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# Evaluation of effectiveness and safety of the CorPath GRX robotic system in endovascular embolization procedures of cerebral aneurysms

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Received 7 February 2023  
Accepted 7 May 2023  
Published Online First  
4 October 2023

## ABSTRACT

**Background** Robotic-assisted neurointervention was recently introduced, with implications that it could be used to treat neurovascular diseases.

**Objective** To evaluate the effectiveness and safety of the robotic-assisted platform CorPath GRX for treating cerebral aneurysms.

**Methods** This prospective, international, multicenter study enrolled patients with brain aneurysms that required endovascular coiling and/or stent-assisted coiling. The primary effectiveness endpoint was defined as successful completion of the robotic-assisted endovascular procedure without any unplanned conversion to manual treatment with guidewire or microcatheter navigation, embolization coil(s) or intracranial stent(s) deployment, or an inability to navigate vessel anatomy. The primary safety endpoint included intraprocedural and periprocedural events.

**Results** The study enrolled 117 patients (74.4% female) with mean age of 56.6 years from 10 international sites. Headache was the most common presenting symptom in 40/117 (34.2%) subjects. Internal carotid artery was the most common location (34/122, 27.9%), and the mean aneurysm height and neck width were 5.7±2.6 mm and 3.5±1.4 mm, respectively. The overall procedure time was 117.3±47.3 min with 59.4±32.6 min robotic procedure time. Primary effectiveness was achieved in 110/117 (94%) subjects with seven subjects requiring conversion to manual for procedure completion. Only four primary safety events were recorded with two intraprocedural aneurysm ruptures and two strokes. A Raymond-Roy Classification Scale score of 1 was achieved in 71/110 (64.5%) subjects, and all subjects were discharged with a modified Rankin Scale score of ≤2.

**Conclusions** This first-of-its-kind robotic-assisted neurovascular trial demonstrates the effectiveness and safety of the CorPath GRX System for endovascular embolization of cerebral aneurysm procedures.

**Trial registration number** NCT04236856

## WHAT IS ALREADY KNOWN

⇒ Robotic-assisted neurovascular intervention was recently introduced, with only a handful of published cases.

## WHAT THIS STUDY ADDS

⇒ This is the first-of-its-kind trial to assess the efficacy and safety of robotics use in neurovascular intervention. From this trial, we now know that robotic-assisted neurovascular intervention is an effective and safe method to embolize cerebral aneurysms.

## HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE, OR POLICY

⇒ This study opens the future potential of robotic integration in neurovascular intervention and is a stepping stone to a future of remote technology in the field of healthcare.

## INTRODUCTION

Cerebral aneurysms affect 2–4% of the population and they can present with a life-threatening rupture with an estimated fatality rate of between 26% and 36%.<sup>1–3</sup> Once an unruptured aneurysm is detected, the decision to intervene balances the risk–benefit profile of the available interventions against watchful waiting.<sup>4–9</sup> Treatment options include surgical clipping or endovascular therapies, including coiling, stent-assisted coiling, flow diverters, and intrasaccular devices.<sup>10 11</sup> The pace of adoption of percutaneous neuroendovascular techniques continues to accelerate, necessitating new technological advancements to improve procedure precision and safety.

The CorPath GRX system is the first robotic platform designed to accommodate the micro guidewires, microcatheters, and microscale movements specific to successful neurovascular interventions. The advent of this robot for percutaneous coronary interventions and peripheral



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**To cite:** Mendes Pereira V, Rice H, De Villiers L, et al. *J NeuroIntervent Surg* 2024;**16**:405–411.

vascular interventions has already begun to address some of the limitations of endovascular interventions.<sup>12–20</sup> The CorPath GRX system translates the manual movements of the interventionalist into precision micromovements during navigation and facilitates precision measurement of anatomy to determine lesion length.<sup>21–22</sup> It also allows the procedure to be performed from a remote, radiation-shielded workstation, which might help to reduce the interventionalist's exposure to ionizing radiation and orthopedic strain.<sup>17–23–25</sup>

