

# Application of Augmented Reality in Percutaneous Procedures—Rhizotomy of the Gasserian Ganglion

Alexander Rau, MD 

Roland Roelz, MD\*

Horst Urbach, MD\*

Volker Arnd Coenen, MD<sup>§</sup>

Theo Demerath, MD\*

Peter Christoph Reinacher,

MD  

\*Department of Neuroradiology, Medical Center - University of Freiburg, Faculty of Medicine, University of Freiburg, Freiburg, Germany; †Department of Neurosurgery, Medical Center - University of Freiburg, Faculty of Medicine, University of Freiburg, Freiburg, Germany; ‡Department of Stereotactic and Functional Neurosurgery, Medical Center - University of Freiburg, Faculty of Medicine, University of Freiburg, Freiburg, Germany; §Department of Stereotactic and Functional Neurosurgery, Medical Center - University of Freiburg, Faculty of Medicine, University of Freiburg, Freiburg, Germany; ¶Fraunhofer Institute for Laser Technology (ILT), Aachen, Germany

## Correspondence:

Peter C. Reinacher, MD,  
Department of Stereotactic and  
Functional Neurosurgery,  
University Medical Center,  
Breisacher Straße 64,  
79106 Freiburg, Germany.  
Email:  
[peter.reinacher@uniklinik-freiburg.de](mailto:peter.reinacher@uniklinik-freiburg.de)

Received, November 17, 2020.

Accepted, March 14, 2021.

Published Online, June 7, 2021.

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2021.

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**BACKGROUND:** Percutaneous rhizotomy of the Gasserian ganglion for trigeminal neuralgia is an effective therapeutic procedure. Yet, landmark-guided cannulation of the foramen ovale is manually challenging and difficult to learn.

**OBJECTIVE:** To overcome these limitations, we assessed the feasibility and accuracy of an augmented reality (AR)-guided puncture of the foramen ovale.

**METHODS:** A head phantom with soft tissue structures of the facial area was built. A three-dimensional (3D)-dataset of the phantom was generated using a stereotactic planning workstation. An optimal trajectory to the foramen ovale was created and then transferred to an AR headset. A total of 2 neurosurgeons and 2 neuroradiologists independently performed 8 AR-guided and 8 landmark-guided cannulations of the foramen ovale, respectively. For each AR-guided cannulation, the hologram was manually aligned with the phantom. Accuracy of the cannulation was evaluated using the Euclidean distance to the target point as well as the lateral deviation of the achieved trajectory from the planned trajectory at target point level.

**RESULTS:** With the help of AR guidance, a successful cannulation of the foramen ovale was achieved in 90.6% compared to the purely landmark-based method with 18.8%. Euclidean distance and lateral deviation were significantly lower with AR guidance than landmark guidance ( $P < .01$ ).

**CONCLUSION:** AR greatly improved accuracy of simulated percutaneous rhizotomy of the Gasserian ganglion.

**KEY WORDS:** Augmented reality, Gasserian Ganglion, Trigeminal neuralgia, Rhizotomy, Cranial nerve, Phantom, Mixed reality, Functional neurosurgery

*Operative Neurosurgery* 21:160–164, 2021

DOI: 10.1093/ons/opab155

**A**ugmented reality (AR) is the real time integration of virtual data in the user's environment. AR may improve medical procedures in the most diverse fields.

Especially in neurosurgical procedures, such as aneurysmal clipping, brain tumor resection, stereotactic biopsy, or percutaneous vertebroplasty, AR has been used successfully to superimpose imaging data on patients or phantoms.<sup>1–8</sup>

Recently developed portable AR devices such as the HoloLens (Microsoft Corporation, Redmond, Washington) or the Magic Leap 1 (Magic Leap, Plantation, Florida) open up new possibilities in the clinical use of AR applications.

