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REVIEW

Devices for non-fragmented removal of thrombus via mechanical grip: a patent review

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ABSTRACT

Introduction: Thromboembolic conditions are a leading global cause of mortality and a major cause of disability. Throughout the years mechanical thrombectomy has become a preferred method of treatment. Removing thrombus in its entirety on first pass decreases procedure time as well as lowers the risk of distal embolization.

Areas covered: This review provides a comprehensive overview and classification of the patent literature on devices for non-fragmented thrombus removal via grip. Patentscope database was used to search for internationally granted patents published any time before the access date (October 2024). The search using keywords and patent classification code led to identifying 141 relevant patents that were then categorized based on location and type of grip they describe.

Expert opinion: The designs found are analyzed in the discussion and a broader context for their relevance is given in the expert opinion section. The following review can provide insight into possible mechanical thrombectomy methods, general trends in the field as well as serve as an inspiration in development of novel devices.

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Patent; stent retriever; thrombectomy; thrombus; ischemic stroke

1. Introduction

Hemostasis is a complex biochemical process that can prevent blood loss in case of vessel wall damage. First the discontinuity in the endothelium is bridged by platelets that are then interwoven by fibrin, and additionally blood coagulation is activated [1]. However, when the process is falsely triggered or unbalanced it can lead to formation of pathological thrombi, which, when displaced by blood flow, become emboli. Such formations can cause vessel occlusion. Thromboembolic events such as myocardial infarction, ischemic stroke, deep vein thrombosis, and pulmonary embolism are a leading global cause of mortality [2]. Blood flow in an occluded vessel can be restored by either dissolving the thrombus with thrombolytic agents or the thrombus can be mechanically removed. During a mechanical thrombectomy (MT) the device is introduced into the vasculature and advanced to the location of occlusion via a catheter. In case of an acute ischemic stroke (AIS), currently available MT devices remove the thrombus either by means of negative pressure (aspiration catheters) or mechanical grasping. In case of grasping-based devices a microcatheter first penetrates the thrombus so that the device can be placed within, alongside or behind the thrombus from where it can be grasped and subsequently removed. They are often used in pair with aspiration catheters. Examples of grasp-based devices would be balloon catheters, coil retrievers and stent retrievers. A balloon catheter is introduced in the vasculature in its deflated state, once it is placed behind the thrombus the balloon inflates, covering the back area of the thrombus and allowing it to be pulled out. The coil retriever (Merci) works in a similar manner, but instead of a balloon the end effector is a coil that is unsheathed from a microcatheter once placed behind the thrombus. A stent retriever (such as Solitaire or Trevo) is a self-expanding, tubular, woven mesh. Once placed within or alongside the thrombus, the structure expands and captures the thrombus, which is subsequently removed. Stent retrievers are likely the most common MT devices used for AIS nowadays, but new generation devices such as a stent retriever integrated with a back filter (Vesalio NeVa Net) or a device comprising spherical, woven cages connected in series (ERIC) are also gaining popularity.

There are several factors that influence favorable outcomes of an MT procedure. Minimizing the procedure time is crucial as to avoid tissue necrosis, especially in the case of ischemic stroke. Vessel wall trauma should be avoided, as even a small endothelial injury can lead to further thrombogenesis and in worst case scenario a perforation of the vessel wall could cause a hemorrhage. Additionally distal embolization should be avoided, when fragments of the thrombus break off during removal. Studies have shown that the first-pass effect (FPE) is associated with favorable outcomes after MT [3]. It is defined as achieving revascularization upon first removal attempt. Logically, repeated attempts lead to longer procedure times and a higher risk of vessel wall damage and distal embolization. Since FPE can be treated as a good indicator of a successful procedure the following review will focus on devices that, in principle, are capable of achieving it. The aim of this review is to create a systematic overview of grasp-based MT device designs present

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Article highlights

- Mechanical thrombectomy has become a preferred method over thrombolysis in treatment of thromboembolic occlusions.
- There is a large variety of designs of devices for mechanical thrombectomy in patent literature.
- Designs of grip-based mechanical thrombectomy devices can be categorized by the placement and type of grip.
- Majority of designs present in patent literature utilize gripping thrombus along its length with a textured gripping surface.
- Each of the categories has their advantages and trade-offs, results can be improved by combining gripping strategies.

in patent literature. The focus of this study are devices in principle capable of non-fragmented removal of thrombus via mechanical grasping. Only the grasping mechanism of the devices will be reviewed. Patent literature has been chosen for this review as it can provide insight into trends and predictions for future developments in the field. The results of the search are divided into categories and the most relevant examples of each category are further described. The designs are further analyzed in discussion and compared to some examples of currently used devices. While the search results are not limited by the intended application and patent literature on this subject rarely mentions whether the device is intended for use in cerebral or other vasculature, the discussion analyzes the devices predominantly in context of use for AIS.

