# Improving side branch access during bifurcation stenting - a finite element study

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*Abstract*—**Stents are supporting tubular mesh structures which are deployed in obstructed arteries in order to reopen them. This is a widely used technique but some problems remain unsolved. Treating the narrowed arteries which occur at the location of bifurcations remains a challenge and is generally associated with an increased complication rate. Several techniques have been proposed to treat these lesions, but all the suggested methodologies have specific limitations. Therefore, further investigations remain very meaningful and numerical simulations may provide interesting insights in the mechanical aspects of the different interventional techniques. In this study, an innovative numerical model to examine one of the proposed techniques (side branch balloon inflation) is presented. The results indicate the complexity of implanting stents at the location of bifurcations. In future, more advanced computer models will be developed in order to account for more realistic behaviour of the arterial wall. Such models can lead to improved stent designs and/or better techniques to treat bifurcation lesions.**

*Keywords*—**bifurcated arteries, stent, balloon inflation, finite element**

## I. Introduction

STENTS are small tube-like medical devices, used to treat clogged sections of blood vessels, a phenomenon frequently encountered in the coronary circulation. Stents improve the local blood flow by partially restoring the normal vessel diameter. This well-established intervention shows good results in most cases. However, some problems remain unsolved. Many of these stenoses occur in bifurcated regions and treating these lesions with stent implantations remains a challenge, because this is associated with a higher complication rate [1], [2]. Several stent implantation techniques have been proposed, but all of them have specific limitations [3], [4]. Computer models are a suitable tool to investigate the numerous proposed techniques. One of these techniques involves the inflation of a balloon to open the side branch after the implantation of a stent in the main branch. This balloon inflation is performed to reduce the disturbance of the blood flow towards the side branch.

## II. Materials and methods

In this study ABAQUS was used for creating the geometrical model and for solving the finite element problems. The model consists of a balloon-expandable stent, resembling the CYPHER$^{TM}$ stent (nominal diameter 3 mm, nominal length 8 mm; Cordis) in its already expanded state. The stent is made of 316L stainless steel, which is described by a Young's modulus of 196000 N/mm$^2$, a Poisson's ratio of 0.3, and a yield stress of 375 N/mm$^2$. The stent is located in the main branch of the anatomical bifurcation (figure 1), which is approximated by two rigid tubes, intersecting at an angle of 45 and with a diameter of 2.5 and 3 mm for the side and main branch respectively.

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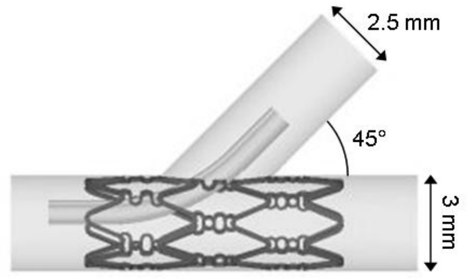


Fig. 1. Initial stent and balloon configuration and anatomical characteristics

A trifolded RAPTOR$^{TM}$ balloon (nominal diameter 2.5 mm, Cordis) is positioned in both the main and side branch, crossing the CYPHER$^{TM}$ stent as depicted in fig. 1 and the opening of the side branch is induced by balloon inflation up to 1.5 N/mm$^2$. The balloon properties are based on the compliance chart provided by the manufacturer. These properties were validated by the virtual expansion of a cylindrical balloon with tapered ends. The numerically obtained pressure/diameter relation shows a very good agreement with the original compliance data (maximum percentage difference less than 4%, i.e. at a pressure of 1 N/mm$^2$), as shown in figure 2.

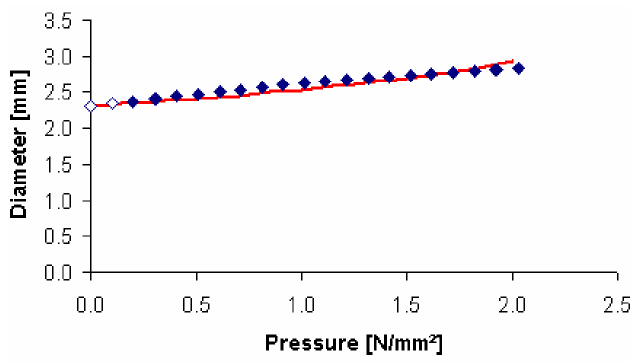


Fig. 2. Data provided by the manufacturer (solid diamonds) and extrapolated values (empty diamonds) compared with the numerical results (line).

