Evolution and Clinical Relevance of a Dedicated Head Holder & Coil Solution for Intraoperative MRI-guided Neurosurgery

Greta Bohr, B.A.[1]; Karl Roessler, M.D.[2]

[1]NORAS MRI products GmbH, Höchberg, Germany
[2]Head of the Department of Neurosurgery, Medical University of Vienna, Austria

Introduction

Since its first groundbreaking use in the early 1990s, intraoperative MR imaging (ioMRI) has become an effective and established tool for neurosurgical interventions (e.g., brain tumor resection, deep brain stimulation (DBS), laser interstitial thermal therapy (LITT)) [1, 2]. Highly detailed, real-time MR images of the brain provide the latest anatomical data to clearly localize critical structures, identify healthy brain tissue, and distinguish these from pathological areas. In that way, ioMRI enhances interventional precision and leads to significantly better patient outcomes [2–4]. However, its effectiveness relies on specialized equipment, particularly head holders and MRI coils, that ensure both stability during surgery and high-resolution image quality [5, 6]. This article explores the evolution, requirements, and clinical relevance of dedicated head holder and coil solutions for ioMRI-guided neurosurgery, with a focus on innovations from NORAS MRI products GmbH, Höchberg, Germany.

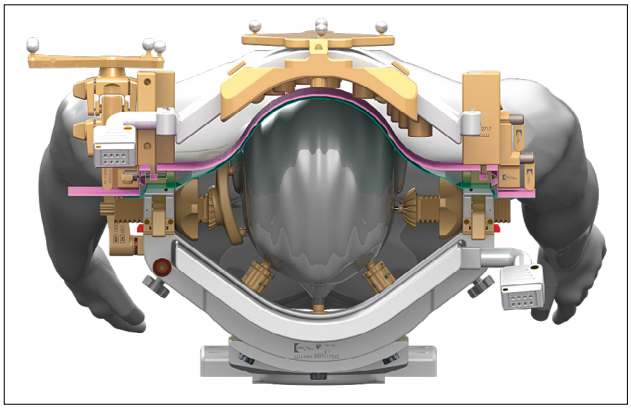
Development history

Implementing ioMRI in neurosurgical practice places high demands not only on medical professionals but also on the technological equipment [1]. As early setups were not specifically designed for ioMRI, their use often led to suboptimal results (e.g., limited image quality and compromised patient positioning). Soon it became evident that a key item for unlocking the advantages of ioMRI guidance was a dedicated head holder & MRI coil combination [6].

NORAS MRI products began developing and producing dedicated MRI head coils and holders in cooperation with Siemens Healthineers in 1998. In 2005, the first dedicated head holder & coil solution was born. Throughout the 2000s and the 2010s, much more research and many advancements led to a variety of improved product versions with new scanner and field-strength compatibilities.

An important innovation arrived when NORAS MRI products invented a revolutionary sterile concept in collaboration with Professor Paul Kremer, M.D. (Asklepios Klinik,

1 The NORAS Head Holder SI7000 was developed for use with the Trumpf Jupiter OR table in combination with the Neuro Miyabi Shell for 1.5T and 3T MRI systems from Siemens Healthineers (MAGNETOM Espree, MAGNETOM Symphony, MAGNETOM Avanto, MAGNETOM Verio, MAGNETOM Trio).



2 Unique sterile concept: One drape covers the patient and has a hole for the intervention. The second drape can be placed on top for MR imaging. Only the parts between the drapes must be sterile.

Heidberg, Germany). The main idea of the concept is to create a sterile chamber between the patient's head and the top coil with two sterile OR drapes. In this way, neither the coils nor the cables have to be plasma-sterilized anymore, which leads to significant time savings.

In 2013, NORAS MRI products launched the FLEXIBILITY OR Head Holder & 8-Ch Coil, which is now an established tool in neurosurgical centers worldwide. As its name suggests, it offers remarkable flexibility in both patient positioning and head fixation. The dedicated coil design delivers outstanding image quality, thanks to high homogeneity and an excellent signal-to-noise ratio (SNR).

