Original article

Influence of vessel morphology and variations on technical and clinical success in mechanical thrombectomy: -In vivo and in vitro analyses-

Silke Hopf-Jensen*, Joana Marques, Stephanie Lehrke, Michael Preiß, Stefan Müller-Hülsbeck

Institute for Diagnostic and Interventional Radiology and Neuroradiology, Diakonissen hospital Flensburg, Knuthstrasse 1, Flensburg 24939, Germany

ABSTRACT

Purpose. – To determine the impact of vessel variation and anatomical features on technical and clinical success.

Materials and methods. – In vitro blood clots ($n = 100$) were introduced into a silicon carotid-T flow model of 2, 3 or 4 mm. The ICA/M1 angle varied at 45°, 90°, 135° and 180°. Peripheral embolism was measured. In vivo 50 pat. (73.5 yrs., ± 15) with MCA occlusion were examined for siphon variation, ICA morphology, vessel diameter and angles. The patients were divided according to the clinical success (mRS): group A: mRS ≤ 2 after 90 day and group B: mRS ≥ 3. Furthermore the technical success (TICI) and number of retrieval (n) were analysed.

Results. – In vitro with larger vessel diameter the migrated thrombus load decreased ($P = .001$). The steeper the M1/ICA angles, the higher thrombus weighs (180°: 2.94 mg; 135°: 6.32 mg; 90°: 8.65 mg, 45°: 10.69 mg; $P < .001$). In vivo patients with mRS ≤ 2 had significantly lower NIHSS (16.5 vs 20, $P = .009$) and higher ASPECTS (9 vs 6, $P < .05$). TICI ≥ 2b was more often achieved (86.6 vs 40% $P = .002$). The procedure time was lower (45 vs. 80 min, $P < .05$) with smaller number of retrieval (1.5 vs 4, $P < 05$). Proximal ICA stenosis offers a trend to unfavourable outcome ($P = .073$). Siphon variation "D" is associated with less retrieval manoeuvre.

Conclusion. – While in vitro there is a close correlation between embolism and vascular anatomy, in vivo carotid artery stenosis and siphon variation influence clinical and technical success.

Introduction

With the establishment of stent-retriever assisted mechanical thrombectomy (MT) techniques the clinical outcome improved continuously.

The influence of vessel variation and tortuosity on technical and clinical success still remains unclear. Previous authors suggest a relationship between vessel curvature and tortuosity and results of MT [1–3]. Especially older patients with a long history of hypertension develop elongated arteries that may influence catheterization and duration of the procedure [1]. Schwaiger et al, find that in patients presenting a middle cerebral artery (MCA) curvature with more than 80° a successful recanalization is significantly less likely [4]. Also Yamamoto et al, shows that a tortuous M1 segment is associated with unsuccessful recanalization using Merci (Concentric Medical Inc., Mountain View, California, USA) retrieval system [5]. Zhu et al., illustrates by the susceptibility vessel sign in T2* gradient echo MRI, that division branches and curving shape of the MCA stem decreases technical and clinical success of Merci retrieval assistant thrombectomy [3]. According to Kaymaz et al., there is a trend for lower successful recanalization rates with increasing internal carotid artery access time (ICA-AT) based on take-off angles and vessel tortuosity of the affected side [2].

In this study, we sought to systematically analyse the complex interaction between vessel anatomy and clinical and technical success in vivo and in vitro.
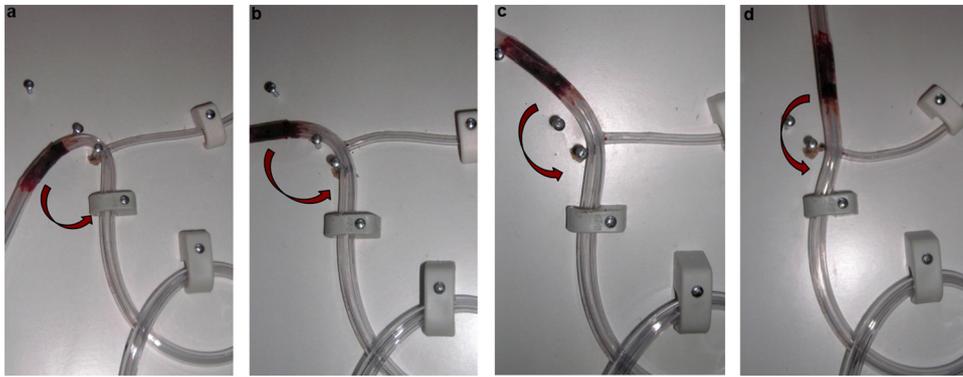
Fig. 1. The flow model consists of an unobstructed silicon tube model mimicking the terminal ICA, carotid-T, the M1 segment of the MCA and the A1 segment of the ACA with varied angels.

