An introduction to Neuronavigation with NousNav

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Nous Nav

NousNav

OPEN SOURCE NEURONAVIGATION

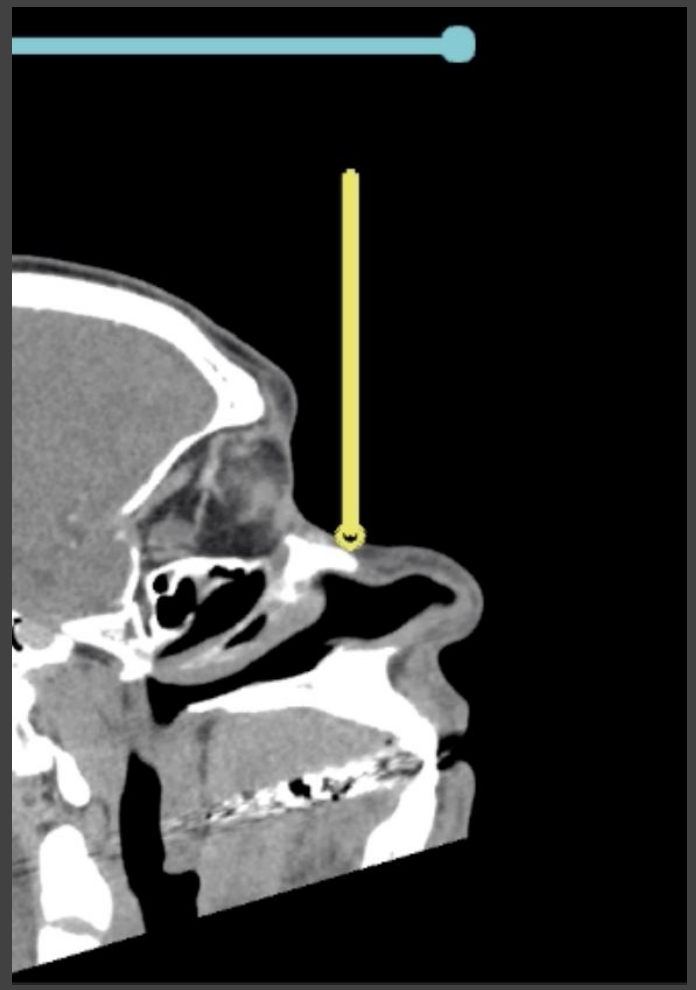
NousNav is an open-source Neuronavigation system for low- and middle-income countries

NousNav

OPEN SOURCE NEURONAVIGATION

Mission

- Provide neurosurgeons cutting-edge neuronavigation tools to perform better surgeries and take on difficult cases
- Serve as a training and collaboration platform for clinical end-users that include neurosurgeons, radiologists, neurologists, physicians, neurosurgical residents and allied healthcare professionals



NousNav
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NousNav provides real-time visualization during surgery of the position of surgical tools relative to preoperative images

NousNav

OPEN SOURCE NEURONAVIGATION

License

- NousNav is free open source software distributed under the 3D Slicer license.
- The license states the code is designed for research and clinical applications are neither recommended nor advised.
- Any clinical use of NousNav requires the obtention of an Institutional Review Board (IRB) approval and is the responsibility of the user.

NousNav Components

The NousNav system is composed of software and hardware:

- The software component of NousNav consists of the NousNav open source platform for neuronavigation

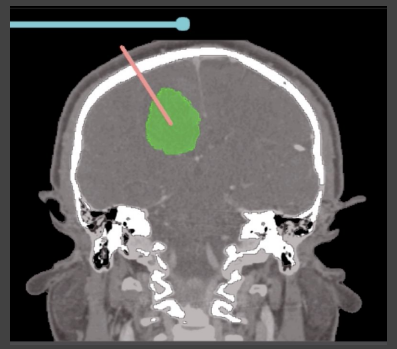
- The hardware components of NousNav include: (1) an optical tracking system, (2) a reference array, and (3) an optical pointer

NousNav Software

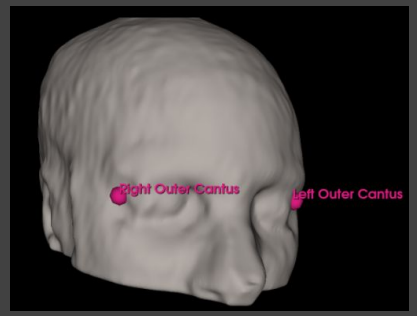
The NousNav open source software platform enables clinicians to perform all the data processing steps of a neuronavigation workflow.

These steps are: Data Loading, Planning, Registration and Navigation.

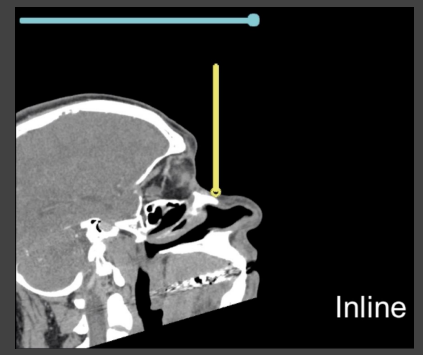
Data Loading



Planning



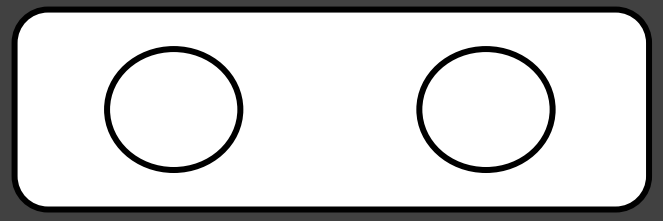
Registration



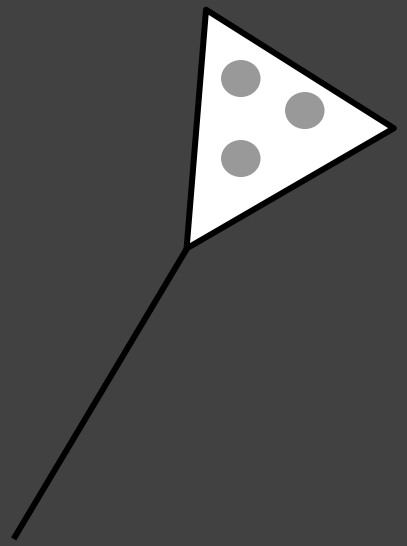
Navigation

NousNav Hardware

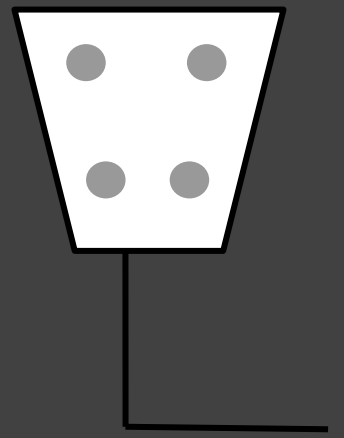
The NousNav hardware components enable clinicians to track in real time the position of surgical tools in the reference frame of the patient



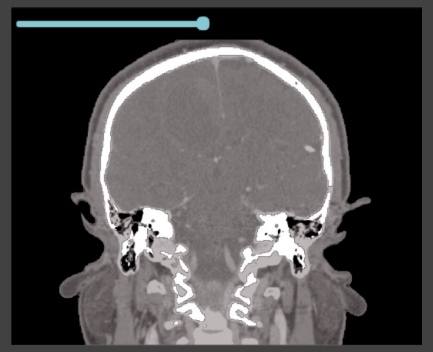
Optical Tracker



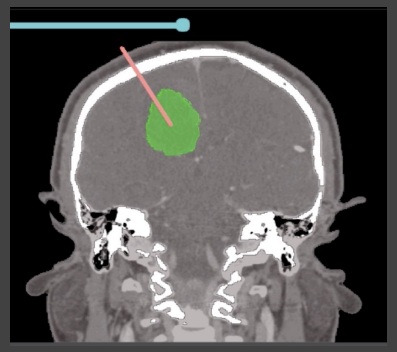
Optical Pointer



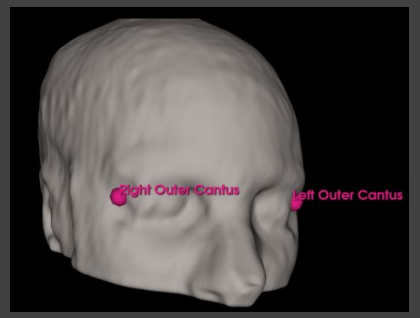
Optical Reference



Data Loading



Planning



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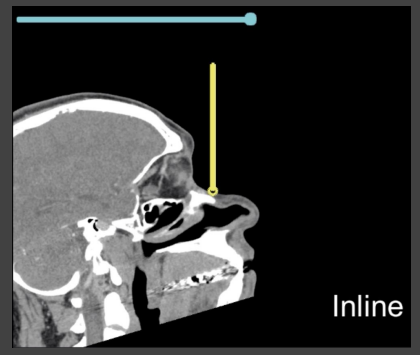
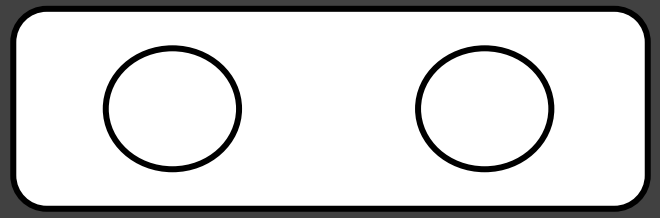
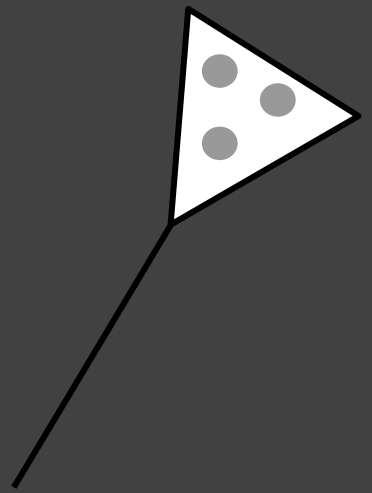


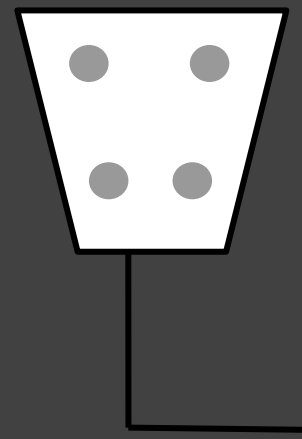
Navigation



Optical Tracker



Optical Pointer



Optical Reference

The NousNav Neuronavigation workflow integrates software-based and hardware-based steps.

