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FLASHLIGHT

Endovascular treatment of tandem lesions in a novel cadaveric stroke model

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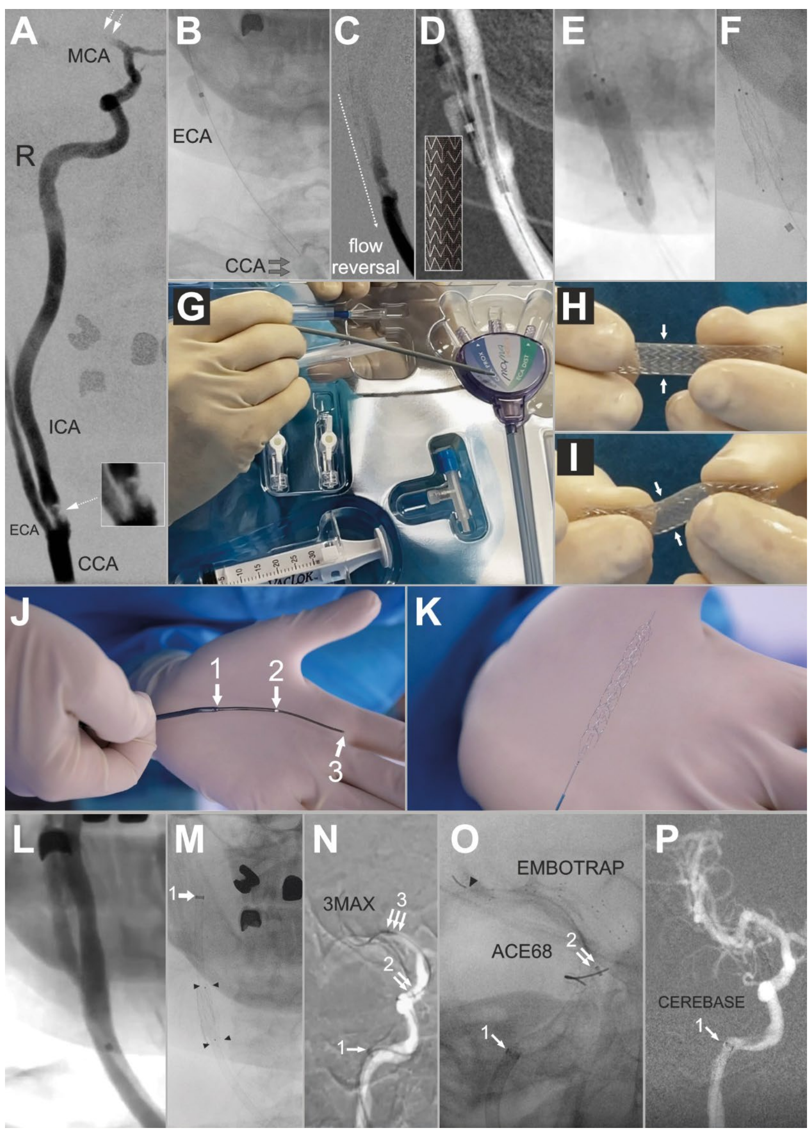

Figure 1. *Key angiographic and procedural images: a live case-like procedure in a female cadaver who died of a tandem stroke aged 78 years (legend in Supplementary data).*

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Today, emergency endovascular stroke treatment (EST) is the Class Ia-evidenced[1] standard of care for acute cerebrovascular occlusions. Despite its unquestionable efficiency, only a minority of the population have effective access to EST due to a shortage of trained teams and capable centres[2,3].

EST requires EST-specific operator training and multispeciality team alignment[3-5]. The emergency nature of EST, irregular and unpredictable case presentations and, to some extent, turf protection hinder the "apprenticeship model". Other current training concepts also have limitations that significantly impact their effectiveness. Three-dimensionally printed bench models can replicate vascular anatomy, but they miss the tissue complexity of cerebral vessels and their susceptibility to, for instance, perforation. High-fidelity simulators may incorporate a virtual environment, but they lack important nuances such as use of real devices, permanent flushing of catheters (a fundamental part of neurointerventions) and continuous drip control to avoid potentially lethal air embolism/thrombus formation. Animal models are poorly applicable to the human cerebral anatomy and lack underlying diseases specific to stroke; they also face ethical concerns and high cost.

