PulseRider-assisted treatment of wide-necked intracranial bifurcation aneurysms: safety and feasibility study

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OBJECTIVE The goal of this study was to assess the safety and feasibility of PulseRider, a novel endovascular stent, in the treatment of intracranial bifurcation aneurysms with wide necks. The authors present the initial results of the first 10 cases in which the PulseRider device was used.

METHODS Patients whose aneurysms were intended to be treated with the PulseRider device at 2 institutions in the United Kingdom were identified prospectively. Patient demographics, procedural details, immediate neurological and clinical status, and immediate angiographic outcomes and 6-month clinical and imaging follow-up were recorded prospectively.

RESULTS At the end of the procedure, all 10 patients showed complete aneurysm occlusion (Raymond Class 1). There were no significant intraprocedural complications except for an occurrence of thromboembolism without clinical sequelae. There was no occurrence of aneurysm rupture or vessel dissection. At 6-month follow-up, 7 and 3 patients had modified Rankin Scale scores of 0 and 1, respectively. All 10 patients had stable aneurysm occlusion (Raymond Class 1) and daughter vessel intraluminal patency on 6-month follow-up catheter angiography.

CONCLUSIONS The authors' early experience with the PulseRider device demonstrates that it is a safe and effective adjunct in the treatment of bifurcation aneurysms with wide necks arising at the middle cerebral artery bifurcation, anterior cerebral artery, basilar apex, and carotid terminus. It works by providing a scaffold at the neck of the bifurcation aneurysm, enabling neck remodeling and coil support while maintaining parent vessel intraluminal patency. Early clinical and radiological follow-up showed good functional outcome and stable occlusion rates, respectively. Further data are needed to assess medium- and long-term outcomes with PulseRider.

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KEY WORDS endovascular; stent; bifurcation aneurysm; aneurysm neck; PulseRider; occlusion; vascular disorders

THE International Subarachnoid Aneurysm Trial (ISAT)26 and the Barrow Ruptured Aneurysm Trial (BRAT)25 have established endovascular therapy as a valid method for treating intracranial aneurysms. Since these landmark studies, development of new endovascular techniques, including balloon remodeling and stents, have enabled geometrically complex aneurysms to be treated with coil embolization.2,17,21,23,27,35

The PulseRider (Pulsar Vascular) is a novel device intended for use in the treatment of wide-necked aneurysms arising at bifurcations.44 It is designed to remodel a bifurcation, provide support at the aneurysm neck, and protect the daughter branches during coil embolization. Early clinical data have recently emerged from using the PulseRider in the US, demonstrating its safe and effective use as an adjunct in the treatment of bifurcation aneurysms.41 These data, however, were based on only 3 cases and limited to terminal bifurcation aneurysms (basilar apex and ca-
rotid terminus). We present the initial results on the first 10 cases in Europe (at 2 institutions in the United Kingdom) that employed the PulseRider device in the treatment of middle cerebral artery and anterior communicating artery as well as terminal bifurcation aneurysms.

Methods

Case Selection

Patients whose aneurysms were intended to be treated with the PulseRider device at 2 institutions in the United Kingdom, Leeds General Infirmary and The Walton Centre, were identified prospectively. Bifurcation aneurysms that were broad necked were considered candidates for treatment with the novel device. Both institutional and departmental approvals were gained for the undertaking of this case series.

All patients had an unruptured wide-necked bifurcation aneurysm (de novo or recurrent) at the basilar tip, terminal carotid artery, anterior cerebral artery, or middle cerebral artery, based on cerebral angiography findings. Each case was discussed in detail at our institutions’ Neuro-vascular Multi-Disciplinary Team (MDT) meeting, attended by the vascular neurosurgeons and interventional neuroradiologists. This was followed by discussion with the individual patients themselves. In all 10 patients, the aneurysm was deemed unsuitable for simple balloon- or Woven EndoBridge (WEB)—assisted coil embolization, based on anatomical and geometric considerations, but the PulseRider was selected as an appropriate treatment approach. In 7 cases craniotomy and clipping was also deemed technically feasible (Cases 1–5, 8, and 9; Table 1). Both treatment options were discussed with these 7 patients in terms of benefits and risks, and all 7 elected to undergo the PulseRider endovascular technique. The remaining 3 patients (Cases 6, 7, and 10; Table 1), for whom there was no surgical alternative, underwent the PulseRider technique. All cases were treated electively.

