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ABSTRACT

SUMMARY: A novel swine model was developed to investigate the underlying reasons for the failure of aspiration thrombectomy. The model allows direct visualization of the target artery during thrombectomy in vessels of different sizes. The behavior of the target artery undergoing aspiration thrombectomy was recorded with high-resolution digital microscopy and fluoroscopic visualization, providing valuable insight into how the different sizes of treated arteries affect the effectiveness of mechanical thrombectomy.

ABBREVIATIONS: CCA = common carotid artery; LVO = large-vessel occlusion; SCA = superficial cervical artery; TIMI = Thrombolysis in Myocardial Infarction

Aspiration thrombectomy is a widely used technique for treating acute ischemic stroke with large-vessel occlusion (LVO).[1-3] Recent advances in catheter technology have improved the effectiveness of the procedure, though the success rate of the first pass remains limited, ranging from 25.1% to 53.7% of cases.[4-6]

The primary reasons hindering successful outcomes were often explained as inadequate aspiration force, insufficient contact between the catheter tip and the clot surface, or clot fragmentation during the procedure.[7,8] Although a consensus exists with interventionalists that a larger-lumen aspiration catheter may enhance recanalization rates, this consensus remains a topic of ongoing debate with limited supporting evidence. To enhance our understanding of how aspiration thrombectomy works, studies using animal models such as swine, canines, and rabbits as well as human cadaver–based models have been conducted.[9-12] However, many aspects remain unknown, including how the size of the target vessel with different flow volumes affects the effectiveness of aspiration thrombectomy.

For bridging this knowledge gap, a novel swine LVO model was developed, enabling real-time visualization of target arteries undergoing mechanical thrombectomy. Two distinct vessel sizes were chosen as targets: the common carotid artery (CCA) and the superficial cervical artery (SCA), simulating the human ICA and M1 segment of the MCA, respectively. The study examined the behaviors of the target vessels during aspiration thrombectomy, encompassing vessel collapse, vessel traction, and local reverse blood flow, to investigate how the size of the target artery impacts the performance of the procedure.

By investigating the underlying causes of the failure of aspiration thrombectomy, this model has the potential to inform about the development of improved aspiration devices and enhance the refinement of endovascular techniques in clinical settings.

TECHNIQUE

All procedures were performed in accordance with the policies of the University of California, Irvine Chancellor's Institutional Animal Care and Use Committee. The SCA, also known as the omocervical artery, originates from the thyrocervical trunk in swine.[13] This straight branch, typically 2–3 mm in diameter with a bifurcation, simulates the human MCA,[14] and it was used to represent a small-diameter artery in this study. On the other hand, the CCA, typically 4–5 mm in diameter, was used to represent a large-diameter artery.

Under general anesthesia, a female swine was intubated and placed on the surgical table. In the supine position, a 20-cm straight skin incision was made along the sternocleidomastoid muscle. The connective tissue of the lateral and dorsal aspect of the muscle was surgically dissected to expose the SCA. Technical details are available elsewhere.[14] Subsequently, the medial connective tissue of the same muscle was dissected to expose the CCA. After carefully dissecting and removing the adventitial layer of the artery to optimize visibility during the procedure, approximately 15 cm of the arterial segment was exposed. A 4–0 Prolene suture (Ethicon) was meticulously placed around the artery. The degree of stenosis was assessed and adjusted to maintain it at <50% stenosis. In cases in which

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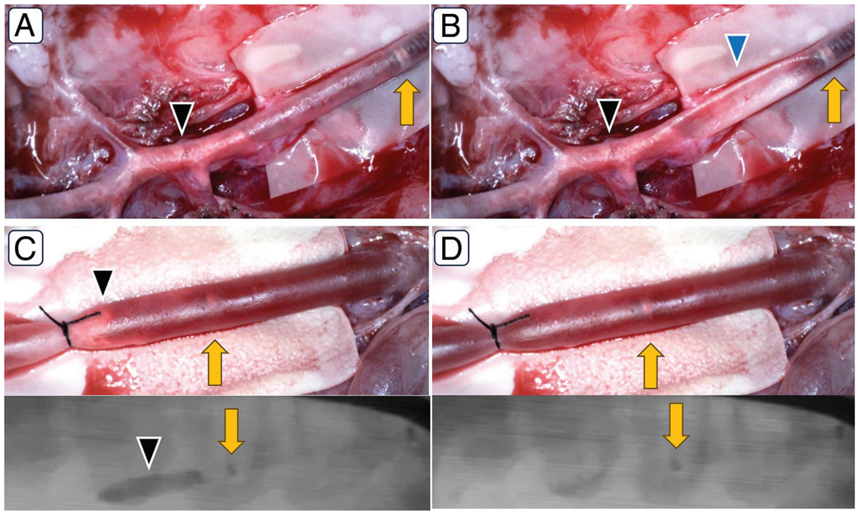