We evaluated the feasibility of performing stroke interventions in the Dundee human cadaveric model. This novel human model inherently incorporates the challenges posed by anatomical variations between individual patients and allows the creation of additional vessel occlusions. Cadavers are prepared using a proprietary method, allowing intracranial vessels to remain open. Using an extracorporeal perfusion pump **(Supplementary Figure 1)**, arterial blood pressure can be modulated. The work complies with ethics regulations and relevant legislation, including the consent of donors in accordance with the Anatomy Act Scotland (1984) and the Human Tissue (Scotland) Act 2006.

Herein, we report the first ever endovascular treatment of a tandem stroke lesion in a perfused human cadaver **(Figure 1, Supplementary Figure 1, Moving image 1-Moving image 5).** The procedure was part of an international operator and team-training workshop, transmitted live via visOR smart glasses (Rods&Cones). It involved devices conventionally used to treat tandem lesions, including aspiration catheters and stentrievers **(Figure 1, Supplementary Figure 1, Supplementary Figure 2)**. Procedural aspects were judged by 5 experienced EST operators involved in the case. The intervention was considered "very realistic" (mean 9.4; scale 0-10: 10 identical to real life, 0 completely different). Online trainees (endovascular operator teams) commented that they would not have realised the case was not being performed in a live human had they not been told afterwards.

Life-like case-based training followed, involving repeated demonstrations of the key procedural steps with interactive discussions **(Supplementary Figure 2)** and repeated intracranial/extracranial **(Moving image 4)** stroke interventions.

One fundamental strength of the Dundee human stroke model is the feasibility to perform life-like "emergency" cerebrovascular interventions for which the timing can be electively chosen to fit training logistics. Key procedural steps can be repeated and explained, including procedural strategies and cerebral protection and thrombus extraction strategies **(Supplementary Figure 2)**. Furthermore, team training with life-like scenarios can be performed, including recognition and management of complications. Angiographic imaging necessitates contrast use **(Moving image 4)**, as in live humans. The perfusate is transparent, allowing intravascular imaging. Limitations are similar to those for live humans: vessels can be perforated, and devices – once implanted – stay. This makes the treatment realistic, necessitating – for instance – crossing the carotid stent for repeated intracranial interventions **(Figure 1)**.

In conclusion, we have developed a life-like human cadaveric model for extra- and intracranial stroke interventions. This model allows safe and scheduled skills acquisition for operators and teams, consistent with recent EST training guidelines[4]. In addition, the model allows medical device familiarisation and evaluation **(Figure 1, Supplementary Figure 1)**.

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Conflict of interest statement

I.Q. Grunwald is Vice-President of the World Federation for Interventional Stroke Treatment (WIST). P. Musialek has proctored and/or consulted for Abbott, W. L. Gore & Associates, InspireMD, and Medtronic; is Global Co-PI in C-Guardians FDA-IDE trial; serves on the ESC Stroke Council Scientific Documents Task Force; and is the Polish Cardiac Society Board Representative for Stroke and Vascular Interventions Treatment. The other authors have no conflicts of interest to declare.

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Supplementary data

Figure 1. Legend.

Supplementary Figure 1. Photographic capture of the fundamental procedural steps.

Supplementary Figure 2. Demonstration of performing some key EST elements (changing roles with onsite trainees).

Moving image 1. Inflation of the Mo.Ma system proximal balloon and flow reversal for cerebral protection against the ICA lesion (stroke culprit) embolism.

Moving image 2. Primary stenting of the stroke culprit carotid atherosclerotic thromboembolic lesion (antegrade strategy).

Moving image 3. Verification and adjustment of the catheter flush with heparinised saline in a "neuro" set-up.

Moving image 4. Stentriever release that followed an (ineffective) aspiration-only attempt **(Figure 1N)**.

Moving image 5. Digital subtraction angiography showing sluggish flow due to thrombus in the distal ICA.