In an initial evaluation of the system in *in vitro* animal neurovascular models,<sup>26</sup> Corindus recently implemented software and engineering modifications to its CorPath GRX Robotic System to address neuroendovascular-specific needs and indications: (1) active device fixation, which maintains the placement of both the guidewire and device while the catheter is advanced or retracted by advancing or retracting the guidewire and device to offset the motion of the catheter, (2) limited speed software to reduce the linear movement of the guidewire or device by half, capping its maximum speed at a rate of 6 mm/s, (3) physical modifications to the hardware to securely, and reliably accommodate, the smaller gauge devices common to neurovascular procedures, and (4) software modifications to allow for increased working length to enable target access for microcatheters and an updated user interface to accommodate the new workflow and automated movements. Robotic neurointervention procedures have been performed<sup>27</sup> and early feasibility studies have demonstrated successful procedural execution and manual comparable long term follow-ups in complex aneurysm treatments.<sup>28–31</sup>

This clinical study is a prospective, single-arm, international, multicenter, non-inferiority study to evaluate the effectiveness and safety of the CorPath GRX Robotic System for endovascular cerebral aneurysm embolization compared with historical manual cerebral aneurysm treatment equivalent controls. The primary effectiveness endpoint was defined as successful completion of the robotic-assisted endovascular procedure in the absence of any unplanned conversion to manual for guidewire or microcatheter navigation, embolization coil(s) or intracranial stent(s) deployment, or an inability to navigate vessel anatomy. The primary safety endpoint consisted of a composite of intraprocedural and periprocedural events, including target aneurysmal rupture, vessel perforation or dissection, and major stroke within 24 hours of postprocedure or discharge, whichever occurs first. The secondary endpoints consisted of clinical outcome using the modified Rankin Scale as well as procedure characteristics, including overall robotic and fluoroscopy time, patient radiation exposure, and angiographic assessment of aneurysm occlusion grade according to the Raymond-Roy Classification Scale.

## MATERIALS AND METHODS

### Study population

The inclusion criteria for this trial were (1) age  $\geq 18$  years, (2) at least one cerebral aneurysm (unruptured) with indication for endovascular treatment; dome to neck ratio  $> 1.5$  or aneurysm neck width  $> 4.0$  mm, (3) the investigator deemed the procedure appropriate for both manual or robotic-assisted endovascular treatment, (4) patients were informed of the nature of the study and have provided written informed consent. Prospective consecutive recruitment was encouraged, and subjects were excluded if there was (1) failure/unwillingness of the subject to provide informed consent

or if the ethics committee has waived informed consent, (2) the investigator determines that the subject or the neurovascular anatomy is not suitable for robotic-assisted endovascular treatment, (3) women who are pregnant, or (4) people under guardianship or curatorship. Subjects were screened for eligibility based on standard of care assessments, by Oculis Imaging LLC (Knoxville, Tennessee, USA), an independent eligibility committee and administration services provider.

This study was conducted at 10 sites in six countries, including a premarket study in Canada and postmarket study in Australia, Austria, France, Spain, and Switzerland. The study was conducted according to Good Clinical Practice guidelines. Informed consent was obtained from all study participants. Each participating site obtained approval from independent ethics committees and approval as defined in the World Medical Association Declaration of Helsinki, Competent Authority review and approval (if applicable), ISO 14155:2020(E), and the Medical Device Regulations (2017/745) of April 5, 2017. Avania (Bilthoven Netherlands), a contract research organization was responsible for implementing and maintaining monitoring services, with written standard operating procedures to ensure that the clinical investigation was conducted, and data were generated, documented (recorded), and reported in compliance with the clinical investigation plan and above-mentioned guidelines. A surveillance committee, composed of three expert physicians in the field of interventional neuroradiology and/or neurosurgery, who were independent and not directly involved in the conduct of the trial, reviewed and adjudicated all adverse events over the course of the study. Any missing data were provided on request by the independent committee.

This study was reported using the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) cohort reporting guidelines.<sup>32</sup>

### Statistical methods

The hypothesis of the endpoints was determined by historical rates from a literature overview (table 1) and pooled results from both arms from three randomized control trials (table 2).

The effectiveness hypothesis was:

- ▶  $H_0$ :  $p \leq 80\%$  (90%–10% non-inferiority margin)
- ▶  $H_a$ :  $p > 80\%$  where  $pP$  = proportion of subjects with a successfully completed endovascular procedure.