With the launch of the LUCY OR Head Holder & 8-Ch Coil in 2018, NORAS MRI products in collaboration with Siemens Healthineers and Getinge (ex. Maquet) took the next big step toward improving workflow and economic efficiency in ioMRI neurosurgery. LUCY combines all the advantages of its predecessor with a completely new concept: Its head holder is now compatible with both MR and CT, and the handling is highly simplified for all clinical staff.

Requirements and technical realization

A dedicated ioMRI head holder and coil solution has to fulfill several, partly contradictory requirements in order to excel in practice. [6] Above all, the set-up design should enable an easy and comfortable workflow while also ensuring the patient's safety during the intervention.

Head holder

The head holder must offer a robust and stable pinning method for different head sizes, and it must flexibly adapt to various patient positions (e.g., supine, prone, lateral) while always ensuring excellent access to the field of intervention. For example, the NORAS head holder set-ups (FLEXIBILITY and LUCY) are height-adjustable and can be rotated, swiveled, tilted, and moved along the z-axis or even laterally.

The fixation needs to stay firm throughout the whole intervention, including the transport to the MR scanner for intraoperative imaging. Adaptable pinning methods from 3 to 7 fixation points with an additional force control guarantee safe and stable mechanical fixation of the head in all positions and for all head sizes, even in challenging cases.

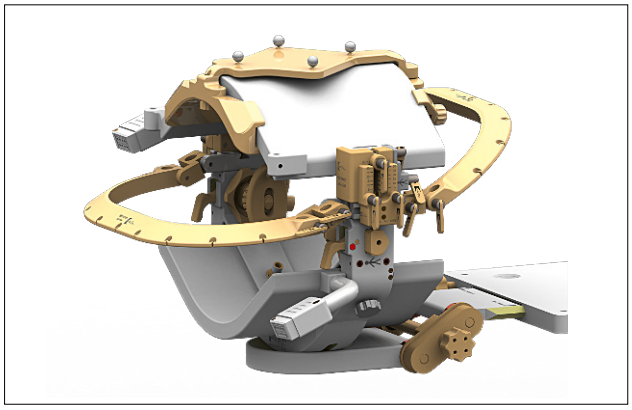
Coil technology

The coils must deliver outstanding image quality with a detailed view on the field of intervention. This means that constantly high SNR and homogeneity are needed for a wide variety of patient positions and head sizes, while the acquisition time should be as short as possible. Therefore, the NORAS coils are arranged seamlessly and as close as possible to the head surface to enable high signal depth for the whole anatomy of interest. Also, their channel layout is optimized for parallel imaging, which shortens acquisition times.

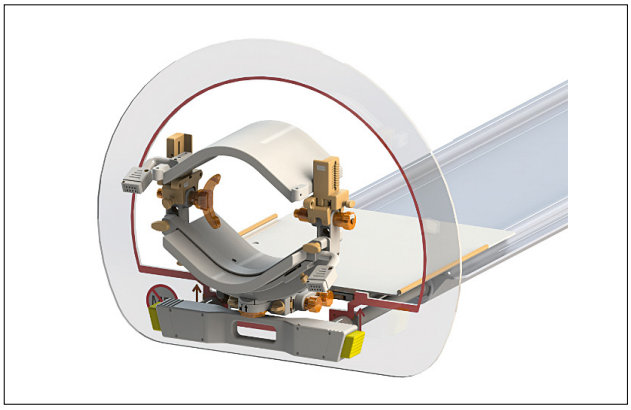
Workflow and compatibility

The head holder and coils must guarantee access to the patient and the life-support system at all times. Mounting and removing the coils needs to be quick and easy, and must not affect the head fixation or the life-support system, regardless of the patient position. The whole setup also has to fit into the MR bore.

For an optimized workflow and to comply with hygiene standards, the product needs to provide a dedicated sterile concept. The setup should be easy to clean and lightweight for simple handling. The materials used must be MR-compatible and durable, while high manufacturing quality should grant stability and safety during the intervention.