NousNav Neuronavigation Workflow

NousNav Neuronavigation Workflow Overview

Step 1: A preoperative CT or MRI scan of the patient is acquired

Step 2: The surgeon loads the preoperative images in NousNav

Step 3: The surgeon builds a patient-specific 3D model of the skin surface

Step 4: The surgeon builds a patient-specific 3D model of the targeted tumor

Step 5: The surgeon plans a trajectory in NousNav

Step 6: The surgeon selects anatomical landmarks in the preoperative images

Step 7: The patient is brought to the operating room, anesthetized, and the head is stabilized using rigid fixation

Step 8: The surgeon affixes an optical reference array to the skull clamp

Step 9: The surgeon positions an optical camera in the operating room facing towards the operative field to enable real-time tracking of instruments

Step 10: The surgeon starts the camera and calibrates the NousNav pointer

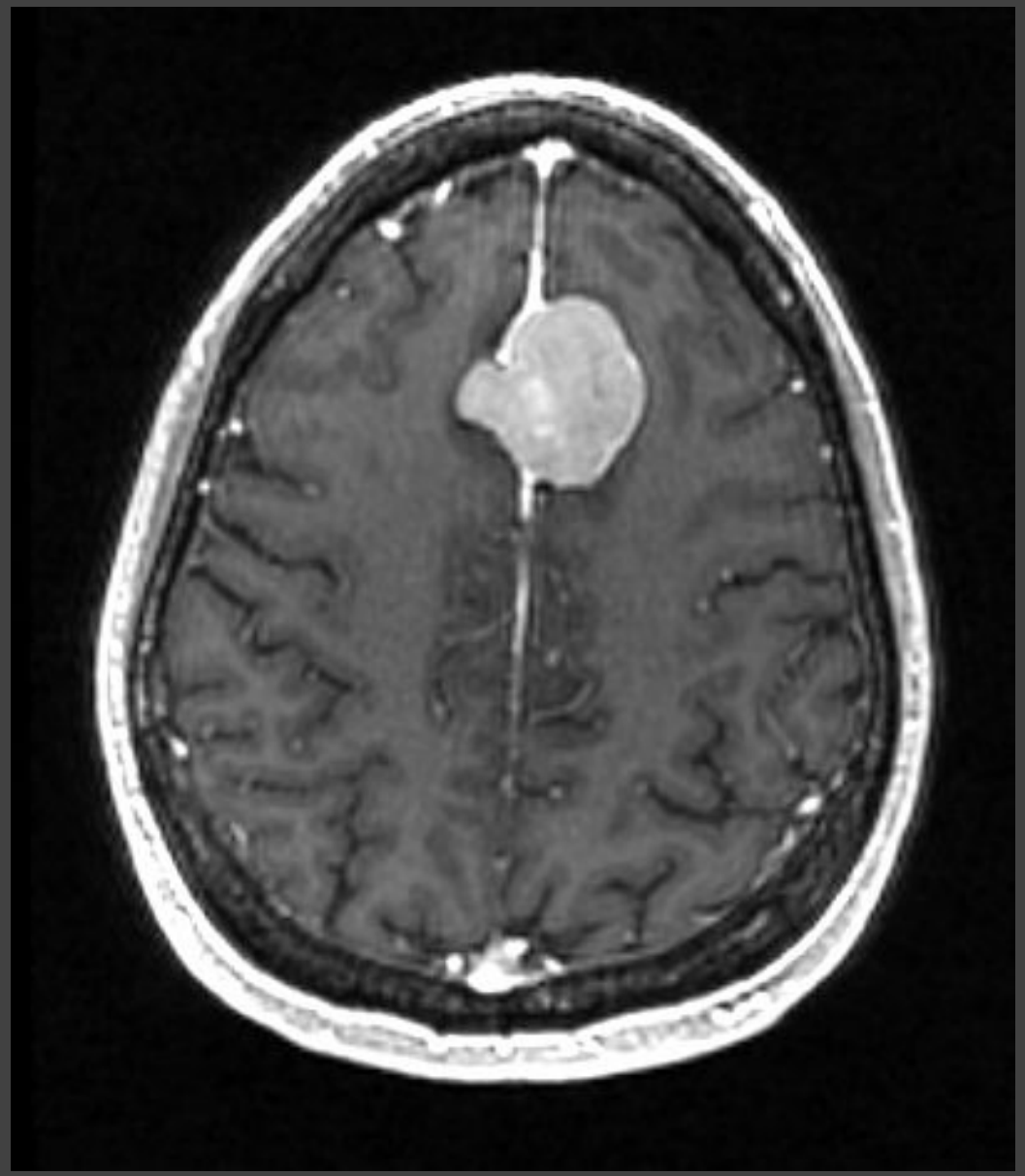
Step 11: The surgeon registers the preoperative images to the patient anatomy

Step 12: The surgeon checks the accuracy of the registration

Step 13: The surgeon checks the accuracy of real-time tracking

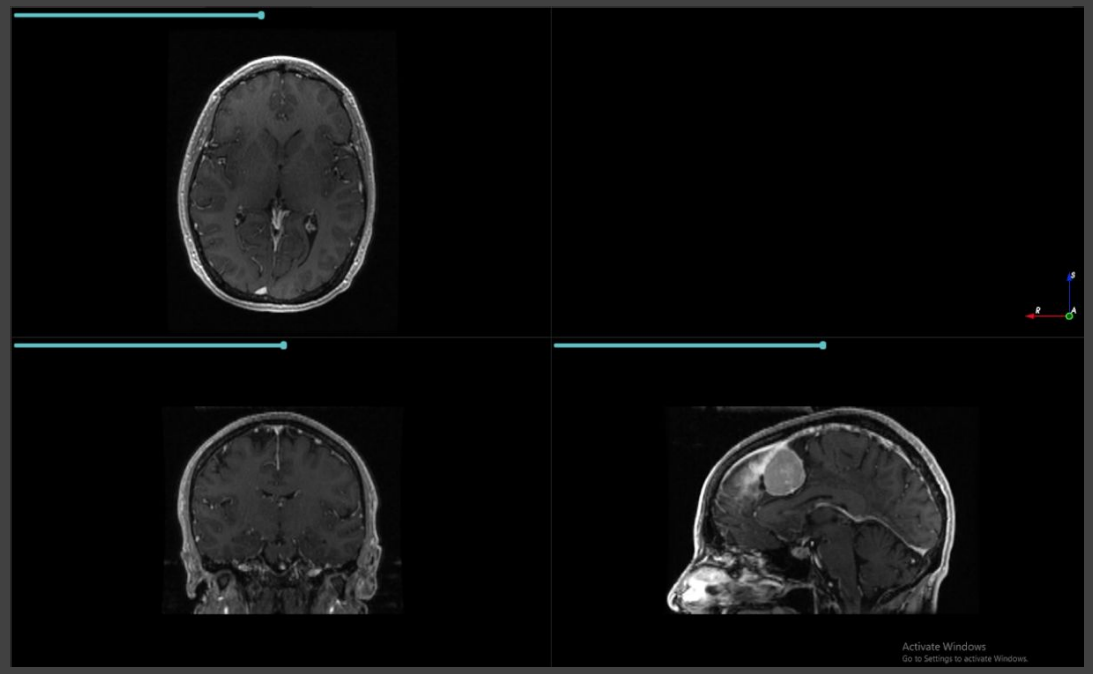
Step 14: The surgeon gets familiar with the anatomy of the patient using NousNav

Step 15: The surgeon uses NousNav to plan the scalp incision, craniotomy and approach toward the lesion



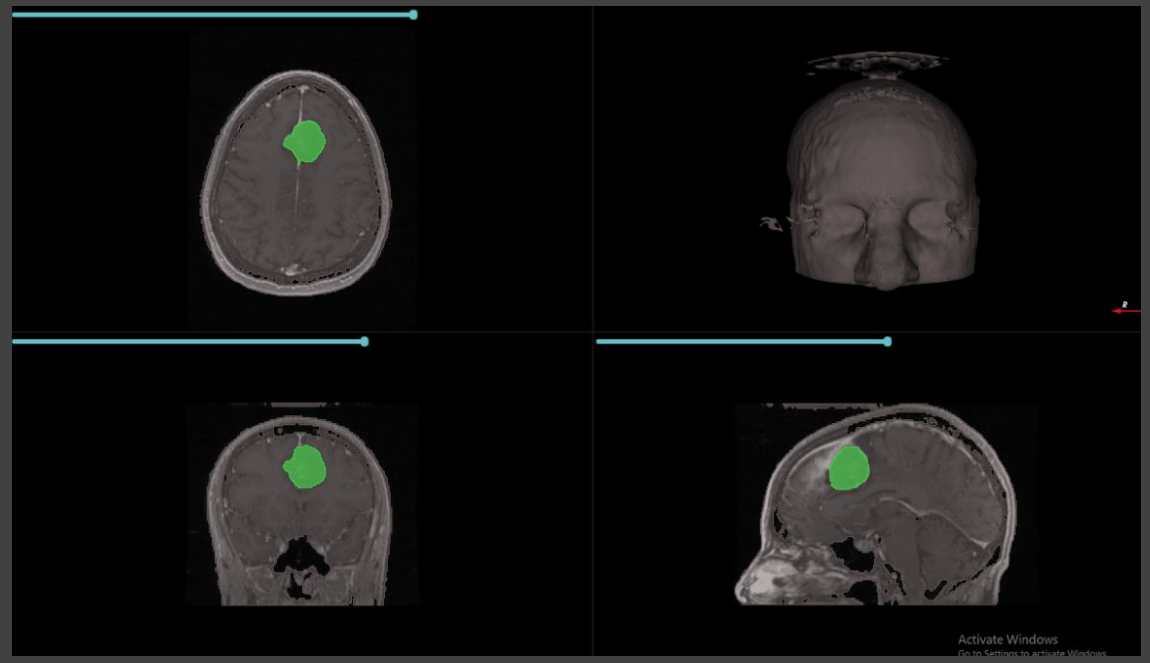
Step 1: A preoperative CT or MRI scan of the patient is acquired

Preoperative MRI and CT data provide detailed anatomical information on brain lesions and their surroundings