Materials and methods

In vitro

The silicon flow model (Fig. 1) for this study consisted of a rotatory pump (Guerbet, KMP, 2000, Sulzbach/Taunus, Germany) and an unobstructed silicon tube model mimicking the ICA, carotid-T, the M1 segment of the MCA and the A1 segment of the ACA. To simulate a carotid artery pulsatile flow, blood-mimicking fluid (sodium chloride solution) was adjusted with a 1.000 ml/min. Blood clots ($n = 100$) from human blood of one healthy volunteer were placed into silicon tubes mimicking the M1 segment with an inner tube diameter (ID) of 2, 3 or 4 mm. The ICA/M1 angle varied with $45°$, $90°$, $135°$ and $180°$. The ICA diameter measured constantly 2.1 mm. Via a short 6F sheath a 6F guide catheter (Cordis, Fremont, California, USA), which was continuously flushed with heparinized saline, was positioned in the virtual cavernous segment of the ICA. In coaxial technique, a 0.018-inch microcatheter (Rebar, Stryker, Kalamazoo, MI, USA) and 0.014-inch micowire (Traxcess 14; MicroVention, Tustin, CA, USA) was positioned across the occlusive clot. The stent-retriever (Solitaire FR, 4×20 mm, ev3/Covidien, Irvine, CA, USA) was deployed for 5 min within the clot. The device and microcatheter were simultaneously retrieved with additional manual aspiration by using a 50 ml lockable syringe. The procedure was performed without proximal flow arrest or intermediate catheter to analyse the influence of vessel morphology. Migrated clots were caught in a filtration system (10 μm) before re-entering a reservoir. The filters, including embolized clots, were weighted (Sartorius Analytical Balance, Göttingen, Germany). After 36 h heat-drying the residual thrombus particles and filters were weighted again. The wet thrombus weight was recalculated by using a factor determinate by heat-drying a series of je 10 wet clots of 49,26 mg ($\pm 2,81$ mg) in a vessel ID of 4 mm, 39,71 mg ($\pm 2,14$ mg) in a vessel ID of 3 mm and 22,41 mg ($\pm 1,43$ mg) in a vessel ID of 2 mm. This was intended to account for the fluid loss during the drying process [6]. Filters with debris were changed after each thrombectomy.

The study and the collection of clinical data was approved by the ethic committee of the Christian-Albrecht University Kiel (D506/13).

In vivo

During a period of 23 months between January 2012 and November 2014, 50 patients (median 73.5 yrs., ± 15 yrs.; female = 30) who underwent endovascular treatment for acute MCA occlusion at the Diaconess hospital Flensburg, Germany were analysed. Clinical and technical data were recorded and measured. Patients with M1 segment ($n = 44$, 88%) and proximal M2 segment ($n = 6$, 12%) occlusion were included. According to recent literature,

neurologic deficit of an NIHSS score of ≥ 7 was required to indicate treatment. The baseline NIHSS score and modified Rankin Scale (mRS) was assessed before and after the procedure and followed up after 3 months. The patients were divided into 2 groups, according to their clinical outcome after 90 days: group A: mRS ≤ 2; group
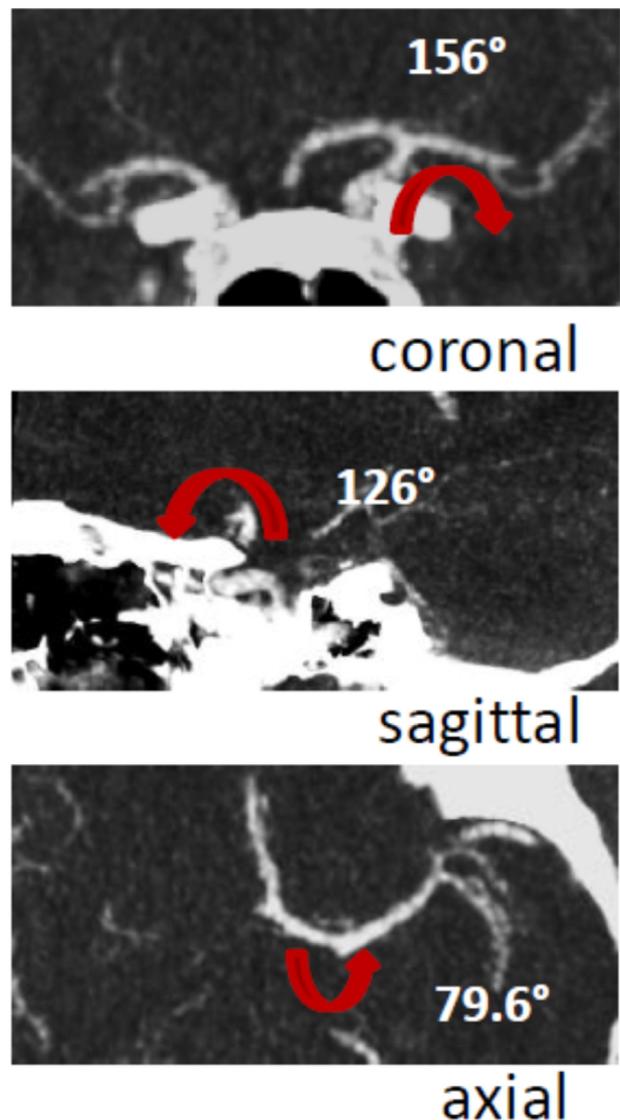

Fig. 2. MIP CT scan (5 mm): Carotid-T angulation was measured in coronal, sagittal and axial reconstruction.