3 FLEXIBILITY OR Head Holder & 8-Ch Coil with universal arch and Brainlab AIR matrix.



4 LUCY OR Head Holder & 8-Ch Coil with bore gauge.

Integrating ioMRI into surgical practice is a complex process, and it requires efficient co-operation of medical equipment. Hence, the head holder & coil solution must be compatible with the MR scanner, the OR table, a navigation system (optionally with automatic image registration (AIR)), and different surgical accessories.

ioMRI in pediatric neurosurgery using the LUCY OR Head Holder & 8-Ch Coil

The neurosurgical department of the Medical University of Vienna launched an intraoperative high-field (3T) two-room MRI (MAGNETOM Skyra, Siemens Healthineers, Erlangen, Germany) set-up in the OR in October 2020.

In total, 148 procedures for 124 pediatric patients[1] (mean age 8.7 years, range 0–18 years) within a 2.5-year period were undertaken in this two-room ioMRI suite. Surgeries were mainly performed for intractable epilepsy (n = 81; 55%) or pediatric brain tumors (n = 65; 44%) in supine (n = 113; 76%) and prone (n = 35; 24%) positions.

IoMRI was applied in 64 out of 148 procedures (43%). In the remaining 39 procedures (26%), ultra-early postoperative MRI was carried out after closure, with the patient still sterile in the head coil. Of the 64 procedures with ioMRI, a second-look surgery was performed in 26% (in epilepsy surgery in 17%, in tumor surgery in 9%). The mean time of ioMRI imaging from draping to re-surgery was 50 minutes.

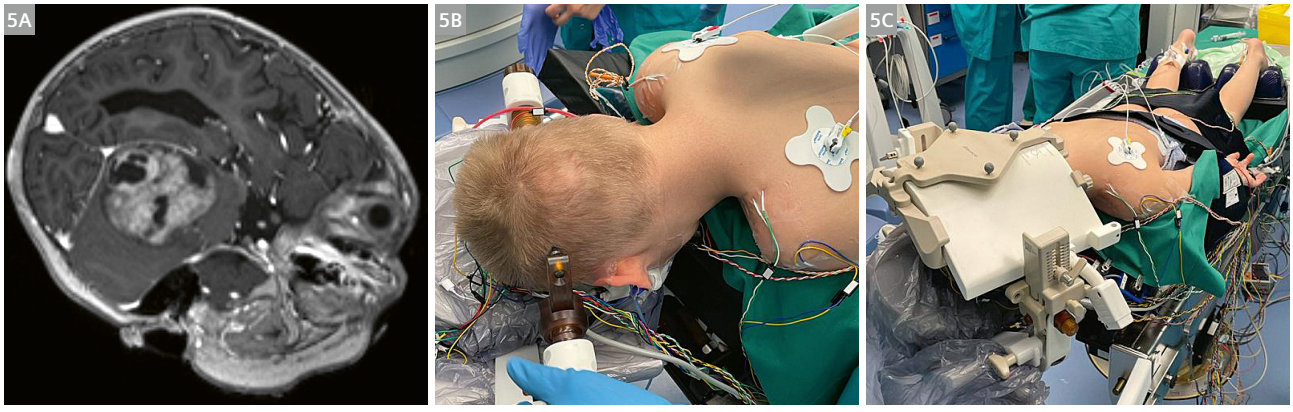
The team routinely performed the following sequences:

- T1-weighted imaging (TR 1800 ms, TE 1.95 ms, TI 900 ms, GRAPPA factor 2, flip angle 8°, slice thickness 1.1 mm, in-plane resolution 1.1 mm, 5:45 min) with and without contrast enhancement;
- T2-weighted imaging (TR 3200 ms, TE 299 ms, variable flip angle, slice thickness 1 mm, in-plane resolution 1 mm, 8:37 min);
- fluid-attenuated inversion recovery (FLAIR) imaging (TR 7000 ms, TE 381 ms, TI 2050 ms, compressed sensing factor 2, variable flip angle, slice thickness 1 mm, in-plane resolution 1 mm, 6:34 min); and
- diffusion tensor imaging (DTI) (TR 4190 ms, TE1 73 ms, TE2 109 ms, GRAPPA factor 3, flip angle 180°, slice thickness 5 mm, in-plane resolution 1.2 mm, 20 diffusion directions, b-values of 0 and 1000 s/mm^2, 10:39 min). The T1 volume sequence after contrast was routinely used to register the navigation system.