2. Method

2.1. Patent search method

The patent search was conducted using World Intellectual Property Organization (WIPO) Patentscope database (accessed October 2024). Patentscope was chosen as it is operated by WIPO, implying that all patents granted by that organization will be included in that database. The used Boolean search term included keywords with prefixes: embol* (such as embolus, emboli, embolization, embolectomy), prefix thromb* (thrombus, thrombi, thromboembolic, thrombolization, thrombectomy), prefix clot* (clot, clots, clotting) or prefix ischem* (ischemia, ischemic, which describe common consequences of thromboembolic vessel occlusion). The search was conducted only within internationally granted patents, i.e. valid in countries that are members of WIPO and only included patents written in English language. Additionally, the search was restricted by international patent classification code A61B17/22: 'Implements for squeezing-off ulcers or the like on inner organs of the body; Implements for scraping-out cavities of body organs, e.g. bones; for invasive removal or destruction of calculus using mechanical vibrations; for removing obstructions in blood vessels, not otherwise provided for.' The patents filed under this code include surgical instruments, devices, and methods for removing obstructions in blood vessels [4]. The publication date range was not limited for the purpose of this search, all patents ever published on the subject were included. The search query was: EN AB:(thromb* OR embol* OR clot* OR ischem*) AND IC:(A61B17/22). The website's filter functions were used to only include internationally granted patents.

2.2. Eligibility criteria

The mentioned search query resulted in 686 hits, which were subsequently manually filtered by scanning abstracts and figures and when more clarification was needed also descriptions. Only patents that fit the following criteria were included in this review:

- Patents describing the end effector of the device that comes in contact with the thrombus.
- Patents including method of use of the device.
- Patents on devices that mechanically create a grip with the thrombus.
- Patents on devices for complete removal of thrombi without fragmenting or dissolving it.
- Patents on devices that capture and remove thrombi, excluding devices that capture already mobilized thrombi (such as embolic filters).

The selection process yielded 141 patents relevant to this review.

3. Results

3.1. Classification

The patented devices found were classified based on where they employ the grip relative to the thrombus, see Figure 1. The "sideways" category, meaning that the grip is deployed anywhere along the length of thrombus (on the outside as well as the inside), was the largest group containing 97 patents including 19 patents that additionally fit another category. The "from behind" category contains 63 patented devices that deploy the grip only after the end effector is positioned behind the thrombus relative to the device's point of entry. The category also includes 19 patents that additionally fit the criteria of another group. The "from the front" category has been included in the categorization for the sake of logical completion however no patent literature describing devices which deploy the grip at the front surface of the thrombus has been found. Within the categories "sideways" and "from behind" devices were grouped by the type of grip they create: friction grasping, microshape grasping and macroshape grasping. The device was defined as a friction grasper if the grip between it and the thrombus is maintained due to friction between their surfaces. Microshape grasping utilizes a patterned surface that can deform the surface of the thrombus in order to vary the direction of normal forces upon contact. In case of macroshape grasping the device encloses or anchors in the thrombus in such a way that normal forces are parallel to the direction of pulling.

3.2. Sideways grasping

3.2.1. Sideways friction grasping

Out of all the results only three patents did not mention utilizing any surfaced pattern or anchoring, meaning it can be assumed they grasp the thrombus relying solely on friction between the surfaces [5–7]. The patent of Noriega et al. [5] describes a grasper-like device which grasps the thrombus