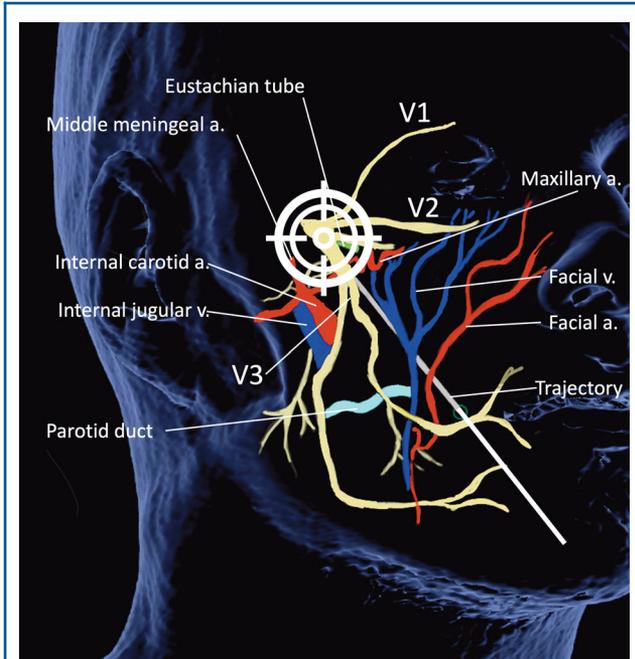
A common but challenging neurosurgical procedure we sought to facilitate is the

percutaneous cannulation of the foramen ovale to access the Gasserian ganglion for rhizotomy, which is used to treat trigeminal neuralgia. Trigeminal neuralgia is defined by paroxysmal attacks of severe pain along the trigeminal nerve's territory affecting approximately 1 in 8000 people per year. The primary cause is a neurovascular conflict at the nerve's root entry zone, while tumors, vascular malformations, or chronic inflammatory diseases are rare causes.<sup>9</sup>

First-line treatment is systemic pharmacological therapy. In refractory courses, the Jannetta procedure—a microvascular decompression of the trigeminal ganglion at the brainstem—is commonly performed. Alternatively or in addition, percutaneous rhizotomy is used among other options including Gamma Knife (Elekta AB), neurolysis, and botox.<sup>9</sup>

Regardless of whether rhizotomy of the Gasserian ganglion is achieved by radiofrequency

**ABBREVIATION:** AR, augmented reality; DICOM, digital imaging and communications in medicine; SEM, standard error of measurement



**FIGURE 1.** Critical neurovascular anatomy surrounding the trajectory towards the foramen ovale: the 3 major branches of the trigeminal nerve, the ophthalmic nerve (V1), the maxillary nerve (V2), and the mandibular nerve (V3); a. for arteries, v. for veins. The typical trajectory is depicted in white outside the skin and grey from entry in the skin to target point (white target symbol). Anatomy according to Alvernia et al 2010.<sup>16</sup>

ablation, glycerol injection or mechanical balloon compression, the ganglion must first be cannulated using a needle. Hartel's approach uses anatomic landmarks such as the midorbital-line and the dorsal third of the zygomatic arch with or without fluoroscopic guidance to target the foramen ovale as that of the lead structure of the ganglion.<sup>10</sup> The correct needle placement is tested by electric stimulation at the needle tip and the mastication muscles' observed motor response.

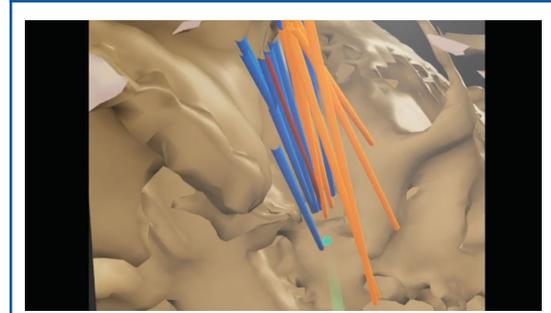
To precisely localize the single trigeminal branches, sensory stimulation is performed, and the patient's feedback is assessed. Thus, the patient must be awake.

Potential complications comprise damage to the internal carotid artery or cranial nerves and the formation of a cerebrospinal fluid leak.<sup>11</sup> Structures at risk along the trajectory are depicted in Figure 1.

In summary, safe and effective percutaneous rhizotomy is challenging. Here, we assess whether AR can simplify the procedure and improve accuracy of the percutaneous cannulation in a model trial.

## METHODS

The head phantom was built using an X-ray dense bone skull model (3B Scientific GmbH, Hamburg, Germany). A 1.6-cm-thick surgical



**VIDEO.** This video demonstrates the planning in AR, how to find the entry point and adjust the trajectory and the postoperative 3D analysis of the performed trajectories with the aid of AR.

