

# Ultrasound B-Flow technology in the follow-up of ICA angioplasty and stenting

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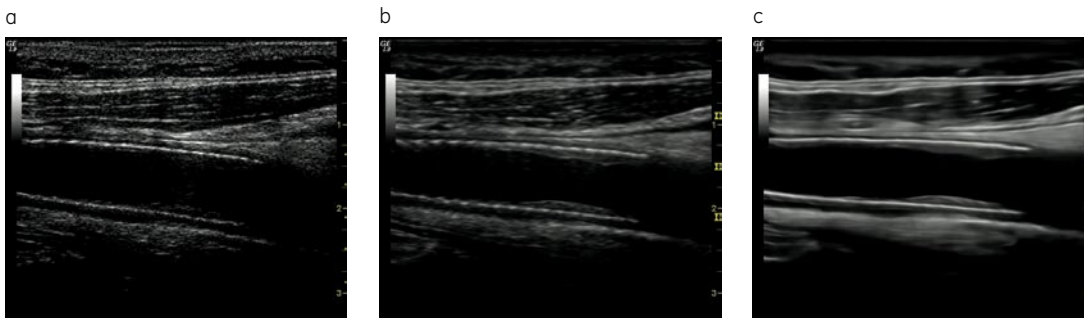
# Introduction

Stenosis of the internal carotid artery (ICA) has been traditionally treated with endarterectomy. Today, angioplasty with stenting has become a viable alternative to angiography.<sup>1-3</sup> This intervention is increasingly being used in both symptomatic and asymptomatic patients and, in some areas, has already become the preferred vessel repair technique. As in carotid endarterectomy, restenosis may occur following angioplasty and stenting. Narrowing of the stented segment is most frequently caused by neointimal hyperplasia, but can also occur as a result of ineffective extension of the stent. Therefore, a non-invasive means for follow-up of stented vessels is necessary.

Doppler velocity criteria developed for evaluation of ICA stenosis in untreated vessels has proven to be less reliable when applied to the post-interventional follow-up of stented internal carotid arteries. These criteria, consisting of cut off velocities of 1.25 m/s and the ratio of peak systolic velocity (PSV) between the ICA and CCA (ICA/CCA ratio) exceeding 3:1, have shown false positive results.<sup>4</sup> Therefore, higher peak systolic velocities have been suggested to improve accuracy in calculating the degree of in-stent restenosis.<sup>5</sup> Levy suggested

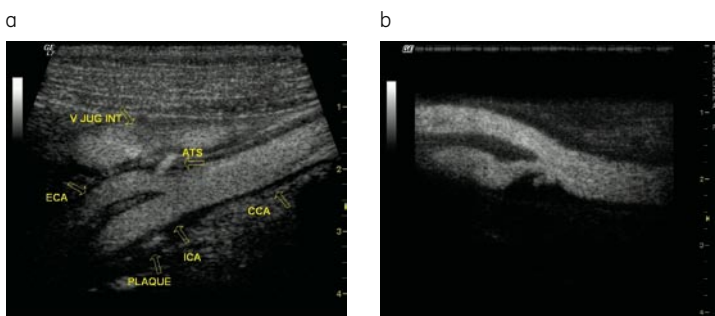
an in-stent peak velocity exceeding 3 m/s as hemodynamically relevant.<sup>6</sup> Lal suggested a combined threshold of PSV 150 cm/s and ICA/CCA ratio of 2.16 as optimal for detecting a residual stenosis of 20% or greater.<sup>5</sup> A restenosis rate between 5% to 14% has been reported in the literature.<sup>6-8</sup>

In contrast to the hemodynamic approach, a morphological characterization of in-stent stenosis may give the best information about the existence and progression of neointimal hyperplasia over time and show how this reaction of the vessel wall affects its patency. In fundamental B-Mode images, the neointimal hyperplasia may easily be overlooked, as it appears almost completely anechoic. The use of Coded Harmonic Imaging (CHI), in conjunction with CrossXBeam™ and Speckle Reduction Imaging (SRI) technologies on the LOGIQ® 9 ultrasound system (GE Healthcare, Milwaukee, WI) enhances definition of the size and surface of the neointima (Fig. 1 a, b, c). B-Flow (GE Healthcare, Milwaukee, WI) is a non-invasive flow imaging tool that gives an accurate morphologic display of the intraluminal blood flow. It is a flow display mode that directly images blood reflectors and tissue information simultaneously (Fig. 2). We have found B-Flow to be a reliable non-invasive imaging tool in the evaluation of in-stent stenosis.



