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The Netherlands

## Biomechanical studies on type B aortic dissection

Veger, H.T.C.

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**Where to Fenestrate in Type B  
Aortic Dissection?  
An ex-vivo study.**

H.T.C.Veger

E.H. Pasveer

M.J.T.Visser

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## **ABSTRACT**

### **Purpose**

Fenestration is a minimally invasive alternative for the treatment of acute symptomatic aortic dissections because it may quickly decrease the pressure gradient of the false lumen. It remains unclear where the optimal location of these fenestrations should be chosen. The purpose of this study was to study false lumen volume after different fenestration strategies in porcine ex-vivo models of aortic type B dissection.

### **Materials and Methods**

An artificial dissection was created in ex-vivo porcine aortas. A total number of six aortic dissection models were made. The dissection flap was divided in three equal parts; proximal, mid and distal sections. In three models a fenestration was made in the center of the proximal section of the dissection flap. In the three others in the center of the distal part of the dissection flap. The aorta was positioned in a validated in vitro circulatory system with physiological pulsatile flow. Volume-measurements of true lumen volume (TLV) and false lumen volume (FLV) were assessed with computed tomography.

### **Results**

Performing a fenestration in the proximal part of the dissection flap resulted in FLV increase in two of the three models. Performing a fenestration in the distal part of the dissection flap resulted in FLV decrease in all three models. False lumen reduction was obtained significantly in the distally fenestrated models compared to the proximally fenestrated models ( $9.6 \pm 3.5\%$  vs.  $0.7 \pm 2.9\%$ ,  $p=0.02$ )

### **Conclusion**

In this in-vitro study, we showed that distal fenestration of the false lumen in aortic dissection will result in the largest false lumen reduction.

## INTRODUCTION

Acute type B Aortic Dissection (ABAD) is still today a catastrophic disorder. Visceral, renal, spinal and iliac malperfusion occurs in up to 30% of patients with ABAD and is strongly associated with worse outcome.<sup>1</sup> Malperfusion can be classified as dynamic or static.<sup>1</sup> Dynamic obstruction is caused by the prolapse of the dissection flap into the vessel ostium. The obstruction is usually evident during the aortic systole and causes about 80% of malperfusion syndromes. Static obstruction is the result of branch vessel compression by extension of the dissection flap into the branch and is present throughout the cardiac cycle.<sup>1</sup> Endovascular interventions in patients with ABAD include proximal entry closure by means of stent-graft implantation, bare metal stent implantation in the true aortic lumen or aortic branch vessels, and percutaneous balloon fenestration of the dissection flap.<sup>2</sup> The first line therapy in acute type B dissection with malperfusion syndrome is currently coverage of the proximal entry tear by Thoracic Endo-Vascular Aortic Repair (TEVAR).<sup>1</sup> When this method is unfeasible, endovascular aortic fenestration has been proposed as an alternative technique.<sup>3</sup> Endovascular aortic fenestration quickly decrease the pressure gradient of the false lumen and can also be an adjunctive tool to other endovascular interventions.<sup>1 3 4 5</sup> The most common endovascular technique to achieve a fenestration is the creation of a communicating hole between the false and the true lumen followed by balloon-dilatation.<sup>5 6 7 8</sup> Balloon-dilatation can be performed at one or multiple sites along the dissection membrane to achieve equalibration of pressures between the true and false lumens.<sup>9</sup> It remains unclear where the optimal location of these fenestrations should be made.<sup>7</sup> So, fenestration at optimal locations would result in acute depressurization of the false lumen with reduction of its volume as result. The objective was to study false lumen volume after different fenestration strategies in porcine ex-vivo models of aortic type B dissection. The impact of the fenestration-site comparing more proximal and distal locations was explored to study the hypothesis.

We hypothesize that a more distal location of the fenestration in the false lumen would lead to better equilibration of pressures and false lumen reduction. We performed two different fenestrations strategies in a validated ex-vivo porcine aorta dissection model in a pulsatile flow-model.<sup>10</sup> Computed tomography angiography was used for imaging and volume-measurements.

