Hydrodynamic boost: a novel re-entry technique in subintimal angioplasty of below-the-knee vessels

Roberto Ferraresi1 · Meneme Hamade2 · Vito Gallicchio2 · Nicola Troisi3 · Giovanni Mauri4

Abstract
Objectives To describe the hydrodynamic boost (HB) technique and report our preliminary results with this technique in the subintimal angioplasty of below-the-knee vessels.

Methods HB was used in 23 cases (14 males, mean age 73±12 years) of critical limb ischemia, with long chronic total occlusion of tibial arteries extended to the ankle level. The operator performs a manual injection of diluted contrast dye through a 4 F catheter into the subintimal space, close to the patent true distal lumen, in order to achieve a tear in the intimal flap and a connection with the true lumen.

Results In 19/23 (83 %) cases, the HB was effective in creating a connection between the subintimal space and the true distal lumen and it was possible to advance a wire and to conclude the procedure. In 4/23 (17 %) lesions, the HB failed and the procedure was successfully completed by retrograde approach. No major complications occurred. Mean length between catheter tip and re-entry point was 8±5 mm.

Conclusions HB seems to be a feasible, safe and effective re-entry technique in distal below-the-knee vessels. This method represents an easy option for re-entry that extends the possibility of antegrade approach to obtain a successful revascularization.

Key points
- In subintimal angioplasty of below-the-knee vessel re-entry can represent a challenge.
- Inability to re-enter may determine the failure of the revascularization procedure.
- HB is a novel re-entry technique feasible in distal below-the-knee vessels.
- HB may increase the success rate of antegrade approach.
- In case of failure, retrograde approach remains feasible.

Key Words Subintimal angioplasty · Below-the-knee vessel · Hydrodynamic boost · Critical limb ischemia · Re-entry technique

Introduction
Subintimal angioplasty (SIA) has been widely applied for treating peripheral artery disease in patients presenting critical limb ischemia (CLI) [1, 2]. Using this technique, a vessel wall dissection is intentionally done to cross a chronic total occlusion (CTO) and to create a channel to a distant patent artery. Initially performed in femoral and popliteal vessels, this technique has been recently reported to be feasible and effective in the treatment of below the knee (BTK) and below-the-ankle (BTA) vessel disease [2–8].
Re-entry of the true distal lumen can be achieved by pushing the looped wire or trying to direct the wire tip towards the patent distal vessel [9]; however, failure of re-entry has been reported in about 15–25% of cases [2, 10]. Furthermore, re-entry into the true distal lumen may occur distally to the level of vessel lumen patency, leading to the risk of damaging the distal vascular segment, which might be the last potential target for bypass surgery. To overcome these limitations, different re-entry devices have been developed in femoro-popliteal vessels [11–13]; however, due to their size, these devices cannot be used in BTK and BTA vessels, that remain a domain of standard antegrade or retrograde approaches [14–18].

Carlino et al. described the subintimal tracking and re-entry technique with contrast guidance in coronary CTO angioplasty [19]. According to this concept, we developed the hydrodynamic boost (HB), a novel re-entry technique for SIA of BTK and BTA vessels. Aim of the present study is to describe the HB technique and to report our preliminary results.

Materials and methods

Standard revascularization technique

Our approach in BTK-CTOs is described elsewhere [14]. Briefly, we follow a step-by-step approach: we always begin trying to maintain an endoluminal position of the wire. In case of failure of this endoluminal approach, we perform a subintimal approach using a 0.035 inch looped wire (Radiofocus® Guide Wire M, Terumo, Japan), supported by a 4 F diagnostic Berenstein catheter (Tempo® Aqua, Cordis, USA). Standard strategy for re-entry consists in a simple pushing of the looped wire or trying to direct the wire tip towards the patent distal vessel. In some cases, when it seems difficult to achieve the re-entry in the most proximal part of the distal target vessel, in order to preserve the distal landing zone that could be damaged by further pushing of the wire, we prefer to shift to alternative approaches, such as retrograde approaches or HB. If the wire goes subintimally beyond the most proximal part of the distal vessel we apply retrograde approaches, as at this point we consider HB no more feasible.

Patients

From February 2014 we started to use HB. Between February 2014 and March 2015, 431 patients underwent 544 percutaneous revascularizations for CLI in our centre. Among these procedures, we have treated 280 CTOs of tibial arteries extended to the ankle or BTA level. Successful endoluminal antegrade recanalization was achieved in 103/280 (37%) of cases; in the remaining 177/280 (63%) cases, we adopted a subintimal approach. In 8/177 (4%) the SIA was abandoned due to inability to dissect the vessel to the distality; in 169/177 (96%) we were able to dissect the distal subintimal space to the ankle level. HB was applied only at this distal level, where vessels have a small size, and it is easier to create a close chamber and to pressurize it. In 104/169 (61%) the wire was able to obtain the true distal lumen in the most proximal part of the distal target vessel; in the remaining 65/169 (39%) cases, in order to preserve the distal target vessel, the operator decided to use alternative approaches. Retrograde approaches were used in 42/65 (64%) and HB was used in 23/65 (36%). The decision was based on the characteristics of the distal target vessel: in case of calcification or obstructive disease, the retrograde approach was preferred; in case of a healthy vessel, the HB was preferred. Patients’ characteristics of the 23 cases (14 male, 9 female, mean age 73±12 years) in whom HB was performed are reported in Table 1.