The safety hypothesis was:

- ▶  $H_0$ :  $p \geq 15\%$  (5%+10% non-inferiority margin)
- ▶  $H_a$ :  $p < 15\%$  where  $p$  = proportion of subjects with a safety event.

Both these endpoints will be summarized along with a two-sided Clopper-Pearson Exact 95% CI. The overall trial sample size was driven by at least 108 subjects enrolled. The secondary endpoints were analyzed with descriptive statistics along with a 95% CI.

The results compiled by this report, include the primary effectiveness and safety endpoints data, monitored through 24 hours postprocedure or hospital discharge, whichever occurred first. All subjects finished this initial timeline for analysis, and the study population is currently being followed up through 180 days for completion of this study.

**Table 1** Rates of safety from the literature for endovascular treatment of unruptured and ruptured aneurysms

	N Aneurysms (subjects)	Mortality at discharge	Overall complication rate	Rupture/ perforation rate (%)	Embolism rate (%)
<i>Ruptured intracranial aneurysms</i>					
Algra <i>et al</i> 2019* <sup>33</sup>	73 066 (71 819)	0.3% (0.2–0.4%)	4.96% (4.00, 6.12%)	0.9% (212/18 520) 95% CI (0.6% to 1.3%)	2.82% (437/16 000) 95% CI (2.3% to 3.5%)
Advanced endovascular methods† <sup>33</sup>	2248	0.4% (0.2–1.1%)	6.1% (4.3, 8.7%)		
Kawbata <i>et al</i> 2018 <sup>34</sup>	1406 (1375)			1.4% (20/1406)	
Coil only	340			1.8% (6/340)	
Stent-assisted coiling	468			0.9% (4/468)	
Balloon-assisted coiling	598			1.7% (10/598)	
From lit review, table 6 in Kawbata <sup>34</sup>	7785	0%		1.4% (108/7785)	
Zheng <i>et al</i> 2016 <sup>35</sup>	1127			1% (11/1127)	
Santillan <i>et al</i> 2013 <sup>36</sup>	217	0%		1.1% (3/217)	
Shigematsu <i>et al</i> 2013 <sup>37</sup>	4767			1.4% (65/4767)	
Oishi <i>et al</i> 2012 <sup>38</sup>	500	0%		1.4% (7/500)	
Im <i>et al</i> 2009 <sup>39</sup>	435	0%		0.9% (4/435)	
Pierot <i>et al</i> 2008 <sup>40</sup>	739 (649)	0.3%		2.4% (18/739)	7.3% (29/398)
(ATENA study)	(700 procs)	1.4% (1 month)	15.4%	2.6% (18/700)	7.1% (per proc)
Pierot <i>et al</i> 2009 <sup>41</sup> (ATENA study, coil alone results)	325	0.9% (3/325)	10.8% (35/325)	2.1% (7/325)	6.2% (20/325)
<i>Ruptured intracranial aneurysms</i>					
Zhang <i>et al</i> 2019 <sup>42</sup>	1004	All cause 9.5% (5.8%, 13.2%) procedure related 1.8% (0.9, 2.7%)	22.7%‡ 95% CI (15.1% to 30.3%)		
Cognard <i>et al</i> 2011 <sup>43</sup> (CLARITY GDC study)	405	1.50%		3.7% (15/405)	13.3% (54/405)
Pierot <i>et al</i> 2011 (CLARITY) <sup>44</sup>	608	5.1% (31/608) cum. treatment-related morbidity/mortality rate 19.6% (119/608) with morbidity/mortality rate)	17.4% (106/608)	4.6% (28/608)	
*Rates presented are pooled crude risk from meta-analysis modeling. †Advanced=stent-assisted coiling, balloon-assisted coiling, flow diverting stents or Woven Endobridge devices. ‡Definition not specified.					

