

2019-10-08


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Chueh J, Kang D, Kim BM, Gounis MJ. (2019). Role of Balloon Guide Catheter in Modern Endovascular Thrombectomy. Open Access Articles. <https://doi.org/10.3340/jkns.2019.0114>. Retrieved from <https://escholarship.umassmed.edu/oapubs/4017>

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Role of Balloon Guide Catheter in Modern Endovascular Thrombectomy

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Proximal flow control achieved with a balloon guide catheter (BGC) during endovascular treatment of acute ischemic stroke is reviewed in this article. In clinical practice, BGCs offer a multi-faceted approach for clot retrieval by creating proximal flow arrest, reducing embolic burden, and shortening procedure time. Evaluation of frontline thrombectomy procedures with BGCs revealed advantages of combined use over the conventional guide catheter (CGC), notably in the significant reduction of distal emboli to both the affected and previously unaffected territories. Recently, new measures of early and complete reperfusion at first thrombectomy pass have been identified as independent predictors of improved outcomes, which were consistently demonstrated with use of BGC as a safe and effective option to minimize number of passes during intervention. Prior randomized controlled trials reported the positive correlation between BGC-treated patients and a lower risk of mortality as well as shortened procedure time. While BGC use is more common in stent retriever-mediated mechanical thrombectomy, preliminary data has shown the potential benefit of device application during contact aspiration thrombectomy to achieve successful recanalization. However, the question of which major endovascular strategy reigns superior as a frontline remains to be answered. Along with clinical case assessments, BGC performance during *in-vitro* simulation was analyzed to further understand mechanisms for optimization of thrombectomy technique.

Key Words : Acute stroke · Balloon occlusion · Endovascular thrombectomy · Thrombectomy.

INTRODUCTION

Rapid evolution in endovascular management of acute large vessel occlusion (LVO) over the past 20 years has enabled neurointerventionalists to offer effective reperfusion treatments to properly selected patients. Evolving endovascular techniques for use in cases of acute LVO include intra-arterial fi-

brinolysis, ultrasound-enhanced fibrinolysis, retrievers, contact aspiration with (and later without) catheter debulking separators, and stent-retrievers^{50,56}. Recently, stent retriever-mediated mechanical thrombectomy (SR-MT) is considered the standard-of-care for selected patients with acute LVO in the anterior circulation due to positive results of recent five randomized clinical trials (RCT)^{2,4,16,22,52}. A Direct Aspiration

• Received : May 9, 2019 • Revised : June 14, 2019 • Accepted : June 21, 2019

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First Pass Technique (ADAPT) or contact aspiration thrombectomy (CAT) using large bore catheters is also employed as another frontline treatment for LVO^{12,24,32}. During the evolution of thrombectomy strategies, the versatile uses of 8 F or 9 F balloon guide catheters (BGC) in different clinical setups have been recognized as BGCs can be paired with a single clot retriever system^{23,48} or combined with other adjunctive thrombectomy procedures^{15,37,39}.

Clot fragmentation is an inevitable consequence of mechanical thrombectomy. Although fragments are generated throughout the procedure, the largest single contributor to distal emboli during SR-MT is associated with bringing the device and embedded clot into a receiver, namely a catheter. Since the majority of the clot remains on the outside of the device⁶³, the clot is sheared off the device as it enters the receiver. Inflation of the BGC causes a momentary blockage of antegrade blood flow during SR-MT. Direct aspiration through the BGC during retrieval, or simply removing the rotating hemostatic valve while withdrawing the SR leads to flow reversal at the tip of the BGC allowing the sheared fragments to be removed from the circulation. Regarding the use of BGC during ADAPT, there is a concern about the compromised efficacy of aspiration due to the limitation of the size of aspiration catheter that can be used with the limited inner diameter of the BGC. However, in real practice, some neurointerventionalists have used BGC during ADAPT and have reported the positive role of BGC compared to CGCs^{25,57}. In addition to lowering the risk of distal embolization, shorter procedure time and higher rate of first-pass success as well as better clinical outcomes are further benefits of using BGCs versus non-BGCs, which will be discussed later in this paper^{40,44,64,69}.

Potential off-label use of BGCs has been described in the previous clinical cases^{11,49}. Direct aspiration from the cervical internal carotid artery (ICA) through BGC without any other aspiration catheter or stent retriever was found to be effective in removing or reducing extensive clot burden such as terminal carotid T- and L-type occlusions. Although the feasibility of this technique may be limited due to the complexity of the clot characteristics, blood supply from communicating arteries, and the tortuosity of the vasculature, successful BGC aspiration in eligible patients is likely to reduce the large clot burden in a short period of time and allow smooth transition to the subsequent treatment option such as SR-MT. Lastly, for patients with severe carotid stenosis, temporary inflation of a

BGC is helpful for endovascular device delivery, particularly for a distal access catheter to enter a proximal ICA stent lumen as illustrated in a previous case¹⁰.

Many neurointerventionalists have been reluctant to use BGCs due to a number of concerns, such as difficulty in handling the device, groin complications in patients who are on anticoagulant drugs, induced occlusion of the feeding artery by the BGCs, and compatibility of BGCs with other devices^{47,54}. A recent study retrospectively evaluated the risk of groin complications associated with the use of a large bore BGC or sheath in 472 LVO patients who received mechanical thrombectomy⁵⁴. The results suggested that the rate of large bore sheath-related groin complications was between 0.4% to 0.8% and such minimal risk should not dissuade neurointerventionalists from using BGCs.

EVALUATION OF BALLOON GUIDE CATHETER IN EXPERIMENTAL MODELS

Successful development of *in-vitro* occlusion models not only makes reproducible simulation of mechanical thrombectomy possible but also provides deeper insight into how current thrombectomy technology can be refined to obtain better clinical outcomes. Measures such as device deliverability, recanalization success, hemodynamic data, and distal embolization can be collected and quantified during the *in-vitro* BGC-related studies.

The key elements of an *in-vitro* model system of cerebrovascular occlusion include a patient-specific vascular phantom with collateral circulation, engineered clot analogues, and a flow loop^{7,14,42,43}. Different manufacturing processes for neurovascular modeling have been described in previous work^{9,31,53}. The silicone elastomer is often selected as a base material for constructing vascular replicas due to its high transparency and the similar stress-strain relationship to the human cerebral vessel from postmortem examination at low stretch⁹. The transparent silicone vascular replica and radiopaque clots allow visualization of clot-device interaction during mechanical thrombectomy. For example, clot shear-off from the stent retriever was observed previously in both the *in-vitro* (Fig. 1) and *in-vivo* studies during the BGC assisted SR-MT when the stent retriever was retracted¹⁷. Parts of the clot were found dislodged and accumulated at the tip of the BGC, compromising the BGC

