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Flow Viewer

Background, principles and applications

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1 Introduction

Flow Viewer is an advanced visualization technique that applies virtual lighting effects to two-dimensional (2D) flow imaging modes in order to render blood vessels in a 3D-like manner. Flow Viewer can be applied in real-time during live imaging, or in post-processing, and is available in all 2D flow imaging modes, i.e., Color Doppler, Power Doppler (Color Power Angio imaging/CPA), Directional Power Doppler (Directional Color Power Angio imaging/DCPA), MicroFlow Imaging (MFI) and MicroFlow Imaging HD (MFI-HD).

This white paper provides a description of the underlying technology and principles of operation, as well as examples from multiple clinical applications and corresponding clinical benefits.

1.1 Shading and lighting effects

When sketch artists draw three-dimensional objects, they rely on a technique called “shading,” which consists in modifying pencil pressure to create brightness variations that represent highlights, midtones and shadows.[1] By mimicking how lighting changes the appearance of objects in the real world, shading gives a 3D-like appearance to a 2D (“flat”) drawing and provides valuable visual cues which enhance the perception of depth (**Figure 1**).

An example of adding shading effects to a “flat” drawing is shown in **Figure 2**.

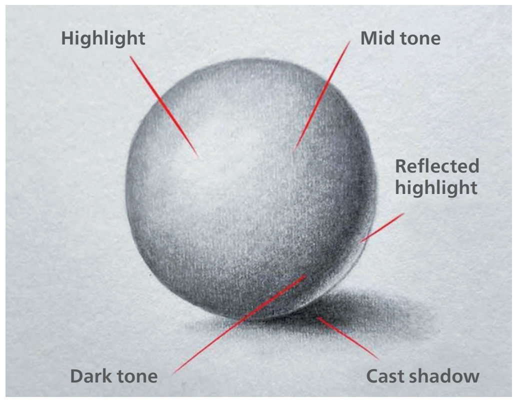

Figure 1
Different types of shading effects applied to a “flat” drawing.

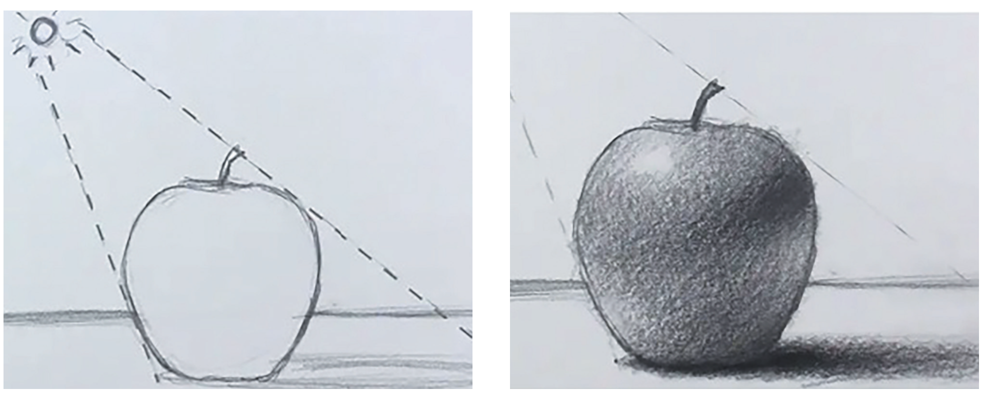

Figure 2
Illustration of how a “flat” drawing (left) can be transformed into a 3D-like scene (right) by introducing into the drawing the light reflections and shadows from a light source.

Shading can also be digitally simulated and realized with numerical algorithms. The computer graphics community and video game industry have for decades developed algorithms to simulate light interactions with objects based on their optical material properties. Physically based rendering models of increasing computational complexity and realism have been widespread not only in domains such as cinematic visual effects, gaming, education, digital art and virtual reality but also in medical imaging, where lighting models are essential to volume rendering algorithms used to visualize 3D ultrasound, CT or MRI datasets.

Simple lighting effects focus on modeling direct reflections on surfaces illuminated by a finite number of point light sources and usually ignore complex physical phenomena such as volumetric absorption, inhomogenous scattering or indirect illumination. These reflection models have been very popular since the early days of computer graphics and are still used today in many real-time applications because they provide good depth perception for a low computational cost. The virtual lighting behind the Flow Viewer feature is based on direct reflections created by a single light source.

1.2 Diffuse and specular reflections

Empirical surface shading models developed in the 1970s were inspired by geometrical optics and describe local illumination as the combination of "ambient," "diffuse" and "specular" reflections.[2,3]

The ambient component represents the original ("flat") image, before applying any lighting effects.