Institutional review board approval was obtained for the retrospective analysis of data and patients’ informed consent was waived.

Hydrodynamic boost re-entry technique

In the subintimal space at the ankle level, the operator removes the wire and positions the tip of the 4 F Berenstein catheter as close as possible to the open distal target vessel, which was identified on the basal angiographic study (Fig. 1). Predilatation of the subintimal space is avoided. The operator connects the catheter with a 10 ml syringe filled with diluted contrast dye (7 mL of contrast [Iodixanol, Visipaque 320, GE Healthcare, USA] and 3 mL of saline solution) and performs a manual injection of 2–8 mL under continuous fluoroscopic guidance. The fluid fills the subintimal space around the catheter tip and tends to reflow back in the dissected subintimal space, replenish collateral vessels and, sometimes, satellite veins (Fig. 2). In case of a connection between the collateral

Table 1  Patient and procedural data

<table>
<thead>
<tr>
<th>Patient number</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male/female</td>
<td>14/9</td>
</tr>
<tr>
<td>Mean age</td>
<td>73±12 years</td>
</tr>
<tr>
<td>Diabetes</td>
<td>18</td>
</tr>
<tr>
<td>Hypertension</td>
<td>17</td>
</tr>
<tr>
<td>Smoking history</td>
<td>14</td>
</tr>
<tr>
<td>HEMODIALYSIS</td>
<td>2</td>
</tr>
<tr>
<td>Number of treated vessels</td>
<td>23</td>
</tr>
<tr>
<td>Mean length of tibial lesion</td>
<td>27.4±7 cm</td>
</tr>
<tr>
<td>Distal target vessel</td>
<td></td>
</tr>
<tr>
<td>- Distal anterior tibial artery</td>
<td>2</td>
</tr>
<tr>
<td>- Dorsalis pedis artery</td>
<td>14</td>
</tr>
<tr>
<td>- Distal posterior tibial artery</td>
<td>3</td>
</tr>
<tr>
<td>- Lateral plantar artery</td>
<td>4</td>
</tr>
</tbody>
</table>
vessels and the true distal lumen, a significant opacification of the target vessel can occur, helping in positioning the catheter tip as close as possible to it (Fig. 3). The operator focuses on the distribution of the contrast dye around the catheter tip. There are two possible outcomes from this manoeuvre:

- Extravasation of the contrast dye outside the vascular space (Fig. 4): the operator immediately stops the injection and the HB is abandoned; the procedure is continued using a standard retrograde approach. Faint extravasation of contrast dye into the veins surrounding the subintimal space or into the collateral vessel is not considered significant.
- Close subintimal space without extravascular leaking: the operator gently holds on and increases the manual pressure in order to create a pressurized chamber.
around the catheter tip, and to achieve the rupture of the intimal flap. In this case, a sudden pouring of contrast dye into the true distal lumen is observed. After this successful manoeuvre, the operator crosses the new connection to the true lumen with a 0.014 inch wire. The type of wire is selected according to the appearance of the connecting pathway. The procedure is completed using standard technique. In case of failure of this manoeuvre in opening a passage to the true distal lumen, the procedure can be continued using standard retrograde approaches.

**Study end-points**

We evaluated the technical success of the HB in obtaining the re-entry into the distal true lumen. The number of patients in whom the HB failed due to extravasation of contrast dye or...
inability to open a connection to the true distal lumen was recorded. The mean length between the catheter tip and the re-entry point was measured.

Results

In 19/23 (83 %) cases, the HB was effective in creating a tear connecting the subintimal space and the true distal lumen. In all these cases, it was possible to advance a wire into the true lumen and to achieve a successful revascularization.

In 3/23 (13 %) of procedures, an extravascular leaking of the contrast dye was noted, and the HB was interrupted (Fig. 2). In one case (4 %), the HB was unable to open a connection between the subintimal space and the true distal lumen. In all these four cases, the procedure was successfully completed by performing a retrograde approach.

No major complications occurred.

Mean length between the catheter tip and the re-entry point was 8±5 mm (mean±standard deviation).