B: mRS ≥ 3. To analyse the technical success the patients were also divided in two groups according to the TICI score: group C: TICI 2b–3, group D: TICI 0–2a.

The third division of the patients in two groups depends on the technical success measured by the number of retrieval manoeuvre (n): group E: $n = 1–2$, group F: $n = > 2$.

The imaging-protocol consists of non-contrast computed tomography (NCCT) and CT Angiography (CTA) on a 64–detector row CT scanner (Discovery CT750 HD, General Electric Healthcare, Waukesha, WI, USA) at admission. Vessel diameter of M1, A1, ICA segment and carotid T- (ICA/M1) angles were determined on primary CTA scan in axial, coronal and sagittal maximum intensity projection (MIP) reconstruction (5 mm, Fig. 2). Siphon variations according to Dilenge type a-d (1962) were analysed (Fig. 3). Cervical ICA morphology with coiling, kinking, elongation and significant stenosis (≥ 60% due to NASCET) were evaluated (Fig. 4). The Alberta Stroke Program Early Computed Tomography Score (ASPECTS, 0–10 points) was calculated. MT was performed in patients who presented within a timeframe of 6 hours after symptom onset. Patients with wake-up stroke were included, if there was an infarct demarcation of less than 1/3 of the MCA territory in the primary CT and the infarct core is less than 33% as detected by CT perfusion. Contraindications for MT were intracranial haemorrhage or tumour. Following the guidelines by the German Society of Neurology, preinterventionally, intravenously (iv) rtPA is applied within a timeframe of 4.5 hours after observed symptom onset if no contraindications existed. A dual energy CT is performed routinely within 24 hours after endovascular procedure.

Recanalization procedures are performed under general anaesthesia in the angio suite (Axiom Artis, Siemens Healthcare, Erlangen, Germany). During the procedure, the patients receive 5000-7500 IU of heparin intraarterially to attain an activated clotting time (ACT) of more than 200 seconds. Via femoral access a 6-F guiding catheter (Cordis, Freemont, California, USA) is placed in the cervical ICA through a short 6F sheath (Terumo, Japan). The sheath is infused with pressurized isotonic sodium chloride solution with heparin. A 0.018-inch microcatheter (Rebar, Stryker, Kalamazoo, MI, USA) is navigated beyond the occluded point over a 0.014-inch microwire (Traxcess 14; MicroVention, Tustin, CA, USA). The Solitaire FR Revascularization Device (4 × 20 mm, ev3, Irvine, CA, USA) is fully deployed within the clot and is retrieved after 5 minutes. The clot is caught by a stent-retriever and retrieved under manual suction without proximal flow arrest and intermediate catheter. Hence, the impact of vessel anatomy and variants could be analysed.

This procedure was repeated until successful recanalization was achieved. Recanalization results were graded in the final angiogram by using the TICI score. TICI 2b and 3 scores correspond to successful recanalization. Intracerebral haemorrhagic, dissection or subarachnoid haemorrhage (SAH) was determined as procedure-related complications. Complications are defined as symptomatic, if the clinical symptoms measured on the NIHSS score increased by more than 4 points.

Statistical Analysis

As statistical software, IBM Social Sciences (SPSS) for Windows version 22 (SPSS, Inc., Chicago, Illinois, USA) was used. Data was presented as mean, value and standard division. Pearson's chi-square tests and Student's t-test were performed to analyse significant differences among the subgroups. For all statistical analyses, the level for a significant difference was set at $P ≤ 0.05$ and for a trend toward significance at $P ≤ 0.1$.

Results

In vitro

An experimental in vitro silicon carotid-T flow model was used for analyses of vessel diameter and angulation, as well as the impact for distal emboli.

Fig. 5a and b demonstrates the emboli weight measured in the filtration system distally to the M1 segment. With a M1 vessel tube ID of 2 mm and a constant ICA/M1 angle of 90°, weight of emboli captured was 11.16 mg (± 0.77 mg), which was significantly more than in the larger M1 ID of 3 mm (9.67 mg, ± 1.28;) or the M1 ID of 4 mm (8.65 mg, ± 0.76, $P < 0.05$). When changing the ICA/M1 angle, there was a significant correlation between the angulation and the volume of embolism. The wider the ICA/M1 angle, the less the embolism weighs observed. The thrombus weight was 10.69 mg (± 0.94 mg) at 45°, 8.65 mg (± 0.76 mg) at 90°, 6.32 mg (± 2.11 mg) at 135° and 2.94 mg (± 1.03 mg) at 180° ($P < .001$).

Fig. 5 c and d illustrates the embolism weight measured in the end of the virtual A1 segment. The wider the vessel diameter in the M1 segment with a constant ICA/A1 angle of 90°, the higher emboli weights in the A1 segment. With a 2 mm ID of the M1 segment, the peripheral emboli weight was 1.01 mg (±0.9 mg), with a 3 mm ID it was 2.43 mg (±01.47 mg), with a 4 mm ID it was 11.32 mg (±0.86 mg) ($P < 0.04$). The wider the ICA/MCA angle, the lower the emboli weights in the A1 segment ($P < 0.05$). An ICA/M1 angle of 45° caused higher emboli weight of 11.32 mg (±0.86 mg), then an ICA/M1 angle of 90° (4.55 mg, ± 0.48 mg), of 135° (3.43 mg, ±0.34 mg) or of 180° (1.55 mg, ±0.762 mg) ($P < 0.05$). The results showed a strong positive correlation between angulations, vessel diameters and distal emboli.