Analysis

Patient demographics, procedural details, complications, immediate and 6-month angiographic outcomes, and 6-month follow-up assessment of global disability using the modified Rankin Scale were recorded prospectively.

PulseRider Device

The PulseRider device is a self-expanding nitinol implant (Fig. 1) that is delivered on a stainless steel delivery wire within any commercially available 0.021-inch-diameter microcatheter. The device is fully retrievable and can be repositioned and torqued to fit the relevant anatomy. It contains significantly less metal than a conventional stent, with the majority of the surface area focused at the neck of the aneurysm. The device is available in both Y- and T-configurations (Fig. 1) to fit the geometry of the daughter vessels arising at the bifurcation. The device is also available in different diameters and lengths. The device provides coil support while maintaining daughter vessel intraluminal patency (Fig. 2).

Coil Embolization Technique

All patients underwent cerebral angiography with 3D reconstruction as deemed necessary prior to the intervention. Patients were pretreated the evening before the procedure with clopidogrel (600 mg orally) and aspirin (600 mg orally). All procedures were performed under general endotracheal anesthesia. After obtaining percutaneous access (transfemoral in all cases), intravenous heparin was administered and an activated clotting time was obtained to achieve a level 2–2.5 times baseline. A 6-F Envoy guide catheter (Codman Neurovascular) was positioned into the vessel of interest, and working views were obtained in both the anteroposterior and lateral projections following a 3D rotational angiogram. In all cases, either a Prowler Select Plus microcatheter (inner diameter 0.021 inches, Codman Neurovascular) or a Headway 21 microcatheter (MicroVention, Aliso Viejo) was navigated over a 0.014-in microwire and positioned at the neck of the aneurysm. An appropriately sized PulseRider device was then deployed, typically across the neck of the aneurysm with limbs in the daughter vessels. A T- versus Y-configuration device was chosen at the surgeon’s discretion based on the geometry of the daughter vessels arising at the bifurcation. The device was initially deployed across the neck, but not detached. In all cases, either an SL-10 microcatheter (Stryker Neurovascular) or Headway 17 microcatheter (MicroVention) was then navigated over a Synchrone 0.014-in microwire (Stryker Neurovascular) through the device into the aneurysm. Coil embolization was subsequently performed with follow-up angiography throughout the remainder of coiling as required. The device was detached at the conclusion of coil embolization.

Postprocedure Management

From the 1st day after the procedure, all patients were maintained on once daily oral 75 mg clopidogrel for 3 months and once daily oral 75 mg aspirin life-long. All patients had a minimum overnight stay in the neurosurgical ward, with complete clinical and neurological assessment prior to discharge. Six-month follow-up MR angiography was performed in all cases. Over the study period, follow-up catheter angiography was performed in all patients.

Results

Table 1 summarizes the results of our 10 patients who underwent PulseRider stent-assisted coil embolization of intracranial wide-necked bifurcation aneurysms. There was no procedural rupture or vessel dissection during any of the procedures. There was one case of small nonocclusive thrombus formation in the parent vessel (Case 3 in Table 1, middle cerebral artery) but this was without clinical sequelae and the patient was asymptomatic. In all patients complete angiographic occlusion (Raymond Class 1) was achieved both immediately at the end of the procedure and at 6-month follow-up cerebral angiography. At the 6-month follow-up, 7 patients had no symptoms while 3 patients had some symptoms—left arm numbness (Cases 1 and 4) and headache (Case 9)—but were able to carry out all usual activities (modified Rankin Scale scores of 0 and 1, respectively).