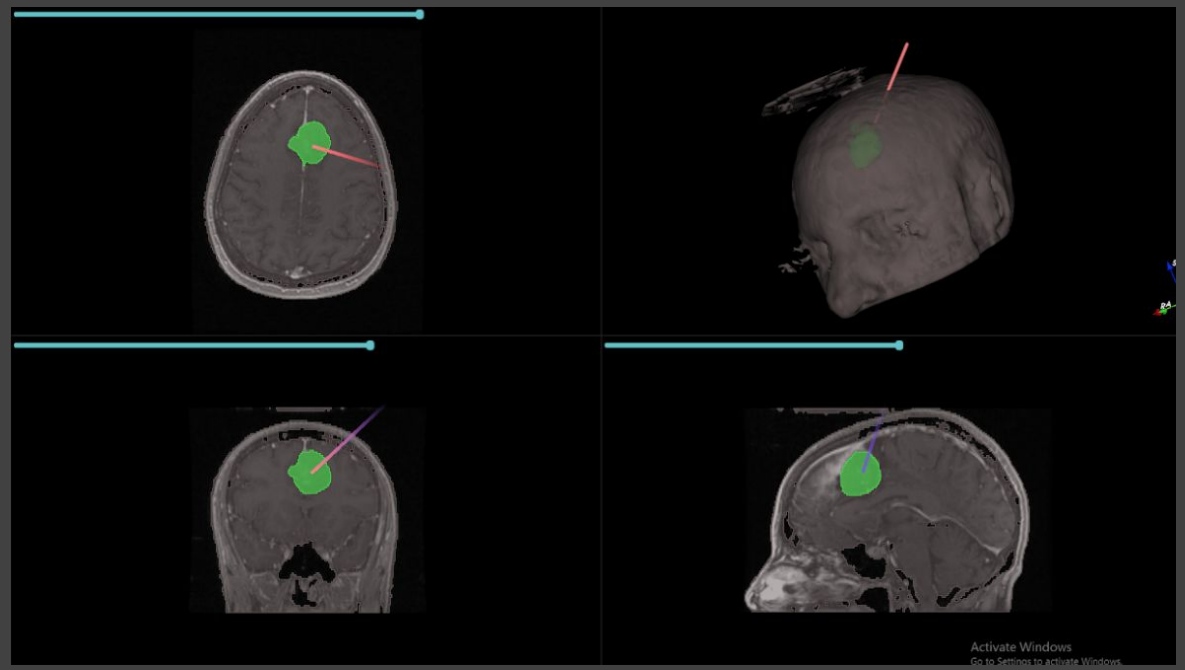
<u>Step 2:</u> The surgeon loads the preoperative images in NousNav

NousNav creates a 3D volume from the axial images of the scan in a process called multiplanar reformation



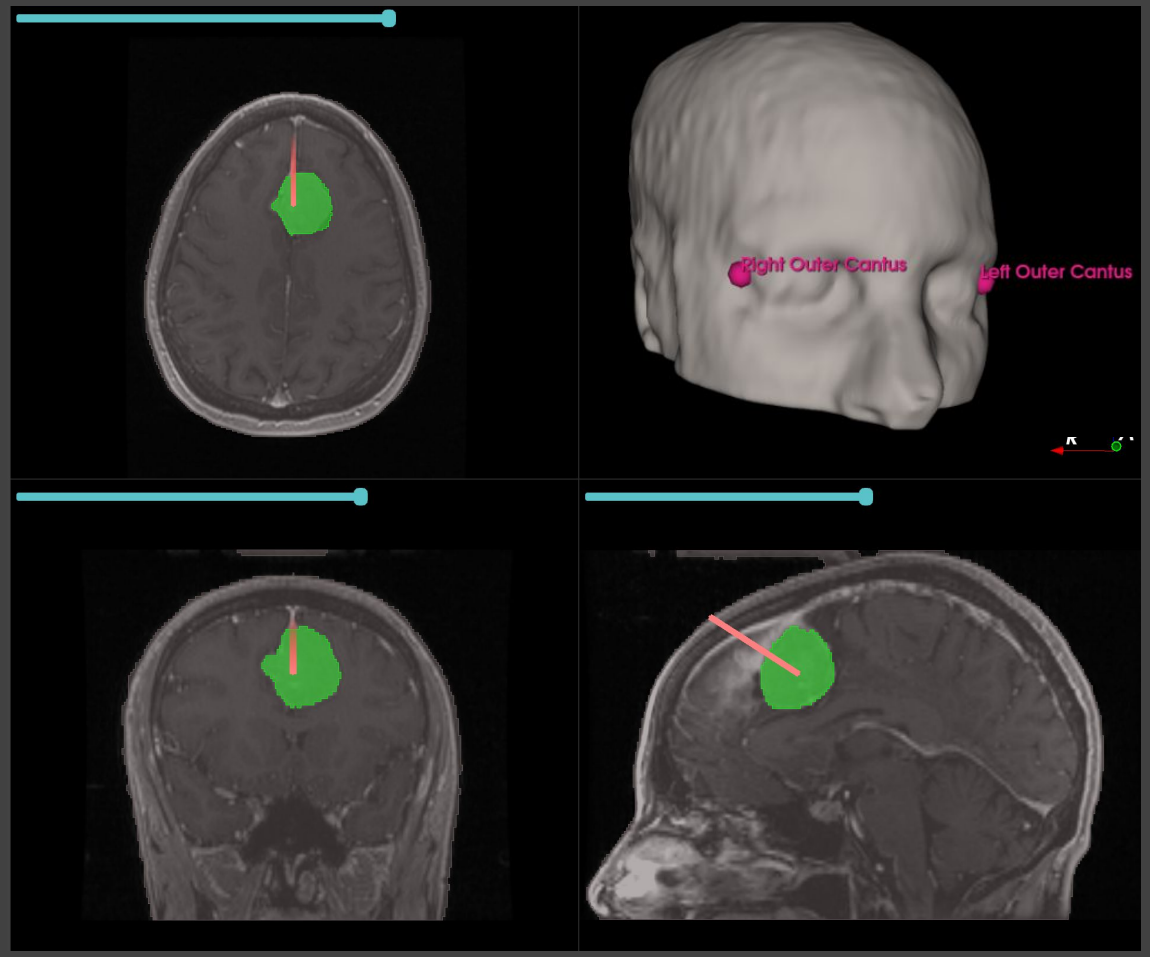
<u>Step 3&4:</u> The surgeon builds a patient-specific 3D model of the skin surface and targeted tumor

Post-processing methods enable 3D reconstruction of anatomical structures of interest from 2D preoperative images



<u>Step 5:</u> The surgeon plans a trajectory in NousNav

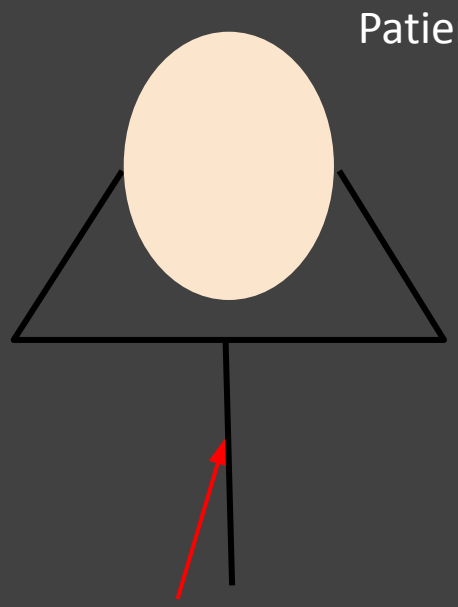
NousNav creates a trajectory line using the target and entry point defined by the surgeon on the images



<u>Step 6:</u> The surgeon selects anatomical landmarks in the preoperative images

Anatomic points which the system uses to perform registration of the patient's head to the images are known as "fiducials"

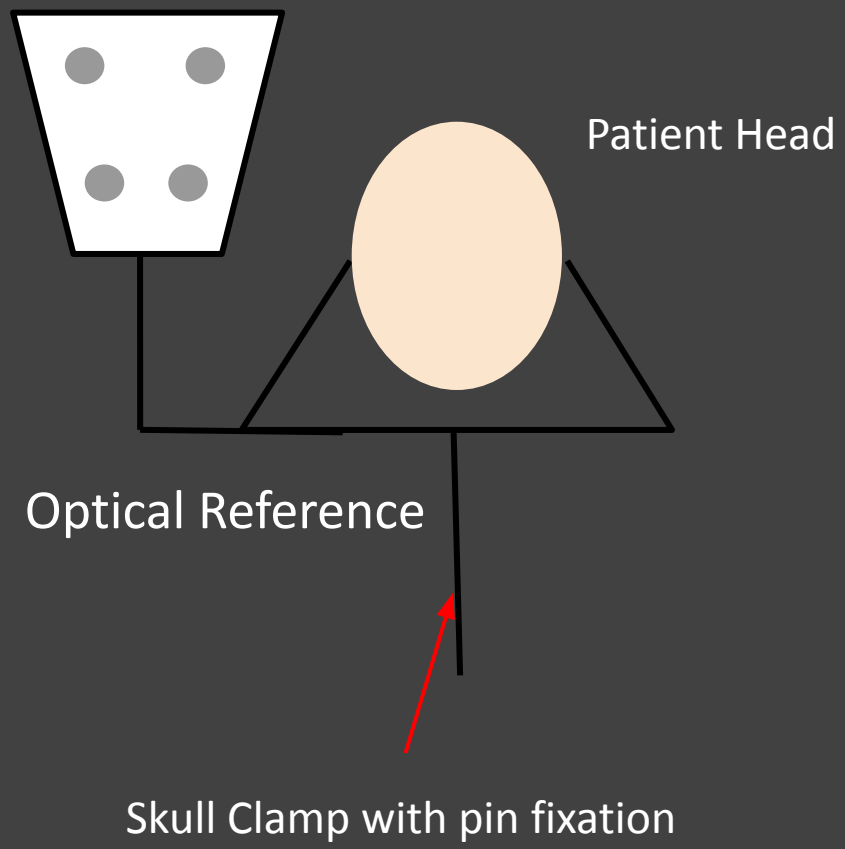
Potential points include tragus, outer canthus, inner canthus, nasion, inion. These points should be visible after the patient is positioned in the operating room