In vivo

Baseline epidemiological data are displayed in Table 1. There were no statistically significant differences between the two groups amongst the distribution of age, gender or occlusion side. In group A (mRS ≤ 2), a higher rate of vessel occlusion in the M2 segment was found than in group B (6 vs 0, $P < 0.03$). NIHSS at admission was significantly lower (16.5 vs 20, $P = 0.009$), with higher ASPECT-score (9 vs 6, $P < 0.05$). No differences were detected for symptom onset-CT time (160 min vs 150 min, $P = 0.717$) and for CT-puncture time (43 min vs 29 min, $P > 0.05$). There was a trend towards preinterventional bridging therapy in group A (43.3% vs 20%, $P = 0.088$).

Peri- und postintervential data are presented in Table 2. The procedure time was significantly shorter in group A (45 vs 80 min, $P < 0.05$) with less number of manoeuvres (1.5 vs 4, $P < 0.05$). TICI score ≥ 2b was more often achieved (86.6 vs 40% $P = 0.002$), as well as TICI 3 score (86.6 vs 40%, $P = 0.002$). Carotid artery stenting was more often necessary in group B (Group A: 13.3%, Group B: 30%, $P = 0.073$).

The clinical status at discharge from hospital differs between the two groups. NIHSS in group A is lower than in group B (2, ±£2, range 0-6 vs. 6, ±£2, range 3-18, $P = 0.009$), as well as mRS (2.1, ±£1, range 0–2 vs. 4.3, ± £1, range 3-5, $P = 0.006$).

According to vessel anatomy (Table 3) in the 2 groups angular measurement ICA/M1 and vessel diameter in M1 and A1 showed no differences. The distribution of carotid siphon variation according to dilenge is similar in both groups ($P > 0.05$). Proximal ICA stenosis offers a trend to unfavourable outcomes ($P = 0.073$). Treatment data and results of tests for differences are summarized in Table 3.

Furthermore the patients were divided in two groups: group C: TICI 2b-3, group D: TICI 0-2a. No significant differences were found between these two groups according to vessel variation
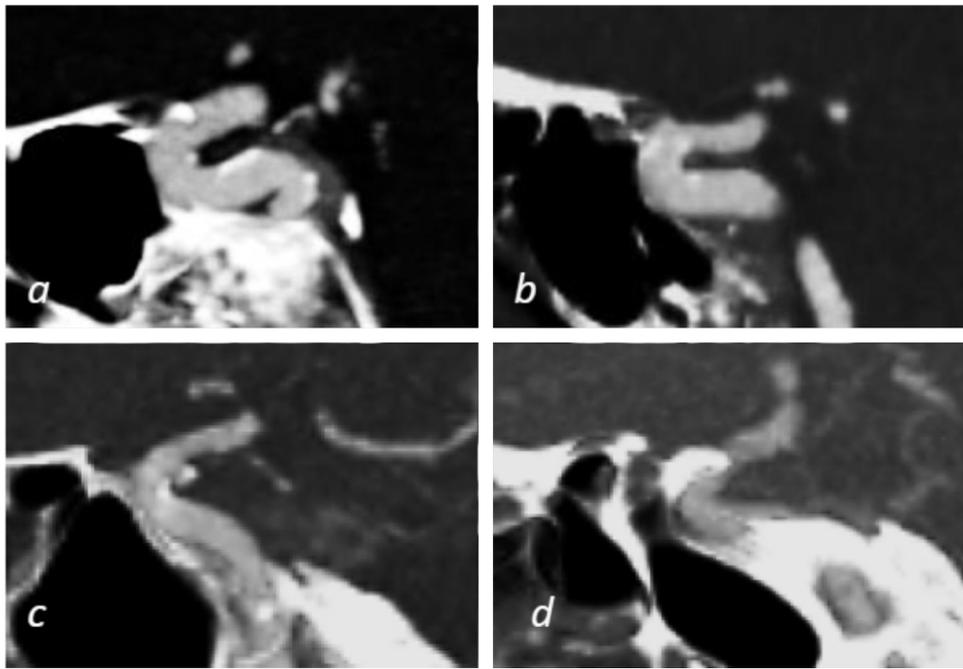
Fig. 3. CTA, sagittal reconstruction. The cavernous segment of the ICA was classified according to Dilenge (1962): type a (omega-form), b (mega-siphon), c (u-form), d (v-form).
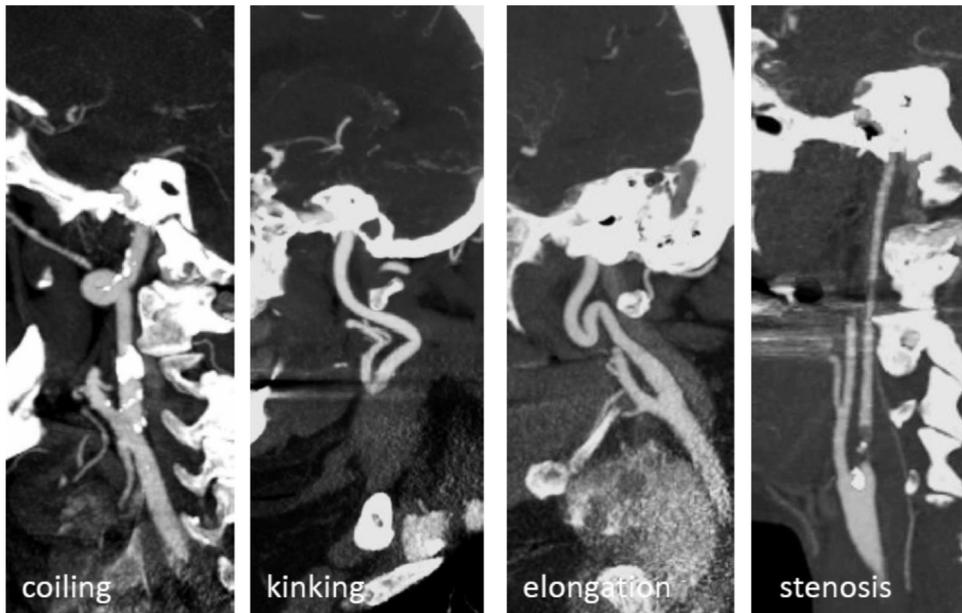