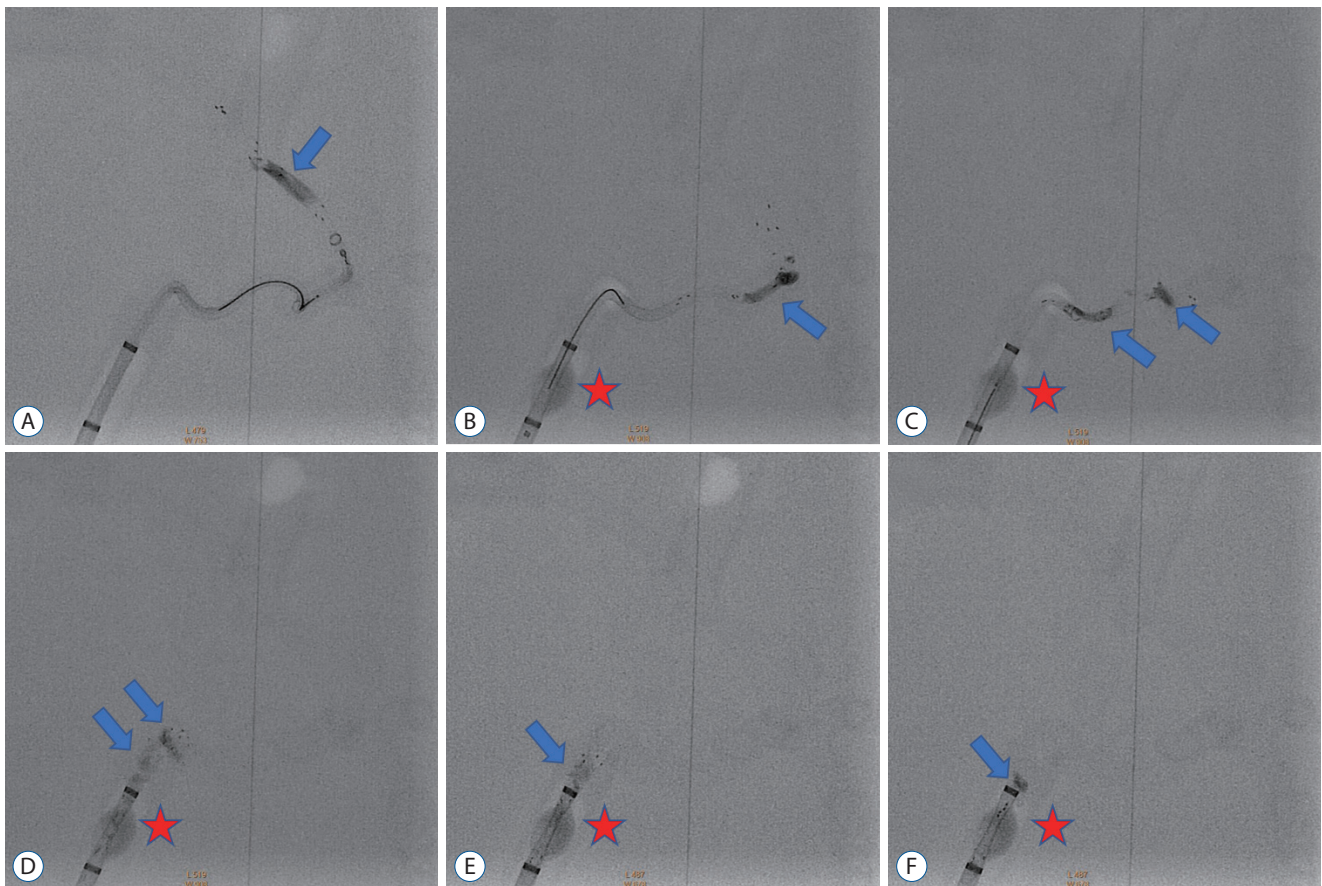


Fig. 1. *In-vitro* observation of clot shear-off from a stent retriever during mechanical thrombectomy. A : A stent retriever is deployed at the MCA to capture the clot (blue arrow). B-E : Prior to clot retrieval, the balloon is inflated (red star) to arrest the ICA flow. Clot fragmentation is observed during clot removal (blue arrows) with the balloon inflated (red star). F : Clot shear-off from a stent retriever is noted, resulting in a portion of the clot remaining (blue arrow) at the tip of the BGC (red star). MCA : middle cerebral artery, ICA : internal carotid artery, BGC : balloon guide catheter.

aspiration efficacy. Identifying such a problem preclinically can help improve the thrombectomy technique and reduce the risk of distal embolization.

Occurrence of embolic shower is one of the undesirable effects of the SR-MT and is technically modifiable. A study with a total of 144 LVO patients enrolled between 2009 and 2011 reported that embolic events happened in 12.5% (18/144) of the patients who received SR-MT and were associated with a higher rate of mortality compared to those with no embolic complications¹³. Interestingly, the incidence of distal emboli or emboli in new territories seems lower in human studies compared to *in-vitro* bench studies. Detection of distal emboli in an *in-vitro* setup was achieved by Mokin et al.⁴³ via gross observation and high-definition video recording. The results of Mokin's study showed that the occurrence of embolization in new territories was significantly reduced by the BGCs,

compared with CGCs ($p=0.0057$). However, the emboli size range analyzed in this study was not specified and there were no differences in number of emboli observed in distal territory between BGCs and CGCs ($p=1.0$).

Another approach for distal emboli characterization was performed by using the Coulter Principle⁶⁻⁸. Saline was circulating in an middle cerebral artery (MCA) occlusion model, and effluent from both the MCA and anterior cerebral artery (ACA) was collected during the thrombectomy procedure for particle characterization. When a particle (clot fragment) traveled through the aperture, change in the impedance across the aperture was measured. The pulse height was proportional to the volume of the sensed particle and was converted to an equivalent spherical diameter. Completion of the particle analysis yielded not only the number, but the size of each clot fragment within the 8–1000 μm range. For particles sized

greater than 1 mm, a caliper was used to measure the maximum length of each particle. Prior *in-vitro* studies using the Coulter Principle for clot measurements found that BGCs significantly reduced the formation of distal emboli when compared to the CGCs⁶⁾, and the BGC-protected thrombectomy was similar to SR-MT with the Lazarus Cover device (Medtronic Neurovascular, Irvine, CA, USA) in terms of the risk of distal embolization⁷⁾. An important finding from these *in-vitro* studies was that the majority of the emboli generated during SR-MT are <20 μm. To date, brain tolerance to emboli is little known; therefore, the ischemic brain damage related to these small particles is difficult to predict. Further investigation through appropriate selection of animal models and advanced imaging techniques should be considered to address the aforementioned issue.

Blood flow control in the cervical ICA has a great impact on the risk of distal or new territory embolization during SR-MT. Quantification of flow reversal and arrest during balloon inflation have been studied in the *in-vitro* MCA occlusion models. The quantitative results demonstrate that MCA flow is

partially restored (Fig. 2A and B, 73.3 mL/min vs. baseline flow of 134.6 mL/min) after deployment of the stent retriever. The presence of the collateral flow keeps the MCA flow constant at 77.9 mL/min after BGC inflation (Fig. 2C). During clot retrieval with the balloon inflated, instantaneous pressure changes are recorded at both proximal and distal ends of the clot (Fig. 2D). A recent study further suggested that when BGC is used in combination with large bore aspiration catheters, the efficacy of proximal aspiration via BGC is minimized. As a result, the flow arrest in the ICA can cause reversed flow from the A1 or posterior communicating artery and can to antegrade flow in the M1 segment³⁸⁾.