**RESULTS**

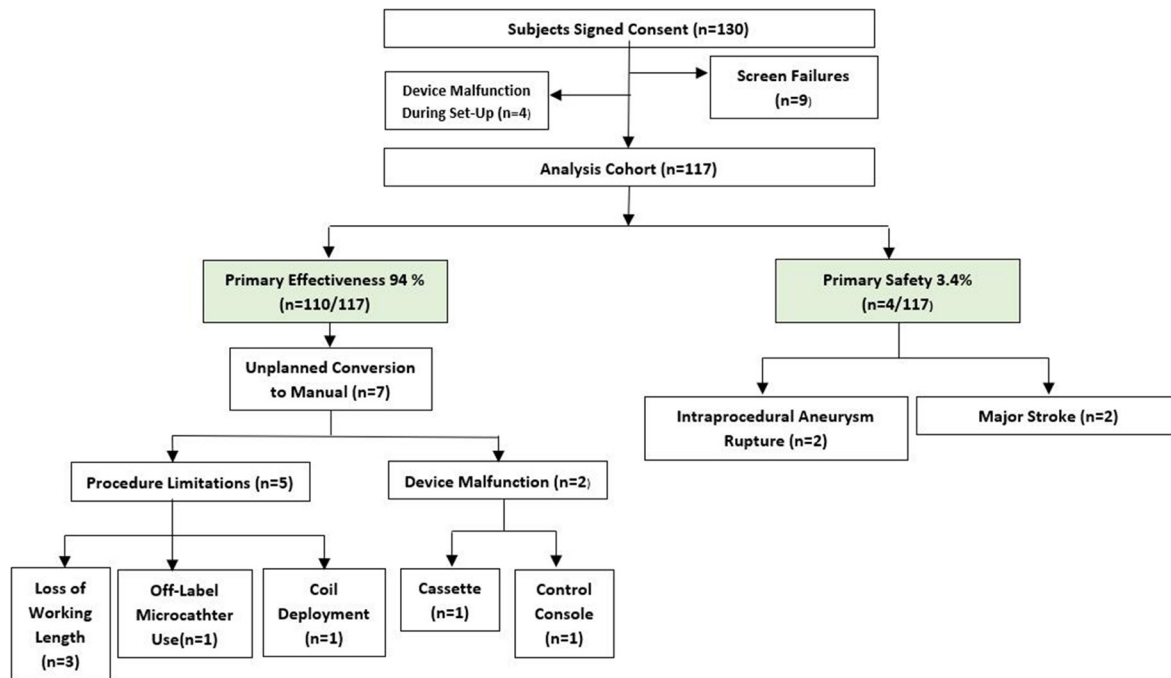
The study is summarized in figure 1. A total of 130 subjects were screened and provided written informed consent between August 2020 and April 2022. The complete follow-up period is 180 days. Nine of these subjects were

screen failures and four device malfunction during set-up, leading to 117 subjects being included in the analysis population, completed by 14 operators.

Four device malfunctions occurred during procedural setup: two extended-reach arm failures, one software initiation failure, and one

**Table 2** Pooled results from three randomized controlled trials

HELPS Trial	N	Mortality	Procedural aneurysm rupture	Thromboembolic complication	Technical success		
White <i>et al</i> 2008 <sup>45</sup>	499	2.2% (11/499) At discharge	3.4% (17/499)	10.2% (51/499)	96.6% (482/499)		
MAPS Trial	N	Mortality	Overall complication rate	Clinical event committee adjudicated		Technical success	
				Rupture/ re-rupture	Ischemic stroke	Hemorrhagic stroke	
McDougall <i>et al</i> 2014 <sup>46</sup>	626	0.2% (1/624) Periproc 2.4% (15/626) 30 day	14.9% (93/624)	0.3% (2/626)	3.4% (21/626)	1.1% (7/626)	97.1% (608/626)
Cerecyte Trial	N	Mortality	Overall complication rate	Procedural aneurysm rupture	Thromboembolic complication	Neuro deterioration	Technical success
Coley <i>et al</i> 2012 <sup>47</sup>	497	0% within 24 hours 0.4% (2/497) discharge	12.3% (61/497)	3.6% (18/497)	5.6% (28/497)	3.0% (15/497)	97.2% (483/497)



**Figure 1** A flowchart of the executive trial summary.

cassette and/or console error. As the procedure was not performed robotically, these subjects were not included in the analysis cohort. Three of these were encountered at the same site. Both extended-reach arm malfunctions happened consecutively, and inspection revealed the cables were not securely connected, with the issue being resolved immediately once the cables were securely attached. The initiation failure happened due to the robot power supply being connected to an outlet controlled by the fluoroscopy pedal, leading to the robotic power being turned off when the fluoroscopy pedal was pressed, which led the robot to not start while the other equipment was in use and was resolved on dealing with this concern. The last one was identified as a cassette and/or console error, which was encountered after connecting the devices, on which an error was noted and prevented the continuation of the procedure robotically.

