Augmented Reality–Assisted Percutaneous Rhizotomy for Trigeminal Neuralgia

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BACKGROUND: Percutaneous rhizotomy of the trigeminal nerve is a common surgery to manage medically refractory trigeminal neuralgia. Traditionally, these procedures have been performed based on anatomic landmarks with fluoroscopic guidance. Augmented reality (AR) relays virtual content on the real world and has the potential to improve localization of surgical targets based on preoperative imaging.

OBJECTIVE: To study the potential application and benefits of AR as an adjunct to traditional fluoroscopy-guided glycerol rhizotomy (GR).

METHODS: We used traditional fluoroscopy-guided percutaneous GR technique as previously described, performed under general anesthesia. Anatomic registration to the Medivis SurgicalAR system was performed based on the patient's preoperative computerized tomography, and the surgeon was equipped with the system's AR goggles. AR was used as an adjunct to fluoroscopy for trajectory planning to place a spinal needle into the medial aspect of the foramen ovale.

RESULTS: A 50-year-old woman with multiple sclerosis–related right-sided classical trigeminal neuralgia had persistent pain, refractory to medications, previous gamma knife stereotactic radiosurgery, and percutaneous radiofrequency rhizotomy performed elsewhere. The patient underwent AR-assisted fluoroscopy-guided percutaneous GR. The needle was placed into the right trigeminal cistern within seconds. She was discharged home after a few hours of observation with no complications and reported pain relief.

CONCLUSION: AR-assisted percutaneous rhizotomy may enhance the learning curve of these types of procedures and decrease surgery duration and radiation exposure. This allowed rapid and correct placement of a spinal needle through the foramen ovale.

KEY WORDS: Augmented reality, Trigeminal neuralgia, Percutaneous glycerol rhizotomy

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Trigeminal neuralgia (TN) is a chronic neuropathic facial pain condition which is classically described as spontaneous with stabbing or electric shock-like bouts of pain, often with facial sensory triggers.[1]

One group of minimally invasive interventions include percutaneous procedures directed to ablate the trigeminal ganglion or its exiting branches at Meckel's cave by various mechanisms, including balloon nerve compression, chemical (using glycerol injection), and radiofrequency thermocoagulation. These procedures, once successful, can lead to immediate pain relief in up to 60% to 80% of the patients, lasting for variables durations.[2]

ABBREVIATIONS: AR, augmented reality; **GR,** glycerol rhizotomy.

Classically, all 3 procedures have been performed based on Hartel anatomic landmarks with guidance and confirmation using intraoperative 2-dimensional C-arm x-ray and fluoroscopy. Although they are considered relatively simple, safe, and effective, the neurosurgeons' experience and familiarity with each of the procedures are key for their success. Owing to more commonly performed microvascular decompression or radiosurgery, fewer surgeons may be skilled in transfacial needle placement. Such a confidence is created after repetitive cannulation of the foramen ovale and the development of haptic feedback. Young and less-experienced neurosurgeons may therefore encounter difficulty in attaining a quick learning curve.[3] Previous studies showed the utility of 3-dimensional (3-D) intraoperative computerized tomography (CT)–based or MRI-based neuronavigation in improving the accuracy of needle localization and trajectory.[4-8]

The purpose of this study was to assess the benefit of incorporating 3-D augmented reality (AR) into the planning and performance of these percutaneous procedures. AR overlays virtual content on the real world and therefore has the potential to improve localization of surgical targets that are unexposed to the human eye.[9,10] This novel technology has the potential to not only fasten the duration of surgery but also enhance the acquisition of surgical skills among surgeons who have not been previously experienced with these types of procedures. Initial experience with AR has been reported in various neurosurgery procedures over the last decade.[11] A study performed on a head phantom previously showed improved rates of successful cannulation of the foramen ovale in comparison with a purely landmark-based approach.[12]

Medivis SurgicalAR is a surgical AR software that has already shown initial promising experience in interventional radiology procedures.[9] We elected to study its potential application in percutaneous TN procedures by using it for the first time, as an adjunct to a fluoroscopy-assisted glycerol rhizotomy (GR) for a patient with recurrent multiple sclerosis–related pain.