The diffuse component is obtained by calculating the diffuse reflections when light hits a rough surface of an object and is scattered in all directions (**Figure 3**). The diffuse component provides 3D-like shapes that offer enhanced appreciation of depth and the relative positions of multiple objects in the same scene.

The specular component is obtained by calculating the specular reflections when the light hits a mirror-like surface of an object (**Figure 4**), which gives a glossy or shiny appearance to objects.

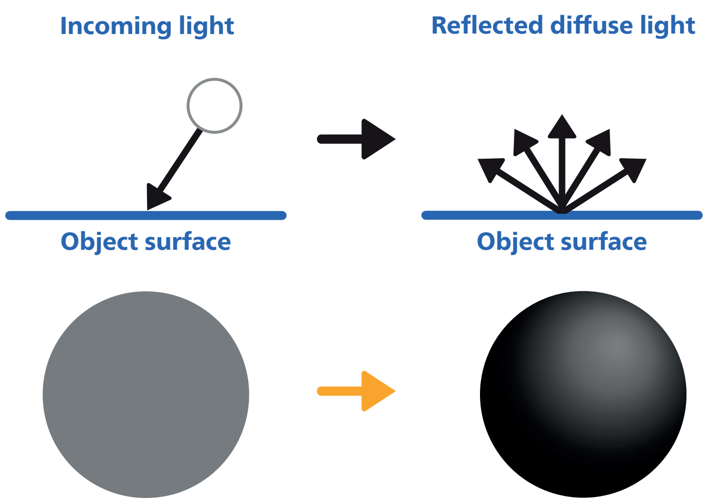

Figure 3
Top: Illustration of the diffuse reflections received from a rough or matte surface. Bottom: Illustration of the diffuse image (right) obtained when diffuse lighting effects are applied to the "flat" circle object present in the ambient image (left).

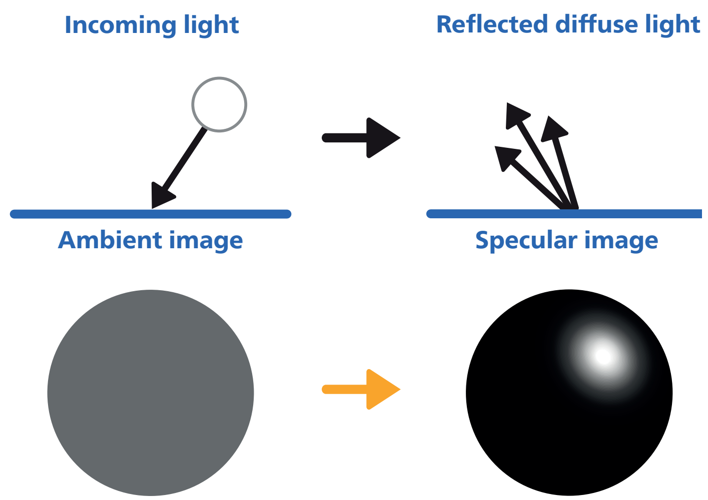

Figure 4
Top: Illustration of the specular reflections received from a smooth or glossy surface. Bottom: Illustration of the specular image (right) obtained when specular lighting effects are applied to the "flat" circle object present in the ambient image (left).

1.3 From 2D ("flat") images to 3D-like rendering

As shown in **Figure 5**, the final (composite) image is obtained by combining the ambient, diffuse and specular components. The incorporation of the diffuse and specular lighting effects into the composite image:

- Allows viewers to perceive the objects present in the "flat" ambient image as "3D-like" shapes
- Provides depth cues that offer significantly enhanced appreciation of the relative position and size of the objects