**Table 3** summarizes the subject demographics and medical history. The mean age of subjects was  $56.6 \pm 12.7$  years, with 74% of the subjects being female. History of smoking was prevalent in 59% of subjects. Hypertension in 49.6% of subjects was the leading comorbidity reported, followed by multiple aneurysms in 38.5% and dyslipidemia in 22.2% of subjects.

Aneurysm characteristics are summarized in **table 4**. Most of the aneurysms were located at the internal carotid artery (27.9%), followed by the anterior communicating artery (22.1%) and middle cerebral artery (9.8%). The mean aneurysm height and neck width was  $5.7 \pm 2.6$  mm and  $3.5 \pm 1.4$  mm, respectively. The mean aneurysm dome to neck ratio was  $1.7 \pm 0.4$ .

Procedural characteristics are presented in **table 5**. The access site was femoral in 60.7% and radial in 37.6% of subjects. All 117 subjects were treated with the primary coiling procedure, with 58 subjects requiring adjunct stenting. The mean number of coils implanted was  $4.8 \pm 3.9$ . Of the 58 stenting subjects, 50 received one stent, alongside eight subjects receiving two or more stents. The overall procedure time was  $117.3 \pm 47.3$  min, with the robotic procedure time of  $59.4 \pm 32.6$  min. The total fluoroscopy time was  $51.9 \pm 27.4$  min with total contrast of  $185.4 \pm 82.3$  cc.

Primary effectiveness success was achieved with the procedure completed robotically in 94.0% (110/117) (88.1%, 97.6%) subjects. Unplanned manual conversion was done in 6.0% (7/117) subjects.

Two device malfunctions occurred: (1) the control console malfunction was attributed to the joystick capacitive functionality, which was not actuating when touched; an investigation identified a loosened joystick cover mounting screws impact from shipping or improper handling, and (2) the cassette malfunction was attributed to an unknown root cause. Five procedural limitations were attributed as follows: three, loss of working length attributed to intermediary catheter placement that contributed to insufficient working length for the microcatheter; one due to off-label microcatheter use during

**Table 3** Baseline demographics and clinical characteristics

Baseline demographics and clinical characteristics	Subjects (n=117)
Age, mean (range)	56.6±12.7 (22 to 79)
Sex	Female 74.4%, males 25.6%
BMI (n=115)	26.7±5.5 (15.6 to -44.3)
Medical history	
History of smoking	59.0% (69/117)
Hypertension	49.6% (58/117)
Multiple aneurysms	38.5% (45/117)
Dyslipidemia	22.2% (26/117)
Family history of UIA or SAH	17.9% (21/117)
History of SAH	17.1% (20/117)
Diagnosed with other rare disease/condition	10.3% (12/117)
Diabetes	8.5% (10/117)
Possible excess alcohol use	6.0% (7/116)
Indications	
Asymptomatic or incidental aneurysm	54.7% (64/117)
Headache	34.2% (40/117)
Aneurysm(s) with a prior SAH from a separate aneurysm	6.0% (7/117)
Stroke	1.7% (2/117)
BMI, body mass index; SAH, subarachnoid hemorrhage; UIA, unruptured intracranial aneurysm.	



**Table 4** Aneurysm characteristics

Aneurysm characteristics	n=122
Location	
Internal carotid artery	27.9% (34/122)
Anterior communicating artery	22.1% (27/122)
Middle cerebral artery	9.8% (12/122)
Posterior communicating artery	9.0% (11/122)
Basilar artery	8.2% (10/122)
Anterior cerebral artery	3.3% (4/122)
Anterior choroidal artery	2.5% (3/122)
Posterior cerebral artery	1.6% (2/122)
Other	15.6% (19/122)
Aneurysm height (mm)	5.7±2.6 (1.5 to 15)
Aneurysm neck width (mm)	3.5±1.4 (1.2 to 9.2)
Dome to neck ratio	1.7±0.4 (0.8 to 3.0)
Relationship to parent wall	
Bifurcation	41.0% (50/122)
Sidewall	59.0% (72/122)

procedure; and one attributed to early detachment of the second coil not allowing its insertion into the aneurysm. **Table 6** summarizes the primary endpoint results.