Discussion

In case of failure of standard antegrade endoluminal or subintimal technique in BTK vessels, up to now the only strategy to achieve a successful recanalization was to switch to retrograde approaches, using the pedal-plantar loop technique, the transcollateral approach, or a retrograde puncture [14–18]. However, these techniques are challenging, time consuming, and require highly experienced operators. Failure of achieving the re-entry can be a principal cause of failure of endovascular recanalization in BTK and BTA vessel CTO. In order to increase the rate of success of endovascular recanalization of the antegrade approach we developed the HB technique.

The basic idea of this technique is to obtain the laceration of the intimal flap by using hydrodynamic pressure. The concept was already described in percutaneous coronary angioplasty and in surgical endarterectomy; however, to the best of our knowledge, this technique has never been reported in peripheral angioplasty. In antegrade angioplasty of coronary CTO, Carlino et al. described the subintimal tracking and re-entry technique with contrast guidance [19]. Manual injections of contrast were used in an attempt to directly open the distal dissection into the true lumen. Once successful, a conventional floppy wire was then manipulated through the dissection plane into the distal true lumen. This technique was considered to be feasible and relatively safe. They also described the “storm cloud dissection”, a diffuse staining of contrast media probably indicating vessel dissection with contrast extravasation into the adventitia, a clear sign to continue the procedure using other approaches. Vascular surgeons used fluid injection (gas or water) to perform endarterectomy [20–22]. This surgical technique provides uniformly smooth endarterectomy dissection planes over the entire length of the operated vessel.

We applied the same concept to percutaneous SIA. While the wire technique (looped or not) explores the subintimal space only in the wire plane, the HB technique expands the whole subintimal space adjacent to the patent true distal lumen and explores every corner of it, looking for the most proximal site of minor resistance. When finding it, the operator observes the rupture of the intimal flap and the sudden pouring of contrast dye into the true distal lumen. In some cases, a gentle injection can be enough to achieve the intimal flap tear, while in other cases a prolonged and stronger injection can be necessary. Two data items are particularly interesting. First, the HB was able to get the true distal lumen in the very proximal part of the distal target vessel, sparing the main body of the vessel as a landing zone in case of future bypass surgery. Second, in some cases, the HB was able to get successful re-entry of very thin distal target vessels, such as the pedal arch, usually considered very difficult for revascularization (Figs. 5 and 6).

For an optimal result of this technique, the subintimal space has to be compact; therefore, we never perform balloon dilation of the subintimal tract before applying HB. Moreover, before using this technique, a careful evaluation of the subintimal space and of the target vessel has to be done; we do not apply this technique in case of diseased or calcified distal target vessel, in order to avoid the possibility that the HB propagates distally to the intimal dissection instead of achieving the re-entry. According to the general principles of subintimal techniques, we considered a calcific vessel wall as a main limitation to re-entry. Femoro-popliteal and proximal BTK vessels were not considered suitable for this technique because of the big size of the subintimal space, where contrast dye injection is unable to create a close chamber and to pressurize it.

In our experience no complications occurred due to the procedure and, in case of failure, the staining of contrast dye outside the vessel wall did not prevent continuing the procedure by performing a retrograde approach.

In our preliminary experience, with the HB technique we were able to achieve the re-entry in 83 % of cases. Notably, this series includes the first patients that were treated with this technique, and the success rate of the technique might be underestimated due to the learning curve that is always present when a novel technique is introduced. In these patients, we were able to obtain endovascular recanalization using an antegrade simple and fast approach, respecting the integrity of the distal target vessel, and sparing the discomfort of a more complex retrograde approach.

Several limitations have to be taken into account. First of all this is the very initial experience with a novel technique,
that has been applied in a small number of patients in a single centre. Selection of cases in which this technique might be successful has been derived from personal experience of the operator, not being present in the literature other reports on the technique. Moreover, results are derived from a retrospective analysis, and no direct comparison with other strategies has been performed. Thus, definitive indication on when to apply HB cannot be derived. The ability of the operator to stop the injection in case of contrast dye extravasation may be dependent on the operator experience and reactivity. We do not know if this technique could be reproducible in centres with a low case-load. Further studies on larger series of patients are needed to better clarify the matter.

In conclusion, HB seems to be a feasible, safe and effective technique for achieving re-entry in ankle and BTA vessels. This method represents an easy option for re-entry that extends the possibility of antegrade approach to obtain a successful revascularization.

Fig. 5 An example of successful HB in the plantar artery. a: basal angiographic study: black arrow indicates the distal target vessel. b,c: injection of contrast dye creates a chamber around the catheter tip. d: sudden pouring of contrast dye into the true distal lumen through a new thin connection. e: final result

Fig. 6 An example of a successful HB in a very thin dorsalis pedis artery. a: basal angiographic study. b: injection of contrast dye creates a chamber around the catheter tip. c: sudden pouring of contrast dye into the true distal lumen. d: final result
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Methodology: retrospective, observational, performed at one institution.

References