## III. Results and discussion

Figure 3 shows the impact of the inflation of the side branch balloon on the stent cell that limits the side branch accessibility. The balloon deforms and enlarges this stent cell, which probably results in an optimized perfusion of the side branch. In order to examine the exact impact of this technique on the blood flow pattern, Computational Fluid Dynamics (CFD) modelling seems appropriate and will be performed in these geometries in future.

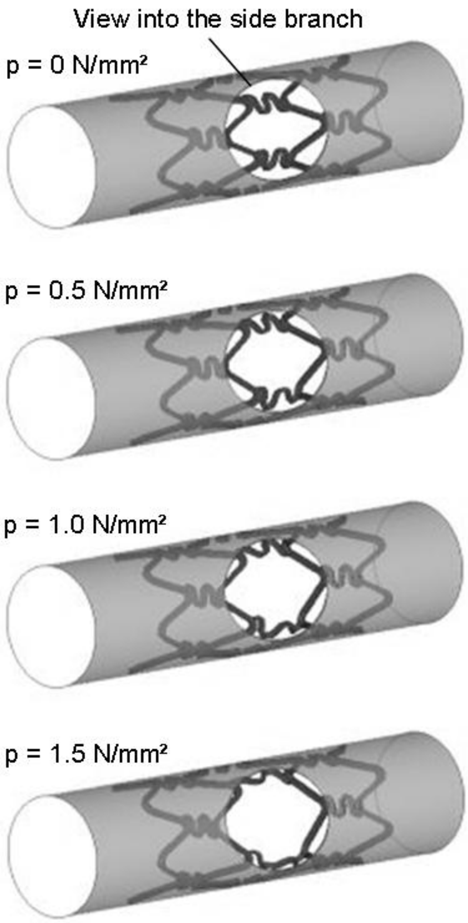


Fig. 3. View into the side branch at different inflation pressures (p) (balloon not shown), showing the gradually increasing cell opening.

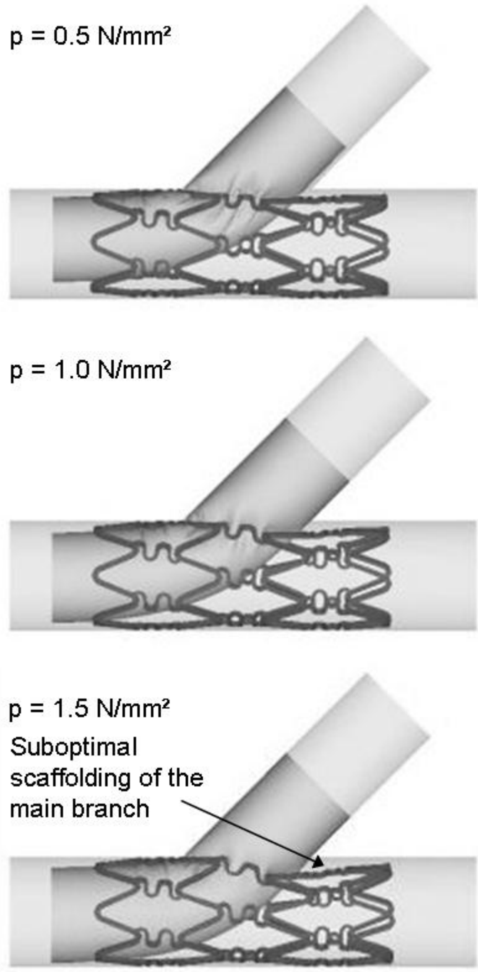


Fig. 4. Inflation of the side branch balloon results in a inadequate scaffolding of the main branch (indicated by the arrow).

Despite the previously described positive consequences of the side branch balloon inflation, there is one major drawback of this intervention. A part of the stent, scaffolding the main branch, is pushed towards the centre of the main branch lumen (figure 4, lower panel). This is of course suboptimal as such a deformation negatively affects the scaffolding properties of the stent.

Therefore, more complex strategies should be considered to improve the side branch accessibility during bifurcation stenting and one promising technique (i.e. kissing balloon inflation) involves the simultaneous inflation of two balloons, one in the main branch and one in the side branch. The main branch balloon guarantees optimal scaffolding, while the side branch balloon enlarges the stent cell that is in front of the side branch opening.

## IV. Conclusion

Many stents are implanted at bifurcation lesions, in such a way that they block the side branch. An optimization of the blood flow towards the side branch can be achieved by inflating a side branch balloon. This technique results in an enlargement of the stent cell blocking the side branch as shown by our numerical results. A major limitation of this straightforward technique is that the scaffolding properties of the stent are negatively affected, and therefore, other strategies such as kissing balloon inflation may be preferred. Future computational studies will include more realistic arterial wall behaviour. More complex techniques used for bifurcation stenting will also be investigated.

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