Fig. 4. CTA, sagittal reconstruction, shows the cervical part of the ICA,: Elongation kinking, coiling and straight vessel with high-grade stenosis (≥ 60%).

(Table 4). The third division of the patients in two groups depend on the number of retrieval manoeuvre (n): group E: $n = 1–2$, group F: $n = >2$. Only siphon variation typ d shows a trend for less number of retrieval (Table 5).

Discussion

Although several trials have shown the efficiency of MT in acute ischemic stroke in anterior circulation, only some factors are understood that may determine a good clinical outcome, including NIHSS (National Institutes of Health Stroke Scale), thrombus length, time to recanalization and TICI (Thrombolysis in cerebral infarction) score [7]. Otherwise several variables still remain unclear. In regards to the expanded indications for MT with wider timeframe and increasing age of the patients with progressive elongation and tortuosity of the supraaortic vessel due to the atherosclerosis and long standing uncontrolled hypertension the impact of anatomic features is one interesting point. In this study, we focused on vessel
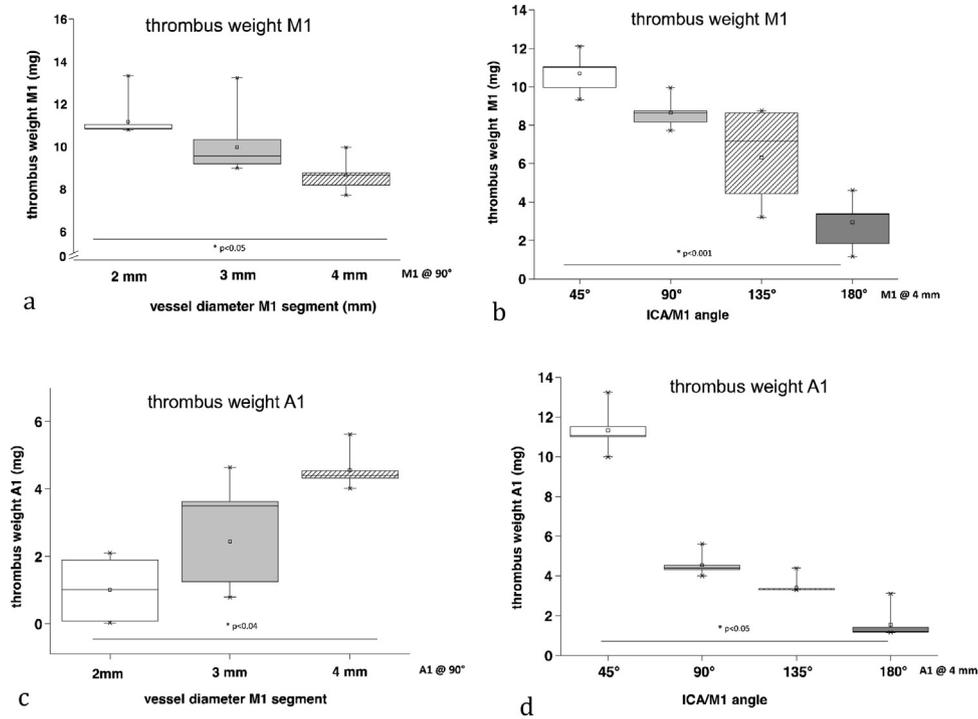
Fig. 5. Data are shown as box plots (mean, ± SD). There is a strong correlation for an inreasing risk of peripheral M1 embolism with smaller M1 vessel diameter and steeper ICA/M1 angel (Fig. 5a and b). In contrast, the thrombus weight in A1 decreased with smaller M1 vessel ID (Fig. 5c). On the other hand stepper ICA/M1 angel caused more embolism in the peripheral A1 segment (Fig. 5d).