Primary safety endpoint occurred in 3.4% (4/117) (0.9%, 8.5%) subjects, with two major strokes and two intraprocedural aneurysm ruptures. A total of 24 adjudicated adverse events were reported. Stroke was the most common serious adverse event reported in 12 subjects, with 10 experiencing a minor stroke and only two with a major stroke. Vascular access site complications were reported in four subjects and intraprocedural aneurysm ruptures in two. Electrolyte disorder occurred in two subjects; and hydrocephalus, vasospasm, respiratory failure, and urine infection were each reported once. **Table 7** summarizes these adverse events, and **table 8** details the presentation and clinical outcome of each adverse event.

**Table 5** Procedural characteristics

Procedural characteristics	
Access Site	
Femoral	60.7% (71/117)
Radial	37.6% (44/117)
Brachial	1.7% (2/117)
No. of coils implanted (n=117)	4.8±3.9 (0 to 31)
Stents implanted	
0	50.4% (59/117)
1	42.7% (50/117)
≥2	6.9% (8/117)
Maximum stent diameter (mm) (n=58)	3.9±0.7 (3 to 6)
Overall procedure time (min) (n=115)	117.3±47.3 (17 to 259)
Robotic procedure time (min) (n=116)	59.4±32.6
Fluoroscopy time (min) (n=117)	51.9±27.4 (10 to 157)
Total contrast (cc) (n=116)	185.4±82.3 (60 to 530)
Subject radiation exposure (mGy.cm <sup>2</sup> ) (n=104)	6 886 135.5±25 767 850.8 (16 814.7 to 143 730 000)
Air Kerma (mGy) (n=98)	2220.4±1526.9 (1914 to 2527)

**Table 6** Primary endpoints

Endpoint	Analysis cohort (Subjects)
Primary Effectiveness	94.0% (110/117) (88.1%, 97.6%)
Procedure Completed Robotically	94.0% (110/117)
Unplanned Manual Conversion	6.0% (7/117)
Device Malfunction	1.7% (2/117)
Control Console Failure	0.9% (1/117)
Cassette Failure	0.9% (1/117)
Procedural Limitation	4.3% (5/117)
Loss of Working Length	2.6% (3/117)
Use of Off-label Microcatheter	0.9% (1/117)
Coil Deployment	0.9% (1/117)
Primary Safety	3.4% (4/117) (0.9%, 8.5%)
Stroke (Major)	1.7% (2/117)
Intraprocedural Aneurysm Rupture	1.7% (2/117)

A postprocedure Raymond-Roy Classification Scale score of 1 was achieved in 64.5% of subjects, signifying complete obliteration; followed by 4.5% having residual neck and the remaining 31% with a residual aneurysm. The modified Rankin Scale (mRS) score was 0 for 78.2% of the subjects post procedure, with no subjects having mRS score ≥3. **Tables 9 and 10** summarize this information. Both, the Raymond-Roy Classification Scale and mRS will be continued to follow-up for all subjects till 180 days, as part of the trial design.

## DISCUSSION

The primary effectiveness success achieved in 94% (110/117) subjects was slightly lower than technical success of the three randomized controlled trials: HELPS, MAPS, and Cerecyte Trial, ranging from 96.6 to 97.2%. Of the seven unplanned conversions to manual treatment that were attributed to not meeting the primary effectiveness endpoint, only two were attributed to device malfunctions that happened during the procedure, with the remaining five procedural limitations. **Table 11** summarizes the literature comparison.

