CASE REPORT

Intracavitary ultrasound (ICARUS): a neuroendoscopic adaptation of intravascular ultrasound for intracerebral hemorrhage evacuation

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SUMMARY

Neurosurgeons performing intracerebral hemorrhage evacuation procedures have limited options for monitoring hematoma evacuation and assessing residual hematoma burden intraoperatively. Here, we report the successful neuroendoscopic adaptation of intravascular ultrasound, referred to here as intracavitary ultrasound (ICARUS), in two patients. Pre-evacuation ICARUS demonstrated dense hematomas in both patients. Post-evacuation ICARUS in patient 1 demonstrated significant reduction in clot burden and two focal hyperechoic regions consistent with pockets of hematoma not previously seen with the endoscope or burr hole ultrasound. These areas were directly targeted and resected with the endoscope and suction device. Post-evacuation ICARUS in patient 2 showed significant reduction of hematoma volume without indication of residual blood. ICARUS findings were confirmed on intraoperative DynaCT and postoperative CT 24 hours later. ICARUS is feasibly performed in a hematoma cavity both before and after hematoma aspiration. ICARUS may provide additional information to the operating surgeon and assist in maximizing hematoma removal.

BACKGROUND

Introduction

Intravascular ultrasound (IVUS) is an important imaging modality in the diagnosis and treatment of vascular disease.^{1 2} IVUS catheters contain numerous ultrasound transmitters and receivers positioned radially at the tip of a catheter to produce a 360-degree cross-sectional ultrasound image. Although IVUS was designed for intravascular applications, its submillimetric diameter gives it the potential to be adapted for a variety of procedures.^{3 4} One such procedure is endoscopic intracerebral hemorrhage (ICH) evacuation, a procedure with limited options for intraoperative imaging and in great need of a method to monitor progress in real time. Here, we present our initial experience, in two patients, applying IVUS for intracavitary ultrasound (ICARUS) during endoscopic ICH evacuation.

Intracavitary ultrasound technique

The 19F endoscope sheath is passed to the distal edge of the hematoma under stereotactic guidance.

The introducer is removed and the IVUS catheter is introduced into the sheath until the tip of the IVUS is flush with that of the sheath at the distal edge of the hematoma. The sheath is retracted (exchanged) a distance equal to the length of the hemorrhage so that the tip of the sheath rests at the proximal edge of the hematoma. With the ultrasound activated, the IVUS catheter is slowly retracted into the sheath to scan the cavity. The process is repeated after evacuation to visualize any residual hematoma (figure 1). Of note, the use of IVUS for intracavitary imaging during ICH evacuation is off-label and not currently cleared by the Food and Drug Administration.

CASE PRESENTATION

Patient 1

A 39-year-old man with hypertension, diabetes, and end-stage renal disease presented with sudden loss of consciousness (LOC), a Glasgow Coma Scale (GCS) of 9, and National Institutes of Health Stroke Scale (NIHSS) of 16, and was found to have a 77 cm³ left-sided ICH (figure 2A). He underwent endoscopic evacuation 72 hours after symptom onset. Baseline ICARUS prior to evacuation demonstrated a dense hematoma (figure 3A; see online supplementary video 1). At the conclusion of the evacuation, ICARUS was repeated and identified two residual pockets of hematoma (figure 3B and C; see online supplementary video 2). Using the information gathered from ICARUS, these pockets were targeted with the endoscope and Apollo System (Penumbra, Alameda, California, USA) for evacuation. Had ICARUS not been performed, the procedure would have been terminated without evacuation of these residual pockets. Subsequent intraoperative DynaCT demonstrated >90% evacuation (figure 2B). CT performed 24 hours later revealed 95% evacuation and no evidence of rebleeding (figure 2C). The patient was discharged to an acute rehabilitation facility with an NIHSS of 10 on postoperative day 18.