<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Presentation</th>
<th>Site</th>
<th>Size (mm)</th>
<th>Type</th>
<th>Size (mm)</th>
<th>Catheter(s)</th>
<th>Embolization</th>
<th>Coils</th>
<th>Complications</th>
<th>Immediate Post-Occlusion</th>
<th>6 Mos Post-Occlusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>52, F</td>
<td>HA, pituitary adenoma, incidental on MRI</td>
<td>Rt MCA bifurcation</td>
<td>Height, 7.7; width, 6.0; neck, 7.0</td>
<td>10-mm T</td>
<td>Length, 10.6; diameter, 2.7–3.5</td>
<td>Prowler plus 21; SL 10</td>
<td>7 Target, 86 cm</td>
<td>None 0</td>
<td>1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>54, F</td>
<td>HA, family history of aneurysm, MRI performed</td>
<td>Rt MCA bifurcation</td>
<td>Height, 6.0; width, 3.5; neck, 4.1</td>
<td>10-mm Y</td>
<td>Length, 10.6; diameter, 2.7–3.5</td>
<td>Headway 21; Headway 17</td>
<td>5 Target, 30 cm</td>
<td>None 0</td>
<td>1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>62, F</td>
<td>Previous aSAH from Lt MCA, unruptured rt MCA</td>
<td>Rt MCA bifurcation</td>
<td>Height, 4.1; width, 3.8; neck, 4.2</td>
<td>10-mm T</td>
<td>Length, 8.6; diameter, 2.7–3.5</td>
<td>Headway 21; Headway 17</td>
<td>2 Target, 10 cm</td>
<td>None 0</td>
<td>1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>53, F</td>
<td>HA, family history of aSAH</td>
<td>Rt MCA bifurcation</td>
<td>Height, 12.0; width, 9.0; neck, 5.3</td>
<td>10-mm T</td>
<td>Length, 10.6; diameter, 2.7–3.5</td>
<td>Headway 21; Headway 17</td>
<td>12 Target, 228 cm</td>
<td>None 0</td>
<td>1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>58, M</td>
<td>Diplopia, incidental on MRI</td>
<td>ACoA</td>
<td>Height, 14.0; width, 9.0; neck, 3.9</td>
<td>10-mm Y</td>
<td>Length, 8.6; diameter, 2.7–3.5</td>
<td>Prowler plus 21; SL 10</td>
<td>6 Target, 140 cm</td>
<td>None 0</td>
<td>1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>41, F</td>
<td>Previous aSAH, bare coils in situ, recurrence at 6 yrs</td>
<td>Basilar tip</td>
<td>Height, 4.8; width, 4.8; neck, 4.3</td>
<td>10-mm Y</td>
<td>Length, 8.6; diameter, 2.7–3.5</td>
<td>Prowler plus 21; SL 10</td>
<td>5 Target, 49 cm</td>
<td>Thrombus (asymp) 0</td>
<td>1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>43, M</td>
<td>Previous aSAH, bare coils in situ, recurrence at 7 yrs</td>
<td>Basilar tip</td>
<td>Height, 8.0; width, 5.6; neck, 8.1</td>
<td>10-mm T</td>
<td>Length, 10.6; diameter, 2.7–3.5</td>
<td>Headway 21; Headway 17</td>
<td>2 Target, 20 cm</td>
<td>None 0</td>
<td>1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>68, M</td>
<td>Unremitting HA, incidental on CT</td>
<td>Rt MCA bifurcation</td>
<td>Height, 6.8; width, 4.9; neck, 4.3</td>
<td>10-mm T</td>
<td>Length, 10.6; diameter, 2.7–3.5</td>
<td>Headway 21; Headway 17</td>
<td>4 Target, 30 cm</td>
<td>None 0</td>
<td>1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>59, M</td>
<td>HA, family history of aneurysm</td>
<td>Rt carotid terminus</td>
<td>Height, 8.1; width, 5.2; neck, 7.7</td>
<td>10-mm T</td>
<td>Length, 10.6; diameter, 2.7–3.5</td>
<td>Headway 21; Headway 17</td>
<td>5 Target, 65 cm</td>
<td>None 1</td>
<td>1 1 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>60, F</td>
<td>Syncope, incidental on CT</td>
<td>Rt MCA bifurcation</td>
<td>Height, 8.0; width, 6.3; neck, 4.8</td>
<td>10-mm T</td>
<td>Length, 11.1; diameter, 3.5–4.5</td>
<td>Headway 21; Headway 17</td>
<td>4 Target, 30 cm</td>
<td>None 0</td>
<td>1 1 1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ACoA = anterior communicating artery; aSAH = aneurysmal subarachnoid hemorrhage; asymp = asymptomatic; HA = headache; MCA = middle cerebral artery; mRS = modified Rankin Scale.

* According to MR angiography and catheter angiography.
Placement of the PulseRider varied depending on the geometry of the aneurysm and the location of the daughter vessels. In some cases, the device was placed at the base with the arch within the side branches; in others, the arch was completely inside the aneurysm. Another alternative was a hybrid placement with one arm of the arch in the daughter vessel and the other arm in the aneurysm. In all cases, coils were successfully deployed inside the aneurysm or remnant and retained by the scaffold (Figs. 3 and 4).

Discussion

Despite advances in stenting and balloon remodeling techniques, broad-necked aneurysms arising at bifurcations remain a particular challenge to endovascular treatment. These aneurysms occur at the junction of 2 essential branching arteries that must remain patent after embolization.