Skull Clamp with pin fixation

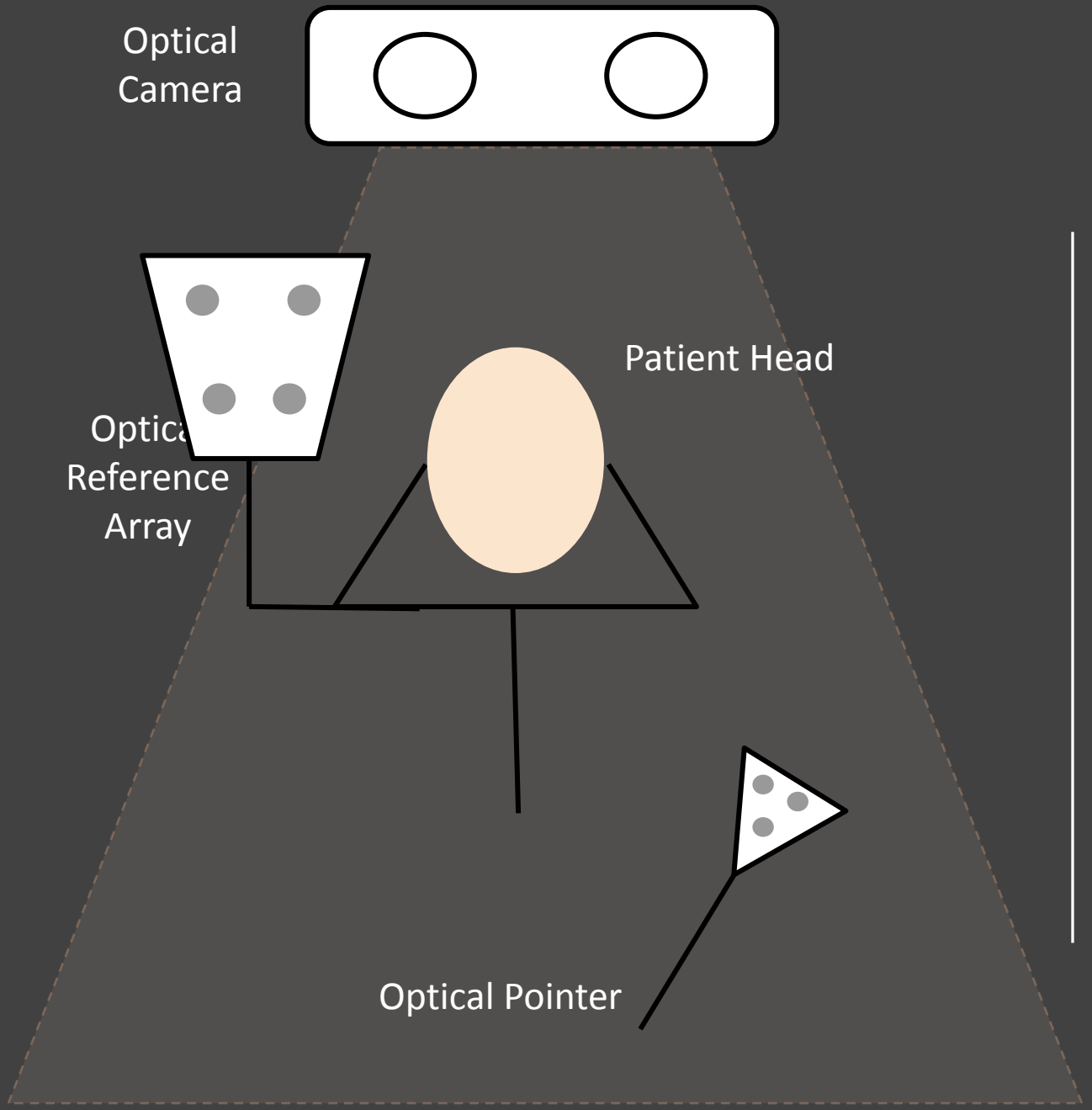
Step 7: The patient is brought to the operating room. The patient is anesthetized and the head is stabilized using rigid pin fixation (e.g. Mayfield skull clamp)

The skull clamp provides rigid cranial fixation for neurosurgical procedures and a fixed frame of reference for NousNav. It is essential that the head is rigidly fixed and cannot slip relative the the frame



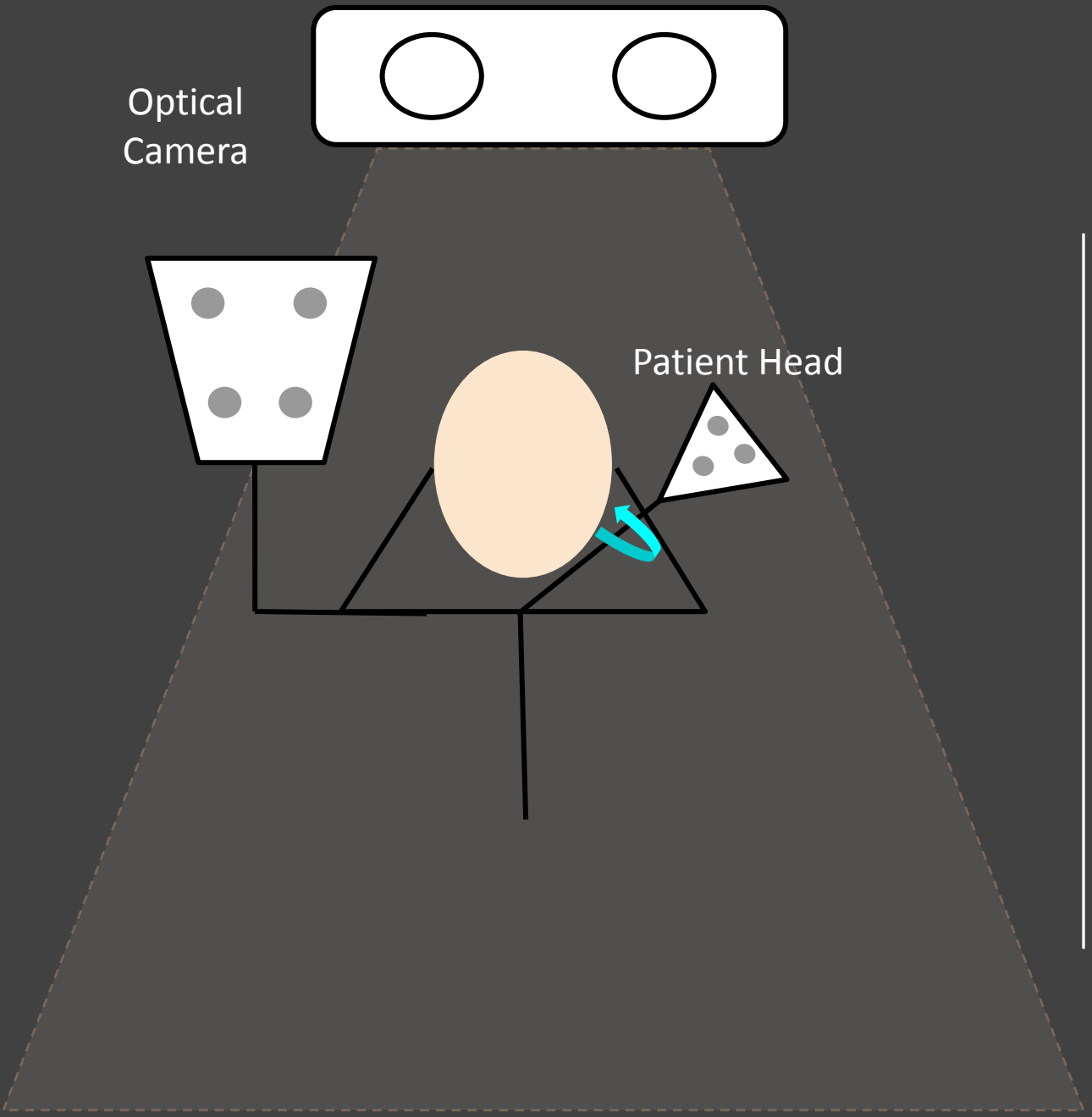
<u>Step 8:</u> The surgeon affixes the non-sterile optical reference array to the skull clamp with the optical markers facing the camera

It is essential that the reference array is rigidly affixed to the skull clamp and the optical markers are pointing to where the camera will be during the procedure



<u>Step 9:</u> The surgeon positions an optical camera in the operating room and checks that the optical reference and optical pointer are in the field of view of the camera

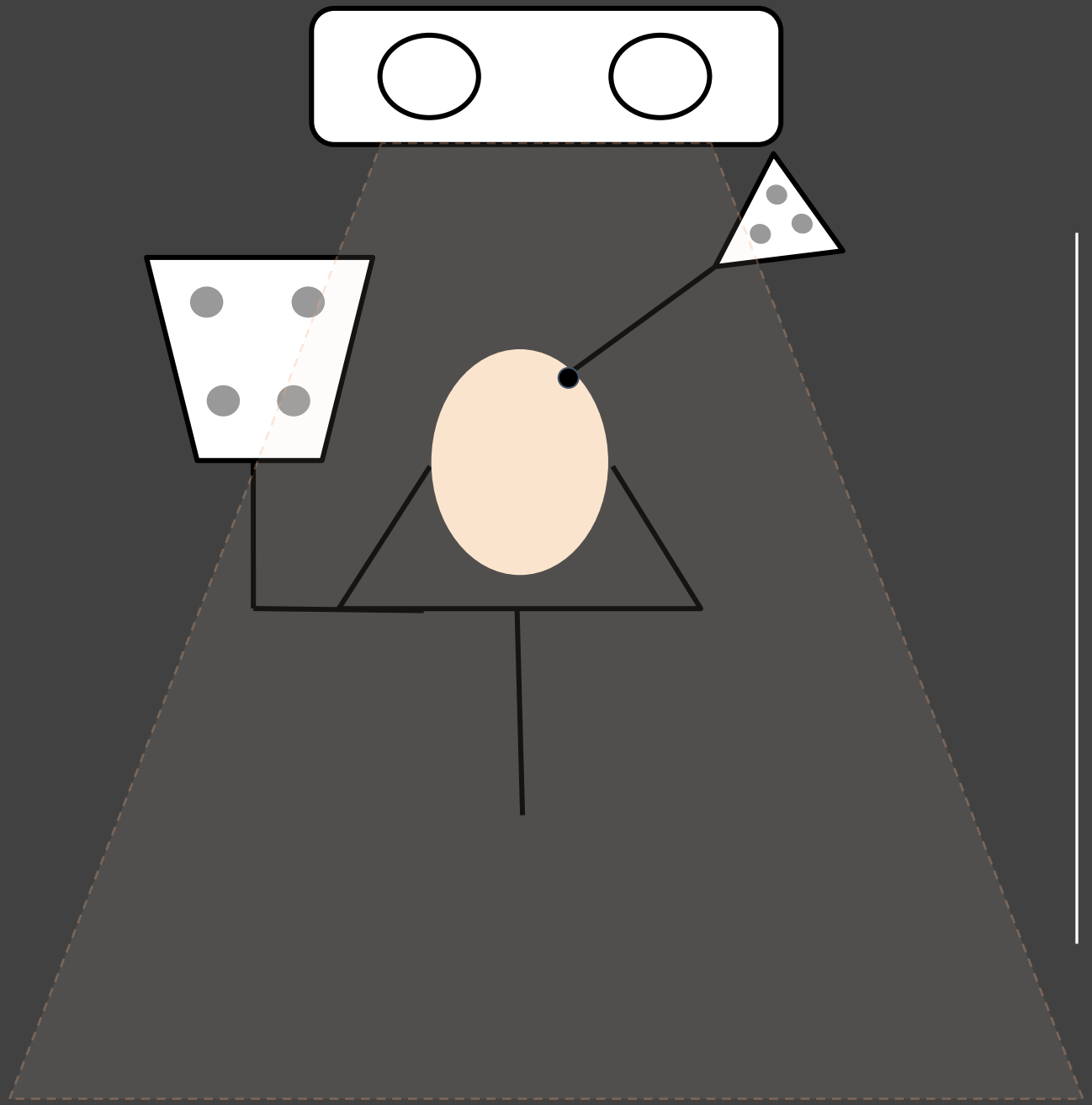
Optical tracking systems enable real-time tracking of instruments in the operating room



Step 10: The surgeon calibrates the NousNav pointer

The surgeon places the tip of the pointer in the center of the divot on the reference array and rotates the tool around its tip.

Tool calibration teaches NousNav the precise relationship of the tool tip to the optical markers.