Most of the experimental models for evaluation of mechanical thrombectomy are embolic occlusion models with a single site of occlusion (e.g., MCA occlusion). Vasospasm, clot-vessel wall interaction as well as various underlying diseases in LVO patients, such as intracranial atherosclerosis, are not incorporated into the *in-vitro* neurovascular modeling. The absence of the abovementioned pathological processes may explain the high recanalization rate observed during the *in-vitro* simula-

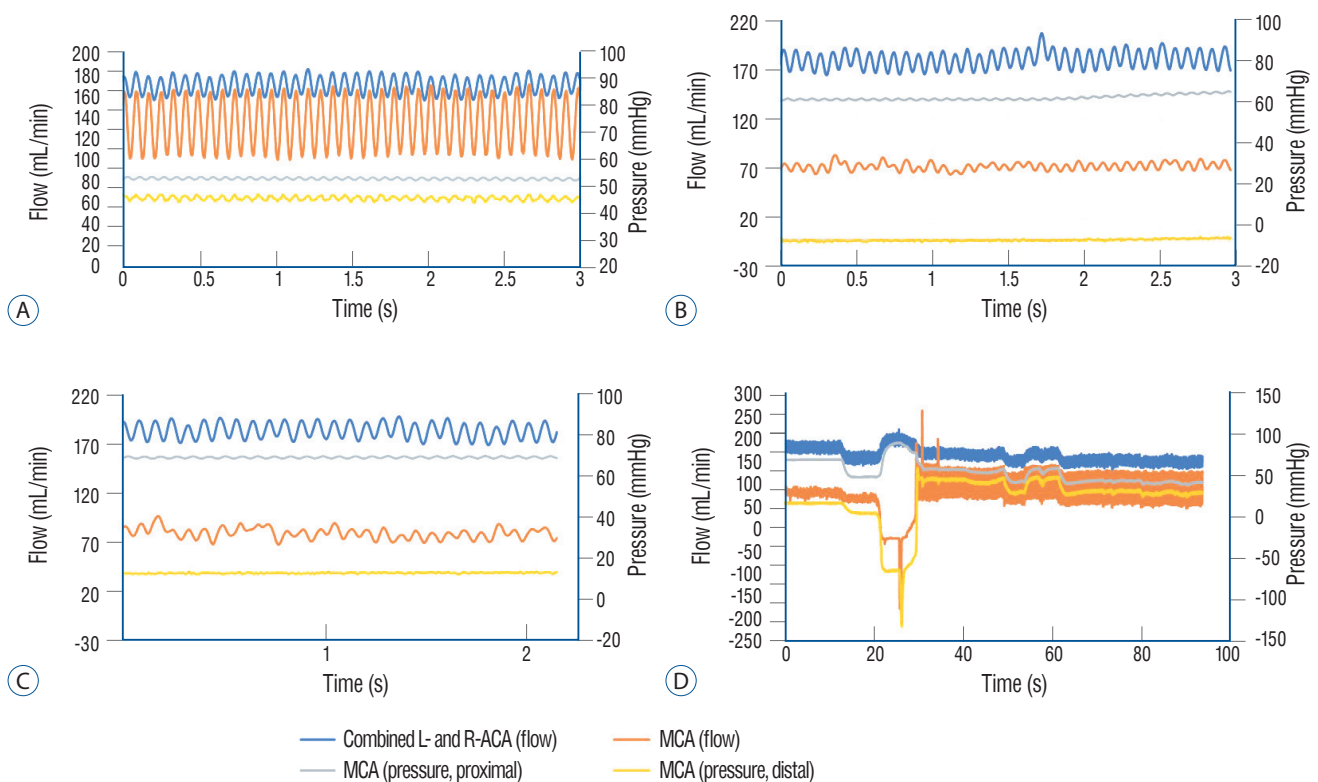


Fig. 2. Simulation of SR-MT in an *in-vitro* setup allows real-time measurements of MCA flow and pressure prior to clot introduction (A), after deployment of stent retriever (B), after balloon inflation (C), and during clot retrieval (D). ACA : anterior cerebral artery, SR-MT : stent retriever-mediated mechanical thrombectomy, MCA : middle cerebral artery.

tion of SR-MT and these limitations may be taken into consideration during data interpretation.

BALLOON GUIDE CATHETER IN STENT RETRIEVER THROMBECTOMY

The North American Solitaire Stent Retriever Acute Stroke (NASA) and Trevo Stent-Retriever Acute Stroke (TRACK) registries are two independent post-marketing registries in the United States that assess the effectiveness and clinical outcome of SR-MT in a real-life setting^{41,44,68}. SR-MT was performed in both registries as the frontline technique for vessel recanalization, with the Solitaire stent retriever in NASA and the Trevo device in TRACK. BGC was inflated during the SR-MT to temporarily stop the antegrade flow in the carotid artery, and a similar rate of BGC use was reported in both studies (NASA : 44% vs. TRACK : 47%). The results of the NASA registry revealed that in comparison to the non-BGC group, patients with BGC had shorter procedure time, less adjunctive therapy and better clinical outcome at 90 days. BGC was an independent predictor of good clinical outcome, and this finding was also noted in the TRACK registry. Based on those results, the use of BGC had become recommended during SR-MT by the manufacturers of Solitaire stent and Trevo device. One suggested explanation for better outcome with the use of BGC is ischemic conditioning^{45,55}. It is the hypothesis that blockage of the antegrade carotid flow via BGC applies the ischemic stimulus to the vascular bed, resulting in the release of neuroprotective agents that may protect the ischemic tissue and improve the clinical outcome²⁰. However, as previously reviewed, BGC protected thrombectomy reduces the number and size of distal emboli which may alone explain the clinical benefit.

A number of animal and benchtop studies reported that SR-MT with BGC reduced the formation of distal emboli; however, surprisingly, there were no significant effects of the BGC use on distal emboli and emboli in new territory in the NASA registry⁴⁴. A similar finding was noted by Ahn et al.¹. Possible explanations for the discrepancy between the experimental and clinical observations include that 1) the micron-sized emboli observed in the *in vitro* studies are not detectable angiographically and 2) publication bias and heterogeneity across the studies can bias the results¹. As of today, there is still a continuing controversy about the use of BGC during mechan-

ical thrombectomy, as reflected in the limited number of cases where BGC is used (approximately 50% of stroke interventions)³. A series of studies have been done with the aim to understand the effects of BGC on the technique and clinical outcomes for patients who underwent SR-MT^{3,34,59,64}. It was found that patients treated with BGCs had a shorter procedure time, lower number of thrombectomy attempts, lower rates of mortality and higher odds of first-pass recanalization as compared to those treated without BGCs. Achieving a Thrombolysis in Cerebral Infarction (TICI) score of 3 with single thrombectomy pass defines the goal to pursue for future development of thrombectomy devices⁶⁷. The first-pass effect, an independent predictor of good clinical outcome, has become a new measure of successful mechanical thrombectomy.

Several innovative treatment strategies have been developed based on the combined thromboaspiration and SR-MT technique, such as ARTS, CAPTIVE, CASPER, PROTECT^{PLUS}, and SAVE^{36-39,58}. The concept of combining local aspiration with a stent retriever is to provide continuous and localized suction via a distal intermediate and aspiration catheter from the proximal end of the occlusion during SR-MT. The rationale of providing suction adjacent to the occlusion is to enhance the clot engagement within the stent retriever and withdraw the clot fragments released during initial stent retriever deployment²¹. In brief, a long sheath or a BGC is placed within the common carotid artery or ICA of the affected side. Subsequently, a large bore aspiration catheter is navigated over a microguidewire (and sometimes a microcatheter) to the level of the occlusion. A stent retriever device, usually Trevo or Solitaire FR, is deployed via a microcatheter. The microcatheter is removed before clot removal to increase cross sectional luminal area and aspiration efficacy of the aspiration catheter⁴⁶. Suction can be applied via manual aspiration using a 20 mL or 60 mL syringe or an aspiration pump. The aspiration catheter serves as a conduit through which the stent retriever along with the clot is removed from the patient. FlowGate (Stryker, Fremont, CA, USA; OD : 8 F, ID : 0.084"), Cello (Medtronic, Irvine, CA, USA; OD : 9 F, ID : 0.085" and OD : 8 F, ID : 0.075"), Optimo (Tokai, Tokyo, Japan; OD : 9 F, ID : 0.088"), 6F Neuron Max (Penumbra, Alameda, CA, USA; OD : 8 F, ID : 0.088") and 6F Cook Shuttle Sheath (Cook Medical, Bloomington, IN, USA; OD : 8 F, ID : 0.087") are common ancillary catheters used with current aspiration catheters. Frequently used aspiration catheters include, but are not limited to, AXS

Catalyst™ 6 (Stryker), Sofia® and Sofia® Plus (Microvention, Tustin, CA, USA) and Penumbra ACE™ (Penumbra).