Patient 2

A 60-year-old man with a history of hypertension, hyperlipidemia, prior left occipital infarct, and chronic aspirin therapy presented with sudden LOC, right-sided weakness, left gaze preference, a GCS 10, and a NIHSS of 22. CT imaging

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Figure 1 Intracavitary ultrasound technique at the conclusion of intracerebral hemorrhage evacuation to scan for residual hematoma. (A) At the conclusion of the procedure, the sheath is advanced to the distal end of the hematoma cavity with the intravascular ultrasound (IVUS) catheter within it. (B) The sheath is retracted, leaving the IVUS catheter tip at the distal edge of the hematoma. (C) With the ultrasound activated, the IVUS catheter is slowly retracted to scan the entire cavity volume. Areas of residual hematoma are captured on ultrasound as hyper-echoic areas (highlighted in red for emphasis).

revealed a 47 cm³ left-sided ICH (figure 4A). He underwent endoscopic evacuation 36 hours after ictus. Baseline ICARUS demonstrated an ellipsoid hematoma (figure 5A; see online supplementary video 3). Postevacuation ICARUS demonstrated complete evacuation without indication of residual hematoma (figure 5B; see online supplementary video 4). Intraoperative DynaCT showed >90% evacuation (figure 4B). CT performed 24 hours postoperatively revealed 0.7 cm³ of residual blood, amounting to an evacuation rate of 98.5% (figure 4C). A PEG tube was placed on postoperative day 6 and he was discharged to an acute rehabilitation facility with a NIHSS of 21 on postoperative day 12.

DISCUSSION

While there is currently no level 1 evidence in support of endoscopic ICH evacuation, preliminary evidence from the Minimally

Figure 2 Patient 1 CT imaging. (A) Preoperative CT scan demonstrated a 72 cm³ left parietotemporal intracerebral hemorrhage. (B) Intraoperative DynaCT confirmed >90% evacuation and no pockets of residual hematoma. (C) Postoperative day 1 CT demonstrating 92.5% evacuation and minor pneumocephalus.

Figure 3 Patient 1 intracavitary ultrasound (ICARUS) imaging. (A) Pre-evacuation ICARUS demonstrated a dense hematoma surrounding the endoscope sheath with little penetration of the ultrasound waves (white arrow) and dura mater (blue arrow) (full ICARUS shown in online supplementary video 1). (B,C) Postevacuation ICARUS identified two residual pockets of hematoma (arrows). These residual pockets can be distinguished from the cavity wall based on the comparatively greater depth of echogenicity (full ICARUS shown in online supplementary video 2).

Invasive Surgery Plus rt-PA for Intracerebral Hemorrhage Evacuation II clinical trial suggests that higher evacuation percentage, at least with minimally invasive catheter drainage, may lead to improved outcomes.^{5–7} Still, small pockets of residual hematoma may have negligible clinical significance. However, residual pockets can, at times, be of quite significant size, especially when a collapsing cavity closes off a large portion of the hematoma. Intraoperative visualization of residual hematoma in these instances is challenging and represents a prominent obstacle to maximizing evacuation percentage. ICARUS, as outlined in the cases above, may represent a promising solution. With its slender profile, the IVUS catheter can be easily introduced into the hematoma cavity during an endoscopic evacuation for intraoperative cavity assessment. With an imaging depth of 30 mm and a resolution of approximately 200 µm, IVUS can clearly visualize the entire hematoma cavity width.

There are two specific instances in which ICARUS may be helpful. As mentioned, in some cases, residual hematoma becomes walled off in a separate cavity as the main hematoma cavity collapses during aspiration. ICARUS may be able to detect these derivative cavities to guide endoscopic exploration, or even an additional stereotactically guided pass directly into the secondary hematoma cavity. ICARUS may also guide targeted investigation of suspicious areas of the cavity. Often, the walls of the cavity are maroon in color and can closely resemble the appearance of blood when viewed with the

Figure 4 Patient 2 CT imaging. (A) Preoperative CT revealed a 47 cm³ left-sided intracerebral hemorrhage. (B) Intraoperative DynaCT confirmed >90% hematoma evacuation. A small pocket of hematoma remained at the distal end of the cavity, which was not visualized with postevacuation intracavitary ultrasound. (C) Postoperative day 1 CT showed a residual hematoma volume of 0.7 cm³ located at the distal end of the cavity, amounting to an evacuation rate of 98.5%.

Figure 5 Patient 2 intracavitary ultrasound (ICARUS) imaging. (A) Pre-evacuation ICARUS demonstrated an ellipsoid hematoma (arrow) (full ICARUS shown in online supplementary video 3). (B) Postevacuation ICARUS showed excellent reduction of hematoma volume and a clear hematoma cavity (arrow) without any indication of residual blood (full ICARUS shown in online supplementary video 4).

endoscope. Exploration of these maroon cavity walls with aspiration carries the risk of causing injury to the pericavity parenchyma or inciting bleeding. ICARUS, however, is atraumatic and may assist in differentiating the cavity wall from residual pockets of hematoma by measuring the depth of increased echogenicity. The cavity wall generally manifests as a thin area of echogenicity whereas a residual hematoma pocket will have a thicker appearance, as was noted in patient 1 (figure 3B,C). This information may represent a useful adjunct to endoscopic views of the cavity, including those acquired with 30-degree and 45-degree endoscope cameras when searching the cavity for residual blood and may lead to more confident probing of what appears to be the cavity wall but may, in fact, be more hematoma.