## MATERIALS AND METHODS

### Aortic dissection model

Unmodified porcine aortas were obtained frozen from the abattoir. They were defrozen and prepared as follows: from the aortic arch to the iliac bifurcation all side branches were ligated with 5.0 Prolene. The aorta was inverted inside out and the intima was punctured by a needle. Injection of water resulted in a dissection and the dissection flap was cut in a proximal location to create a primary entry. This technique was previously described by Qing et al.<sup>11</sup>



**Figure. 1.** (A) A turned over porcine aorta with an artificially created dissection. The fenestration in the dissection flap was made by a 10 x 40-mm Percutaneous Transluminal Angioplasty (PTA) balloon (Abbott Vascular, CA). (B) The fenestration in the dissection flap after removal of the PTA balloon is shown.

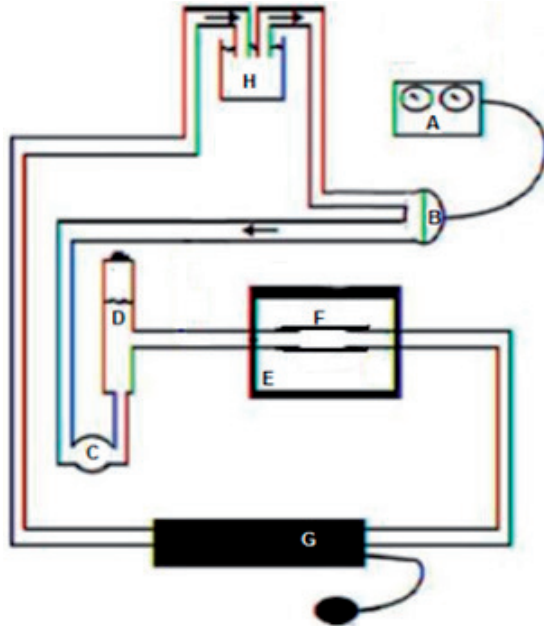
A total of six aortic dissection models were made. The dissection flap was longitudinally divided in three equal sections; proximal, mid and distal. In three models a fenestration was made in the center of the proximal section of the dissection flap. In the others in the center of the distal section of the dissection flap. The fenestration in the dissection flap was made by a 10 millimeter by 40 millimeter Percutaneous Transluminal Angioplasty balloon (Abbott Vascular, California, USA) (Figure 1.).

### **In-vitro circulatory system**

A validated in-vitro circulatory system with physiological flow and pressure characteristics was used to mimic the human circulatory system.<sup>10, 12 13</sup> The main components of this circulatory system are a pneumatically-driven pulsatile pump, a compliance chamber and the watertight synthetic box with the aortic dissection model (Figure 2). All components are connected by a silicone tubing system and water was used for circulating fluid with a small concentration of contrast agent (Ultravist, Bayer, Germany). During the experiments the pneumatically-driven pulsatile pump was set on the parameters presented in table 2. The synthetic box with the aortic dissection model was placed inside the CT gantry.

### **Imaging and data processing**

Computed tomography (Toshiba Aquilion One Genesis Edition™ Japan) was used for imaging making 1 millimeter slices. The lumen area of one slice proximal to the dissection was determined in each phase of the systolic and diastolic cardiac cycle, using Mass Research Software (Leiden University Medical Center) with manual contour segmentation (Figure 3).<sup>14</sup> Each phase was analyzed



**Figure. 2.** Circulation set-up. A schematic representation of the circulation set-up, which consisted of an artificial heart driver (A), left ventricle (B), a ball valve (C), an air chamber (D), a watertight synthetic box (E), the aortic dissection model (see Fig. 2) (F), a blood pressure cuff (G), and an open reservoir (H).

and the phase with the largest lumen area was chosen for volume calculations of the false and true lumen using in-house developed software with manual contour segmentation.

Two CT-scans per model were made; one at baseline (without any fenestration) and one after fenestration of the dissection flap.

## RESULTS

The general flow characteristics of the in vitro circulation in the models are presented in Table 1. The models had a similar morphology at baseline but differed in lumen diameter and dissection width resulting in differences in True Lumen Volume (TLV) and False Lumen Volume (FLV) as presented in Table 2. Balloon fenestration of the dissection flap was performed in model 1, 3 and 5 proximally and in model 2, 4 and 6 distally.