FIG 1. Direct visualization of the vessels undergoing aspiration thrombectomy. *A*, The SCA before remote aspiration. The surgically exposed SCA is occluded with a clot analog (*black arrowhead*). Note that the distal end of the aspiration catheter is visible through the translucent vessel wall (*yellow arrow*). *B*, The SCA after remote aspiration. Vessel collapse (*blue arrowhead*) is observed immediately after the application of the aspiration force. The position of the clot remains unchanged (*black arrowhead*), indicating an unsuccessful recanalization. *C*, The CCA before remote aspiration. A 5-0 Prolene suture is placed on the surgically exposed CCA to replicate mild stenosis and stabilize the clot analog (*black arrowhead*). The radiograph below shows that the tip of the catheter is remote from the clot analog (*black arrowhead*). *D*, The CCA after remote aspiration. A local reverse flow was induced near the tip of the aspiration catheter (*yellow arrowhead*), and the clot was aspirated into the catheter, resulting in successful recanalization. Note that there was no observed vessel collapse during the maneuver. The radiograph below shows that the clot analog is no longer visible because it was aspirated into the catheter.

vasospasm resulting from surgical maneuvers was observed in the target vessels, a topical application of papaverine (3 mg/mL) was administered to alleviate the vasospasm.

Intraprocedural, continuous observation of the target vessels was performed using a high-resolution digital microscope camera (Dino-Lite Edge 3.0 AM73115MTF; AnMo Electronics) (11.9 × 3.3 cm). The microscope camera has an extralong working distance, allowing the farthest available working distance of 70 cm with a magnification of 10×–70× at 45 frames per second. Real-time video images were displayed on a dedicated monitor, and the captured images were processed using the DinoCapture 2.0 software (Dino-Lite). Additionally, vessel size was verified in the angiographic images using ImageJ software (https://imagej.net/ij/download.html).

An angiographic system (OEC 9800; GE Healthcare) was used for selective DSA followed by endovascular procedures. An 8F femoral sheath was placed in the right femoral artery, and a 6F guiding sheath, 0.088-inch Ballast catheter (Balt), was navigated to the origin of the right subclavian artery followed by the SCA. Next, under roadmap image guidance, a clot analog was injected into the SCA. The fibrin-rich clot analogs used in this model were reproduced following the established methodology described in multiple publications in the past.[8,14,15] They were produced from allogeneic whole blood characterized by its fibrin-rich component using a modified chandler loop technique. A control angiogram was performed to confirm the complete occlusion of the target vessel. The same procedure was repeated for the CCA.

By means of the 2 different types of vessels described above, performance of aspiration thrombectomy was evaluated and recorded. We used different sizes of aspiration catheters: 0.058-inch ID (Catalyst 5; Stryker Neurovascular), 0.068-inch ID (React 68; Medtronic) and an 0.088-inch ID. The procedure was always initiated with remote aspiration with the tip of the catheter placed 20 mm away from the clot, and continuous aspiration of 4 minutes was applied using a 60-mL syringe. If no recanalization was seen, the aspiration catheter was advanced with 5-mm increments and the same maneuver was repeated. If remote aspiration failed, contact aspiration was performed with the aspiration catheter in direct contact with the clot analog under direct visualization.

Vessel behaviors under direct visualization during the procedure, such as vessel collapse, vessel traction, vasospasm, clot fragmentation, and cavitation in the target vessels, were recorded. After each procedure, the degree of reperfusion was described using the Thrombolysis in Myocardial Infarction (TIMI) scale. The typical behaviors of 2 different-sized vessels, the CCA group versus SCA group, undergoing aspiration thrombectomy were compared, and the mechanism of successful/unsuccessful reperfusion on each target artery was described.

RESULTS

A total of 3 CCAs and 4 SCAs in 3 animals with a mean weight of 68.3 kg (range, 56–87 kg) were surgically exposed, and concurrent fluoroscopic and transmural direct visualization were successfully performed in all vessels. All target vessels were successfully occluded (TIMI 0) immediately after the injection of the clot. In all cases, injected clot analogs, the tip of aspiration catheter, and the vessel behaviors during the thrombectomy procedure were observed and allowed us to assess the mechanism of successful/unsuccessful reperfusion.

The mean diameter was 5.2 mm (range, 5.0–5.5 mm) for the CCA group and 2.3 mm (2.0–3.0 mm) for the SCA group. Figure 1 shows the typical behavior of the vessels undergoing aspiration thrombectomy. In the SCA group (4 vessels) with remote aspiration, we observed the following findings: 1) vessel collapse (all 4 vessels): the immediate collapse of the vessel segment between the tip of catheter and the proximal end of the clot (no movement of the clot was seen during the aspiration regardless of the catheter size [058, 068, and 088 mm]); 2) vessel traction (1 case): vessel collapse followed by substantial traction of target vessel (approximately 20 mm) in 1 SCA sample, while the aspiration catheter (058 mm) was retracted with continuous aspiration. In the SCA group with contact aspiration, successful recovery of the clot was