**Figure 1**

Neointimal hyperplasia of the CCA portion of the stent (10L probe, LOGIQ 9, GE Healthcare, Milwaukee, WI). a) Fundamental image b) CHI image c) CHI and SRI image.



**Figure 2**

a) Carotid bifurcation using B-Flow. The flow image suggests normal lumina; gray scale background shows a thickened intermedial (IM) layer. B-Flow demonstrates a smooth plaque surface. b) ICA stenosis with a small ulceration indicating an unstable plaque.

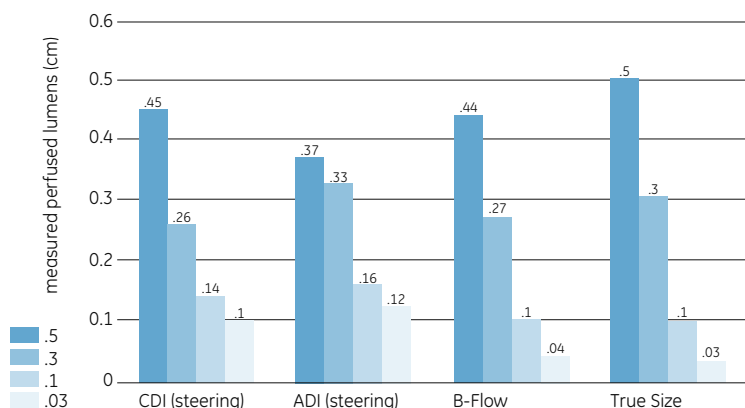
# Optimizing intravascular imaging

After intervention, lipid material from the plaque may be pressed through the stent and become nearly invisible using traditional gray-scale imaging techniques. Intimal hyperplasia may also occur as a vessel wall reaction to the stent. This is usually accompanied by an elevated high sensitive C-reactive protein (CRP) level.<sup>8</sup> Both lipid and intimal hyperplasia have a very low reflectivity, thus making their detection difficult. The visibility of lipid and neointimal hyperplasia can be improved by applying CHI, CrossXBeam and SRI.

In imaging the true lumen, color Doppler has a number of disadvantages including overwriting of the vessel wall (blooming), low frame rates, persistence and angle dependency. B-Flow overcomes these shortcomings and very accurately images intraluminal blood flow without blooming and has a high degree of sensitivity.<sup>9</sup> Table 1 summarizes the main advantages and shortcomings of color Doppler imaging (CDI) and B-Flow.

In a flow phantom study, we compared the perfused diameter of different sized silicon tubes when using color Doppler, power Doppler, and B-Flow at low velocities.<sup>10</sup> B-Flow was also compared to spiral CT and MRI measurement results. MRI could not image flow in the 0.03 cm tube, all other lumens were overestimated in size (Fig. 3).

## Ultrasound imaging modality



## B-Flow vs. contrast spiral CT vs. contrast MR angiography

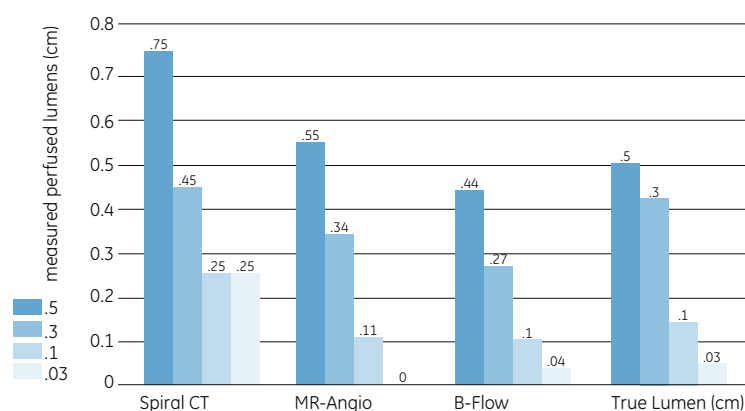


Figure 3

Top: Mean perfused tube diameter (out of three measurements at different tube locations). In bigger tubes (0.3 cm, 0.5 cm) the wall could be seen on a gray scale image. In smaller tubes, (0.1 cm, 0.03 cm) only B-Flow correctly imaged the true size.

Bottom: Comparison between B-Flow, spiral CT and MRI. (All ultrasound studies were performed with a LOGIQ 700, GE Healthcare, Milwaukee, WI).