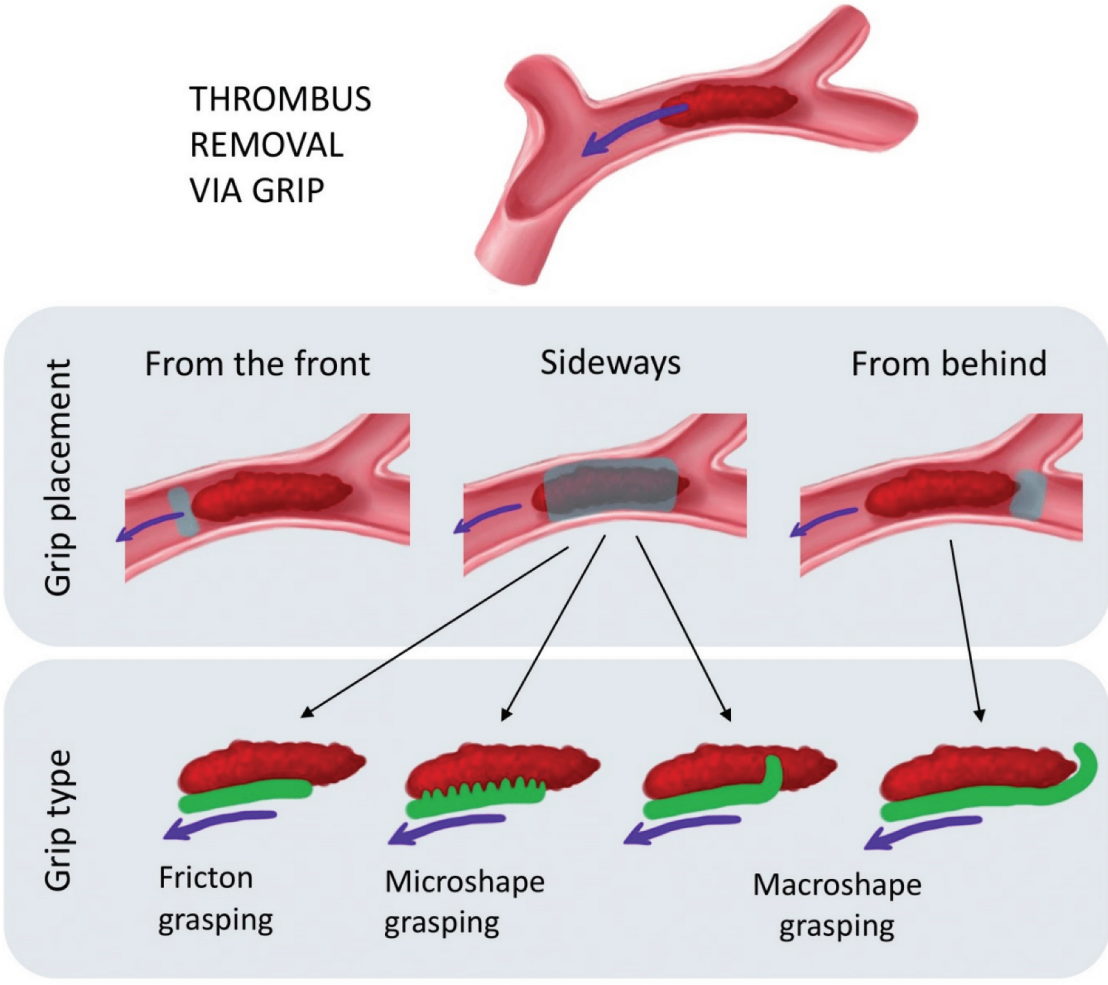

Figure 1. Classification of included patents.

using pairs of opposing arms (Figure 2 left). Once the catheter reaches the site of the occlusion it is anchored to vessel walls by means of an inflatable element and the end effector is slid out of the catheter. The grasper is in open position by default, it is then advanced until its arms are located between the thrombus and the vessel walls. As the end effector is retracted in the catheter its opposing arms close in on each other, compressing the thrombus and maintaining a friction grasp. Another grasper-like device has been described by Morsi [6] (Figure 2 center). The end effector of the device comprises

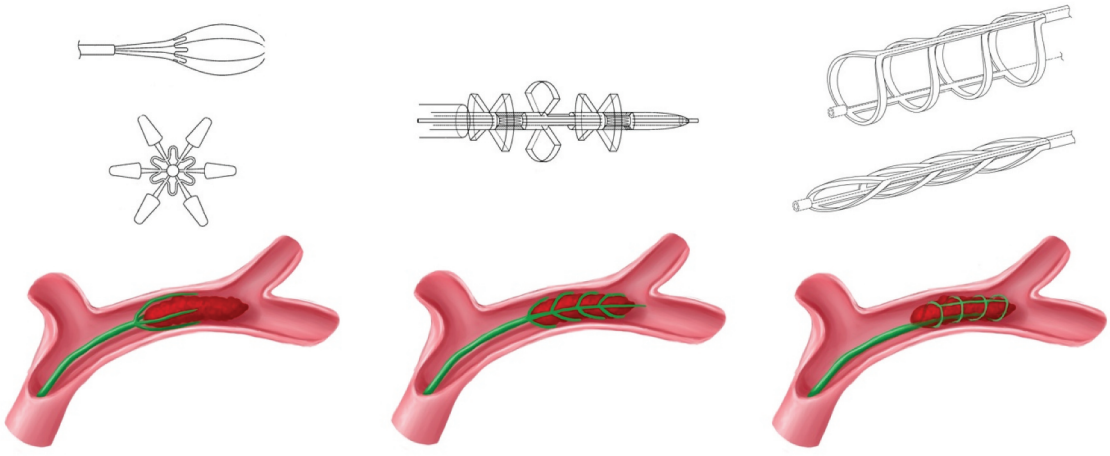

Figure 2. Devices utilizing friction grasping. Left: side and front view of the end effector from Noriega et al. [5] and illustration of the device on the thrombus. Center: perspective view of the end effector from Morsi [6] and illustration of the device on the thrombus. Right: perspective views of the open and closed configurations of the end effector from Huffmaster [7] and illustration of the device on the thrombus.