Table 1
Pre-interventional epidemiologic data shows differences in occlusion location (M1,M2), clinical status at admission (NIHSS and mRS) and ASPECT score.

Pre-interventional	Group A: mRS $\leq$ 2	Group B: mRS $\geq$ 3	P-Value
Patients (n)	30	20	
Age (year)	70.5 ± 16.1 (33–89)	76.5 ± 12.15 (40–91)	0.073
Gender: female	19 (63.3%)	11 (55%)	> 0.05
Occlusion side right	15 (50%)	11 (55%)	> 0.05
M1	24 (80%)	20 (100%)	0.033
M2	6 (20%)	0 (0%)	0.033
Wake up	4 (13.3%)	5 (25%)	> 0.05
Simultan MI	1 (3.3%)	1 (5%)	0.768
NIHSS	16.5 ± 3.9 (7–25)	20 ± 4.4 (8–28)	0.009
mRS	5 ± 0.51 (4–5)	5 ± 0.3 (4–5)	0.006
ASPECTS	9 ± 1.53 (5–10)	6 ± 2.32 (2–10)	< 0.05
Symptom onset - CT	160 ± 67.7 (30–270)	150 ± 93.19 (25–258)	0.717
CT–XA	43 ± 21.9 (15–120)	39.5 ± 25.09 (11–95)	> 0.05
Bridging	13 (43.3%)	4 (20%)	0.088

Data are displayed as number (percentage) or mean ± SD, range: minimum–maximum.

Table 2
Peri-interventional data show differences in procedure time, number of retrieval and TICI score.

	Group A: mRS $\geq$ 2	Group B: mRS $\geq$ 3	P-Value
Peri-interventional			
Time XA (min)	45 (± 26.7, 15–120)	80 (± 31.11, 40–120)	< 0.05
Retrieval (n/%)	1.5 (± 1.38, 1–6)	4 (± 2.84, 1–12)	< 0.05
i.a. Lysis (n/%)	7 (23.3%)	9 (45%)	0.108
ICA stenting	4 (13.3%)	6 (30%)	0.073
TICI2b/3	29 (96.6%)	15 (75%)	0.054
TICI 3	26 (86.6%)	8 (40%)	0.002
Post-interventional			
NIHSS at discharge	2 (± 2, 0–6)	6 (± 2, 3–18)	0.009
mRS at discharge	2.1 (± 1,0–2)	4.3 (± 1, 3–5)	0.006
Symptomatic ICH	0 (0%)	1 (5%)	> 0.05
Contrast enhancement	2 (6.6%)	3 (15%)	0.336

Postinterventional data demonstrate complications and features according to the dual energy CT 24 h after thrombectomy.

Table 3
Illustrates vessel morphology and variability.

Vessel morphology	Group A: mRS ≤ 2	Group B: mRS ≥ 3	*P*-Value
Angular measurement			
Coronar	141.2 (±12.9, 117.7–177.2)	139.5 (±17.2, 120.6–176.9)	0.504
Sagittal	84.2 (±50.7, 25.6–180)	94.75 (±38.1, 23.9–176.9)	0.949
Axial	131.7 (±20.3, 93.2–176.6)	127.35 (±16.6, 94.4–161.3)	0.101
Vessel diameter			
ICA (mm)	3.3 (±0.4, 2.6–4.4)	3.4 (±0.47, 2.2–4.2)	0.959
M1 (mm)	2.5 (±0.4, 1.8–3.9)	2.6 (±0.41, 1.6–3.2)	0.376
A1 (mm)	2.25 (±0.4, 1.3–3)	2.15 (±0.32, 1.6–3)	0.722
ICA extracranial			
Elongation	8 (26.6%)	8 (40%)	0.322
Coiling	0 (0%)	1 (5%)	0.216
Kinking	6 (20%)	3 (15%)	0.652
Stenosis bifurcation (>60%)	4 (13.3%)	6 (30%)	0.073
Carotid siphon (Dilenge)			
a	6 (20%)	6 (30%)	0.599
b	10 (33,3%)	3 (15%)	0.224
c	8 (26.6%)	7 (35%)	0.529
d	6 (20%)	4 (20%)	1.000

Data are displayed as number (percentage) or mean ± SD, range (min–max.). The vessel diameter was measured in the proximal M1 and A1 segment, as well as the terminal ICA segment. The morhology of the internal cerebral artery was classified in elongation, coiling, kinking and proximal stenosis (> 60%). The carotid siphon was characterized in typ a-d according to Dilenge classification. Only the ICA stenosis was a predictor for unfavorable outcome.

Table 4
Presentation of technical success measured by the TICI recanalization score.