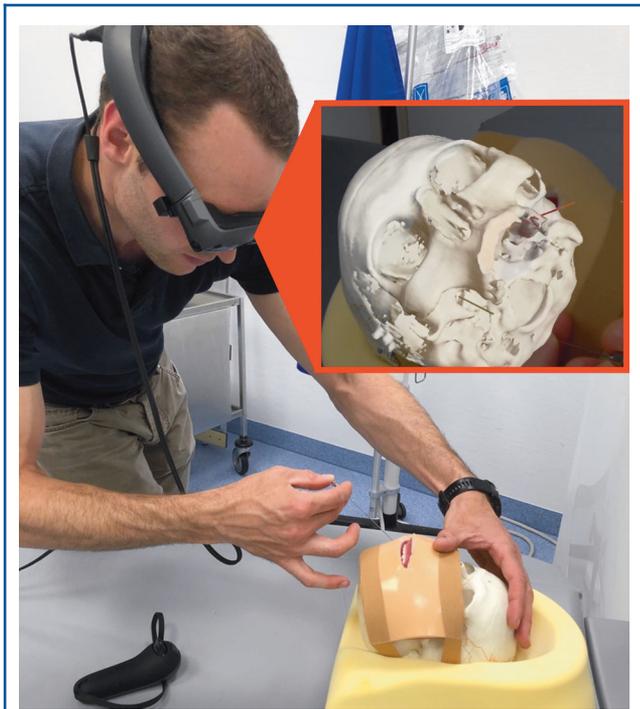
training skin and elastic foam material were used to cover the facial part and form the buccal soft tissue structures. The anatomic landmarks for Hartel's approach were left uncovered. The foramen ovale in the model measured  $6 \times 8$  mm ( $37 \text{ mm}^2$ ) and the distances between the foramen ovale and the corners of the mouth were 90 mm on the right and 85.9 mm on the left.

A computed tomography (CT) scan of the phantom was acquired (Siemens Somatom Scope, Siemens Healthcare, Forchheim, Germany, voltage 130 kV, exposure, 90 mAs, pitch factor 0.33, tilt  $0^\circ$ , slice thickness 1.2 mm, helical mode). The digital imaging and communications in medicine (DICOM) files were transferred to a neurosurgical planning workstation (Brainlab Elements, Brainlab AG, Munich, Germany), where the optimal trajectory for foramen ovale cannulation was determined by an experienced functional neurosurgeon and superimposed into a three-dimensional (3D)-dataset. The 3D-model with the optimal trajectory for both oval foramina was then transferred to the AR headset (Magic Leap 1). See Video for a video demonstrating how to find the entry point and adjust the trajectory. A total of 2 neurosurgeons experienced in performing the Gasserian ganglion rhizotomy and 2 neuroradiologists (without relevant experience with the procedure) independently performed 8 oval foramen cannulations using AR for guidance in each cannulation. Therefore, the phantom's holographic projection (hologram) was manually aligned with the phantom (see Figures 2 and 3). Once sufficiently aligned, the proband tried to replicate the virtual trajectory to place a 120 mm long 20-gauge needle (Special Cannula; Medioplast AB, Malmö, Sweden) (Figure 2). The probands were allowed to adjust the needle if they suspected a deviation from the virtual trajectory.

Additionally, each proband performed 8 cannulations in the same phantom without using AR based on Hartel's approach. Again, adjustment of the needle was allowed with respect to the anatomic landmarks. After each needle placement, a CT scan was performed to assess and document the needle tip position and trajectory.

To address training effects and habituation, the sequence of procedures regarding both side and technique (AR vs Hartel's approach) was randomized for each proband.

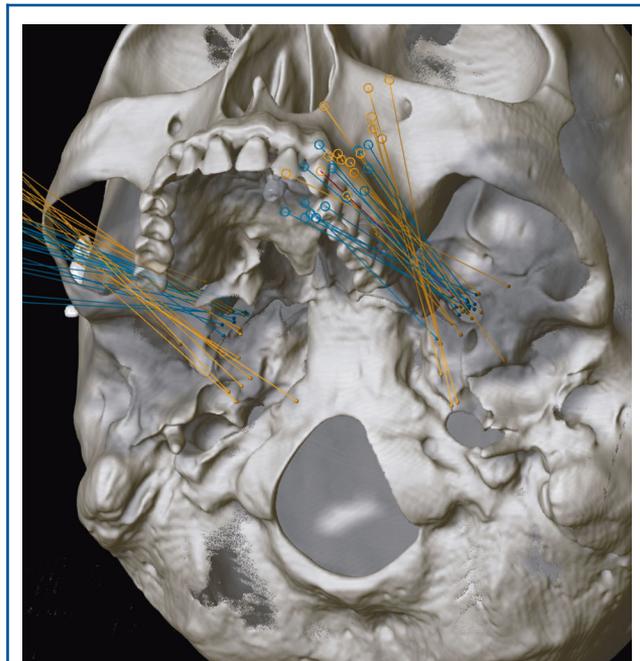
The CT scans after each needle placement were transferred to the planning workstation and both the Euclidean distance between achieved needle tip position and the target point (the center of the foramen ovale) as well as the lateral deviation between the achieved trajectory and the optimal trajectory at the level of the target point were analyzed. Since