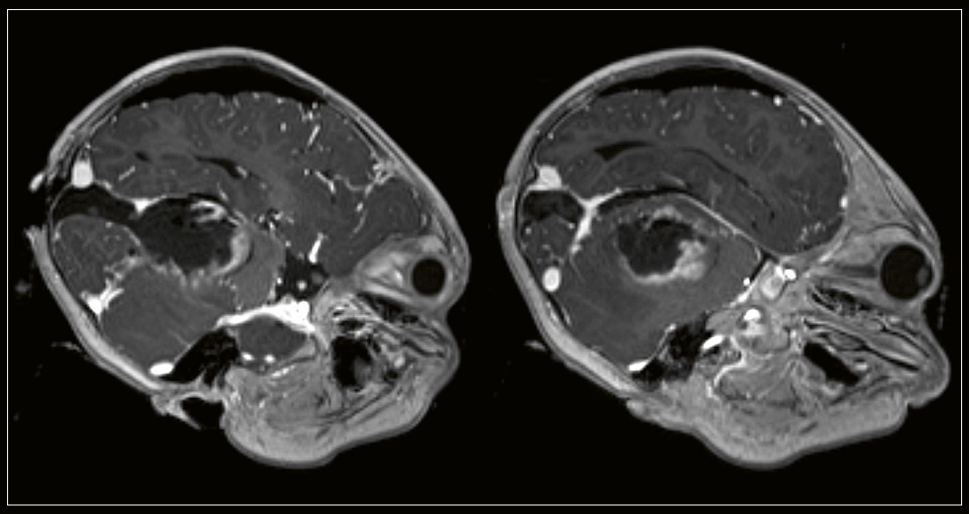
Case presentation

A 3-year-old boy presented with headache and vomiting. A posterior fossa tumor, suspected pilocytic astrocytoma, was diagnosed. Surgery was performed in prone position with intraoperative neuromonitoring (MR-compatible wires) using the LUCY OR Head Holder & 8-Ch Coil for head positioning and neuronavigation. For neuronavigation, the upper part of the NORAS head coil is equipped with MRI markers for automatic registration of the Brainlab Curve. A dorsal interhemispheric approach was chosen [8].

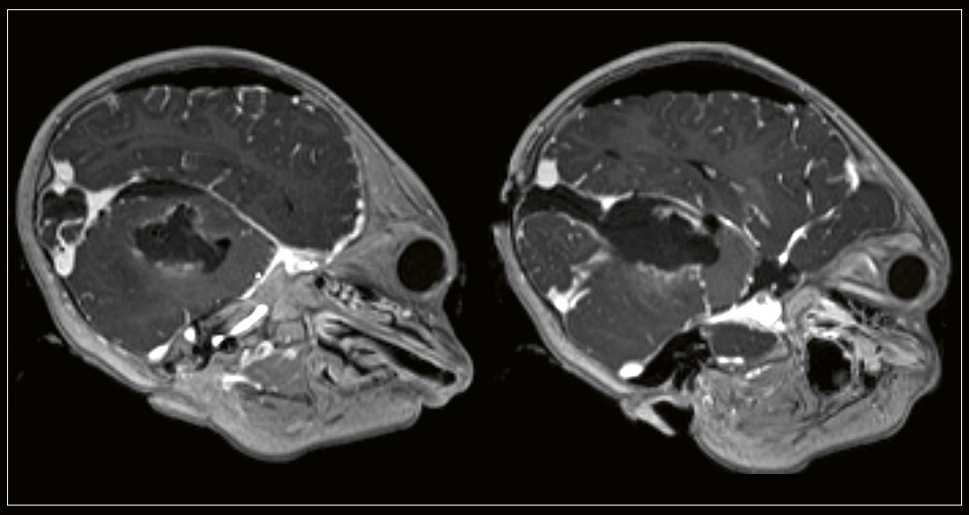
[1] *MR scanning has not been established as safe for imaging fetuses and infants less than two years of age. The responsible physician must evaluate the benefits of the MR examination compared to those of other imaging procedures.*