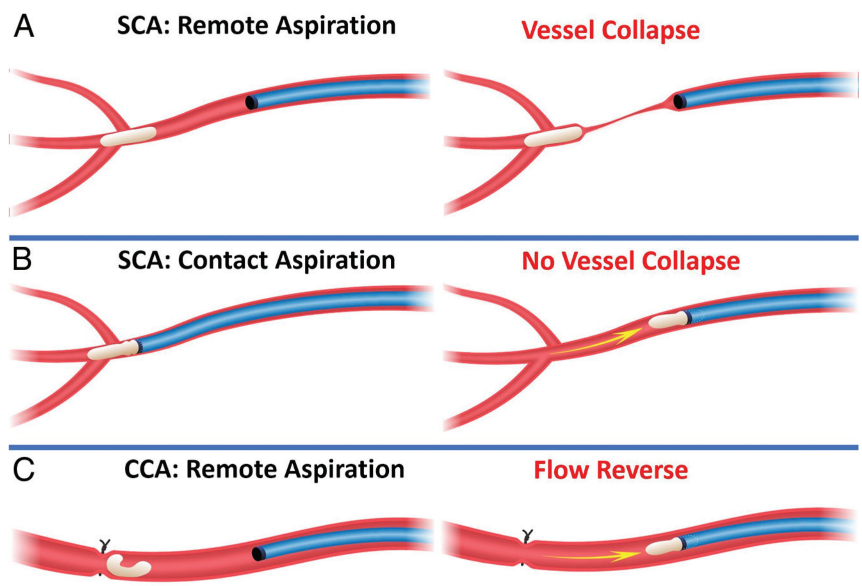

FIG 2. Schematic view showing the impact of vessel size on target vessel behavior during aspiration thrombectomy. *A*, SCA remote aspiration. The target vessel remains occluded with a clot analog after remote aspiration, and vessel collapse it seen. *B*, SCA contact aspiration. The tip of the catheter is placed against the proximal end of the clot. The clot is engulfed in the tip of the catheter, and successful recanalization is seen. *C*, CCA remote aspiration. A focal reverse flow is induced near the tip of the catheter, and the clot is aspirated into the catheter, achieving successful recanalization.

observed in 3 vessels (058 and 068 mm) (TIMI 3), and 1 vessel showed partial recanalization (TIMI 2) due to clot fragmentation during the retrieval (058 mm). In the CCA group with remote aspiration, successful recanalization was achieved in all 3 vessels (TIMI 3) and did not require contact aspiration. The aspiration catheters used were 068, 088, and 088 mm, respectively. Local reverse flow was generated during the aspiration, and none of the vessels showed vessel collapse except 1 in which a temporal reduction of the vessel diameter was seen at the beginning of the aspiration (088 mm). No vessel pulling and elongation during aspiration catheter pullback were observed in the CCA group. Figure 2 depicts a schematic view showing the impact of vessel size on target vessel behavior during aspiration thrombectomy.

DISCUSSION

The procedure, mechanical thrombectomy, incorporates a semi-blinded maneuver, given that the operator lacks direct visibility of the clot or vessel being manipulated. Therefore, it remains uncertain whether the clot has been effectively engaged and captured during the aspiration thrombectomy until the devices are retrieved, followed by another control angiogram.

Flow arrest within the aspiration tube is often used as an indicator of successful clot capture during aspiration thrombectomy.[16] If no backflow is observed in the aspiration tube, which is under continuous negative pressure while withdrawing, it is often inferred that the clot has been captured inside the catheter or at its tip. However, flow arrest can also result from the catheter tip merely being in the collapsed vessel without engaging the clot. The animal model described in this report clearly demonstrated that vessel collapse can occur immediately after the application of aspiration in relatively small-sized vessels.

Previously reported various LVO models have described a similar phenomenon.[11,12] What remained unknown, however, was whether vessels of varying sizes have distinct responses to the same thrombectomy maneuver. The model presented in this report indicates that the performance of aspiration thrombectomy may indeed vary significantly depending on the vessel size, suggesting a need for potential adjustments in treatment strategies accordingly.

While this model sheds light on catheter-vessel interactions during thrombectomy, some limitations exist. For instance, human intracranial arteries are known to have different histologic features compared with peripheral arteries or arterioles. These arteries are less elastic, contain fewer elastic fibers, and have thinner layers of smooth muscle. The arteries used in our study were from swine; thus, variations stemming from different species should also be considered. Additionally, clot-related factors can impact aspiration thrombectomy outcomes, such as clot components, length, and fragility. Hence, further research with a larger sample size, diverse clot types, and systematic catheter variations, as well as stent retrievers, is warranted.

CONCLUSIONS

A new swine LVO model was created to study artery behavior undergoing aspiration thrombectomy. The model simulated vessel collapse, vessel traction, and reverse blood flow in vessels of different sizes, revealing how the size of the target vessel impacts the performance of the thrombectomy procedure. Further investigation with an increased number of sample sizes with different types of clot analogs and aspiration catheters is warranted to better understand the mechanism of aspiration thrombectomy.

Disclosure forms provided by the authors are available with the full text and PDF of this article at www.ajnr.org.

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