**FIGURE 2.** Experimental setup. While inserting the needle the holographic projection (hologram) of the phantom CT scan (red box) and the needle can be seen through the augmented reality (AR) headset, visualizing the target structure (foramen ovale).



**FIGURE 3.** Planned trajectories to the oval foramina (red and green).



**FIGURE 4.** Reconstruction of the needle positions ( $n = 64$ ) in the postprocedural CT-scan, orange trajectories carried out conventionally using landmarks, blue trajectories using augmented reality (AR) guidance.

this is a pure phantom study without patients involved, there was no need for an ethical approval.

**Statistics**

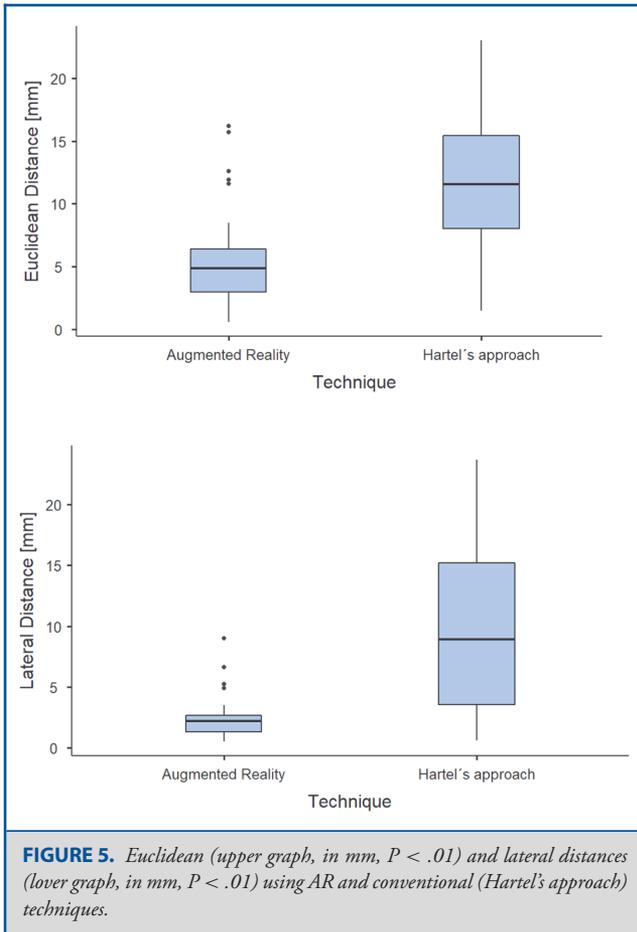
Continuous data are presented as mean  $\pm$  standard deviation (SD) and 95% confidence interval (95%CI) as appropriate. The normal distribution was tested using the Shapiro-Wilk test. Independent samples test was student’s  $t$  for normally distributed and Mann-Whitney- $U$  for non-normally distributed. All statistical analyses were performed using R statistics (R Core Team, <https://www.R-project.org>).

**RESULTS**

Overall, the foramen ovale was successfully cannulated in 35 out of 64 procedures: 29 out of these 35 successful cannulations were performed using the AR as depicted in Figure 4.

The mean Euclidean distance in AR-guided cannulations was 5.7 mm (SD 3.9 mm, variance 15.2 mm, range 0.6-16.2 mm); the mean lateral distance was 2.5 mm (SD 1.8 mm, variance 3.2 mm, range 0.5-9 mm). With the conventional Hartel’s approach, the mean Euclidean distance was 11.9 mm (median 11.6 mm, standard error of measurement (SEM) 0.74) while the mean lateral distance measured 9.7 mm (SD 6.9 mm, variance 47.8 mm, range 0.6-23.7 mm) (shown in Figure 5).