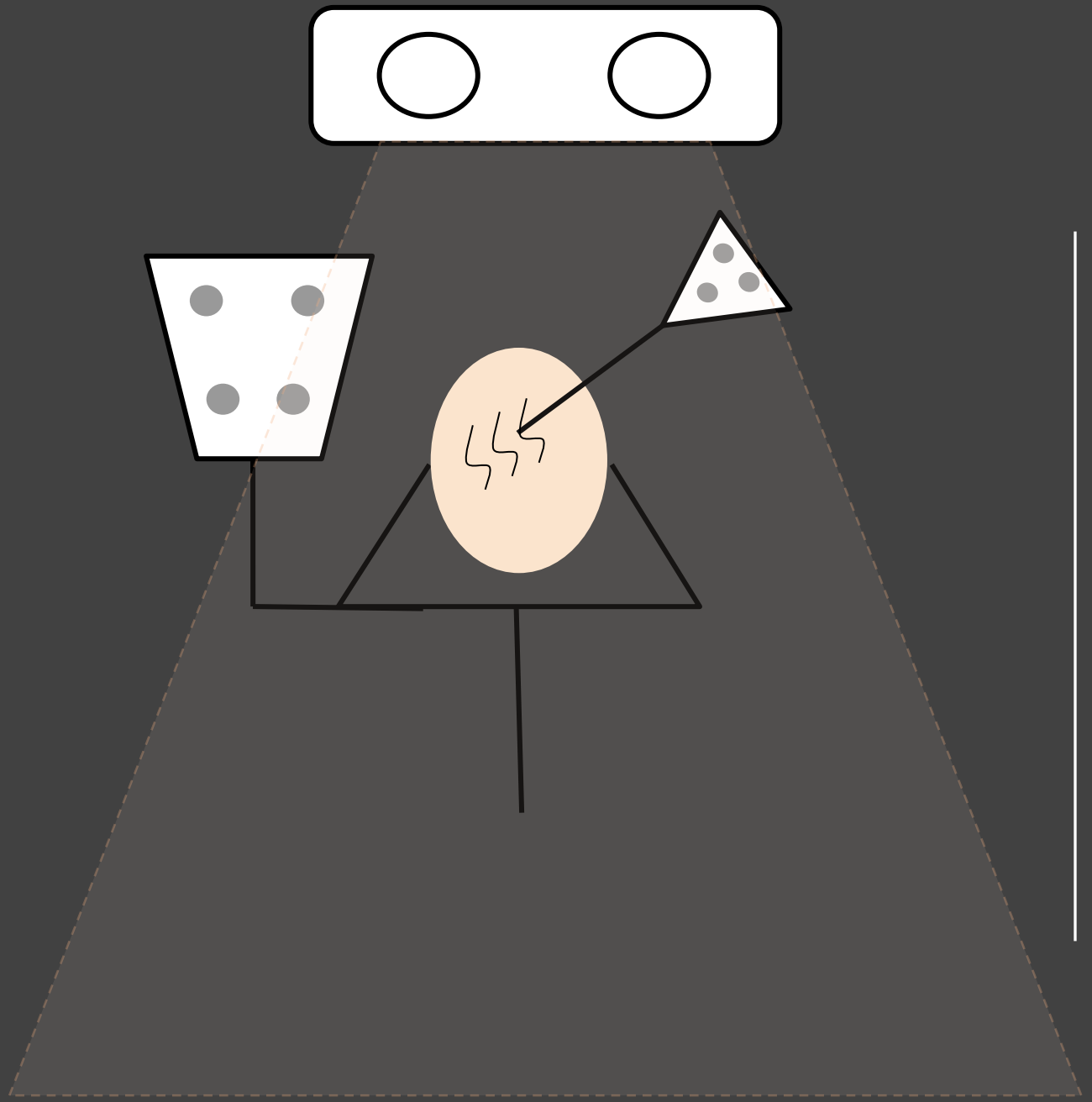


Step 11a: The surgeon initializes the registration of the preoperative images to the patient head anatomy

The surgeon removes accessories that might distort registration such surgical tape or ET tube distorting the patient nose.

Using the tracked pointer, the surgeon touches the anatomical landmarks corresponding to the anatomic landmarks marked in the preoperative images loaded into NousNav in Step 6.

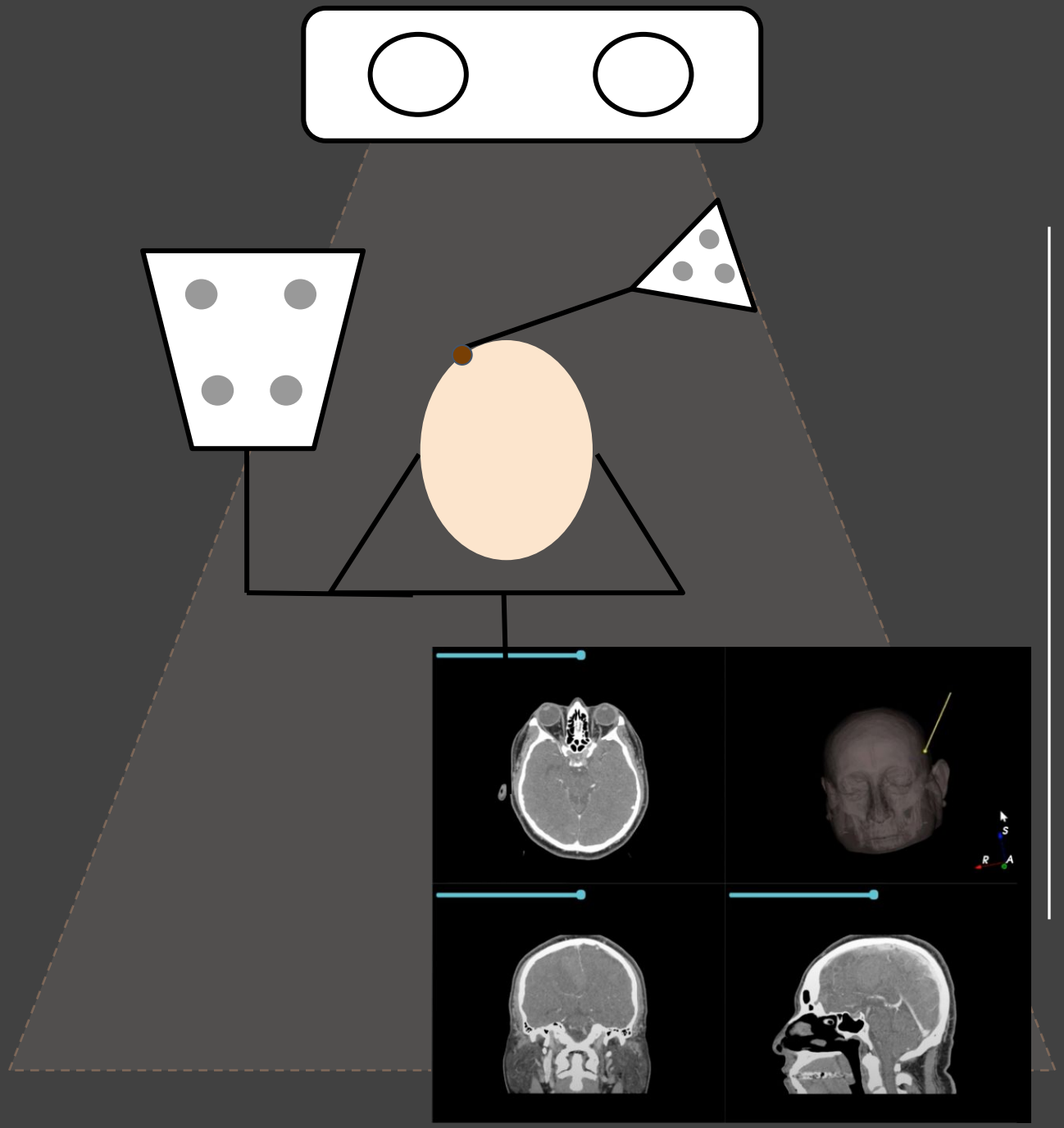
NousNav matches the points on the patient's head to the matching points marked on the images to initialize the surface matching registration between the coordinate system of the patient and the coordinate system of the images.



Step 11b: The surgeon completes registration of the preoperative images to the patient head anatomy

Using the tracked pointer, the surgeon traces the surface of the head.

Additional surface points improve the registration. Be sure to keep the pointer tip on the surface of the skin and press as lightly as possible in order to not deform the skin. Points should be acquired from both sides of the head and from a broad area. Be sure to acquire points from areas of unique anatomy such as around the eyes, bridge of the nose, etc. Do not acquire points from areas which are cut off on the imaging (e.g. tip of the nose, vertex) or areas where there is a lot of soft tissue deformation.

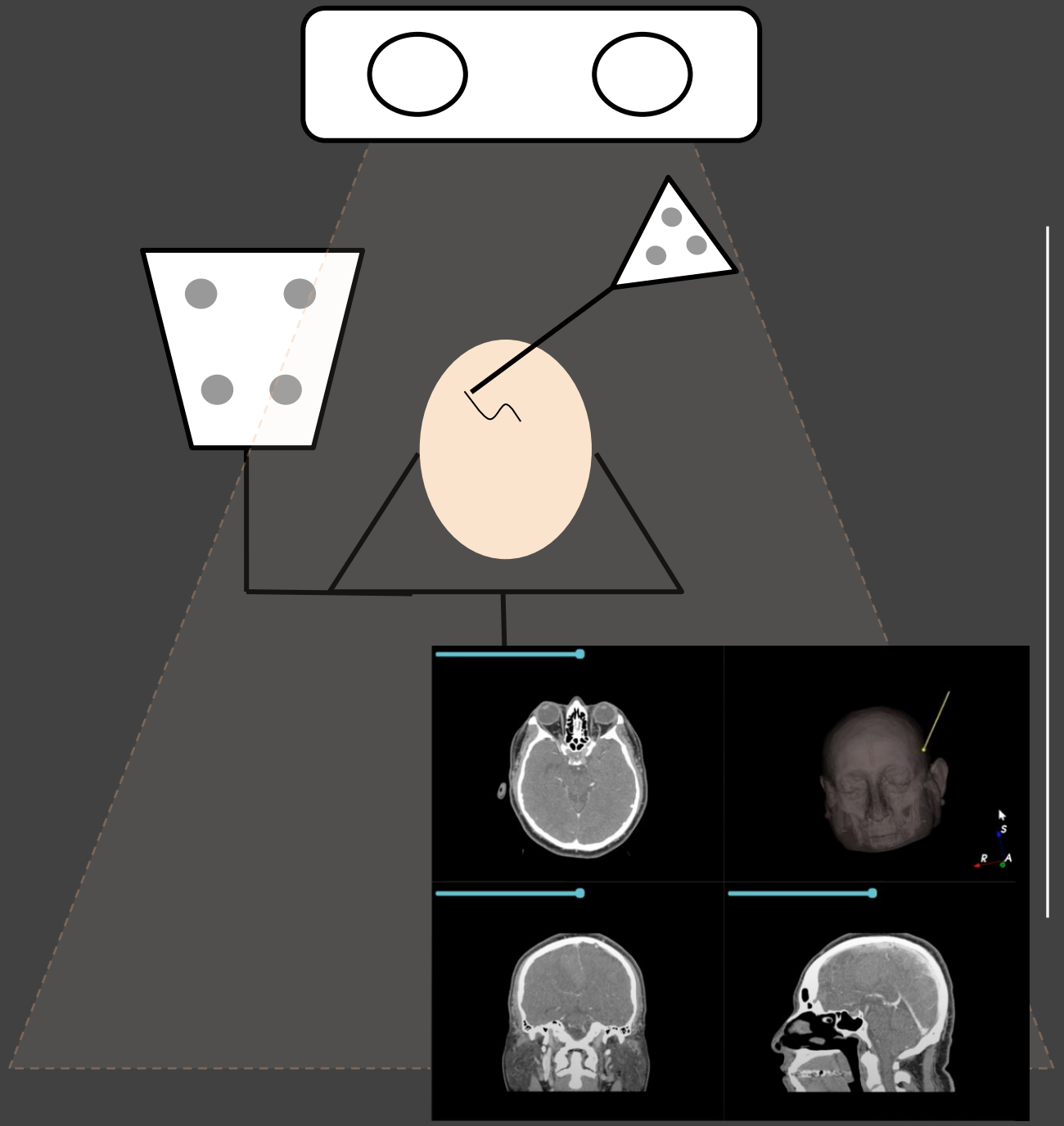


Step 12: The surgeon checks the accuracy of the registration

The surgeon touches anatomical landmarks on the patient's head and carefully checks that NousNav correctly displays their position in the preoperative images.