Slight variations in procedure exist between the ARTS, CAPTIVE, CASPER, PROTECTPLUS and SAVE techniques. One example is the proximal aspiration with the guide catheter proposed in the SAVE method. Another notable difference is that the BGC is used in the ARTS and PROTECTPLUS techniques, whereas the large guiding sheath is recommended for the CAPTIVE, CASPER and SAVE techniques. It should be addressed that limited use of BGC may be due to the size incompatibility between BGCs and the principal chosen technique⁵. Despite these variations, all techniques achieved successful recanalization (modified TIC1 $\geq 2b$) in nearly 100% of the cases, according to the prior retrospective studies. In addition, first-pass modified TIC1 3 recanalization was observed in between 43% to 72% of the patients, depending on the technique^{36-39,58}. These results are encouraging, although still preliminary, for the development of innovative treatment strategies to benefit patients with acute LVO.

BALLOON GUIDE CATHETER IN CAT

Based on the results of five RCTs^{2,4,16,22,52}, most stroke guidelines recommend endovascular treatment using SR-MT for acute LVO patients^{19,51,65}. In real practice, however, two major frontline endovascular treatment methods, CAT and SR-MT, are currently used. In a recent survey of U.S. neurointerventionalists, 39.7% of respondents reported using CAT as frontline therapy followed by 28.2% opting for SR-MT, and 28.2% adopting for combined usage of a retrievable stent with aspiration¹². Moreover, the Contact Aspiration vs Stent Retriever for Successful Recanalization (ASTER) and COMPASS studies demonstrated that there were no significant differences in the rates of recanalization and good outcomes at 3 months between CAT and SR-MT^{32,61}. Thus, proper designation of case-dependent utilization of CAT versus SR-MT remains a challenge for future procedures.

BGC use has been recommended for SR-MT cases in previous RCTs, but not with CAT. Investigations regarding the role of BGC use in CAT are rare because the major group of CAT users (specifically ADAPT users) mostly use a 6 F neurosheath as a guiding catheter, usually a Neuron Max (Penumbra)^{60,62}. However, given the majority of CAT cases have sig-

nificant portions of clot outside the tip of the aspiration device (“corked” configuration), there is a risk of shearing the clot off of the aspiration device when entering the receiver, similar to that is occurred using the SR device. Recently, neurointerventionalists have used the BGC and have reported positive results with BGC use during CAT. In one case series consisting of 31 patients with an acute anterior circulation stroke, the authors proposed that the combination of two available methods for preventing distal clot migration, proximal flow arrest via use of a BGC and distal aspiration through a large bore catheter could improve the outcome of the thrombectomy procedure⁵⁷. The 8F Cello BGC (Medtronic) was used for the proximal flow control and the SOFIA catheter (Microvention) was used for the distal aspiration. Mechanical thrombectomy was performed under balloon occlusion of the proximal ICA and simultaneously with continuous distal aspiration, which resulted in a 96.8% successful recanalization rate (modified TIC1 $\geq 2b$), with good functional recovery (modified Rankin Scale 0–2 at 3 months) in 51.6% of cases.

In addition to the prevention of distal clot migration, recent reviews have suggested another positive effect of BGC use in mechanical thrombectomy^{28,66}. Theoretically, two primary factors determine how much force will be required to retrieve the clot: the impaction force and the combined force of friction and adhesion between the thrombus and the vessel wall. The impaction force is determined by the pressure gradient across the thrombus (Fig. 3). Therefore, lower systemic blood pressure acting on the proximal surface of the thrombus and better retrograde collateral flow on the distal surface of the thrombus will result in a smaller pressure gradient across the occluding thrombus. Inflation of a BGC can markedly reduce the systemic blood pressure acting on the proximal clot face, leading to a decrease in the pressure gradient across the clot⁶⁶. This can enhance the function of an aspiration catheter in CAT, as well as a stent retriever in SR-MT. The impaction force is also likely to explain the decreased rate of successful recanalization among patients with worse collaterals³⁵.

A recent analysis compared data of the BGC and the CGC groups in frontline CAT cases using a Korean multi-center registry²⁵. In the study, a total of 429 patients were enrolled, with the BGC used in 45.2% of patients. Compared to the CGC group, BGC use significantly reduced the number of CAT passes (mean, 2.6 vs. 3.4; $p < 0.001$), puncture-to-recanalization time (mean, 56 minutes vs. 64 minutes; $p = 0.018$), and

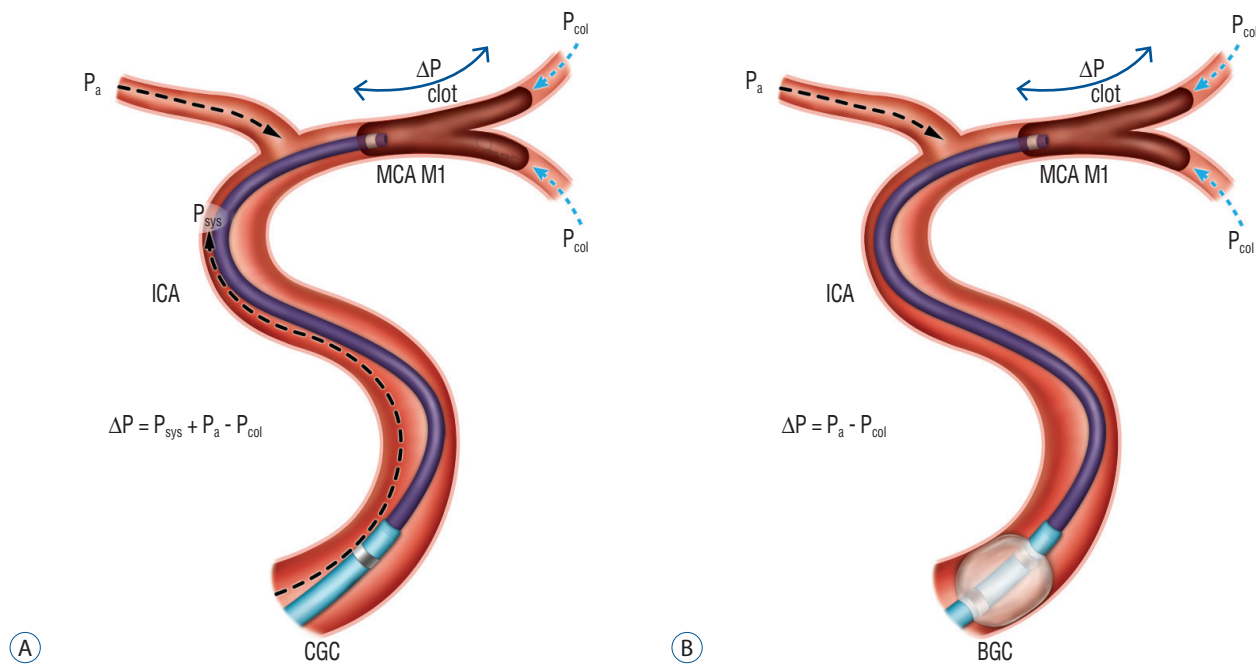


Fig. 3. Comparison of the pressure gradient (ΔP) across the clot between conventional guide catheters and balloon guide catheters in contact aspiration thrombectomy procedures. A : Contact aspiration under conventional guide catheter (CGC). $\Delta P = P_{\text{sys}} + P_a - P_{\text{col}}$. B : Contact aspiration under balloon inflation of balloon guide catheter (BGC). $\Delta P = P_a - P_{\text{col}}$. MCA : middle cerebral artery, ICA : internal carotid artery.