Both lateral and Euclidean distance differed significantly between AR-guided cannulation and Hartel’s approach ( $P < .01$  each). No difference was observed considering the cannulation



**FIGURE 5.** Euclidean (upper graph, in mm,  $P < .01$ ) and lateral distances (lower graph, in mm,  $P < .01$ ) using AR and conventional (Hartel's approach) techniques.

side (left vs right) independent of the approach (Euclidean  $P = .113$  and lateral  $P = .285$ ).

## DISCUSSION

We see a great potential of AR-based planning and execution for minimizing risks of cannulating of the foramen ovale. This minimally invasive procedure is challenging and is subject to several considerable risks due to the proximity of the foramen ovale to critical (vascular, cerebral, neural) structures. An area of about 35 mm<sup>2</sup> must be hit precisely at a depth of 7 to 12 cm from the corner of the mouth. For neurological testing, the procedure has to be carried out on an awake patient. We aimed to facilitate the currently established Hartel's method which uses anatomic landmarks for guidance. This lowers the risk of complications, and increases accuracy and patients' comfort as repeated correction of the needle position is perceived as very unpleasant.<sup>9</sup>

With the increasing availability of portable AR devices combined with an established trajectory planning software such as the Magic Leap 1 and Brainlab Elements, we tested the applicability of AR for percutaneous rhizotomy. In this experimental setting, AR-guided foramen ovale cannulations were shown to

have a significantly higher rate of successful punctures than the conventional landmark-based approach.

A model trial was chosen for this purpose, as this allows a systematic analysis with reproducible conditions for this invasive procedure. The model equipped with surgical training skin provided realistic conditions, offering haptic feedback for bone and soft tissues during cannulation.

All probands reported that AR facilitated the placement of the needle in the foramen ovale. This finding was objectively confirmed.

While Lin et al<sup>12</sup> demonstrated a 73.8% successful foramen ovale cannulation rate in 42 consecutive patients with CT guidance and neuronavigation, the AR-guided success rate in this model trial was 90.6%.

Other than CT guidance, intra- or perioperative imaging modalities such as magnetic resonance imaging (MRI) have also been established. However, these are usually resource-intensive, ie, MRI conditional material is required. Radiation exposure is inherent to X-ray based procedures, while intraoperative MRI is costly and complex. Neuronavigation or a stereotactic frame require invasive head fixation and extend the procedure. Neuronavigation in awake patients is further complicated because, in contrast to AR, the coregistration is not constantly checked or visible.<sup>13</sup>

Concerning foramen ovale cannulation, virtual reality has been successfully applied in training,<sup>14</sup> though it is only a 3D representation of computer-generated content and not an overlay of virtual content on the physical environment, whereas AR, on the other hand, allows this overlay explicitly.

In line with previous reports,<sup>15</sup> AR coregistration imposes minor challenges. The benefits of AR, however, by far outweigh procedural demands.

In principle, intracranial misplacement of the needle through the foramen ovale is possible and may cause life-threatening complication. In contrast to the conventional approach, AR allows a direct control of the puncture depth, although this was not addressed by our experiment and needs to be assessed in further investigations.

## Limitations

Our study is subject to the limitation that we did not provide fluoroscopic needle position control for both groups. Thus, the 18.6% do not correspond to the final success rate, but only to purely landmark-based puncture without position control by fluoroscopy. However, this is in line with common clinical routine where the fluoroscopy is typically used after the first cannulation attempt to confirm correct needle placement or to assist correction of the trajectory.

## CONCLUSION

In this experimental and realistic phantom-based setting for cannulating the foramen ovale, our AR-based procedure was superior to Hartel's conventional method.

AR greatly improved the accuracy of foramen ovale cannulation compared to Hartel's free-hand approach in this realistic phantom-based trial.

## Funding

This study did not receive any funding or financial support.

## Disclosures

Dr Reinacher has received personal honoraria for lectures or advice from Brainlab. He has also received research support from Else Kröner-Fresenius Foundation, Fraunhofer Foundation (ATTRACT), German Ministry for Economic Affairs and Energy, and Medical Faculty of the University of Freiburg. He has received personal honoraria for lectures or advice from Boston Scientific, Inomed, and Fraunhofer Foundation and is consultant to Boston Scientific and Inomed. The other authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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