multiple sets of grasper arms along the main body, which can be deployed into an open position by being inflated and closed by deflation. The main body is positioned inside the clot. Once its distal end is beyond the clot the grasping arms are inflated, sectioning the clot. Subsequently the arms are deflated, collapsing onto the main body and trapping the clot. In the patent of Huffmaster [7] the end effector of the device is a basket that comprises two spines connected by multiple loops (Figure 2 right). Shifting the position of the spines relative to each other opens or collapses the basket. The basket is introduced in a catheter in a collapsed state. When the catheter reaches the site of the occlusion, the end effector is unsheathed and the basket opens, either due to lack of compression or, in case it is manufactured from a shape memory alloy, due to heat. The device is subsequently advanced as to enclose the clot and once the clot is located inside the basket it can be collapsed and retracted.

3.2.2. Sideways microshape grasping

A total of 82 patents were assigned to this group, including 18 that fit more than one group [8–89]. A large majority of these devices are variations of a stent retriever (Figure 3 left) [34–87]. A stent is a tubular woven mesh that when placed within a catheter collapses, but when unsheathed expands due to the elasticity of the mesh. During the thrombectomy procedure the catheter containing the collapsed stent is pushed either into the thrombus or between the thrombus and the vessel wall. The catheter is then retracted, deploying the stent, which engages the thrombus that can then be removed from the vasculature. A variety of mesh weaving patterns which optimize either thrombus penetration or grip can be observed throughout patent literature. Porter's patent [46] (Figure 3 left) utilizes non-uniform weaving, resulting in the cells of the cage having differing radial strengths so that at least some of them are able to engage with the thrombus. Some of the stent retrievers, for example the one described by Brady et al. [39], also include a filter-like structure at the back, which can catch any emboli that may have detached from the thrombus in the process. A slightly different type of a woven, tubular structure than a stent is a part of the system patented by Bose et al. [10]. The end effector is deployed in front of the clot. The front of the end effector is open and its walls touch the vessel walls when deployed. The end effector is then advanced over the clot, the end effector's walls being placed between the clot and the vessel walls. The structure of the device is designed to ensure attachment to the clot and little resistance with the vessel walls when pulled, but minimal friction on both the clot and the vessel walls when pushed. Because of that the end effector in principle can be easily placed over the clot during the pushing motion but remains attached to the device when removed by pulling. A system that also uses a mesh structure that is positioned around the clot is described in the patent of Greenhalgh and Wallace [20]. This device (similar to Figure 3 center) utilizes traction to capture the thrombus. The traction element, which is a tube made of meshed or woven material is pulled over the distal end of the catheter. When the catheter reaches the clot, the end of the traction tube which is inside the catheter is pulled away from the clot, causing the part of the traction tube which is outside to be pulled in, thus inverting the tube. The traction surface engages with the sides of the clot and the inverting motion pulls the clot inside the catheter. As the traction element is inverted the catheter is continuously advanced as to remain in contact with the clot. Meshed surfaces are the most common way to deform the surface of the thrombus in this application, however microshape grasping can also be achieved by using a coil-like or helical structure. Osborne and Kuppurathanam [12] aim to mitigate the issues caused by the devices that grasp the clot only after passing through it. Their patented device (Figure 3 right) has a double helix end effector which is screwed onto the clot from the front, the friction during this rotational screw motion is assumed to be low, but when pulled the clot stays fixed to the device due to the helical structure being embedded in the surface of the clot.

3.2.3. Sideways macroshape grasping

A total of 14 patents that utilize anchoring in the clot somewhere along its length were found, five of which using additional methods that also fit in other categories [14,21,90–101].