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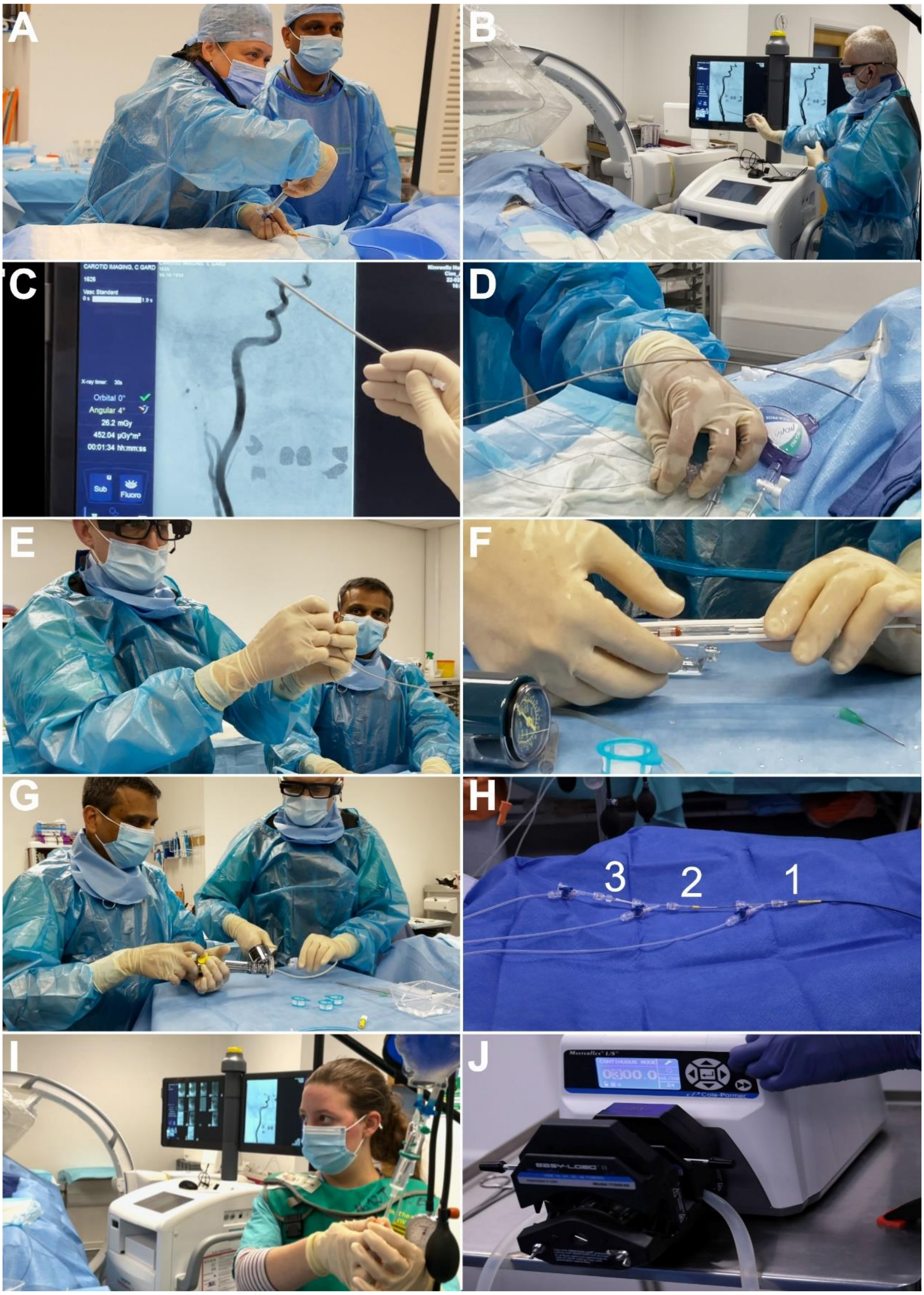
Supplementary data

Figure 1. Key angiographic and procedural images: a live case-like procedure in a female cadaver who died of a tandem stroke aged 78 years.