### Proximal fenestration of the dissection flap

Performing a fenestration in the proximal section of the dissection flap resulted in FLV increase in models 3 and 5. However in model 1 it resulted in FLV decrease (Table 2.). The average false lumen volume change of minus 0.7% (SD 2.9%) was observed after proximal fenestration.

## Distal fenestration of the dissection flap

Performing a fenestration in the distal section of the dissection flap resulted in FLV decrease in all three models. The average false lumen volume change of minus 9.6% (SD 3.5%) was observed after fenestration (Table 2.).

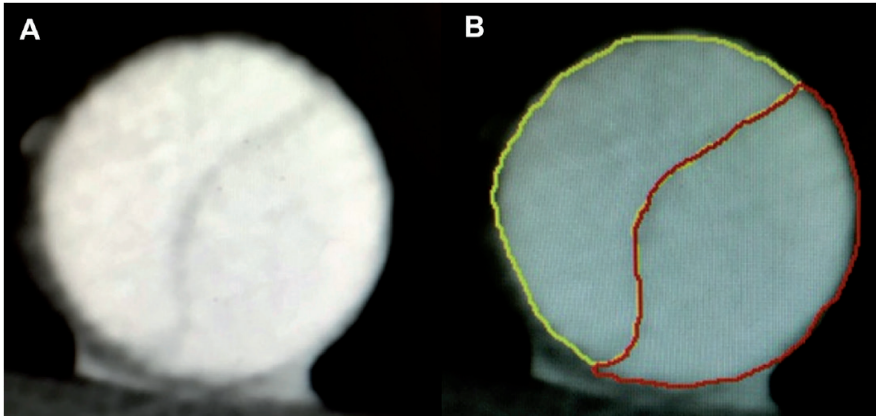
False lumen reduction was obtained significantly in the distal fenestrated models compared to the proximal fenestrated models ( $9.6 \pm 3.5\%$  vs.  $0.7 \pm 2.9\%$ ,  $p=0.03$ )

**Table I.** In vitro circulatory system flow characteristics

| In vitro circulatory system flow characteristics |           |
|--------------------------------------------------|-----------|
| Heart beat/min                                   | 70        |
| Systolic pressure                                | 130-mm Hg |
| Diastolic pressure                               | 70-mm Hg  |
| Mean stroke volume/beat                          | 40 mL     |
| Output volume/min                                | 2800 mL   |

**Table II.** True and false lumen outcomes by model

| Model                 | True lumen volume (TLV) (mL) | False lumen volume (FLV) (mL) | False lumen % of total lumen volume | False lumen change | P value |
|-----------------------|------------------------------|-------------------------------|-------------------------------------|--------------------|---------|
| 1                     |                              |                               |                                     |                    |         |
| Baseline              | 9.75                         | 6.25                          | 39.0                                |                    |         |
| Proximal fenestration | 11.42                        | 6.17                          | 35.1                                |                    |         |
|                       |                              |                               |                                     | -3.9%              |         |
| 3                     |                              |                               |                                     |                    |         |
| Baseline              | 10.76                        | 4.42                          | 29.1                                |                    |         |
| Proximal fenestration | 10.65                        | 4.73                          | 30.8                                |                    |         |
|                       |                              |                               |                                     | 1.7%               |         |
| 5                     |                              |                               |                                     |                    |         |
| Baseline              | 18.52                        | 15.36                         | 45.3                                |                    |         |
| Proximal fenestration | 17.21                        | 14.32                         | 45.4                                |                    |         |
|                       |                              |                               |                                     | 0.1%               |         |
| Model                 |                              |                               |                                     |                    |         |
| 2                     |                              |                               |                                     |                    |         |
| Baseline              | 10.25                        | 8.88                          | 46.4                                |                    |         |
| Distal fenestration   | 11.82                        | 8.13                          | 40.7                                |                    |         |
|                       |                              |                               |                                     | -5.7%              |         |
| 4                     |                              |                               |                                     |                    |         |
| Baseline              | 9.18                         | 5.16                          | 36.0                                |                    |         |
| Proximal fenestration | 11.37                        | 3.91                          | 25.6                                |                    |         |
|                       |                              |                               |                                     | -104%              |         |
| 6                     |                              |                               |                                     |                    |         |
| Baseline              | 6.01                         | 5.97                          | 49.8                                |                    |         |
| Proximal fenestration | 7.28                         | 4.3                           | 37.1                                |                    |         |
|                       |                              |                               |                                     | -12.7%             |         |



**Figure 3.** (A) and (B). Transverse CT image of model 2 at the beginning of the dissection with manually marked contours (B) of the false lumen (red) and true lumen (yellow).