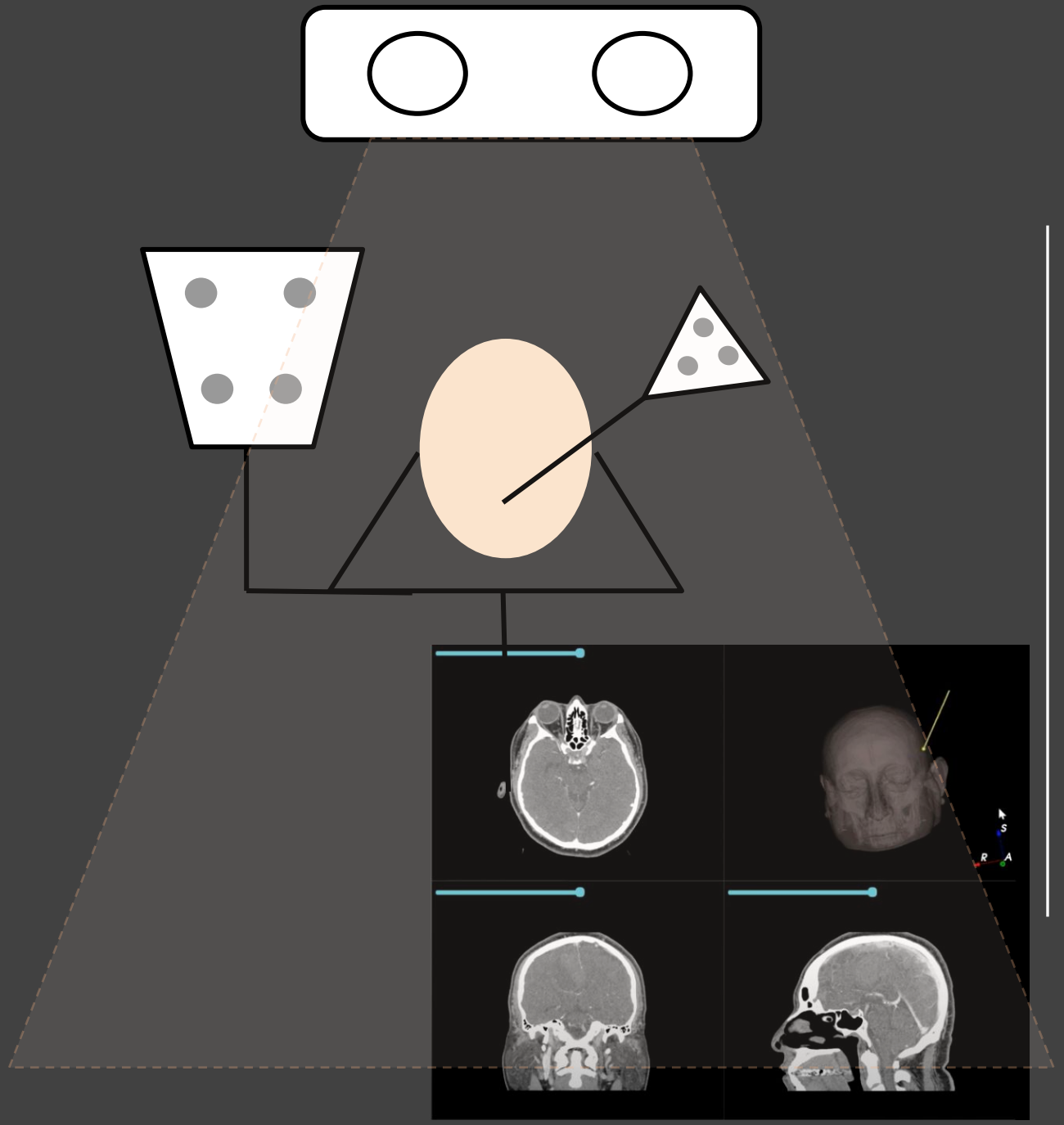
Note: Once the registration step is completed, the optical reference array cannot be moved.

If the reference array is moved, the registration is no longer valid, and the surgeon must redo Step 10 and Step 11



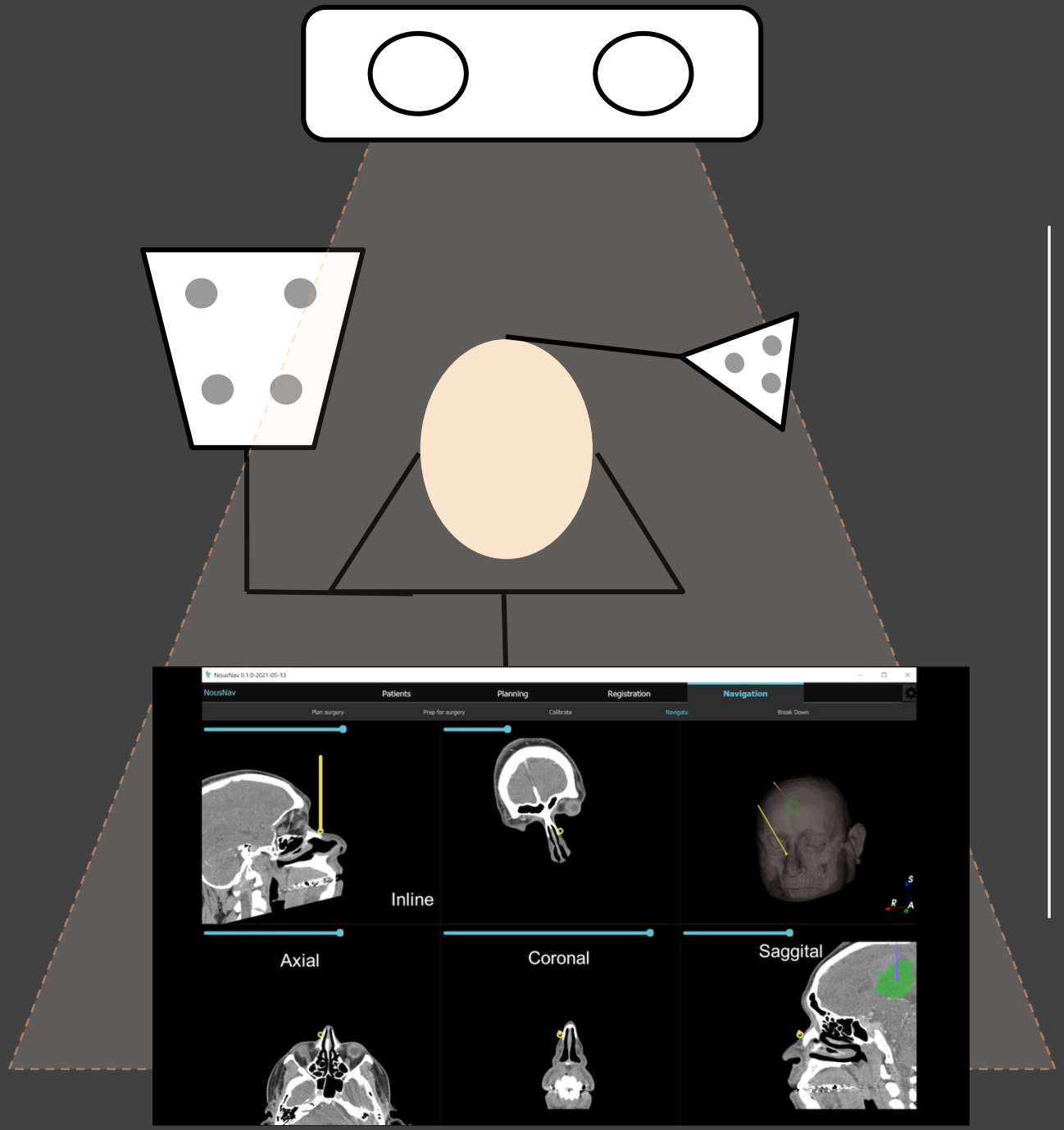
<u>Step 13:</u> The surgeon checks the accuracy of real-time tracking

The surgeon moves the tip of the pointer on the patient head and checks that NousNav updates the position of the tip of the pointer on the images with no delay.



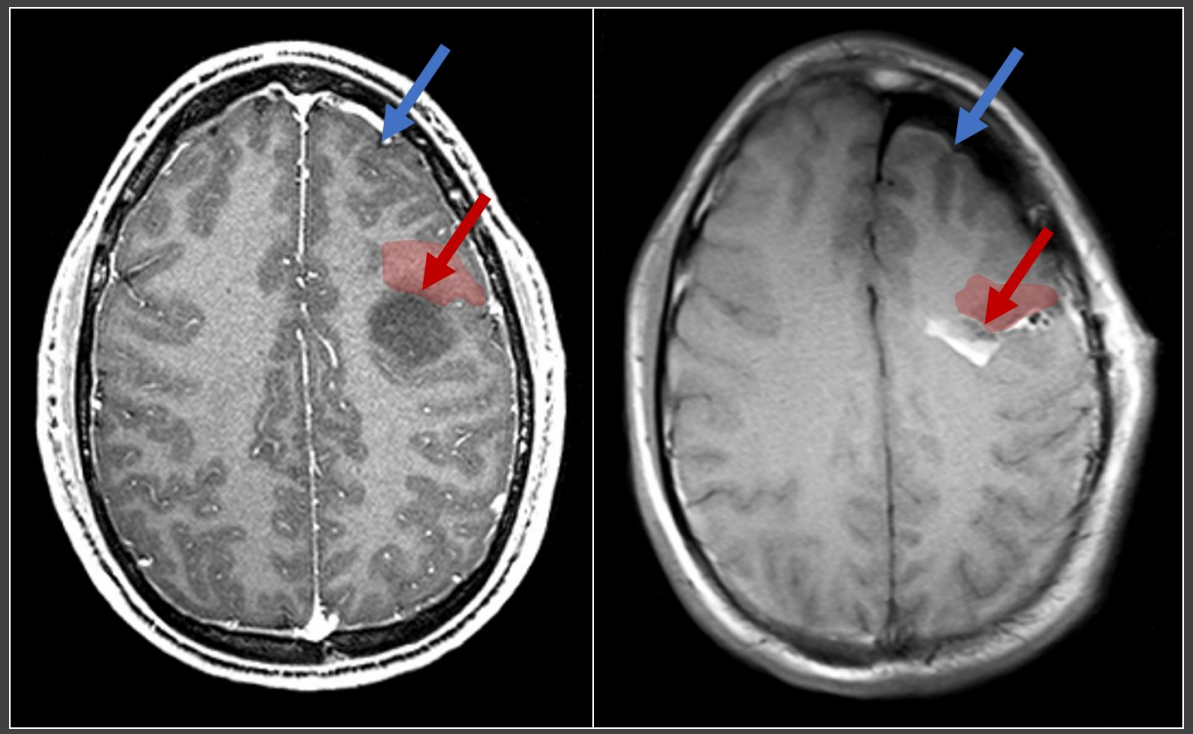
Step 14: The surgeon gets familiar with the anatomy of the patient using the NousNav system

The surgeon moves the pointer on the skin of the patient and checks that NousNav updates in real-time the preoperative images with the position of the optical pointer.