Baseline angiogram (A), performed via the right femoral common artery with the use of Bern/5 Fr diagnostic catheter (Boston Scientific), showed right-sided (R), irregular, high-grade internal carotid artery (ICA) stenosis (white arrow) and proximal middle cerebral artery (MCA) occlusion (tandem lesion). Following Supra Core 0.035' (Abbott) wiring of the external carotid artery (ECA), a Mo.Ma/9 Fr double-balloon proximal neuroprotection system (Medtronic) was introduced. After angiographic confirmation of the optimal position of the Mo.Ma device for treating the stroke-causing carotid atherosclerotic lesion, the system balloons were inflated, resulting in ECA and then CCA (double arrow) balloon occlusion (B; double arrow marks the inflated proximal CCA Mo.Ma occluded balloon). By opening the Mo.Ma system valve, reversed contrast medium flow was established and confirmed by angiography (effective proximal cerebral protection, C; see also **Moving image 1**). Under flow reversal, the ICA lesion was crossed with the 0.014' HT BMW coronary wire (Abbott) and MicroNet-covered antiembolic stent (CGuard 9x20 mm [InspireMD]) was positioned at the lesion level for primary stenting (D; a low-volume contrast injection was performed for illustrative purposes and to demonstrate the efficacy of "natural" cerebral protection by flow reversal that followed immediately; see also **Moving image 2**). Post-dilatation stent embedding was performed with a 5.5x20 mm non-compliant balloon (E). Optimal stent opening is shown in F. G-K are captures of a live presentation of the devices used to perform tandem stroke treatment in this case (G presents the Mo.Ma system ports; H and I show the MicroNet-covered neuroprotective stent and its adaptability in relation to an open-cell nitinol frame; J demonstrates the distal tips of a three-catheter aspiration system, subsequently positioned *in situ* in N, according to the "tower of power" principle, including a guiding catheter (in this case, CEREBASE 8 Fr [CERENOVUS]), aspiration catheter (in this case, ACE68 [Penumbra]) and a support catheter (in this case, 3MAX [Penumbra]), marked with numbered arrows: 1: guide, 2: aspiration, 3: support catheter; K shows a stent retriever to be applied if the aspiration-alone technique fails; *see* O). Completed optimal revascularisation of the culprit carotid lesion (antegrade strategy) was confirmed by angiography (L) and it was followed by insertion through the stent of a guiding catheter for cerebral mechanical thrombectomy (note the guiding catheter's position above the distal edge of the ICA/CCA in M; the distal catheter tip is marked with a white arrow). The intracranial mechanical thrombectomy aspiration system was successfully inserted, and its appropriate positioning was confirmed by angiography (N; the tips of three respective catheters are marked with arrows and are numbered as indicated in J). In this case, the aspiration technique alone was not effective in opening the MCA occlusion, consistent with real-life scenarios of stroke interventions. The stent retriever (in this case, EMBOTRAP [CERENOVUS]) was positioned and opened in the M1 right-sided segment of the MCA (O; see also **Moving image 4**). With the use of the Solumbra technique (stent retriever thrombus capture paired with simultaneous aspiration), MCA recanalisation was achieved, with Thrombolysis in Cerebral Infarction-3 flow confirmed by angiography (P; the guiding catheter tip is marked with an arrow). For a capture of the key procedural steps as well as the training steps, which followed, see **Supplementary Figure 1, Supplementary Figure 2,** and **Moving image 1-Moving image 4**.



Supplementary Figure 1. Photographic capture of the fundamental procedural steps.

(A) Performing baseline angiogram.

(B-C) Procedural planning (discussing antegrade vs retrograde strategy in a tandem lesion).

(D-E) Guidewire and stent insertion into Mo.Ma system.

(F) Demonstration of stent deployment **(Moving image 2)**.

(G). Balloon preparation (post-dilatation).

(H) 3-catheter aspiration system *in situ* **(Figure 1J)**.

(I) Catheter/sheath flush monitoring **(Moving image 3, Supplementary Figure 2D)**.

(J) Perfusion pump ensuring pulsatile arterial flow with feasibility of the arterial pressure regulation to mimic real-life stroke scenarios.

Supplementary Figure 2. Demonstration of performing some key EST elements (changing roles with on-site trainees).

(A-C) The operator/assistant roles in the thrombus aspiration steps:

(A) explanation of aspiration technique requiring simultaneous aspiration and a smooth, coordinated catheter retraction.

(B) Preparing for catheter retrieval after confirmation of optimal aspiration tip positioning at the thrombus distal end.

(C) Catheter retraction with aspiration.

(D-E) Drip control of the catheter flush: the “neuro” set-up.

(D) Technician controlling adequate pressure in catheter flush system.

(E) Adaptation of flush speed after achieving adequate pressure in flush bag.

Moving image 1. Inflation of the Mo.Ma system proximal balloon and flow reversal for cerebral protection against the ICA lesion (stroke culprit) embolism.

Note that this is performed under real-life procedural fluoroscopic imaging (radiation dose in the left segment of the left panel).

Moving image 2. Primary stenting of the stroke culprit carotid atherosclerotic thrombo-embolic lesion (antegrade strategy).

This step was preceded by discussing the stroke tandem lesion procedure strategy in this particular case **(Supplementary Figure 1 B-C)**.

Moving image 3. Verification and adjustment of the catheter flush with heparinised saline in a “neuro” set-up.

After the live case, training of another non-scrub nurse followed **(Supplementary Figure 2 D-E)**.

Moving image 4. Stentriever release that followed an (ineffective) aspiration-only attempt **(Figure 1N)**.

Moving image 5. Performing angiogram starting the next stage of training: management of culprit thrombus in distal ICA.