### CDI

- ↑ Aliasing (flow character)
- ↑ Indicates flow direction
- ↑ Semi quantification of flow (brightness of color)
- ↑ High penetration
- ↓ Blooming
- ↓ PRF setting defines a range of displayed velocities
- ↓ Angle dependent
- ↓ Tissue and flow information are separately analyzed (overlying technique)
- ↓ Low spatial and time resolution

### B-Flow/Color B-Flow

- ↑ No aliasing
- ↑ No blooming
- ↑ All velocities imaged simultaneously
- ↑ Angle independent
- ↑ Flow direction indicated
- ↑ Tissue and B-Flow information are displayed simultaneously
- ↑ High spatial and time resolution
- ↓ No flow quantification
- ↓ No aliasing
- ↓ Limited penetration

Table 1

Main advantages (blue arrows) and disadvantages (gray arrows) of color Doppler and B-Flow. Note: Aliasing may diagnostically be an advantage as well as a disadvantage.

# The challenge of detecting minimal changes of a vessel wall after intervention

In contrast to Doppler techniques, B-Flow does not display velocities, limiting its demonstration of the hemodynamic characteristics of a stenosis. The advantage of B-Flow lies in its ability to display the inner vessel contour more accurately and free of artifacts. As the detection of moving intraluminal scatterers is angle independent, 90° cross sectional imaging is the preferred way to demonstrate the area of the perfused vessel lumen. Vessel area calculation is, however, angle dependent. For example, a vessel measured at 60° has an error of 100% resulting in twice the area (Fig. 4). At 80°, an area of 0.14 cm<sup>2</sup> or of 0.31 cm<sup>2</sup> will have an area increase of 1.54% (0.142 cm<sup>2</sup> or 0.314 cm<sup>2</sup>) and at 70° a 6.42% (0.149 cm<sup>2</sup> or 0.329 cm<sup>2</sup>) increase. An ideal angle of insonation displays a vessel lumen with the smallest area that is closest to a circle like shape.<sup>11</sup>

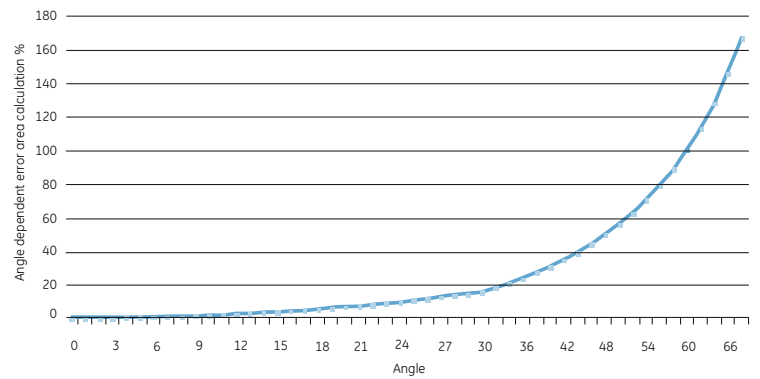


Figure 4

Source of error: Area calculation at different angles of insonation. With decreasing angle (<90°) the vessel area becomes increasingly oval shaped.

As in angiography, the B-Flow technique uses a morphological approach; therefore, a local and distal diameter stenosis can be calculated. The disadvantage of calculating diameter stenosis lies in the nature of most stenoses: As plaques do not grow concentrically, the majority of stenoses are eccentric and the residual lumen is often not circular, but rather has an oval shape. In long axis views the degree of stenosis depends on the scan plane. Therefore, the narrowing of the lumen can best be imaged by using cross sectional planes. Measurements of the affected area require an examination technique that is nearly angle independent, such as B-Flow (Fig. 5).