<u>Step 15:</u> The surgeon uses the NousNav system to plan the scalp incision, the craniotomy and the approach toward the lesion, and to see under the surface

The system displays in real-time the position of the optical pointer in the preoperative images. As the surgeon moves the instrument, NousNav updates the preoperative images centered on the new position of the tip of the pointer



A. Preoperative MRI showing a low-grade glioma (dark region). B. iMRI after near-complete resection with significant brain shift. Brain shift can occur far from the surgical site (in blue). More clinically relevant, it can cause significant deformation and displacement near margins of the resection cavity (in red), precisely where surgeons could most benefit from accurate image guidance.

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Limitations

Intraoperative brain distortion, also called "brain shift", can cause error in neuronavigation as the position of the brain changes during surgery.

Brain shift significantly reduces the validity of neuronavigation from preoperative data.

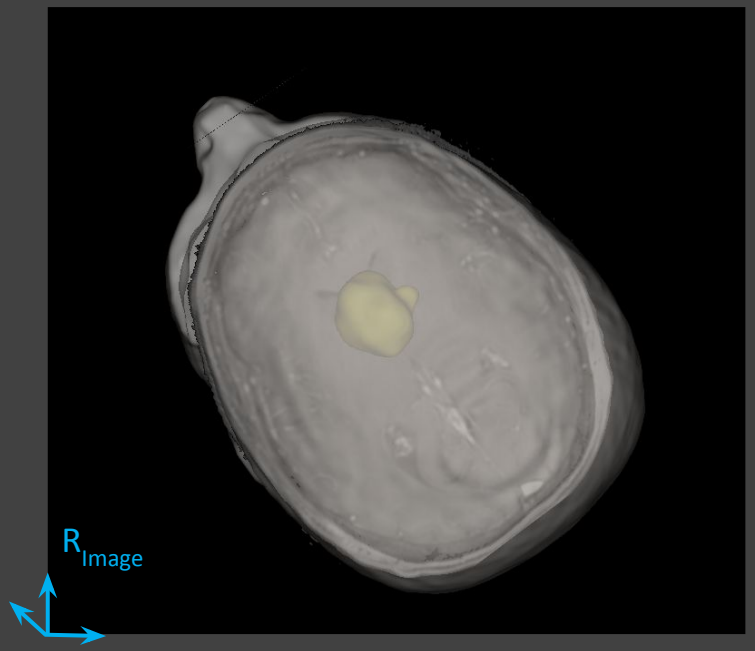
Intraoperative imaging can address some of these issues.

Fundamentals of Neuronavigation

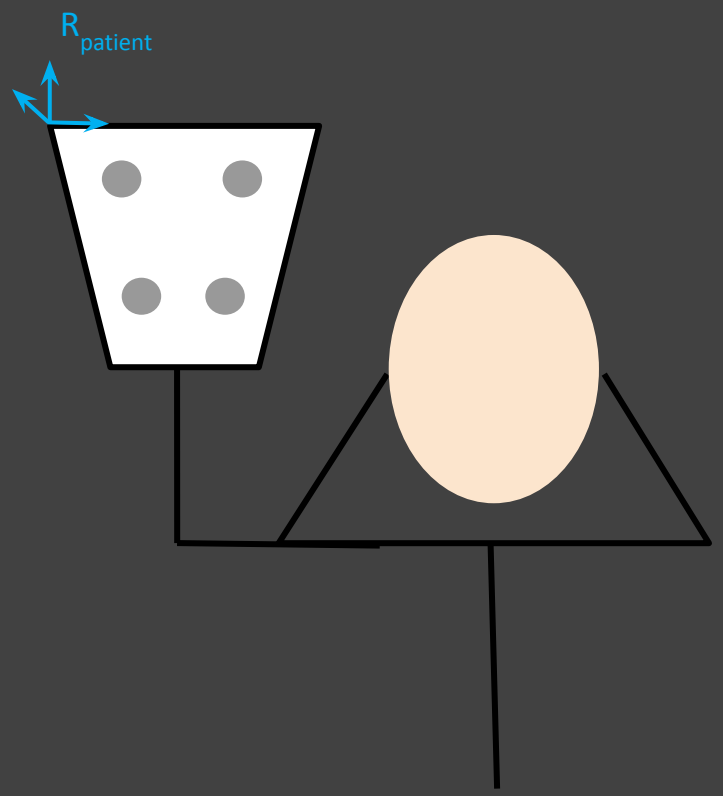
Reference frames are essential components of a neuronavigation system.

The following section describes the reference frames involved in NousNav.

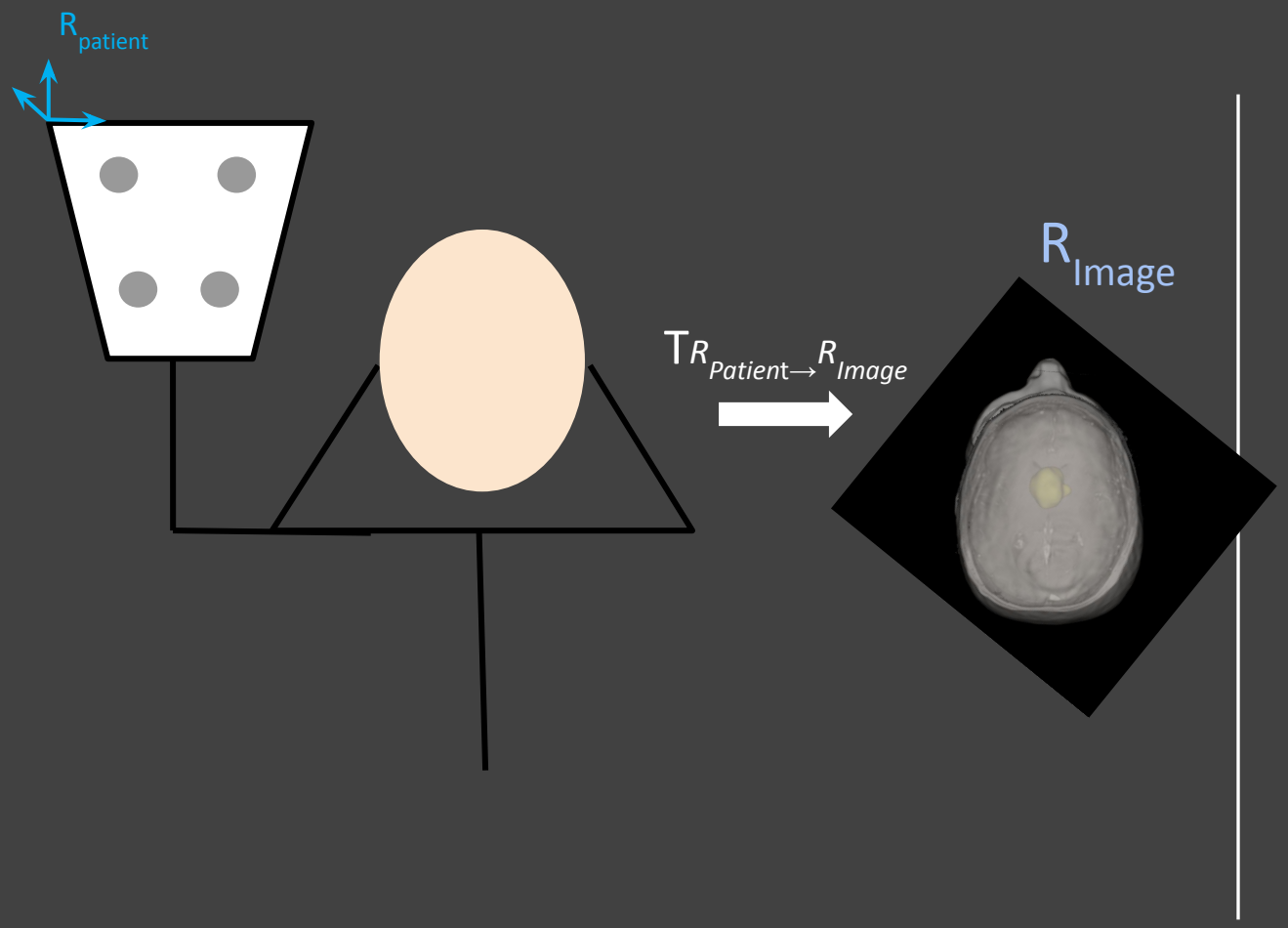
A basic understanding of the different reference frames is important to perform neuronavigation safely.