METHODS

Surgical Technique

A traditional fluoroscopy-guided percutaneous glycerol rhizotomy technique was previously described.[13]

Under general anesthesia, the patient was placed supine on an operating table with the head held in a horse-shoe head rest. Anatomic registration to the Medivis SurgicalAR system was performed based on the patient's preoperative CT, and the surgeon was equipped with the system's AR goggles (Figures 1 and 2, Video).

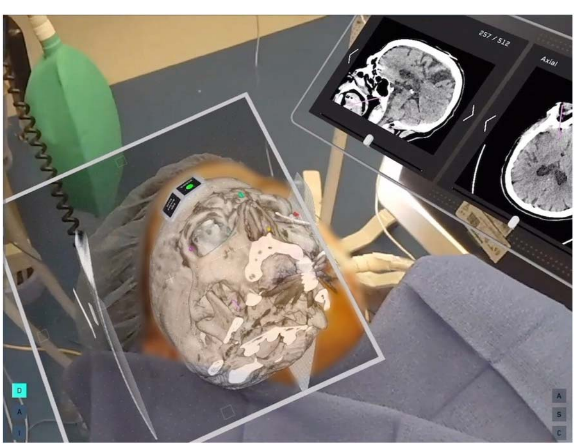

FIGURE 1. *Augmented reality–assisted fluoroscopy-guided percutaneous glycerol rhizotomy. As visualized on the surgeon's goggles, the patient's preoperative computerized tomography is superimposed intraoperatively on her real-world head, while showing the trajectory of the spinal needle advancing toward the foramen ovale (Medivis SurgicalAR).*

FIGURE 2. *Simulated needle trajectory toward the trigeminal cistern is kept, even after repositioning the patient to the semisitting position, as viewed by the Medivis SurgicalAR system.*

We positioned a C-arm fluoroscopy machine in the anteroposterior trajectory of the head so that the petrous ridge and the inferior orbital rim were at the same level. The foramen ovale was demonstrated inferior and lateral to the intersection of the inferior and medial orbital rims. The patient's face was cleaned and draped. The entry point was marked on the painful side, 2.5 cm lateral to the corner of the lips. A point in line with the medial ipsilateral pupil, 2.5 cm anterior to the external acoustic meatus was used to mark our target trajectory. A virtual 9-cm spinal needle was introduced into the patient's simulated foramen ovale, based on the AR navigation system. According to the virtually created trajectory, a real 25-gauge needle was used for intradermal injection of 1% lidocaine. We then anesthetized the deeper layers of the cheek. With a gloved finger, positioned in the oral cavity, we prevented penetration of the mucosa while injecting local anesthesia or during the passage of the spinal needle used for rhizotomy. Under the guidance of the Medivis SurgicalAR system, while validating our position with anteroposterior fluoroscopy, the 20-gauge needle was inserted along the marked trajectory toward the skull base (Figure 1). Using AR guidance and confirming with lateral fluoroscopy, the needle tip was then directed at a point 1 cm behind the posterior clinoid along the angle of the clivus. Placement of the needle into the foramen ovale lead to cerebrospinal fluid (CSF) egress within seconds.

Once CSF flow was identified, we performed a contrast cisternogram with the patient in the sitting position, which was intended to verify appropriate needle position and evaluate the size of the trigeminal cistern and how much glycerol would be required (Figure 2). Sterile iohexol was injected under fluoroscopy in 0.05 mL increments until the contrast completely filled the cistern (Figure 3). Glycerol and radio-opaque tantalum powder were then

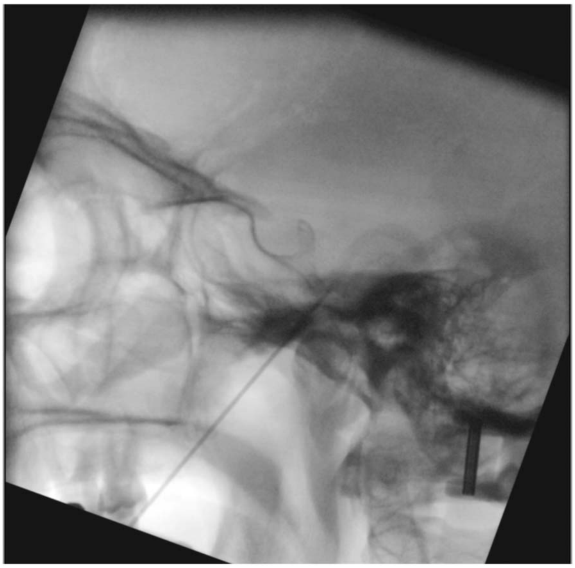

FIGURE 3. *Fluoroscopy-guided fluoroscopy and cisternography confirming proper needle position within the trigeminal cistern.*

injected (0.3 mL). The patient was kept in a semisitting position for 2 hours to prevent escape of glycerol into the posterior fossa.