## DISCUSSION

Endovascular aortic fenestration quickly reduces the high pressure in the false lumen by communicating the false with the true lumen.<sup>15</sup> It remains unclear where the optimal location of these fenestrations should be chosen. We hypothesized that distal fenestration of the false lumen will result in the largest false lumen reduction and thereby more adequate depressurisation of the false lumen. An ex-vivo study was performed with porcine aortas with a surgically-constructed false lumen to study this hypothesis.

In only one of the three aortic models with a balloon fenestration in the proximal part of the dissection flap FLV reduction was observed. In the others two aortic models a slight FLV increase was observed. These results are in contrast with the FLV's of the models where a balloon fenestration in the distal section of the dissection flap was performed. All three dissection models with a balloon fenestration in the distal section of the dissection flap showed a FLV decrease. The observations of this ex-vivo study are that performing a distal fenestration in the dissection flap result in significant ( $p=0.03$ ) FLV decrease compared to performing a proximal fenestration.

Ex-vivo models are useful to study hemodynamic changes in aortic pathologies. Factors in this complex circulation system can be isolated and analyzed. Previous ex-vivo studies used synthetic polymer or silicon tubing for simulating aortic dissection in contrast to the used porcine aorta in our model.<sup>16,17</sup> The morphology of the surgically created false lumen is comparable to a human aortic dissection as showed in previous publication.<sup>18</sup> Additionally we used CTA for imaging and volume measurements, this imaging modality is not previously described in in-vitro studies.<sup>16-18</sup>

<sup>19</sup> Although volume of the false lumen and pressure in the false lumen are strongly correlated a drawback might be the fact that measurements of the pressure gradients were not performed. To study the changes of the pressure gradient in the false lumen invasive pressure measurement should be performed. In pilot experiments we found out that pressure measurements of the false



lumen by a cannula or pressure wire were highly influenced by the exact position of the cannula or pressure wire in the false lumen. During cardiac cycle the position of the tip of the cannula changed all the time and would not result in objective pressure measurements of the false lumen.

Translation of the results from the ex-vivo model to a physiological in-vitro situation is, of course, limited. The presented ex-vivo model has limitations. The circulatory medium was water instead of blood, which is not a thrombotic medium. Use of a thrombotic medium results in spontaneous thrombosis that could either block the tubing system, false lumen or disturb the function of the pulsatile pump.<sup>18</sup> The porcine aortas were prepared, frozen, and thawed after 1 day, which might have altered the elastic properties of the arterial wall. Thirdly the aortic model was not surrounded by connective tissue, which will influence the compliance of the true and false lumen.

Endovascular treatment of aortic dissection consists usually of implantation of thoracic tubular stent-grafts to cover the proximal entry tear and redirect flow into the true lumen.<sup>1</sup> Aortic fenestration is still in use in malperfusion syndromes and in cases not suitable for proximal aortic tear coverage.<sup>3,5,8</sup> The advantages of endovascular aortic fenestration are directly relieving organ or limb ischemia in a faster way than by aortic graft replacement. Although aortic fenestration is rarely used it should be in one's endovascular therapeutic arsenal for treating aortic dissections.

Further ex-vivo experiments are required to obtain more insight between different types of dissections with different morphology and vascular wall characteristics. But also the role of fenestrations by branch vessels originating from the false lumen could be researched.

In conclusion, in this ex-vivo study, we showed that performing a fenestration in the distal part of the false lumen in an aortic dissection will result in the largest false lumen reduction. This observation might contribute in case endovascular fenestration must be performed.

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