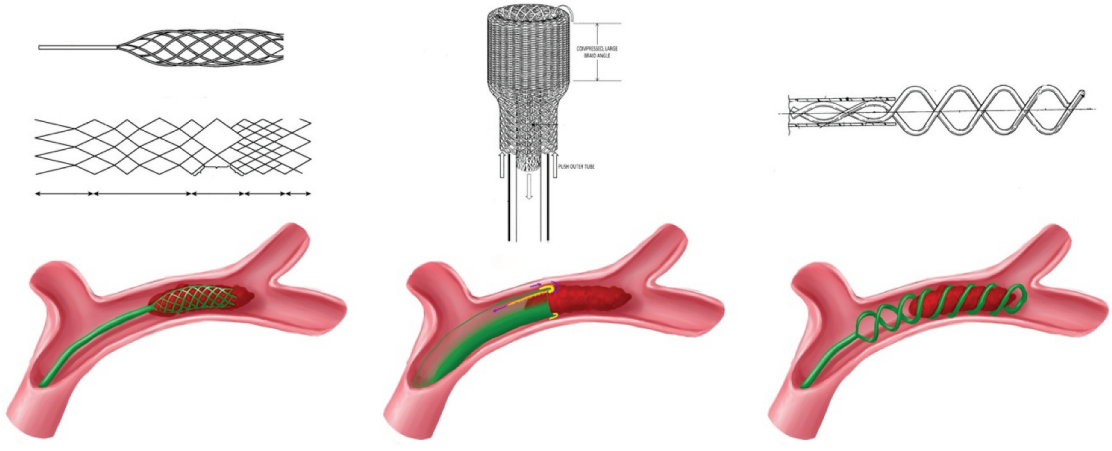

Figure 3. Devices utilizing sideways microshape grasping. Left: side view of the end effector from Porter [46] and its non-uniform weaving pattern and illustration of the device on the thrombus. Center: the inverting traction tube from Wallace and Greenhalgh [23] and illustration of the device on the thrombus with a see-through section, the traction tube is presented in a section view. Right: side view of the end effector from Osborne and Kuppurathanam [12] decompressing upon exiting the catheter and illustration of the device on the thrombus.

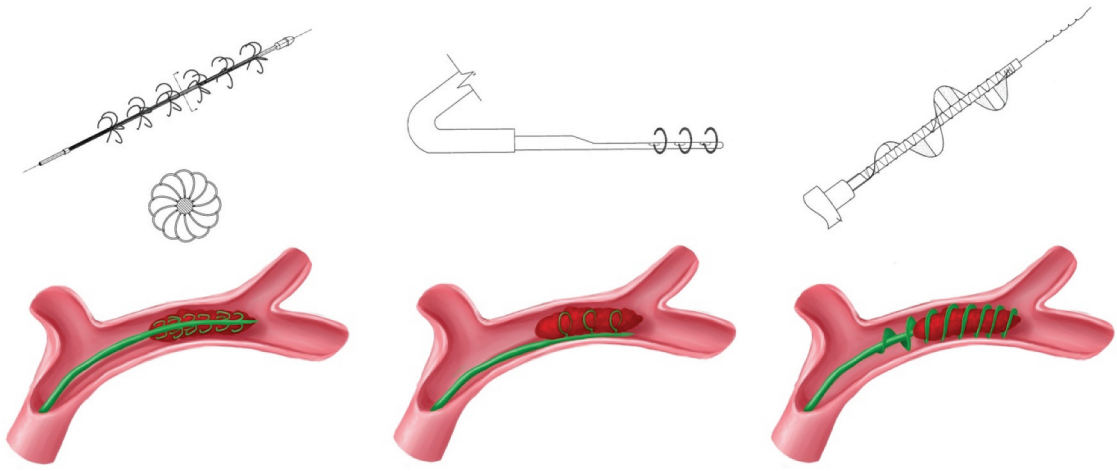

Figure 4. Devices utilizing sideways macroshape grasping. Left: perspective and front view of the end effector from Rosenbluth et al. [94] and illustration of the device on the thrombus. Center: side view of the end effector from Olsen et al. [93] and illustration of the device on the thrombus. Right: side view of the end effector from Gifford and Gifford [99] and illustration of the device on the thrombus.

Rosenbluth et al. [94] describe a device consisting of a rod containing several sets of radially spaced hooks along its length (Figure 4 left). The rod is placed within a catheter which first passes through the clot. When the rod is unsheathed, the hooks expand and anchor themselves within the clot, allowing the clot to be pulled out. The end effector in Morero's patent [92] is a coil which is unsheathed from the catheter after it reaches behind the clot and then is screwed into the clot, anchoring itself in it. The device described by Olsen et al. [93] consists of several hooks along its length (Figure 4 center). The hooks are semicircular in the radial plane and are deployed once the introducer tube is placed between the thrombus and the vessel wall. All above-mentioned devices are capable of applying force to a relatively small area of the thrombus in the radial plane. The device patented by Gifford and Gifford [99] covers entire area of the clot in the radial plane using a mechanism resembling an Archimedes screw (Figure 4 right). The end effector is screwed inside the clot from the front and then pulled, the normal forces being in the direction of pulling on a much larger area of the thrombus compared to previously mentioned devices.