embolization to distal or different site (0.5% vs. 3.4%, $p=0.045$). The BGC group showed significantly higher final (89.2% vs. 72.8%, $p<0.001$) and first-pass recanalization success rates (24.2% vs. 8.1%, $p<0.001$). Those results were consistent with previous clinical studies that involved frontline SR-MT, which also reported the advantages of BGC, such as a decrease in distal embolization and an increase in the flow reversal effect.

To enhance the efficacy of CAT, there have been attempts to use early and active switching from CAT to SR-MT or to use a combination of CAT and SR-MT (incidence of switching : 32% to 47.3%)^{26,27,33,58}. For example, one study compared 119 patients treated with frontline SR-MT to 124 patients treated with frontline CAT; when recanalization failed with the frontline CAT, a large-bore aspiration catheter was used to introduce a stent retriever³³. Although the rate of successful recanalization by CAT only was 50.8% (63/124), rescue switching to SR-MT resulted in success in 69.6% of cases (39/56). As a result, frontline CAT group achieved a higher rate of final successful revascularization as compared to SR-MT (82.3% vs. 68.9%; $p=0.022$). However, the use of adjunctive devices was higher in the CAT group than in the SR-MT group (38.7% vs. 13.3%; $p<0.001$). In the ASTER study, the first RCT to com-

pare frontline CAT and SR-MT, at least three attempts were required to be completed prior to switching to rescue therapy³². Although there was no significant difference in revascularization rates (CAT, 85.4% vs. SR-MT, 83.1%; $p=0.53$) and rates of good functional recovery (modified Rankin Scale 0–2 at 3 months; CAT, 45.3% vs. SR-MT, 50%; $p=0.38$), rescue therapy was more common in the CAT group than in the SR-MT group (32% vs. 23.8%; odds ratio, 1.57; $p=0.05$). Considering the high rate of switching to SR-MT in frontline CAT procedures and the current recommendation of BGC use in SR-MT, the BGC also seems a better option as a guiding catheter in CAT. However, whether to use the BGC during the CAT procedure remains controversial due to limited evidence. The positive results of the previous studies warrant a further prospective study in a large population to compare the outcomes of use of the BGC and the CGC in frontline CAT procedures.

OTHER APPLICATION OF BALLOON GUIDE CATHETER : REMOTE PROXIMAL ASPIRATION WITHOUT CLOT CONTACT

Despite the rapid evolution of endovascular devices and

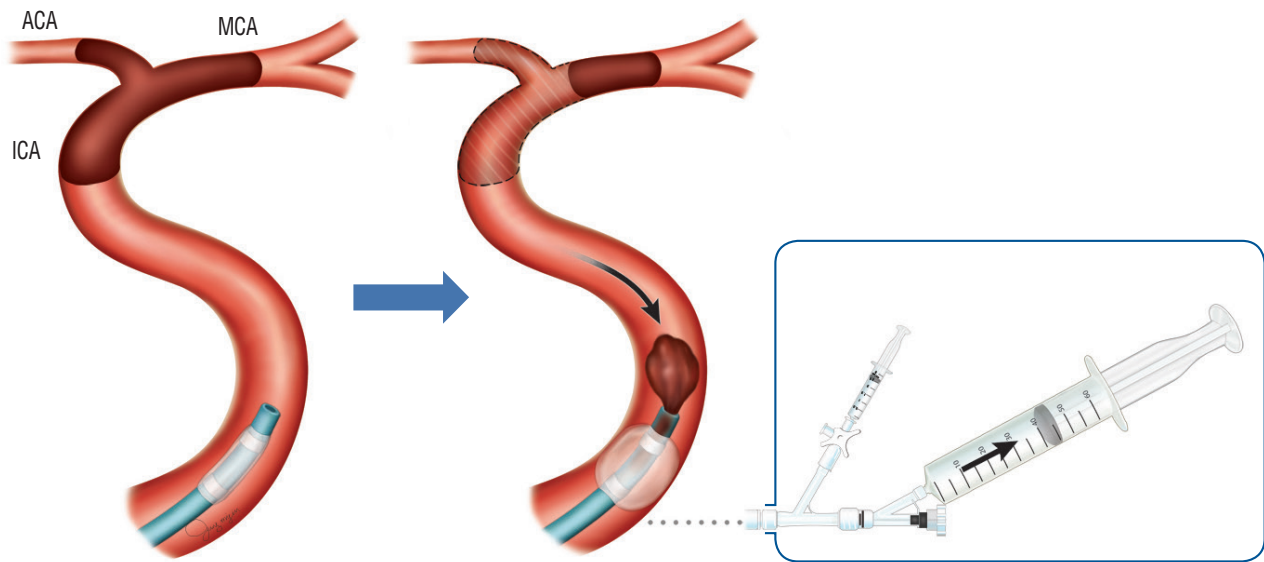


Fig. 4. Illustration of the off-label use of BGC to clot burden reduction in an intra-cranial ICA T-type occlusion. Direct manual aspiration using a 60 mL syringe is performed through an 8 F or a 9 F BGC which was positioned in the proximal ICA to create proximal flow arrest. ACA : anterior cerebral artery, ICA : internal carotid artery, MCA : middle cerebral artery, BGC : balloon guide catheter.

techniques for recanalization of LVO, mechanical thrombectomy still fails in about a quarter of cases^{2,4,16,22,52}). Extensive burden of the occluding thrombus has been regarded as one of the main etiologies leading to complicated or failed thrombectomy procedures along with anatomical challenges, tandem occlusions, and occlusions with underlying atherosclerosis²⁹). A larger thrombus burden may complicate the endovascular procedure by requiring more passages with the thrombectomy device leading to a prolonged time to recanalization. Such delays in recanalization can result in larger territory infarctions and a worse functional recovery. Additionally, more extensive thrombi may cause the occlusion of important collateral channels, as the original thrombus itself or migration of the thrombus may pervade noninvolved vascular territories. Off-label use of BGCs has been attempted to remove or reduce the LVO with extensive clot burden^{11,18,30,49}).

One such method involved remote aspiration through the BGC without any clot contact with a catheter or a stent retriever in distal ICA occlusions¹¹). During remote aspiration, manual aspiration using a 60 mL syringe was performed through an 8 F BGC that was positioned in the cervical carotid vasculature to create proximal flow arrest (Fig. 4), resulting in a significant reduction of the clot burden, which facilitated further intervention leading to full recanalization. Thereafter, a few case reports describing similar BGC use followed^{18,49}).