Several balloon remodeling techniques have been used to treat bifurcation aneurysms: a more compliant balloon (e.g., HyperForm and Transform) can be used to mold the neck of the aneurysm and the origin of bifurcation branches; two balloons can be used instead of one (1 balloon in each of the bifurcated arterial branches); and navigation of the balloon through the circle of Willis to cross and protect the aneurysm neck and the navigation of a dual-lumen balloon in front of the neck can be used to allow coil deposition through the second lumen of the balloon microcatheter.

Unassisted coiling or single-stent techniques are frequently insufficient to protect the remaining daughter vessels and prevent coil prolapse leading to arterial occlusion. Indeed, conventional coil therapy was reported as one of the predictors of delayed recurrence and retreatment in a recent study of 209 patients. Over the last decade, various techniques have been introduced to assisted coiling to prevent recurrence and promote reconstruction of the parent vessel. In particular, the use of these techniques has been justified in complex bifurcation and wide-necked aneurysms. The wide-necked aneurysm has demonstrated worsening of occlusion in up to 62.1% of cases in the CLARITY study. More recently, double stenting in a Y or X configuration may be used to treat a subset of wide-necked bifurcation aneurysms. The use of 2 stents in a Y-shaped configuration (Y-stenting) to assist with coil embolization of complex bifurcation aneurysms was first described in 2004. Since that time, several reports have been published that demonstrated acceptable morbidity and mortality rates associated with Y-stenting, and it has been accepted as a safe and reasonable alternative to clip reconstruction for a select subset of challenging aneurysms.

Recently introduced, flow diversion stenting takes advantage of changing the parent artery/aneurysm sac interface, altering in-flow and out-flow jets, to induce aneurysm thrombosis. However, this method is not ideal in treating bifurcation aneurysms because it would effectively jail one of the limbs of the bifurcation and has been associated with the risk of daughter vessel, side branch, and perforator occlusion.

Balloon remodeling techniques and X- and Y-stenting remain technically challenging, require many steps to be performed successfully, and, although feasible, are associated with relatively higher rates of periprocedural morbidity and mortality. Compared with X- and Y-stent reconstruction, the PulseRider has a very low metal-to-artery ratio, with the highest density of metal positioned to cover the aneurysm neck and support a coil mass. As a result, there is no jailing of daughter branches, and there is minimal intraluminal hardware that is not opposed to vessel intima. The device is fully retrievable and can be repositioned and recaptured until it is detached with an electrolytic detachment mechanism. This results in a technically easier procedure that is more streamlined, as only one device is required to be positioned to reconstruct the
bifurcation. Fewer steps will theoretically result in fewer technical adverse events during the procedure. In addition, employing a single device for vessel reconstruction may provide a higher value (quality vs cost) compared with strategies using multiple devices.

WEB is a new endovascular approach to treating wide-necked bifurcation aneurysms by disrupting intrasaccular flow to cause thrombosis. Early data demonstrated complete occlusion rates between 80% and 89% and a 3% to 7% risk of complications, including thromboembolism, WEB retrieval, and inadvertent detachment.\(^\text{22,33}\) The device has been associated with worsening aneurysm occlusion at a rate of 7%.\(^\text{22}\) However, it does not address neck reconstruction in some cases. This is true in cases in which daughter branches are part of the aneurysm neck.

The PulseRider device has received European CE Mark approval since 2013. The European CE–approved indication is the treatment of complex intracranial bifurcation aneurysms (with no limitation or specification as to particular vessels). The FDA has granted an investigational device exemption for the clinical trial use of PulseRider for the treatment of wide-necked bifurcation aneurysms, specifically at the basilar tip and carotid terminus. Indeed, there is only one previously published study of PulseRider stents in the US, which assessed 3 patients with wide-necked bifurcation aneurysms specifically at the basilar tip or carotid terminus.\(^\text{41}\)

In our early experience we have found the use of PulseRider to be simple and safe, being readily delivered in a standard method very similar to other available stents, making the procedure more familiar to an operator new to the device. It is conformal and delivered without difficulty through any 0.21-inch microcatheter, even in tortuous anatomy. The device is easily recaptured and can be turned by pulling it back into the catheter while torqueing on the device and then redeploying it until it conforms to the specific anatomy. Once deployed across the neck, the device can be crossed readily by navigating a standard coiling microcatheter over a 0.014-inch microwire. Since the majority of the metal mass of the stent is concentrated at the neck, it is likely that patients could be managed safely with shorter dual antiplatelet regimens or even a single antiplatelet medication. Lastly, in our experience the metal support at the neck has proved to be sufficient to support a coil mass.

