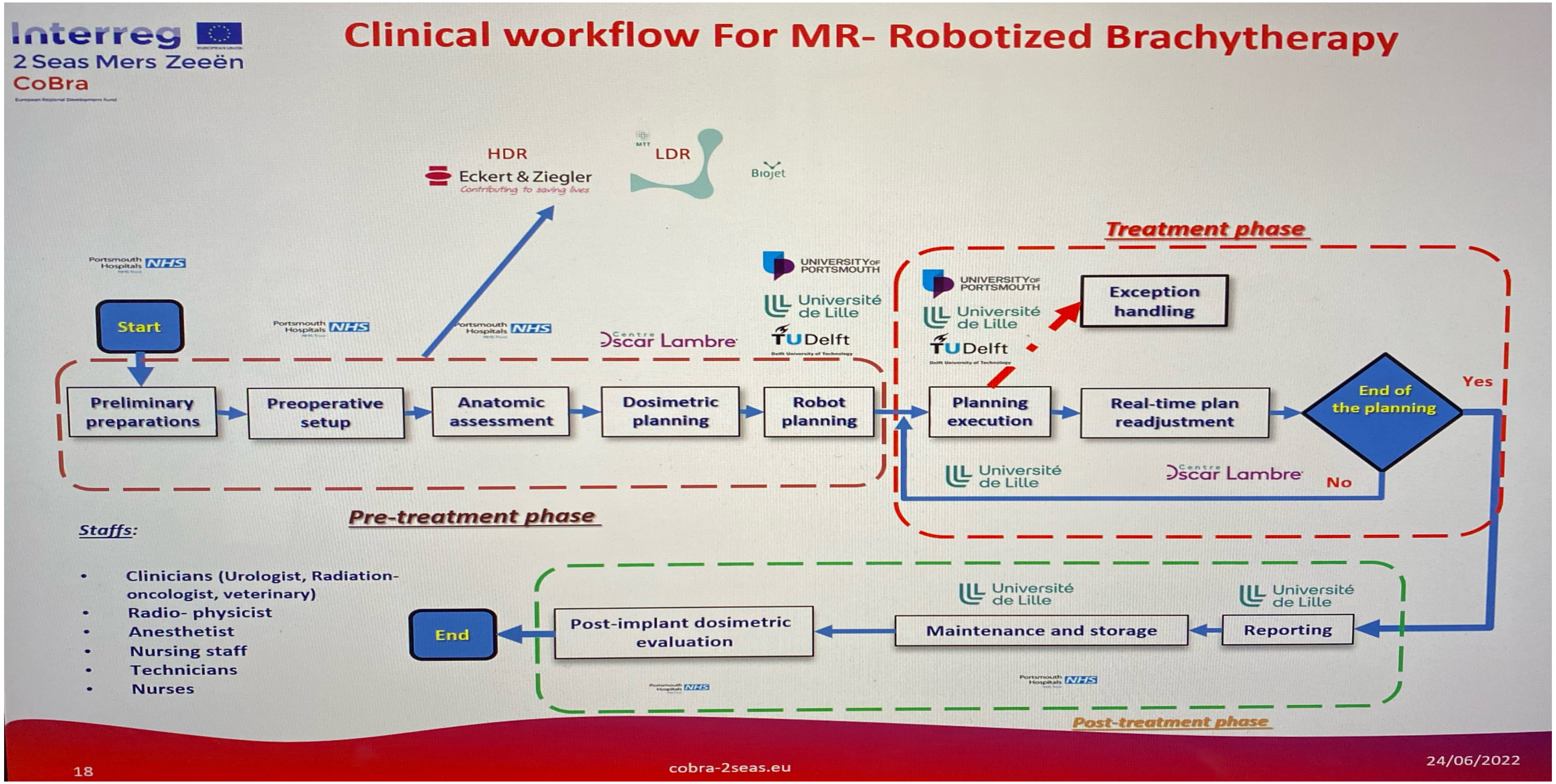
Siepel et al. Curr Robot Rep (2021) 2:73–84



+ TREATMENT PLANNING & QA PROCEDUDES …

POTENTIAL ROBOTS in INTERVENTIONAL RADIOTHERAPY

The European CoBra-2seas project



CONCLUSION

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