Patient's consent or approval by the institutional review board was not required in this case report because AR technology was adjunct to the traditional procedure, and it did not alter our standard of care. Any of the patient's identifying signs were hidden to avoid publication of protected health information.

RESULTS

A 50-year-old woman with multiple sclerosis–related right-sided classical TN had persistent pain, refractory to medications, previous gamma knife stereotactic radiosurgery, and percutaneous radiofrequency rhizotomy performed elsewhere. The patient underwent AR-assisted fluoroscopy-guided percutaneous GR under general anesthesia, as described above. Preoperative AR system setup time took nearly 5 minutes. Anatomic registration to the AR navigation system was easily performed with the assistance of the Medivis SurgicalAR technical team within 2 to 3 minutes, while using AR goggles and based on the patient's preoperative CT (Video). Figures 1 and 2 show patient's anatomic registration and the chosen virtual needle trajectory, targeting the foramen ovale. The patient was prepped, and a virtual needle trajectory was created. After administering local anesthetics, the needle was correctly placed into the right trigeminal cistern within seconds. Needle location and proper injection of glycerol and contrast agent were verified by fluoroscopy (Figure 3). The entire duration of the procedure, between entering and leaving the room, lasted 77 minutes. The surgical procedure itself, including setting the AR system and registration, patient prepping, needle insertion, glycerol injection, and fluoroscopy verification, took around 20 minutes. Needle placement on the first pass took 15 seconds from skin penetration to the observation of CSF egress. The patient was discharged home after a few hours of observation with no complications and reported pain relief.

DISCUSSION

We describe the novel technique by applying 3-D AR into traditional anatomy-based and 2-dimensional fluoroscopy guiding methods for performing percutaneous rhizotomy in patients with TN (Video).

Patients with TN who are not candidates for microvascular decompression or those who choose to avoid craniotomy are often referred to percutaneous interventions, which, as a group, intend to stop ephaptic transmission by the trigeminal ganglion or its exiting nerves at the level of Meckel's cave.[2] In this report, we describe a traditional fluoroscopy-guided percutaneous GR technique merged with AR technology. From the experience of the senior author with the fluoroscopy-guided technique, long-lasting pain relief was achieved in 77% of the patients, while 55% were weaned from all pain medications and 22% remained on some pharmacological treatment.[13] Other series reported different results of pain relief, ranging from 19% to 58% in a follow-up period of 4.5 to 8 years. In comparison, balloon nerve compression resulted in immediate pain relief in up to 94% of the patients with complete pain relief and long-term response rates of 68% (55-80) in a 4 to 10 years follow-up. Radiofrequency thermocoagulation can reach rates of initial pain relief as high as 98% with complete pain relief rates of 58% (range, 26-28), 3 to 9 years after the procedure.[1,2]

With the evolution of imaging and navigation tools, recent studies have discussed the potential benefits of advanced neuronavigation for improving operative and clinical outcomes of percutaneous techniques for TN. These were shown by using navigation based on either preoperative or intraoperative CT or MRI; however, success and complications results of long-term studies are still required.[4-8]

Furthermore, in a more recent study, 2 neurosurgeons and 2 neuroradiologists were asked to cannulate the foramen ovale of a head phantom. Successful cannulation rates were significantly higher with the use of AR technology (90.6%), in comparison with the purely anatomy landmark–based method (18.8%, $P < .001$).[12] Initial experience with AR in neurosurgery has already been attempted in oncology, skull base, spinal, and neurovascular surgeries, and its use has significantly increased in the last decade.[11]