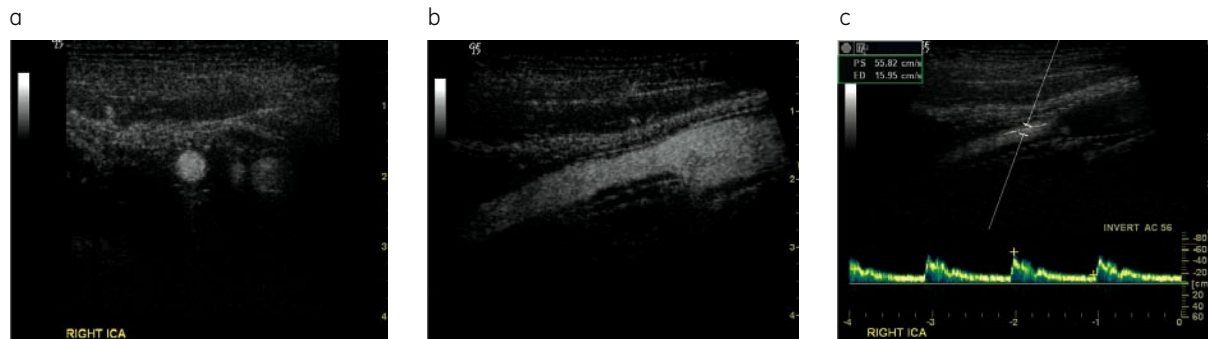
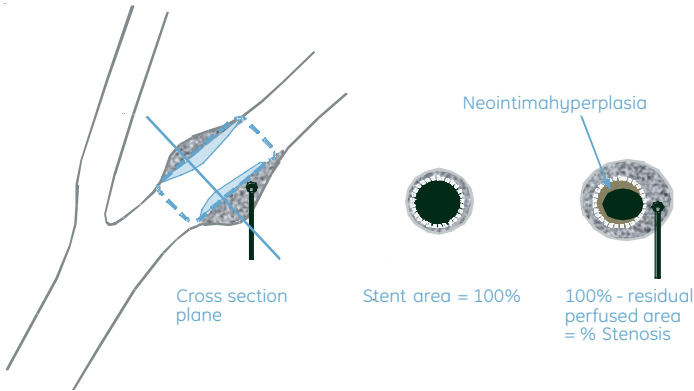


Figure 5

Eccentric neointimahyperplasia of the Right ICA in a longitudinal (a) and cross sectional image (b). No increase of peak velocities in the Right ICA (c).

As flow detection is nearly angle independent, cross sectional images using B-Flow best demonstrate the patent lumen, the plaque surface and the geometry of the residual lumen (Fig. 6).

### ICA cross section planes

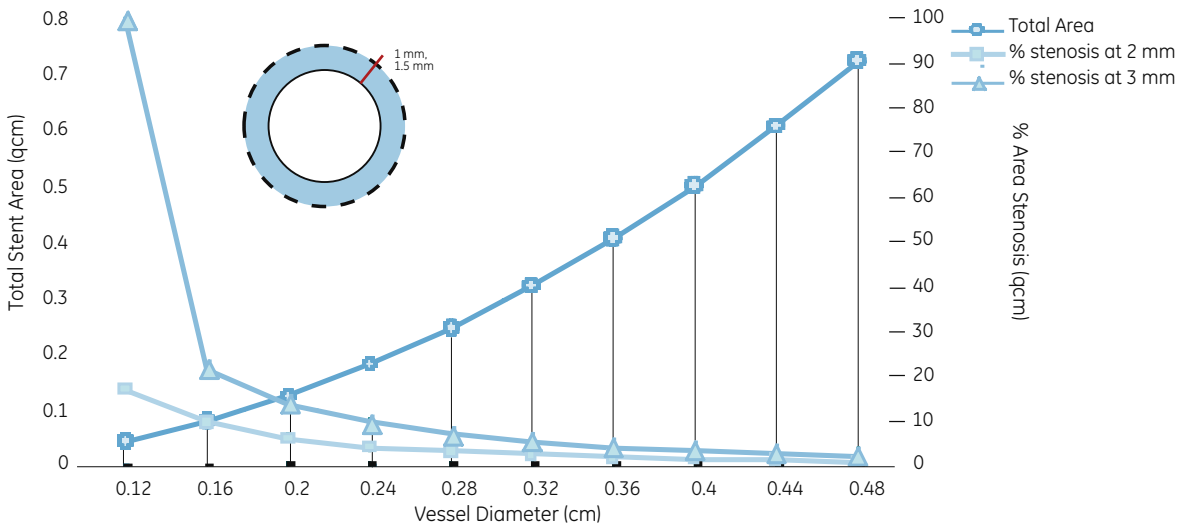


**Figure 6**

In a cross section the perfused ICA area is correlated to the total stented ICA segment in the same scan plane.

We evaluated the long-term patency after ICA stenting by calculating the perfused residual lumen and peak velocities using B-Mode, CDI, PW Doppler and B-Flow and compared results.

In-stent stenosis may occur due to an insufficient dilatation of the stent, especially in small vessels, but is most often due to inadequate growth of the neointima. The hemodynamic relevance of the neointimal thickening becomes more significant as the stented vessel size becomes smaller (Fig. 7).