Limitations

The primary limitation of ICARUS is the directionality of the ultrasound image. While the IVUS catheter 360-degree emitter-receiver array, which was originally designed and intended for intravascular vessel wall imaging, is excellent for imaging of the cavity walls along its axis, the areas directly in front of the IVUS catheter tip are not well visualized, leaving a 'blind spot' at the very distal end of the cavity. This was noted in patient 2, in whom a small residual pocket of blood, which was not visualized on ICARUS intraoperatively, was seen on both intraoperative and postoperative CT.

The 30mm cross-sectional radius of IVUS presents another potential limitation in cases of large hematomas with a diameter greater than 60 mm. While pertinent in these cases, the majority of hematomas amenable to evacuation have a cross-sectional diameter less than 60 mm. Moreover, during the course of hematoma evacuation, a degree of cavity collapse is expected, which may allow for improved visualization of the distal edges of these larger hematomas.

Finally, the current costs and availability of IVUS may make use of this intraoperative imaging technique impractical for many medical centers. As catheter-based imaging technologies improve and become more popular, the costs can be expected to decrease and availability increase. Further reports demonstrating the versatility of catheter-based ultrasound technology may assist in accelerating its wider use and availability.

Alternative imaging techniques

Intraoperative CT has been proposed to measure the extent of hematoma evacuation and assess the volume of residual blood.⁸

Intraoperative CT offers higher spatial resolution and improved residual hematoma volume assessment, but is, relative to ICARUS, time-consuming, not available in all operating rooms, and disruptive to workflow.

Intraoperative intracranial, extracerebral ultrasound ('burr hole ultrasound') is routinely used in ICH evacuation to assess hematoma size and location. Like ICARUS, it can also be used to periodically assess the size of the hematoma during the course of an ICH evacuation procedure. While burr hole ultrasound is less invasive and may have higher image resolution than catheter-based ultrasound technology, it has several disadvantages that make it impractical for use during endoscopic ICH evacuations. First, burr hole ultrasound requires direct contact with the surface of the brain and, therefore, during endoscopic ICH evacuations, requires removal of the endoscope sheath from the burr hole. Subsequent reintroduction of the endoscope sheath into the brain to evacuate more hematoma introduces greater risk of injury to the parenchyma. On the other hand, ICARUS is performed through an endoscope sheath and therefore does not require additional endoscope sheath passes. Second, while burr hole ultrasound may have superior imaging characteristics, resolution and identification of residual pockets with ICARUS does not appear to be an issue, in our experience. ICARUS has the advantage of being in close proximity to the imaging target (the cavity wall) and, as shown in the two cases presented above, easily demarcates pockets of residual blood for identification. In fact, we find that burr hole ultrasound is more difficult to interpret intraoperatively. Burr hole ultrasound only provides visualization in a single plane at any one time, making three-dimensional interpretation more complex, and suffers from degraded image quality in the post-evacuation cavity due to echogenicity of the evacuation tract. ICARUS, by contrast, has a 360-degree view that is automatically supplemented by a reconstructed image along the longitudinal axis, providing comprehensive views in two planes, concurrently. Furthermore, ICARUS is unencumbered by the narrow confines of the burr hole.

Burr hole ultrasound through a second burr hole has also been proposed to monitor ICH evacuation progress in real time.⁹ Although the authors found it to be practical and reported improved evacuation rates, the need for a second burr hole limits its widespread acceptance.

Conclusions

IVUS was feasibly adapted for use during an endoscopic ICH evacuation procedure to assist in identifying residual clot burden. Further investigation of this adapted technology is warranted to determine its full diagnostic value and impact on hematoma evacuation efficiency.

Learning points

- ▶ Neurosurgeons performing intracerebral hemorrhage (ICH) evacuation have limited options for monitoring hematoma evacuation and assessing residual hematoma burden intraoperatively.
- ▶ Intravascular ultrasound was feasibly adapted for use during an endoscopic ICH evacuation procedure to assist in identifying residual clot burden.
- ▶ Further investigation of this adapted technology is warranted to determine its full diagnostic value and impact on hematoma evacuation efficiency.

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