3.3. Grasping from behind

Patents that describe devices that deploy the grip after reaching behind the thrombus were classified in the grasping from behind category. By definition, all of them utilize macroshape grasping. Total of 63 patents fit those criteria, including 19 patents that additionally fit criteria of other groups [9,11,13,15,24,38–40,42,50,54,71,75,76,78,80,97,98,100,102–145]. A variety of structures are used to accomplish grasping from behind. The end effector is usually housed in a compressed state within a catheter, once the catheter reaches behind the clot (either through it or between the clot and the vessel wall) the end effector is unsheathed and the structure expands to a deployed state, which covers the back of the clot. Wensel and Gobin [102] utilize a conically shaped coil (Figure 5 left), which is stretched out lengthwise within the catheter, Jenson and Drasler [111] describe a butterfly net resembling device (Figure 5 center) made of specially woven wire in a conical shape. The end effector in Dinh [134] is a spherical meshed structure (Figure 5 right) that can be stretched out into a slender tube within a catheter and compressed into a disc-shape when deployed. Apart from having an element blocking the back of the clot, some of the devices within this group also have an element deployed in front, for example in Nguyen et al. [126]. The additional element is supposed to minimize the risk of clot fragmenting and migrating.

4. Discussion

Out of 141 patents referenced in this review four were filed by academic institutions (3%), 17 by individual applicants (12%) and 120 by companies (85%), suggesting that this field is mostly industry-driven. It is worth mentioning that the oldest patent included in this study, published in 1997, originates at a university and was the basis of the first coil retriever to be approved for use in thrombectomy [102,146]. As the first FDA approved MT device for AIS treatment, the coil has largely influenced the future trajectory of the field.

About 2% of the patents rely solely on friction grasping. Since the surface of the thrombus is usually at least slightly deformable adding a patterned surface to those devices would probably improve their grip and that might be the reason why friction graspers are uncommon among patent literature. However, all three designs compress the thrombus during its retrieval. This potentially leads to decreasing the device volume and consequentially decreasing forces enacted on the vessel walls by the device, possibly making it safer.

Over a half (58%) of patents utilize microshape grasping and 67% of those are variations of a stent retriever, making them the most common solution among the patent literature on the subject. The TREVO 2 [147] and SWIFT [148] trials have shown that the stent retrievers not only provide good revascularization rates and clinical outcomes, but also are more

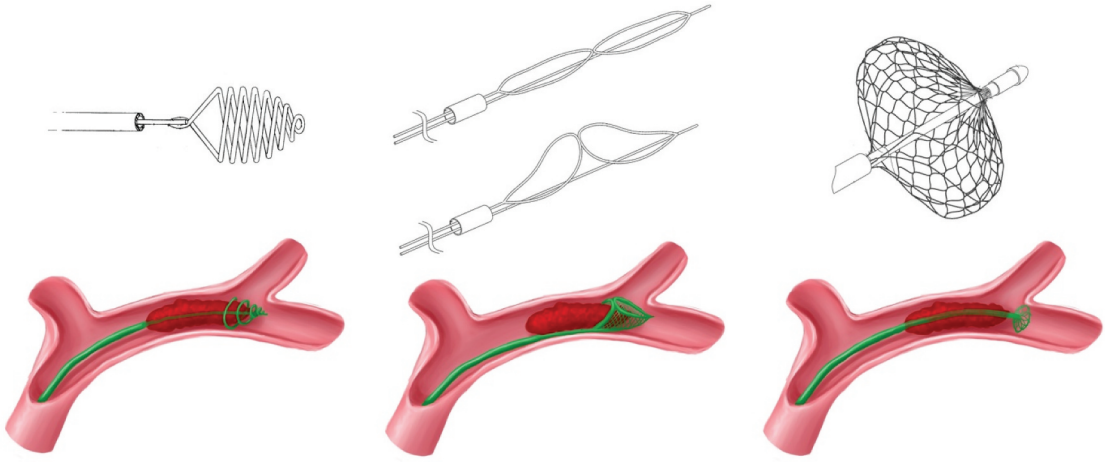

Figure 5. Devices utilizing grasping from behind. Left: side view of the end effector from Wensel and Gobin [102] and illustration of the device on the thrombus. Center: mechanism of the net from Jenson and Drasler [111] closing and opening and illustration of the device on the thrombus. Right: perspective view of the end effector from Dinh [134] and illustration of the device deployed behind the thrombus.