In subjects treated with the CorPath GRX System, a total of 25 adverse events subjects were reported. All these events were reviewed and classified by an independent clinical events committee. Ten of these events were attributed to minor strokes with a National Institutes of Health Stroke Scale score <3, and each of them required no further intervention, with the subjects being clinically observed and discharged with an mRS score of either 0 or 1. Of the five main serious events that constituted primary safety endpoint failures, two

**Table 7** All adverse events within 24 hours (adjudicated)

Adverse event type	No. of subjects (%)
Stroke (minor)	10/117 (8.5%)
Stroke (major)	2/117 (1.7%)
Intraprocedural aneurysm rupture	2/117 (1.7%)
Vascular access site complication	4/117 (3.4%)
Electrolyte disorder	2/117 (1.7%)
Hydrocephalus	1/117 (0.9%)
Vasospasm	1/117 (0.9%)
Respiratory failure	1/117 (0.9%)
Urine infection	1/117 (0.9%)

**Table 8** Adverse event presentation and outcome

All adverse events: classification and outcome	
Stroke (Minor)	
01–29	Seizure episode - home discharge on third postoperative day with mRS score 1
01–35	Headache and loss of strength/sensation episode overnight - home discharge on third postoperative day with mRS score 0
02–19	NIHSS score 2 Stroke - home discharge on fifth postoperative day with mRS score 1
02–20	NIHSS score 1 Stroke - private rehab discharge on ninth postoperative day with mRS score 1
02–22	NIHSS score 2 Stroke - home discharge on fifth postoperative day with mRS score 1
02–23	Left extremities' weakness - home discharge on sixth postoperative day with mRS score 0
02–25	Right upper limb weakness and sluggish pupil - home discharge on ninth postoperative day with mRS score 0
02–27	Aphasia/altered sensation/panic episode - home discharge on fifth postoperative day with mRS score 1
07–10	Somnolent with acute respiratory insufficiency – home discharge on ninth postoperative day with mRS score 1
11–02	'Discrete micro-ischemia' on Imaging – home discharge on second postoperative day with mRS score 0
Stroke (major)	
01–05	NIHSS 1 Stroke with anterograde amnesia – home discharge on second postoperative day with mRS score 1
04–06	Right hemi-paresis requiring intra-arterial fibrinolysis - home discharge on third postoperative day with mRS score 1
Intraprocedural aneurysm rupture	
01–19	Rupture during second coil deployment, with hemostasis rapidly achieved with heparin reversion and further coiling
04–04	Rupture during coil deployment, with extravasation stopped via manual carotid compression and remodeling balloon inflation at aneurysmal neck
Vascular access site complication	
01–33	Minor hematoma at puncture site
05–10	Pseudoaneurysm requiring 2 units of blood transfusion
05–19	Hematoma requiring a follow-up CT scan, leading to extended hospitalization
10–11	Retroperitoneal hematoma requiring 1 unit of blood transfusion
Electrolyte disorder	
04–04	During hospital course of same subject with intraprocedural aneurysm rupture
04–06	During hospital course of same subject with major stroke
Hydrocephalus	
04–04	Same subject with intraprocedural aneurysm rupture, requiring external ventricular drainage placement
Vasospasm	
04–06	Same subject with major stroke - focal vasospasm, responded to nimodipine infusion
Respiratory failure	
07–10	Same subject with minor stroke – acute respiratory insufficiency due to chronic emphysema
Urine Infection	
05–08	Antibiotic treatment requiring prolonged hospitalization

mRS, modified Rankin Scale; NIHSS, National Institutes of Health Stroke Scale.

were major strokes, and both subjects were discharged home clinically stable on the second and third postoperative, day respectively, with an mRS score of 1. Previous literature highlights thromboembolic complications ranging from 5.6% in the Cerecyte Trial to 10.2% in the HELPS Trial. Combining both minor and major stroke, constitute 10.26% (12/117), which is comparable to the upper limit reported by these randomized controlled trials described, all of our strokes concluded with the subjects discharged clinically stable with

an mRS score ≤1. The two remaining events considered primarily safety endpoint failures, were intraprocedural aneurysm ruptures (1.7% subjects), which occurred within the range of these trials mentioned above: 2.2% in MAPS to 3.6% in Cerecyte.