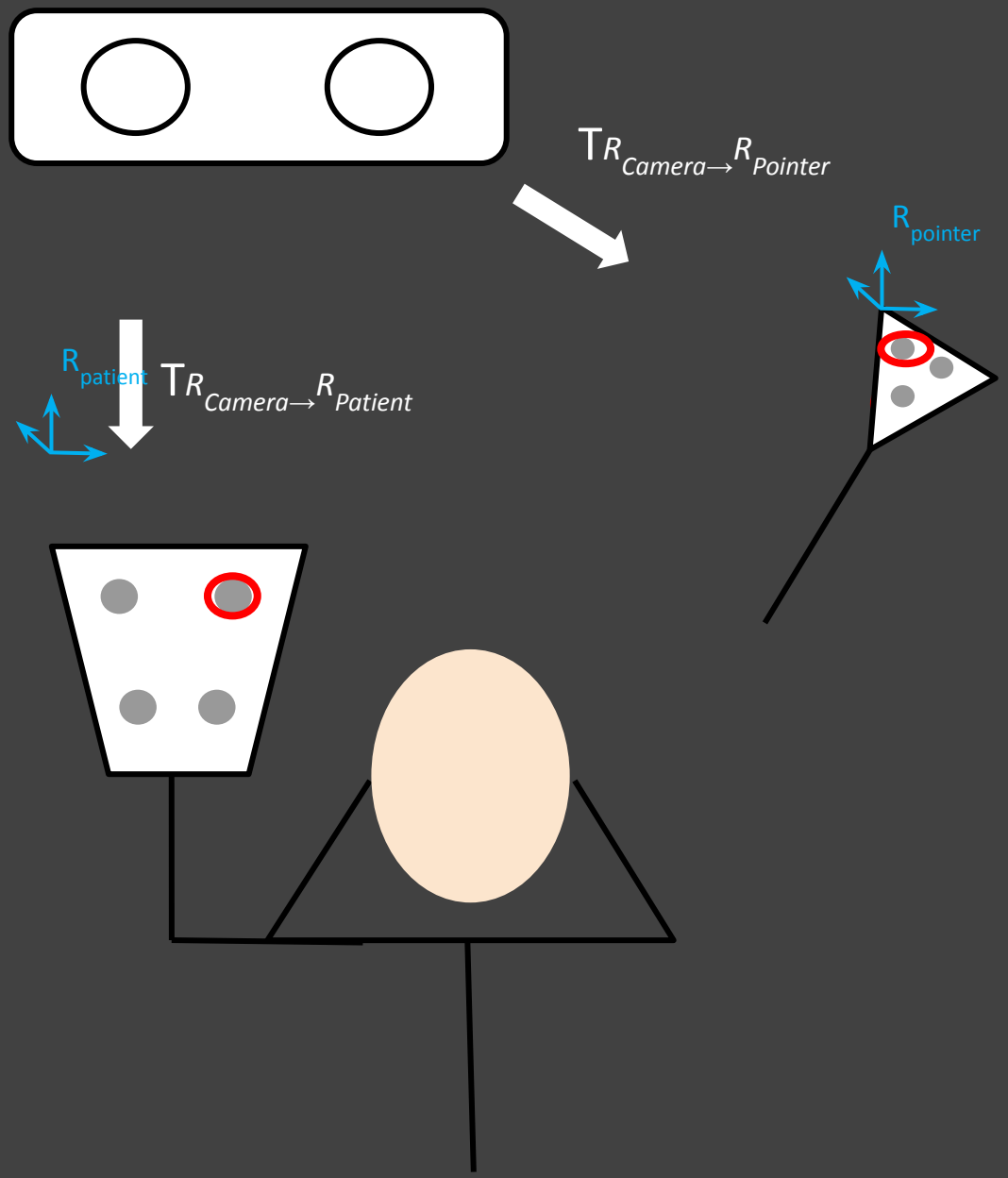
The preoperative imaging dataset is a geometric volume to which a reference frame R_{Image} can be applied



The patient head is considered a geometric volume to which a reference frame $R_{Patient}$ can be applied



Neuronavigation systems compute the spatial transform between $R_{Patient}$ and R_{Image} in a process called registration

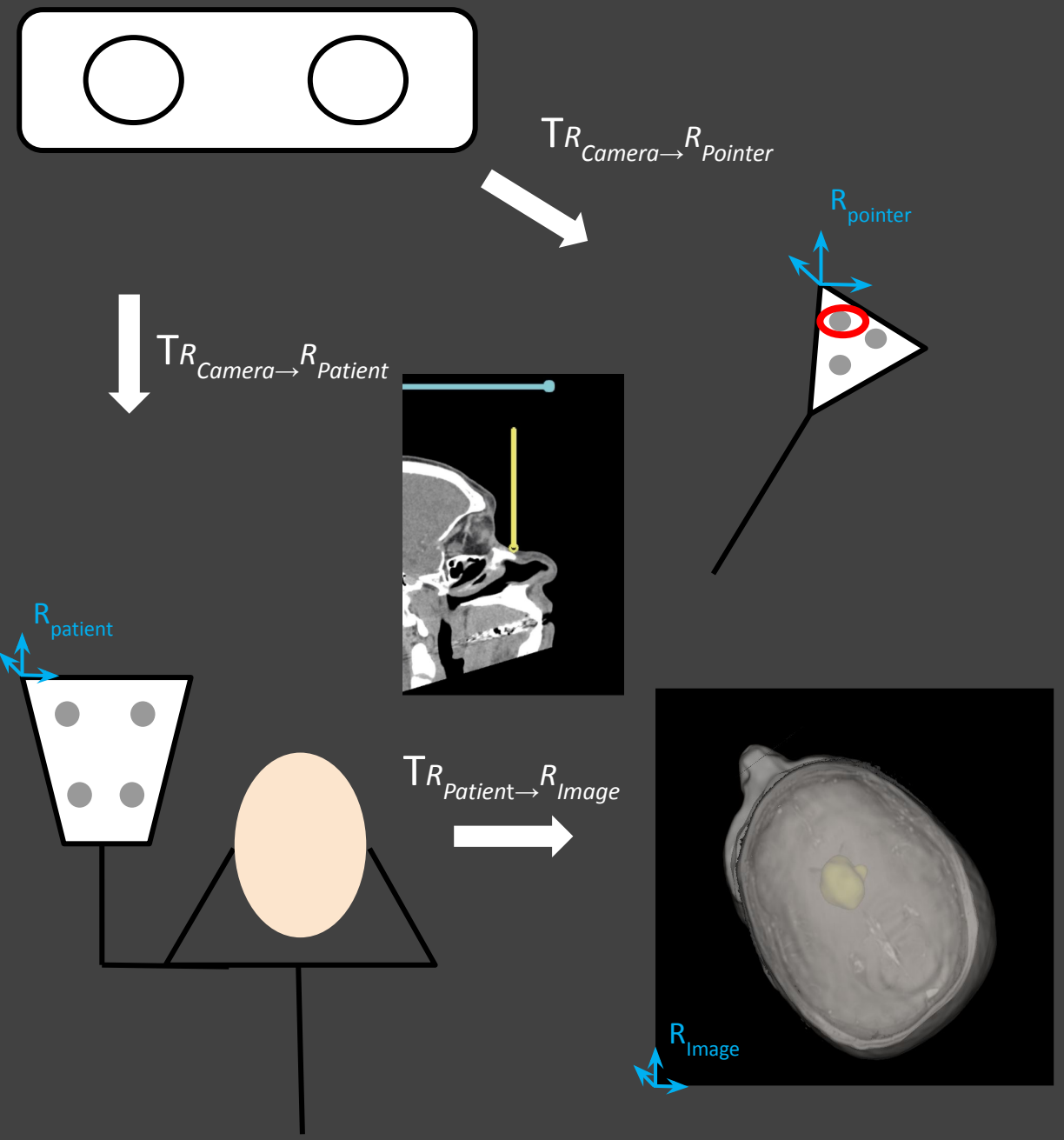


Cameras track the position of the patient head and surgical instruments using optical markers. A reference frame R_{Camera} can be attached to an optical camera.

Optical markers are small objects with reflective surfaces that can be recognized and tracked by cameras

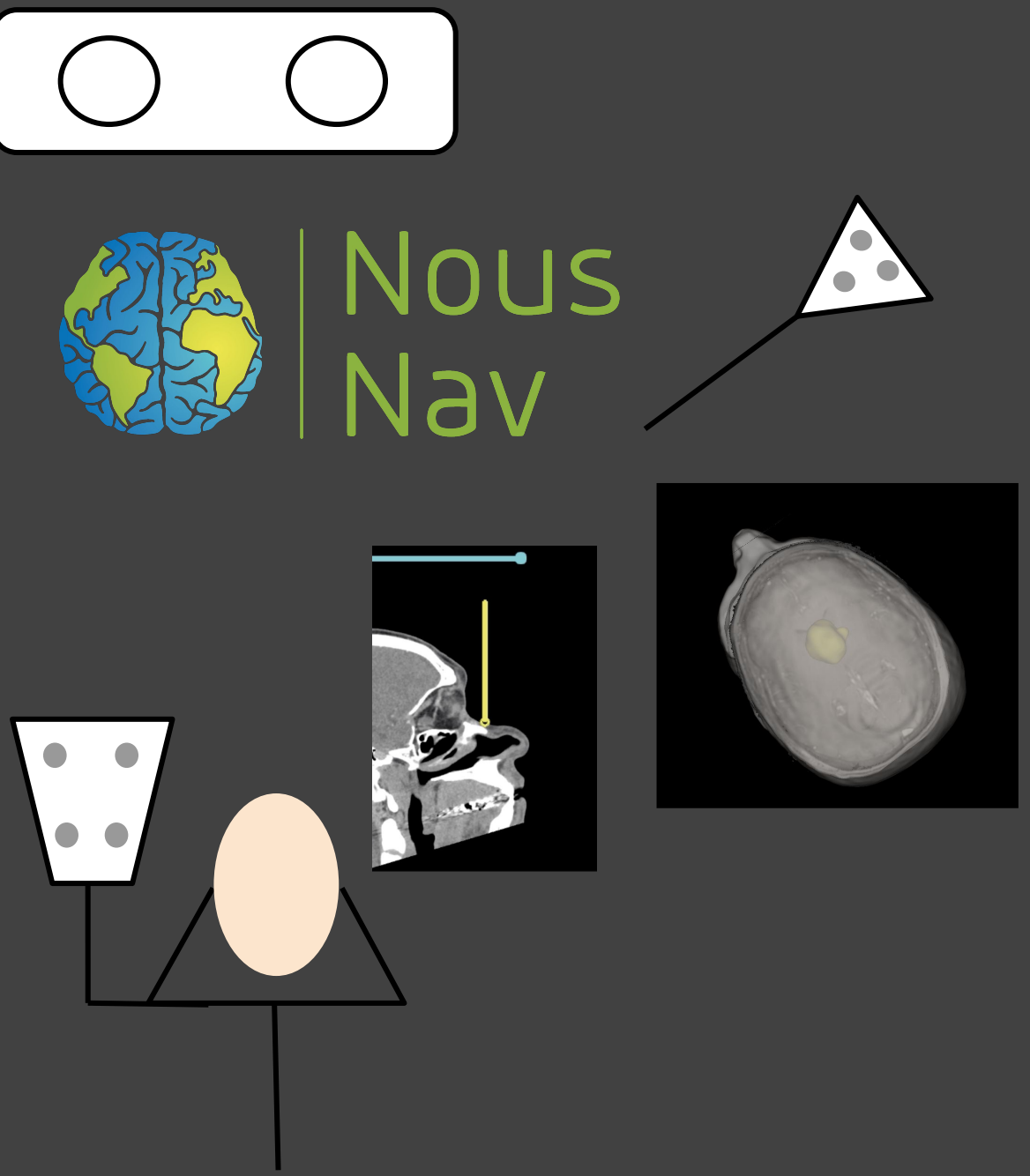
Optical markers need to be visible to the camera to enable registration and subsequent tracking.

A reference frame $R_{Pointer}$ can be attached to an optical pointer.



By combining registration and optical tracking, neuronavigation systems enable real-time visualization of the position of the tip of surgical instruments in the reference frame of pre-operative images

Nous Nav



NousNav makes neuronavigation technology freely available to the global clinical and scientific communities