effective than the coil retriever. In author's opinion the effectiveness of stent retrievers is attained by the following factors. The meshed surface structure assures microshape grip along its length. The device is usually longer or equal to the length of the thrombus, ensuring grip along the thrombus' entire length. The radial expansion force additionally counteracts the normal force with which the vessel wall acts on thrombus and thus disrupts the thrombus-wall attachment. On the other hand, the meshed structure can lead to thrombus fragmentation upon expansion from within and subsequently to distal embolization. Additionally, the maintained radial force on the vessel wall can cause damage to the vessel during removal.

While stent retrievers contribute to the majority of the designs in the microshape grasping category, the remaining patents also showcased a large variety in designs. The examples of patents described in section 3.2.2 do not require the device to first penetrate the thrombus. That could minimize the risk of thrombus fragmentation or pushing it further down the bloodstream during the procedure. Like in case of stent retrievers the largest advantage of this category is the large contact area with the thrombus, surface pattern varying normal forces and disruption of the vessel-thrombus adhesion. A device similar to Figure 3 center has recently been granted FDA approval, so hopefully in the future more clinical data about a different type of microshape grasping devices will become available.

About 10% of the patented devices mention some kind of anchoring in the thrombus, here categorized as sideways macroshape grasping. The end effector of some of the designs does not necessarily come in contact with the vessel walls, therefore minimizing the risk of endothelial injury. On the other hand, that lack of contact does not provide direct disruption of thrombus-vessel adhesion, possibly making them less effective. These devices would need to penetrate the thrombi, which can lead to pushing the thrombi further down the vasculature. Additionally, anchoring within the thrombus can cause it to break and fragment at the site of anchoring. The disadvantages mentioned may be the reason why none of the currently commercialized devices use this principle.

Devices grasping the thrombus from behind make for about 45% of the patents. As previously mentioned, one of these patents has been commercialized as the first coil retriever. The MERCI trial [149] has proven the device to be safe and effective to use within the first 8 hours after symptoms onset. At the time of the trial that meant superiority to thrombolytic therapy. Currently coil retrievers are no longer commercially available, as they have been overtaken by newer generation, more efficient devices. In general devices utilizing grasping from behind have relatively little contact area with the thrombus and do not disrupt the attachment to vessel wall. That lack of disruption not only causes continuous resistance from the wall-thrombus interaction, but possibly axially compressing the thrombus causes it to expand in radial direction which increases that resistance. Specifically in the case of the coil retriever it has also been speculated that the loops of its coil loosen up during retrieval, in some cases causing it to pass through the thrombus [148]. In general devices grasping the thrombus from behind can have the same size regardless of thrombus length, although longer thrombus will have more interaction with vessel wall and thus cause more resistance to removal. Such designs also rely on blocking the entire vessel lumen behind the thrombus. That means the radial size of the device must vary based on the location of the occlusion, however most designs found in this category showcased a degree of adjustability of the radial size. Largest advantage of devices utilizing grasping from behind is that they can minimize the risk of distal embolization, unless the fragmentation occurred during thrombus penetration, before the device was fully deployed.

Several of the patents included in this study utilize both microshape grasping and grasping from behind (thus why the percentages quoted in this section do not add up to 100). Such designs can combine advantages of both categories. Studies conducted on stent retrievers that employ an embolic filter show that such feature improves the rates of FPE [150,151]. Designs as such have all the advantages of microshape grasping mentioned previously while also utilizing the

advantages of grasping from the back, mostly protection against distal embolization.

As mentioned in the methodology section none of the found patents utilized grasping the front surface of the thrombus. It is not surprising as maintaining a mechanical grasp at the front surface would be very challenging. On top of that such device would not disrupt the thrombus-vessel interaction, although thrombus would be in tension, possibly decreasing its radial area and as such decreasing the forces on the wall. That however would only be the case assuming the thrombus would not fragment prior to that. Although not a form of mechanical grasp, it might be worth mentioning that a type of device removing the thrombus from the front is an aspiration catheter. Devices utilizing negative pressure to remove thrombus have similar efficiency to stent retrievers [152].

5. Conclusions

This work provides a comprehensive overview of the patent literature on the subject of grip-based, non-fragmented thrombus removal methods. Search using Patentscope database yielded 141 relevant publications that were then categorized based on location and type of grip they describe. Several examples of end effectors were discussed, revealing that microshape grasping is the most often used strategy. Both in patent literature and among commercialized devices stent retrievers are the most common devices for this application. This study has shown that apart from that there is a large variety of thrombus gripping techniques as well as end effector structures that serve that purpose. The provided overview may help identify still existing gaps in thrombectomy innovation as well as offer inspiration for designing novel devices in the field.