	Group C TICI 2b-3			Group D TICI 0-2a			*P*-value
	n (%)	Median	SD	*n* (%)	Median	SD	
Patients (n)	44 (88%)			6 (12%)			
Angle							
Coronar		141.1	14.53		139.3	17.1	>0,05
Sagittal		94.7	45.54		79	53.1	>0,05
Axial		130.8	19.02		125.9	16.3	>0,05
Vessel diameter							
ACI		3.3	0.44		3.5	0.36	>0,05
M1		2.5	0.37		2.45	0.78	>0,05
A1		2.2	0.33		2.2	0.5	>0,05
ICA extracranial							
Elongation	14 (31.8%)			2 (33.3%)			n.sign.
Coiling	0 (0%)			1 (16.6%)			n.sign.
Kinking	7 (15.9%)			2 (33.3%)			n.sign.
Stenose	8 (18.1%)			1 (16.6%)			n.sign.
Carotid siphon (Dilenge)							
a	12 (27.3%)			1 (16.6%)			n.sign.
b	11 (25%)			1 (16.6%)			n.sign.
c	13 (29.5%)			2 (33.3%)			n.sign.
d	8 (18.1%)			2 (33.3%)			n.sign.

TICI scores were assessed on the final angiographic series. A TICI score of 2b or 3 was regarded as successful recanalization. The patients werde devided in two groups: group C: TICI 2b-3, group D: TICI 0-2a. No significant differences were found according to vessel variation.

Table 5
Division of the patients in two groups depend on the technical success measured by the number of retrieval maneuver (n): group E: *n* = 1–2, group F: i => 2.

	Group E retrieval *n*: 1–2			Group F retrieval *n*: >2			*P*-value
	n (%)	Median	SD	*n* (%)	Median	SD	
Patient (n)	23 (46%)			27 (54%)			
Angle							
Coronar		140.5	15.52		141.7	14.14	> 0,05
Sagittal		102.8	46.85		86.5	45.11	> 0,05
Axial		130.2	20.49		130.1	18.05	> 0,05
Vessel diameter							
ICA		3.3	0.48		3.4	0.41	> 0,05
M1		2.3	0.43		2.6	0.4	> 0,05
A1		2.2	0.38		2.2	0.32	> 0,05
Vessel-morphology							
Elongation	7 (30.4%)			9 (33.3%)			n.sign.
Coiling	1 (4.3%)			0 (0%)			n.sign.
Kinking	4 (17,3%)			5 (18.5%)			n.sign.
Stenose	5 (21.7%)			4 (14.8%)			n.sign.
Siphon-variaten							
a	5 (21.7%)			8 (29.6%)			n.sign.
b	4 (17,3%)			8 (29.6%)			n.sign.
c	6 (26.1%)			9 (33.3%)			n.sign.
d	8 (34.8%)			2 (7.4%)			< 0,05

Only siphon variation type d shows a trend for less number of retrieval. n.sig.: not significant.

variability in the in vitro and in vivo. In the flow model we analysed distal embolization according to different vessel angulation and diameter.

In literature, recent studies emphasize the impact of vessel anatomy on clinical outcome or technical success of intracranial procedures [8]. Yamamoto et al., showed that a tortuous M1 segment was associated with unsuccessful recanalization using Merci retrieval system and therefore supported the theory of anatomical dependency [5].

Lee et al., described that the tortuosity of proximal vessels is a risk factor for technical failures of intracranial endovascular procedures. In 11 cases of 73 symptomatic intracranial stenosis (>50%), standard techniques of navigating the stent-delivery system into the intended lesion failed because of vascular tortuosity [8]. According to Kaymaz et al., supraartic vessel tortuosity significantly influences the internal carotid artery access time (ICA-AT) in MT. Take-off angle of the left common carotid artery and the brachiocephalic trunk as well as the tortuosity of the CCA had the highest impact on ICA-AT. There furthermore was a trend for lower successful recanalization rates with increasing ICA-AT. Schwaiger et al., showed in a retrospective analysis that patients without successful recanalization (TICI 0–2a) had both significantly larger ICA/M1 and M1/M1 angles in proximal vessel occlusions and larger M1/M2 angles in distal vessel occlusions [1]. Zhu et al., analysed clot shape and vessel curvature as shown by the susceptibility vessel sign in axial T2* gradient echo sequences, and its influence on recanalization results [3]. Extension of thrombus into middle cerebral artery division branches and curving shape of the middle cerebral artery stem decreases technical and clinical success of Merci thrombectomy in M1 occlusions [3].

In a study that analyses the safety and efficacy of the pREset device, a successful recanalization is significantly less likely in patients presenting an MCA curvature with more than 80° [4]. The interaction between stent retriever, embolism and vessel anatomy when retracting the stent retriever toward guiding balloon catheter or the distal-access catheter following kinking, coiling or curved vessel segments is not fully understood. The stent retriever may be stretched or may diminish its full spatial extension and thus the grip and interacting forces on the thrombus may be reduced [1]. Only a few authors postulate that carotid elongation measured on preinterventional CT does not affect angiographic results [9].