Although the thrombectomy techniques were differently named in each report, such as ‘remote aspiration thrombectomy’ and ‘simple Aspiration with Balloon Catheter (ABC) technique’, the fundamentals of the techniques were very similar. One study reported three cases of acute ICA occlusion treated with ‘remote aspiration thrombectomy’ which was direct manual aspiration with a 60 mL syringe through a 9 F BGC in the cervical ICA and resulted in complete recanalization. Another study reported two cases of cardioembolic ICA occlusion that were successfully treated with the ‘simple ABC technique’. This technique also involved simple manual aspiration through an inflated 9 F BGC in the proximal ICA. All the above-mentioned studies demonstrated that the off-label use of the BGC proved useful in removing or reducing the clot burden and was a relatively safe and simple procedure. However, the interpretation of the results should be noted with caution since these technical case reports included a small number of patients. Other variables, such as clot consistency, vessel tortuosity, and the presence of a prominent posterior communicating artery, which can prevent adequate flow arrest, may also determine the efficacy of the remote aspiration¹¹).

A larger case series, which enrolled 86 ICA occlusion patients treated with mechanical thrombectomy during a 5-year period, compared the outcomes of endovascular strategies

with or without the use of direct manual aspiration through a BGC at the cervical ICA³⁰). Although in this series, the maneuver was referred to as ‘proximal aspiration thrombectomy (PAT)’, but the technique was similar to the previously mentioned techniques. In phase 1 of the study, standard thrombectomy without PAT was used for removal of the ICA occlusions (n=33). In phase 2, PAT was initially used, followed by the standard thrombectomy for any remaining occlusion (n=53). The authors defined ‘responders’ as patients who had part of the clot retrieved by PAT with partial or full recanalization achieved. Fifteen of 53 patients (28.3%) in phase 2 responded to PAT and the responders had a significantly higher incidence of atrial fibrillation compared to non-responders (86.7% vs. 57.9%; $p=0.046$). The procedure time was significantly reduced (94.5 minutes vs. 56.0 minutes; $p=0.002$) and the rate of successful reperfusion was improved (TICI $\geq 2b$: 45.5% vs. 73.6%; $p=0.009$) without increasing the incidence of procedure-related complications or intracranial hemorrhage. Overall, off-label use of a BGC seems to reduce clot burden in ICA occlusions. Further investigation in a larger patient cohort will be required to confirm the utility and safety of this approach.

CONCLUSION

With the rapid advancement of endovascular treatment therapy over time, varying thrombectomy techniques are being continuously fine-tuned to deliver the best possible functional outcome for stroke patients. Key procedural features of the BGC include minimization of distal emboli as a result of antegrade flow control, increased rates of first-pass efficacy, and the ability to pair it with adjunctive devices to achieve successful reperfusion. In addition to allowing a shorter duration of intervention, the availability of crossover rescue with BGC as an alternative strategy for failure during CAT is critical for patients with LVO. As SR-MT and CAT are currently recognized as major frontline treatment methods, assessment of SR-MT with use of BGC has been correlated with clinically and angiographically favorable outcomes. However, limited evidence exists to prove significant benefit of BGC use in combination with distal aspiration. Further evaluation to analyze the role of BGC in CAT may be tested in the *in-vitro* system of cerebrovascular occlusion, which is necessary to deter-

mine potential clinical usefulness of the technique. With the first-pass effect now considered the benchmark of successful thrombectomy, focus of future study should aim to explore the capability of BGCs to lower the rate of adverse events, maximize the number of TICI 3 cases, and reduce the number of thrombectomy attempts during clot retrieval.

CONFLICTS OF INTEREST

JYC: Consultant for InNeuroCo and Stryker Neurovascular.

MJG: Has been a consultant on a fee-per-hour basis for Cerenovus, Imperative Care, Medtronic Neurovascular, Mivi Neurosciences, Phenox, Route 92 Medical, Stryker Neurovascular; holds stock in Imperative Care and Neurogami; and has received research support from the Research support from the National Institutes of Health (NIH), the United States – Israel Binational Science Foundation, Anaconda, Cerenovus, Cook Medical, Gentuity, Imperative Care, InNeuroCo, InSera Therapeutics, Magneto, Microvention, Medtronic Neurovascular, MIVI Neurosciences, Neuravi, Neurogami, Philips Healthcare, Rapid Medical, Route 92 Medical, Stryker Neurovascular, Syntheon, and the Wyss Institute.

INFORMED CONSENT

This type of study does not require informed consent.

AUTHOR CONTRIBUTIONS

Writing - original draft : JYC, DHK

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References

1. Ahn JH, Cho SS, Kim SE, Kim HC, Jeon JP. The effects of balloon-guide catheters on outcomes after mechanical thrombectomy in acute ischemic strokes : a meta-analysis. **J Korean Neurosurg Soc** 62 : 389-397, 2019
2. Berkhemer OA, Fransen PS, Beumer D, van den Berg LA, Lingsma HF, Yoo AJ, et al. : A randomized trial of intraarterial treatment for acute ischemic stroke. **N Engl J Med** 372 : 11-20, 2015