6. Expert opinion

Advances in mechanical thrombectomy devices have greatly impacted clinical practices and outcomes. Introduction of mechanical thrombectomy has given a chance at recovery to patients who could not be administered thrombolytic drugs. Further developments in the field such as the introduction of stent retrievers allowed more efficient thrombus removal i. e. lower risk of distal embolization, vessel trauma and shorter procedure times. This patent review shows that the designs of stent retrievers are being constantly improved upon as well as newer generation devices, which combine sideways grasping and grasping from the back, are being introduced with promising clinical outcomes. New designs for end effectors of thrombectomy devices can be implemented into clinical practice relatively easily as they all follow similar procedure steps i. e. introduction via catheter. The key areas of improvement in MT are reducing procedure time, risk of distal embolization and risk of vessel trauma. Those factors can be translated to qualities of the grasping devices in the following ways. Procedure time can be reduced by maintaining grip along the entirety of thrombus as to allow removal upon first attempt. The risk of distal embolization can be reduced by minimizing the device fragmenting the thrombus i.e. avoiding sharp parts and using just enough force to maintain grip. Distal embolization can also be avoided by implementing a blocking member at the back of the thrombus. Similar qualities apply to avoiding vessel trauma: no sharp parts, just enough radial force on the vessel to minimize thrombus-wall adhesion as well as the device being compliant when navigating tortuous vasculature. It is visible throughout the years of patent literature how new designs are being optimized for the above-mentioned factors. The design patented by Bose et al. [10] implements barb-like structures to improve directional grip, the flexible connection between spherical, woven cages connected in series improves navigation and the embolic filter added to the back of a stent retriever captures fragmented emboli. However, the largest limitation in improving these designs is size: not only does the device need to fit in very small blood vessels with diameter of 2 mm, but it is also often necessary for the end effector to be able to collapse to even smaller sizes in order for it to fit inside a microcatheter which must pass through/by thrombus. For that reason, designs often incorporate a woven wire like structure. While providing large compliance in tortuous vessel and collapsibility within microcatheter such structures have very small contact area with the thrombus, providing little grip. Wire-like structure can additionally cut through the thrombus and lead to fragmentation. These devices face an inherent trade-off: minimizing the size while maximizing the grip, which often needs large contact area. Another issue is that the grip/friction between the device and the thrombus is often of a similar magnitude as the one between the device and the vessel wall. Small surface area of the device often makes it hard to implement different surface type inside/outside the device i.e. high friction surface interacting with the thrombus and low friction surface interacting with the vessel. But can the grasping MT device be infinitely improved? To answer whether the research has a definitive endpoint let us imagine a perfect device. It can be collapsed to an infinitely small size when passing through/by thrombus so it does not disturb it at all. It maintains a 100% efficient grip with the thrombus once deployed and does not allow the thrombus to fragment or it employs a structure that captures all broken off pieces. The device disrupts the thrombus-vessel interaction while also not enacting any force on the vessel wall. Obviously, that is not possible. In the authors' opinion the advancement of MT devices will continue in a kind of logarithmic manner until reaching a plateau. Although the developments might already be nearing that plateau, future developments in the field can still be incredibly beneficial. Even though mechanical methods have their limitations they are often the safest option as compared to methods using heat or drugs. However, the removal of the thrombus itself is just one of many steps required to achieve a successful recovery. The procedure time is usually a very small fraction of time that it takes from first symptoms to removal, the time of recognition of symptoms, transportation to hospital, diagnosis and insertion of catheter to the site of occlusion play a crucial role. Apart from reducing symptoms-to-intervention time, more detailed diagnostics could prove extremely useful. Imaging techniques revealing the composition of the thrombus, and with that its mechanical properties,

could help the intervention team in choosing the most efficient method to remove it. In the authors' opinion, in the next five years MT devices will continue to be improved. More devices will combine various grasping techniques. Perhaps more advanced manufacturing techniques will allow more intricate designs which improve grasping, navigation, and reduce fragmentation. It is also very likely that alongside the development of MT devices, more advanced imaging and image analysis tools will be developed which would help interventionists use the devices to their full potential. Recently medical devices research seems to focus more on sustainability. Most of the devices currently used for thrombectomy, and presumably, the ones described in the patents, are single-use, non-sterilizable devices. It would be interesting to see more devices designed for re-use.

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Declaration of interest

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