Comparison of the core-laboratory reviewed Raymond-Roy Scale postprocedure showed that CorPath GRX had the highest cohort of complete obliteration score in 64.5% subjects, and residual aneurysm

**Table 9** Raymond-Roy Classification scale

Raymond-Roy Classification Scale (postprocedure) n=110	
1	64.5% (71/110)
2	4.5% (5/110)
3a	25.5% (28/110)
3b	5.5% (6/110)

**Table 10** Modified Rankin Scale

Clinical outcome		
Modified Rankin Scale	Preprocedure	Postprocedure
n=mean±SD (range)	115=0.4±0.6 (0 to 2)	78=0.3±0.5 (0 to 2)
0	65.2% (75/115)	78.2% (61/78)
1	28.7% (33/115)	17.9% (14/78)
2	6.1% (7/115)	3.8% (3/78)

**Table 11** Aneurysm treatment prospective studies literature used for comparison

	HELPS Trial	MAPS Trial	Cerecyte Trial	CorPath GRX
Technical success	96.6 %	97.1 %	97.2 %	94.0 %
Intraprocedural aneurysm rupture	3.4 %	2.2 %	3.6 %	2.6 %
Thromboembolic complications	10.2 %	4.5 %	5.6 %	10.25 %
Mortality	2.2% at discharge	0.2% periprocedural	0.4% before discharge	0% at discharge
Raymond-Roy Scale postprocedure	Operator self-assessed	Core-laboratory review	Core-laboratory review	Core-laboratory review
1	47.5 %	36.1 %	26.2 %	64.5%
2	34.5 %	26.2 %	49.5 %	4.5 %
3	18.0 %	37.7 %	24.3 %	31.0 %
Clinical assessment at discharge	WFNS		mRS	mRS
	0	38.5 %	0	81.8 %
	1–2	55.3 %	1	15.9 %
	≥ 3	6.0 %	2	2.3 %
			≥ 3	0 %

mRS, modified Rankin Scale; WFNS, World Federation of Neurological Surgeons.

in 31.0% of subjects, which was in comparison with the range of 24.3% in Cerecyte to 37.7% in MAPS. The modified Rankin Scale was almost similar to the those reported by Cerecyte, with no patient having an mRS score of  $\geq 3$ .

### Limitations

The current generation of robots has technical limitations that should be taken into consideration when planning surgery: the ability to manage a total of only one microcatheter and one microwire or device at a time; the requirement for the access system be placed manually; and the length of working time for a procedure. Future generations of the robotic system are expected to overcome these issues.

### CONCLUSION

This first-of-its-kind robotic-assisted neurovascular trial demonstrates the effectiveness and safety of the CorPath GRX System for endovascular embolization cerebral aneurysm procedures.

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**Correction notice** Since this paper first published, the author David S Liebeskind has been added to the article.

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Acquisition of data: all authors. Analysis and interpretation of data: VMP, MP and RDT. Drafting the article: VMP, MP, RB, RDT, HR and XYEL. Critically revising the article: all authors. Approved the final version of the manuscript: all authors.

**Funding** This study was funded by Siemens Healthineers Endovascular Robotics.

**Competing interests** VMP is an unpaid consultant for Siemens Healthineers Endovascular Robotics. The following authors have one or more competing interests: HR, NS, FC, DH, MP, JG, MK-O, RDT, RB. These competing interests include board membership, consultancy, employment, expert testimony grants, contract research, lectures/other education events, speakers' bureau, and receipt of equipment or supplies, royalties, stock/stock options/other forms of ownership.

**Patient consent for publication** Consent obtained directly from patient(s)

**Ethics approval** This study involves human participants and was approved by The Unity Health Toronto Research Ethics Board; REB 20-333; Les Comités de Protection des Personnes IORG0009918; Gold Coast Hospital and Health Service Human Research Ethics Committee EC00160; University Health Network Research Ethics Board 19-5517; Research Ethics Committee with Medicines of the Hospital Universitari Vall d'Hebron IRB00002850; Gesundheits-, Sozial- und Integrationsdirektion Kantonale Ethikkommission für die Forschung, Ethikkommission Bern 2021-D0024; Ethikkommission für das Bundesland Salzburg 1222/2021; Comité de Ética de la Investigación con Medicamentos Área de Salud Valladolid Este Hospital Clínico Valladolid CASVE-PS-20-443. Participants gave informed consent to participate in the study before taking part.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Data availability statement** Data are available upon reasonable request.

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