In our study, we analysed retrospective data between 2012-2014 without proximal balloon occlusion or intermediate catheter. Current data with triaxial technique may change the results. We found a strong correlation between vessel diameter, angulation and peripheral embolism in vitro. With stepper ICA/MCA angel the emboli weight in the distal M1 and A1 segment increased. With larger M1 vessel diameter, the weight of the emboli in the M1 segment decreased, while the emboli weight in the A1 segment increased. This is maybe due to fact, that the ACA diameter remains unchanged small. Taking into account the physical behaviour of liquids, that increases in speed in narrower tubes. Blood flow increases in smaller vessels and may lead to faster distal occlusion. In larger MCA vessels with introduced stent retriever the blood flow will be slower and the stent retriever can catch and keep the thrombus more easily.

Chueh et al., illustrated in a flow model, that the risk of embolic shower was influenced by the thrombectomy device. The Merci device generated the fewest number of large fragments compared with the Penumbra system ($P < 0.05$) and Solitaire (not significant) [6]. In our study, we only used one stent retriever type to obtain unbiased results.

In contrast to the in vitro results we showed only subtle influence of vessel anatomy to the clinical outcomes in vivo. We analysed the ICA anatomy in cervical and cavernous segment on CTA as well as the ICA/M1 angulation and vessel diameters. Only the proximal ICA stenosis offers a trend to unfavourable outcomes. Consequently MT in elder patients with progressive elongation and tortuosity of the vessel segments can although lead to positive clinical outcomes. No significant differences were found according to vessel variation and successful recanalization according to the TICI score. Therefore TICI 2b-3 can also be reached in elongated vessel with complex variation, kinking or coiling. According to the number of retrieval more patients with first- or second pass thrombectomy (number of retrieval 1-2) showed a siphon variation type d (34.8% vs 7.4%). This v-form may favour fast and comfortable retriever manoeuvre compared to the omega or megasiphon.

So far in vitro results, showing a strong dependency of vessel anatomy and technical success, have lacked direct comparisons with in vivo results. These findings confirm that anatomical criteria should be keeping in mind but not only used for patient selection criteria suitable for MT.

This study has several limitations, mainly due to the small sample side. Data with intermediate catheter were excluded, due to their support for the retrieval manoeuvre and secondary impact of elongation and angles. The flow model was built of silicon tubes, missing the flexibility of human vessels and atherosclerotic irregularity. In vitro results could therefore not provide the interaction of the stent retriever with the vessel wall. The flow model could not imitate possible local vasospasm or modification of the angulation due to the withdrawal of the retriever system. Therefore these data need to be extrapolated with care to clinical scenario.

Conclusion

In our experimental flow model we found a strong positive correlation between peripheral embolism and vascular anatomy. The emboli weight increased with smaller vessel diameter and steeper angulation. In vivo, vessel variation and variability in anterior circulation had no relevant influence on the outcome of MT. Only in terms of carotid artery stenosis the cervical vessel variation shows a trend to unfavourable clinical outcomes.

Disclosure of interest

The authors declare that they have no competing of interest.

Acknowledgments

References

[1] Schwaiger BJ, Gersing AS, Zimmer C, Prothmann S. The Curved MCA: Influence of Vessel Anatomy on Recanalization Results of Mechanical Thrombectomy after Acute Ischemic Stroke. AJNR Am J Neuroradiol 2015;36(5):971–6.

[2] Kaymaz ZO, Nikoubashman O, Brockmann MA, Wiesmann M, Brockmann C. Influence of carotid tortuosity on internal carotid artery access time in the treatment of acute ischemic stroke. Interv Neuroradiol 2017;23(6):583–8.

[3] Zhu L, Liebeskind DS, Jahan R, et al. Thrombus branching and vessel curvature are important determinants of middle cerebral artery trunk recanalization with Merci thrombectomy devices. Stroke 2012;43:787–92.

[4] Schwaiger BJ, Kober F, Gersing AS, et al. The pREset stent retriever for endovascular treatment of stroke caused by MCA occlusion: safety and clinical outcome. Clin Neuroradiol 2014.

[5] Yamamoto S, Yamagami H, Todo K, Kuramoto Y, Ishikawa T, Imamura H, et al. Correlation of middle cerebral artery tortuosity with successful recanalization using the Merci retrieval system with or without adjunctive treatments. Neurol Med Chir (Tokyo) 2014;54(2):113–9.

[6] Chueh JY, Wakhloo AK, Gounis MJ. Effectiveness of mechanical endovascular. thrombectomy in a model system of cerebrovascular occlusion. AJNR Am J Neuroradiol 2012;33(10):1998–2003.

[7] Kaschka IN, Kloska SP, Struffert T, Engelhorn T, Gölitz P, Kurka N, et al. Clinical and radiological outcome after mechanical thrombectomy in acute ischemic stroke: What matters? Neuroradiol J 2016;29(2):99–105.

[8] Lee TH, Choi CH, Park KP, Sung SM, Lee SW, Lee BH, et al. Techniques for intracranial stent navigation in patients with tortuous vessels. AJNR Am J Neuroradiol 2005;26(6):1375–80.

[9] Yilmaz U, Mühl-Benninghaus R, Simgen A, Reith W, Körner H. Carotid Elongation. Does Not Affect Angiographic Results of Mechanical Thrombectomy in Acute Stroke. Clin Neuroradiol 2016;26(2):183–7.