3. Brinjikji W, Starke RM, Murad MH, Fiorella D, Pereira VM, Goyal M, et al. : Impact of balloon guide catheter on technical and clinical outcomes: a systematic review and meta-analysis. **J Neurointerv Surg** **10** : 335-339, 2018
4. Campbell BC, Mitchell PJ, Kleinig TJ, Dewey HM, Churilov L, Yassi N, et al. : Endovascular therapy for ischemic stroke with perfusion-imaging selection. **N Engl J Med** **372** : 1009-1018, 2015
5. Chalumeau V, Blanc R, Redjem H, Ciccio G, Smajda S, Desilles JP, et al. : Anterior cerebral artery embolism during thrombectomy increases disability and mortality. **J Neurointerv Surg** **10** : 1057-1062, 2018
6. Chueh JY, Kühn AL, Puri AS, Wilson SD, Wakhloo AK, Gounis MJ : Reduction in distal emboli with proximal flow control during mechanical thrombectomy: a quantitative in vitro study. **Stroke** **44** : 1396-1401, 2013
7. Chueh JY, Puri AS, Gounis MJ : An in vitro evaluation of distal emboli following lazarus cover-assisted stent retriever thrombectomy. **J Neurointerv Surg** **9** : 183-187, 2017
8. Chueh JY, Puri AS, Wakhloo AK, Gounis MJ : Risk of distal embolization with stent retriever thrombectomy and adapt. **J Neurointerv Surg** **8** : 197-202, 2016
9. Chueh JY, Wakhloo AK, Gounis MJ : Neurovascular modeling: small-batch manufacturing of silicone vascular replicas. **AJNR Am J Neuroradiol** **30** : 1159-1164, 2009
10. Demerath T, Reinhard M, Elsheikh S, Keuler A, Urbach H, Meckel S : Balloon guide catheter in complex anterior circulation mechanical thrombectomy: beyond proximal occlusion and flow reversal. **Clin Neuroradiol** **26** : 369-373, 2016
11. Eesa M, Almekhlafi MA, Mitha AP, Wong JH, Goyal M : Manual aspiration thrombectomy through balloon-tipped guide catheter for rapid clot burden reduction in endovascular therapy for ICA L/T occlusion. **Neuroradiology** **54** : 1261-1265, 2012
12. Fargen KM, Arthur AS, Spiotta AM, Lena J, Chaudry I, Turner RD, et al. : A survey of neurointerventionalists on thrombectomy practices for emergent large vessel occlusions. **J Neurointerv Surg** **9** : 142-146, 2017
13. Gascou G, Lobotesis K, Machi P, Maldonado I, Vendrell JF, Riquelme C, et al. : Stent retrievers in acute ischemic stroke: complications and failures during the perioperative period. **AJNR Am J Neuroradiol** **35** : 734-740, 2014
14. Gilvarry M, Vale D : The role of in-vitro modeling in addressing challenging occlusions. **J Neurointerv Surg** **8** : A93, 2016
15. Goto S, Ohshima T, Ishikawa K, Yamamoto T, Shimato S, Nishizawa T, et al. : A stent-retrieving into an aspiration catheter with proximal balloon (asap) technique: a technique of mechanical thrombectomy. **World Neurosurg** **109** : e468-e475, 2018
16. Goyal M, Demchuk AM, Menon BK, Eesa M, Rempel JL, Thornton J, et al. : Randomized assessment of rapid endovascular treatment of ischemic stroke. **N Engl J Med** **372** : 1019-1030, 2015
17. Gralla J, Schroth G, Remonda L, Nedeltchev K, Slotboom J, Brekenfeld C : Mechanical thrombectomy for acute ischemic stroke: thrombus-device interaction, efficiency, and complications in vivo. **Stroke** **37** : 3019-3024, 2006
18. Haussen DC, Bousslama M, Grossberg JA, Nogueira RG : Remote aspiration thrombectomy in large vessel acute ischemic stroke. **J Neurointerv Surg** **9** : 250-252, 2017
19. Hong KS, Ko SB, Yu KH, Jung C, Park SQ, Kim BM, et al. : Update of the Korean clinical practice guidelines for endovascular recanalization therapy in patients with acute ischemic stroke. **J Stroke** **18** : 102-113, 2016
20. Hougaard KD, Hjort N, Zeidler D, Sørensen L, Nørgaard A, Hansen TM, et al. : Remote ischemic preconditioning as an adjunct therapy to thrombolysis in patients with acute ischemic stroke: a randomized trial. **Stroke** **45** : 159-167, 2014
21. Humphries W, Hoit D, Doss VT, Elijovich L, Frei D, Loy D, et al. : Distal aspiration with retrievable stent assisted thrombectomy for the treatment of acute ischemic stroke. **J Neurointerv Surg** **7** : 90-94, 2015
22. Jovin TG, Chamorro A, Cobo E, de Miquel MA, Molina CA, Rovira A, et al. : Thrombectomy within 8 hours after symptom onset in ischemic stroke. **N Engl J Med** **372** : 2296-2306, 2015
23. Kammerer S, du Mesnil de Rochemont R, Wagner M, You SJ, Tritt S, Mueller-Eschner M, et al. : Efficacy of mechanical thrombectomy using stent retriever and balloon-guiding catheter. **Cardiovasc Intervent Radiol** **41** : 699-705, 2018
24. Kang DH, Hwang YH : Frontline contact aspiration treatment for emergent large vessel occlusion: a review focused on practical techniques. **J Stroke** **21** : 10-22, 2019
25. Kang DH, Kim BM, Heo JH, Nam HS, Kim YD, Hwang YH, et al. : Effect of balloon guide catheter utilization on contact aspiration thrombectomy. **J Neurosurg**, 2018 [Epub ahead of print]
26. Kang DH, Kim JW, Kim BM, Heo JH, Nam HS, Kim YD, et al. : Need for rescue treatment and its implication: stent retriever versus contact aspiration thrombectomy. **J Neurointerv Surg**, 2019 [Epub ahead of print]
27. Kang DH, Kim YW, Hwang YH, Park J, Hwang JH, Kim YS : Switching strategy for mechanical thrombectomy of acute large vessel occlusion in the anterior circulation. **Stroke** **44** : 3577-3579, 2013
28. Kang DH, Park J : Endovascular stroke therapy focused on stent retriever thrombectomy and direct clot aspiration: historical review and modern application. **J Korean Neurosurg Soc** **60** : 335-347, 2017
29. Kim BM : Causes and solutions of endovascular treatment failure. **J Stroke** **19** : 131-142, 2017
30. Kim YW, Kang DH, Hwang YH, Park J, Kim YS : Efficacy of proximal aspiration thrombectomy for using balloon-tipped guide catheter in acute intracranial internal carotid artery occlusion. **J Korean Neurosurg Soc** **59** : 379-384, 2016
31. Knox K, Kerber CW, Singel SA, Bailey MJ, Imbesi SG : Rapid prototyping to create vascular replicas from ct scan data: making tools to teach, rehearse, and choose treatment strategies. **Catheter Cardiovasc Interv** **65** : 47-53, 2005
32. Lapergue B, Blanc R, Gory B, Labreuche J, Duhamel A, Marnat G, et al. : Effect of endovascular contact aspiration vs stent retriever on revascularization in patients with acute ischemic stroke and large vessel occlusion: the ASTER randomized clinical trial. **JAMA** **318** : 443-452, 2017
33. Lapergue B, Blanc R, Guedin P, Decroix JP, Labreuche J, Preda C, et al. :