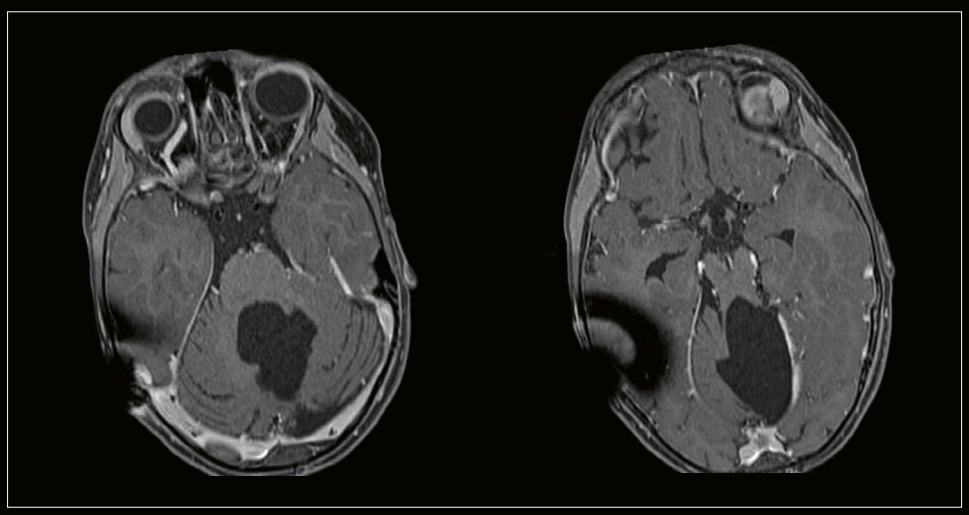
5 **(5A)** MRI T1 post contrast: Typical aspect of a posterior fossa pilocytic astrocytoma, mainly solid, partly cystic tumor mass, demonstrating strong contrast enhancement. **(5B)** Positioning of the head in the LUCY OR Head Holder & 8-Ch Coil in prone position. **(5C)** Upper part of the head coil, equipped with MRI marker (inside) and reflectors (outside) for navigation.



6 First intraoperative MR scan demonstrated a good decompression of the tumor mass, but showed that the 4th ventricle had not been reached, with significant residual tumor parts. With this information and the refreshment of the neuronavigation, the 4th ventricle was depicted and the residual tumor resected during this second-look surgery (SLS).



7 Second intraoperative MR scan confirmed complete resection of the tumor. Visible contrast medium at the borders represents blood-brain barrier disruption, confirmed by fusion of pre- and intra-operative scans.



8 Follow-up MRI at three months post-surgery, demonstrating complete resection.

Conclusion

While a growing number of hospitals now recognize the benefits of ioMRI-guided neurosurgery, its capabilities are constantly improving due to further technology innovations such as high- and low-field MRI, and AI integration. These factors will most likely increase the demand for pioneering tools like dedicated ioMRI head holder & coil solutions as essential products for exploiting the full scope for advancing brain surgery techniques. As ever, close collaboration between clinicians, engineers, and manufacturers is crucial for optimal outcomes. [7]

Contact

Professor Karl Roessler, M.D.
Head of the Department of Neurosurgery
Medical University of Vienna
Waehringer Guertel 18–20
1090 Vienna
Austria
Karl.roessler@meduniwien.ac.at

Greta Bohr
NORAS MRI products GmbH
Leibnizstr. 4
97204 Höchberg
Germany
Greta.Bohr@noras.de

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