To our knowledge, this is the first report of AR-assisted percutaneous GR. As the experience with AR technology grows, fluoroscopy is expected to take less role in the initial parts of the procedure and therefore surgical time and radiation exposure should decrease. AR may improve the learning curve of young and less-experienced neurosurgeons who treat TN. It may also be beneficial for more experienced physicians in the treatment of patients whose anatomy is not standard or those who failed prior attempts of percutaneous rhizotomies. However, we believe that the use of intraoperative fluoroscopy is still crucial to confirm the proper position of the needle and to assess the volume of glycerol required for the particular patient. As with other navigation tools, preplanning the procedure on preoperative imaging can improve surgical outcomes and avoid complications by tailoring the surgery to the specific anatomy of the patient. This concept may be even easier to implement intraoperatively in the AR environment, in comparison with the more standard and commonly used neuronavigation tools.

Limitations

This is a case report showing our first experience in incorporating AR into a well-established technique of fluoroscopy-guided percutaneous GR. To ascertain safety and a successful outcome, we did not skip any step of the traditional method, including the initial fluoroscopy-guided advancement of the needle toward the skull base. AR system setup and registration were performed with the assistance of the Medivis SurgicalAR technical team. Therefore, reported procedure times of this case may not reflect real independent use of this system, and additional training is required. However, further experience and additional cases with the novel technology presented here will allow studying its benefits in comparison with traditional methods regarding saving operation durations, radiation exposure, and clinical outcomes.

CONCLUSION

AR-assisted fluoroscopy-guided percutaneous rhizotomy may enhance the learning curve of young neurosurgeons of these types of procedures and decrease surgery duration and radiation exposure. Furthermore, research is required to evaluate the potential benefits of this novel technology in improving surgical outcomes.

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Disclosures

Osamah J. Choudhry owns equity in Medivis, Inc. 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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VIDEO. Case demonstration of augmented reality–assisted fluoroscopy-guided percutaneous glycerol rhizotomy, performed on a 50-year-old woman with multiple sclerosis and right-sided trigeminal neuralgia.

COMMENTS

The authors report the use of augmented reality to enhance effortless placement of a standard spinal needle through the foramen ovale during a percutaneous procedure for trigeminal neuralgia. While the anatomic correct placement of the needle has been defined in most patients using anteroposterior and lateral fluoroscopic imaging, in some patients, the foramen ovale location is not easy to see (in the X plane at the point of the lateral inferior orbit when a true AP image is obtained so that the inferior orbit and the petrous bone superimpose and the Y and Z target point at the point of superimposition of the petrous bone on the clivus during lateral imaging). In some patients, a basal view can depict the foramen but the view is not anatomical. In some patients, the foramen ovale is difficult to penetrate because of stenosis. The present technique must begin with a high-definition CT bone window of the skull base which is not always routinely done in trigeminal neuralgia patients in the current era of high-definition MRI. With some learning curve and with assistance of the Medivis team, the AR addition seemed to make proper needle placement pretty slick and reasonably quick. With the introduction of any new technique in the OR, the first rule is that the additional tool must aid the surgeon and patient, not simply add more time to the standard procedure. This technique seems to fit that criterion, at least in some patients where fluoroscopic placement is insufficient. The second rule is that the new technique must show sustaining cost effectiveness. That criterion will require additional experience.

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The application of augmented reality (AR) to assist percutaneous glycerol rhizotomy for trigeminal neuralgia is an interesting new tool to educate young neurosurgeons and enhance their learning curve while performing the apparently easy task to gain percutaneous access to Meckel's cave. Experienced neurosurgeons knowing the technique well can also benefit by the introduction of AG providing real-time anatomic feedback as the Meckel's cave ostium can be stenotic or obstructed by scar tissue left by previous procedures.

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The authors summarize a case using augmented reality assistance to perform a percutaneous glycerol rhizotomy for trigeminal neuralgia including a brief video. Increasingly, there will be opportunities for surgeons to enhance visualization using such methodologies. The late Professor Albert Rhoton would state that we need to understand anatomy in its finest detail so that we might use our "X-ray vision" to perform surgeries safely and effectively. Augmented reality offers the potential for real-time enhancement of the surgeon's "X-ray vision" to improve the safety and accuracy of surgery. Much work is still needed to determine in which cases application of such technology is most appropriate from both a clinical and a financial perspective. The authors are to be congratulated on this unique application of this technology.

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