- A direct aspiration, first pass technique (ADAPT) versus stent retrievers for acute stroke therapy: an observational comparative study. **AJNR Am J Neuroradiol** **37** : 1860-1865, 2016
34. Lee DH, Sung JH, Kim SU, Yi HJ, Hong JT, Lee SW : Effective use of balloon guide catheters in reducing incidence of mechanical thrombectomy related distal embolization. **Acta Neurochir (Wien)** **159** : 1671-1677, 2017
 35. Liebeskind DS, Jahan R, Nogueira RG, Zaidat OO, Saver JL; SWIFT Investigators : Impact of collaterals on successful revascularization in solitaire fr with the intention for thrombectomy. **Stroke** **45** : 2036-2040, 2014
 36. Maegerlein C, Berndt MT, Mönch S, Kreiser K, Boeckh-Behrens T, Lehm M, et al. : Further development of combined techniques using stent retrievers, aspiration catheters and BGC : the PROTECTPLUS technique. **Clin Neuroradiol**, 2018 [Epub ahead of print]
 37. Massari F, Henninger N, Lozano JD, Patel A, Kuhn AL, Howk M, et al. : Arts (aspiration-retriever technique for stroke): initial clinical experience. **Interv Neuroradiol** **22** : 325-332, 2016
 38. Maus V, Behme D, Kabbasch C, Borggrefe J, Tsogkas I, Nikoubashman O, et al. : Maximizing first-pass complete reperfusion with save. **Clin Neuroradiol** **28** : 327-338, 2018
 39. McTaggart RA, Tung EL, Yaghi S, Cutting SM, Hemendinger M, Gale HI, et al. : Continuous aspiration prior to intracranial vascular embolectomy (CAPTIVE): a technique which improves outcomes. **J Neurointerv Surg** **9** : 1154-1159, 2017
 40. Menon BK, Sajobi TT, Zhang Y, Rempel JL, Shuaib A, Thornton J, et al. : Analysis of workflow and time to treatment on thrombectomy outcome in the endovascular treatment for small core and proximal occlusion ischemic stroke (ESCAPE) randomized, controlled trial. **Circulation** **133** : 2279-2286, 2016
 41. Mokin M, Abou-Chebl A, Castonguay AC, Nogueira RG, English JD, Farid H, et al. : Real-world stent retriever thrombectomy for acute ischemic stroke beyond 6 hours of onset: analysis of the nasa and track registries. **J Neurointerv Surg** **11** : 334-337, 2019
 42. Mokin M, Ionita CN, Nagesh SV, Rudin S, Levy EI, Siddiqui AH : Primary stentriever versus combined stentriever plus aspiration thrombectomy approaches: in vitro stroke model comparison. **J Neurointerv Surg** **7** : 453-457, 2015
 43. Mokin M, Setlur Nagesh SV, Ionita CN, Levy EI, Siddiqui AH : Comparison of modern stroke thrombectomy approaches using an in vitro cerebrovascular occlusion model. **AJNR Am J Neuroradiol** **36** : 547-551, 2015
 44. Nguyen TN, Malisch T, Castonguay AC, Gupta R, Sun CH, Martin CO, et al. : Balloon guide catheter improves revascularization and clinical outcomes with the solitaire device: analysis of the north american solitaire acute stroke registry. **Stroke** **45** : 141-145, 2014
 45. Nguyen TN, Malisch TW, Zaidat OO; North American Solitaire Acute Stroke Registry : Response to letter regarding article, "balloon guide catheter improves revascularization and clinical outcomes with the solitaire device: analysis of the north american solitaire acute stroke registry". **Stroke** **45** : e86, 2014
 46. Nikoubashman O, Alt JP, Nikoubashman A, Büsen M, Heringer S, Brockmann C, et al. : Optimizing endovascular stroke treatment: removing the microcatheter before clot retrieval with stent-retrievers increases aspiration flow. **J Neurointerv Surg** **9** : 459-462, 2017
 47. Nikoubashman O, Wischer D, Hennemann HM, Sandmann J, Sichtermann T, Müschenich FS, et al. : Balloon-guide catheters are needed for effective flow reversal during mechanical thrombectomy. **AJNR Am J Neuroradiol** **39** : 2077-2081, 2018
 48. Oh JS, Yoon SM, Shim JJ, Doh JW, Bae HG, Lee KS : Efficacy of balloon-guiding catheter for mechanical thrombectomy in patients with anterior circulation ischemic stroke. **J Korean Neurosurg Soc** **60** : 155-164, 2017
 49. Okamura A, Kuroki K, Shinagawa K, Yamada N : Simple aspiration with balloon catheter technique (simple ABC technique) against proximal internal carotid artery occlusion in cases of cardiogenic cerebral embolism. **Interv Neuroradiol** **24** : 317-321, 2018
 50. Pierot L, Soize S, Benaissa A, Wakhloo AK : Techniques for endovascular treatment of acute ischemic stroke: from intra-arterial fibrinolytics to stent-retrievers. **Stroke** **46** : 909-914, 2015
 51. Powers WJ, Derdeyn CP, Biller J, Coffey CS, Hoh BL, Jauch EC, et al. : 2015 American Heart Association/American Stroke Association focused update of the 2013 guidelines for the early management of patients with acute ischemic stroke regarding endovascular treatment: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. **Stroke** **46** : 3020-3035, 2015
 52. Saver JL, Goyal M, Bonafe A, Diener HC, Levy EI, Pereira VM, et al. : Stent-retriever thrombectomy after intravenous t-PA vs. t-PA alone in stroke. **N Engl J Med** **372** : 2285-2295, 2015
 53. Seong J, Sadasivan C, Onizuka M, Gounis MJ, Christian F, Miskolczi L, et al. : Morphology of elastase-induced cerebral aneurysm model in rabbit and rapid prototyping of elastomeric transparent replicas. **Biorheology** **42** : 345-361, 2005
 54. Shah VA, Martin CO, Hawkins AM, Holloway WE, Junna S, Akhtar N : Groin complications in endovascular mechanical thrombectomy for acute ischemic stroke: a 10-year single center experience. **J Neurointerv Surg** **8** : 568-570, 2016
 55. Simonsen CZ, Sørensen LH, Andersen G : Letter by simonsen et al Regarding article, "balloon guide catheter improves revascularization and clinical outcomes with the solitaire device: analysis of the north american solitaire acute stroke registry". **Stroke** **45** : e85, 2014
 56. Smith WS, Furlan AJ : Brief history of endovascular acute ischemic stroke treatment. **Stroke** **47** : e23-e26, 2016
 57. Stampfl S, Pfaff J, Herweh C, Pham M, Schieber S, Ringleb PA, et al. : Combined proximal balloon occlusion and distal aspiration: a new approach to prevent distal embolization during neurothrombectomy. **J Neurointerv Surg** **9** : 346-351, 2017
 58. Stapleton CJ, Leslie-Mazwi TM, Torok CM, Hakimelahi R, Hirsch JA, Yoo AJ, et al. : A direct aspiration first-pass technique vs stentriever thrombectomy in emergent large vessel intracranial occlusions. **J Neurosurg** **128** : 567-574, 2018
 59. Teleb MS : Endovascular acute ischemic stroke treatment with flowgate balloon guide catheter: a single-center observational study of flowgate

- balloon guide catheter use. **Interv Neurol** 7 : 327-333, 2018
60. Turk AS, Frei D, Fiorella D, Mocco J, Baxter B, Siddiqui A, et al. : ADAPT FAST study: a direct aspiration first pass technique for acute stroke thrombectomy. **J Neurointerv Surg** 6 : 260-264, 2014
61. Turk AS, Siddiqui A, Fifi JT, De Leacy RA, Fiorella DJ, Gu E, et al. : Aspiration thrombectomy versus stent retriever thrombectomy as first-line approach for large vessel occlusion (COMPASS): a multicentre, randomised, open label, blinded outcome, non-inferiority trial. **Lancet** 393 : 998-1008, 2019
62. Turk AS, Spiotta A, Frei D, Mocco J, Baxter B, Fiorella D, et al. : Initial clinical experience with the ADAPT technique: a direct aspiration first pass technique for stroke thrombectomy. **J Neurointerv Surg** 6 : 231-237, 2014
63. van der Marel K, Chueh JY, Brooks OW, King RM, Marosfoi MG, Langan ET, et al. : Quantitative assessment of device-clot interaction for stent retriever thrombectomy. **J Neurointerv Surg** 8 : 1278-1282, 2016
64. Velasco A, Buerke B, Stracke CP, Berkemeyer S, Mosimann PJ, Schwindt W, et al. : Comparison of a balloon guide catheter and a non-balloon guide catheter for mechanical thrombectomy. **Radiology** 280 : 169-176, 2016
65. Wahlgren N, Moreira T, Michel P, Steiner T, Jansen O, Cognard C, et al. : Mechanical thrombectomy in acute ischemic stroke: consensus statement by ESO-Karolinska Stroke Update 2014/2015, supported by ESO, ESMINT, ESNR and EAN. **Int J Stroke** 11 : 134-147, 2016
66. Yoo AJ, Andersson T : Thrombectomy in acute ischemic stroke: challenges to procedural success. **J Stroke** 19 : 121-130, 2017
67. Zaidat OO, Castonguay AC, Linfante I, Gupta R, Martin CO, Holloway WE, et al. : First pass effect: a new measure for stroke thrombectomy devices. **Stroke** 49 : 660-666, 2018
68. Zaidat OO, Castonguay AC, Nogueira RG, Haussen DC, English JD, Satti SR, et al. : Trevo stent-retriever mechanical thrombectomy for acute ischemic stroke secondary to large vessel occlusion registry. **J Neurointerv Surg** 10 : 516-524, 2018
69. Zaidat OO, Mueller-Kronast NH, Hassan AE, Haussen DC, Jadhav AP, Froehler MT, et al. : Impact of balloon guide catheter use on clinical and angiographic outcomes in the stratis stroke thrombectomy registry. **Stroke** 50 : 697-704, 2019