All cases in our series had an aneurysm neck size greater than 4 mm, which we considered appropriate based on our personal experience. Had the neck size been less than 4 mm, we would have preferred standard or balloon-assisted coil embolization approaches. The PulseRider was only used in those patients in whom the stent could be passed through an adequately sized parent vessel and daughter branches and safely deployed to adequately cover the neck of the aneurysm. This decision was made following meticulous evaluation of the 3D angiographic images. Arterial bifurcation configurations with a T shape and Y shape are both appropriate for PulseRider use. However, based on our limited personal experience, which is still evolving, we have found that if the angle between the daughter branches is too acute (< 60°) the satisfactory deployment

FIG. 3. Case 8. PulseRider-assisted coil embolization of a previously coiled recurrent bifurcation aneurysm in a 76-year-old man. A: Digital subtraction angiogram in a sagittal working projection, demonstrating a recurrence (arrow) of a previously coiled left anterior cerebral artery wide-necked bifurcation aneurysm. B–D: Working projection roadmap images (B and C) and angiogram (D) after deploying the PulseRider device, demonstrating the device across the neck of the aneurysm (arrows) assisting coil embolization. E: Final immediate treatment angiogram obtained in the sagittal working projection, demonstrating complete occlusion of the aneurysm. F: Follow-up catheter angiography 7 months postprocedure showing stable aneurysm occlusion and daughter vessel intraluminal patency.
of the stent becomes more challenging. We have therefore found that T-shaped and gentle Y-shaped bifurcations with an angle between the daughter branches greater than 60° are most appropriate and correspond to the default stent configurations of the manufacturer (T-shaped and gentle Y-shaped). The stent is available in diameters of 2.7–3.5 mm and 3.5–4.5 mm, and lengths of 8.6 mm, 10.6 mm, and 11.1 mm. Therefore, the correct stent for use has to be selected based on a parent vessel size ranging between 2.7 and 4.5 mm in diameter, appropriate vessel length, and adequate branch vessel dimensions (although no specific limitations have been advised by the manufacturer) as well as the neck dimensions that have to be spanned. Intuitively, we will not use the stent in a vessel that is too small to accommodate, which itself depends on the size of stent available. This forms a potential limitation for the device, in that it is only available in 2 configurations with a limited range of sizes.

Limitations of the PulseRider device are that it has no flow-diverting effects that may be seen using braided stents or X- or traditional Y-shaped stents, and also it is a new device with as yet unknown long-term outcomes. Follow-up MRI shows stent artifact and dropout at the level of markers on the device, and catheter angiograms are needed at this stage to assess the stability of the aneurysm. Furthermore, PulseRider has not yet been assessed in an acute setting for the treatment of ruptured aneurysms in our series.

Conclusions

We have presented, to the best of our knowledge, the first case series in Europe and the largest case series to date of the PulseRider device for the treatment of complex wide-necked intracranial bifurcation aneurysms arising from the middle cerebral artery bifurcation, anterior cerebral artery, basilar apex, and carotid terminus. Our early experience demonstrates that PulseRider is a safe adjunct that provides a scaffold at the neck of the bifurcation aneurysm, enabling neck remodeling and coil support while maintaining parent and daughter vessel intraluminal patency. In each of the 10 cases presented, the procedure was successfully completed without aneurysm rupture or vessel dissection. Our early clinical and radiological follow-up shows good functional outcome and stable complete occlusion rates from the procedure, respectively. Additional clinical work at our institutions is planned to better evaluate the medium- and long-term safety and performance of this novel device.

References


Disclosures
Dr. Patankar states that he is a proctor for PulseRider.

Author Contributions
Conception and design: Mukherjee, Chandran, Patankar. Acquisition of data: Mukherjee, Chandran, Gopinathan, Patankar. Analysis and interpretation of data: Mukherjee, Chandran, Gopinathan, Putharan, Goddard, Eldridge, Patankar. Drafting the article: all authors. Critically revising the article: Mukherjee, Chandran, Gopinathan, Putharan, Goddard, Patankar, Nahser. Reviewed submitted version of manuscript: Mukherjee, Chandran. Approved the final version of the manuscript on behalf of all authors: Mukherjee.

Supplemental Information
Previous Presentations
The data within this paper were presented orally at the Society of British Neurological Surgeons (SBNS) Autumn Meeting, York, United Kingdom, on September 10, 2015.

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