**Figure 7**

At a given hyperplasia, the degree of in-stent stenosis depends on the total area of the repaired ICA. Correlation between stented ICA segment and in-stent stenosis: relationship between the total area of the dilated ICA segment and the local stenosis due to a given neointimal hyperplasia of 1.0mm diameter (squares) and 1.5mm diameter (triangles). The total stented area (circles) ranges in this mathematical model between 0.12 cm (=0.045 cm<sup>2</sup>) and 0.48 cm (=0.60cm<sup>2</sup>).

## Examination technique

A complete study following ICA angioplasty with stenting included B-Mode imaging in two scan planes (including Coded Harmonic Imaging, CrossXBeam, and SRI), CDI, PW Doppler and B-Flow.

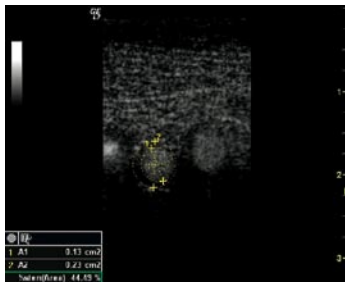
For all area calculations we considered standard non-colored B-Flow measurements as the most accurate technique. Using B-Mode and B-Flow, vessel lumen areas were calculated from 90° cross sectional images. The local degree of stenosis was also calculated (perfused lumen compared to total stented area), (Fig. 7). CDI and PW Doppler were performed in long axis views (angle  $\leq 60^\circ$ ).

Follow up began within the first post-interventional days, and again at 4 to 6 weeks. In the absence of neointimal hyperplasia exceeding 1.0 mm follow-up was continued at 6 and 12 months later. Additional, ultrasound exams were performed on a yearly basis, (Fig. 8, 9, 10). In previous studies, the area of the CCA, bulb, and ICA in males and females show a dependency on age and gender (Table 2).

	RCCA / LCCA	R Bulb / L Bulb	RICA / LICA
<b>Male (n=28)</b>	0.31±0.06 / 0.29±0.07	0.51±0.13 / 0.48±0.15	0.18±0.04 / 0.18±0.05
<b>Female (n=28)</b>	0.27±0.05 / 0.24±0.06	0.37±0.09 / 0.34±0.08	0.15±0.03 / 0.14±0.03

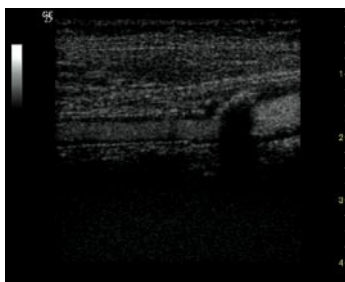
**Table 2**

Areas of CCA, bulb and ICA (B-Flow, LOGIQ 700). Numbers in cm<sup>2</sup> and standard deviation.<sup>11</sup>



**Figure 8**

Calculation of the local area stenosis at a 90° cross-section 6 months after stenting. Peak ICA velocity was <1.2 m/s. Total cross-section area is quite large (0.23 cm<sup>2</sup>). During follow up the patient had no neurological symptoms, after more than 34 months showed no further progress of the in-stent stenosis was shown.



**Figure 10**

Right ICA in-stent stenosis. ICA PSV: 1.8 m/s. Local area stenosis: 52%. No neurologic symptoms or further progress of the neointimal hyperplasia after 6 months.

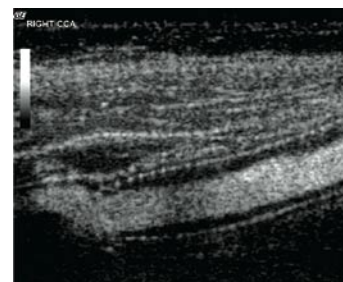
## Conclusion

Due to their anti-inflammatory effects, statins have the potential to reduce neointimal hyperplasia<sup>13</sup>. We experienced B-Flow to be a reliable, non-invasive imaging tool to prove this therapeutic effect. In conclusion, B-Flow displays the inner contour of the stented vessel accurately and free of artifacts. We found B-Flow measurements to be an accurate technique for non-invasive follow-up after angioplasty and stenting.



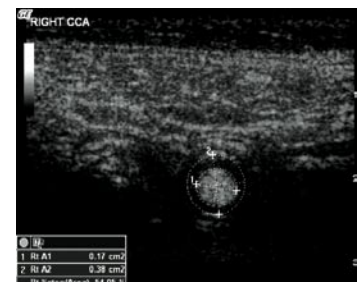
### Special thanks to our author

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**Figure 9**

Sagittal image of stent in the Right ICA and Right CCA. Peak Right CCA velocity was 0.9 m/s, slightly eccentric neointimal hyperplasia.



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