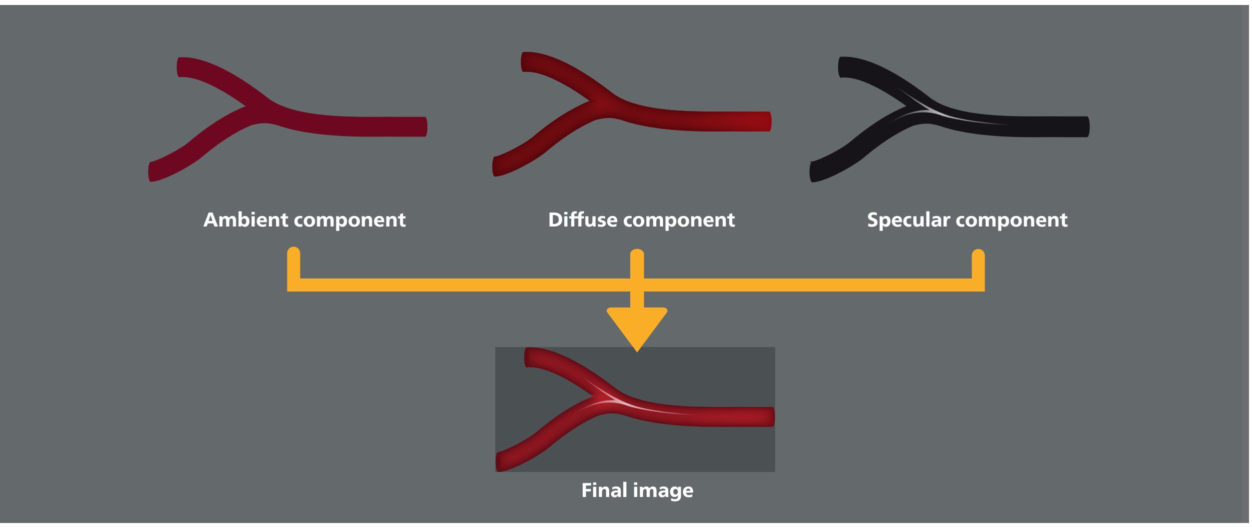

Figure 5
Illustration of the ambient, diffuse and specular components as well as the final (composite) image obtained by combining these three individual components

Flow Viewer is based on the principle illustrated above, i.e., combining the ambient (original) flow image with the diffuse and specular components. Flow Viewer is available on all flow imaging modes (Color Doppler, CPA, DCPA, MFI, MFI-HD). An example of applying the Flow Viewer 3D-like rendering to Color Doppler, CPA and MFI images of the same umbilical cord is shown in **Figure 6.**

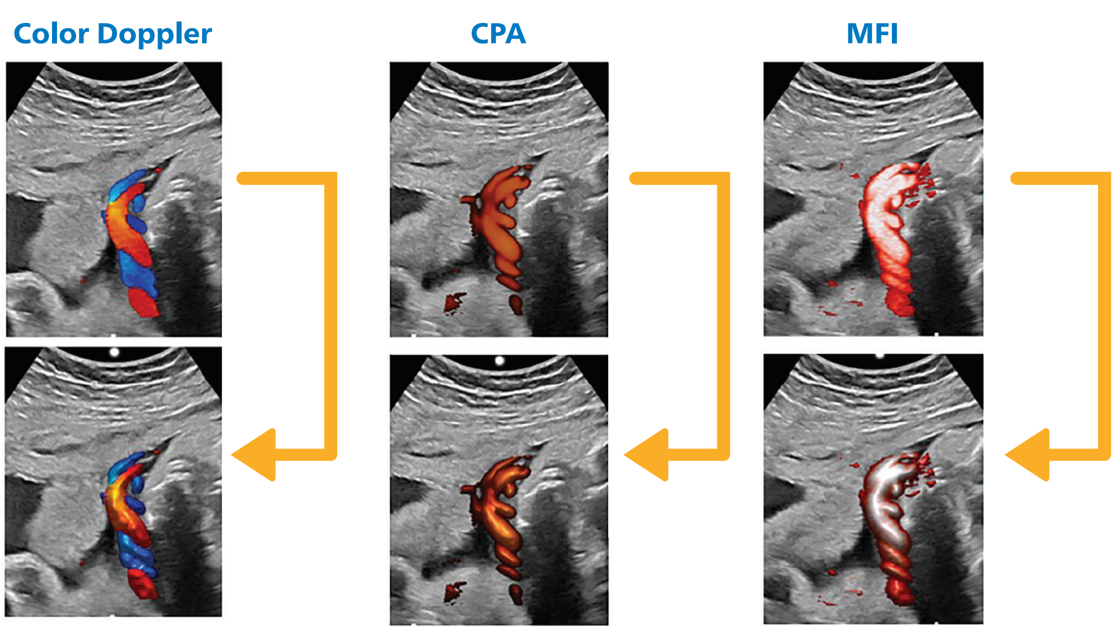

Figure 6
Top: Original ("flat") Color Doppler, CPA and MFI images of an umbilical cord. Bottom: Flow Viewer 3D-like rendered versions of the above images.

2 Flow Viewer principles of operation

Flow Viewer principles of operation vary depending on whether the input images contain Doppler Velocity estimates (Color Doppler) or Doppler Power estimates (CPA, DCPA, MFI, MFI-HD).

This schematic representation (**Figure 7**) of the Flow Viewer operation when processing an image type containing Doppler Power estimates shows the input image (in this example, CPA) that provides the ambient component, whereas the diffuse and specular components are derived by applying lighting effects to the underlying Doppler Power estimates, and the output image (composite component) is obtained by combining the ambient, diffuse and specular components. As can be seen in **Figure 8**, which displays magnified versions of the Flow Viewer input and output images, in addition to 3D-like rendering, the diffuse and specular components add significant detail enhancement to the Flow Viewer output image.

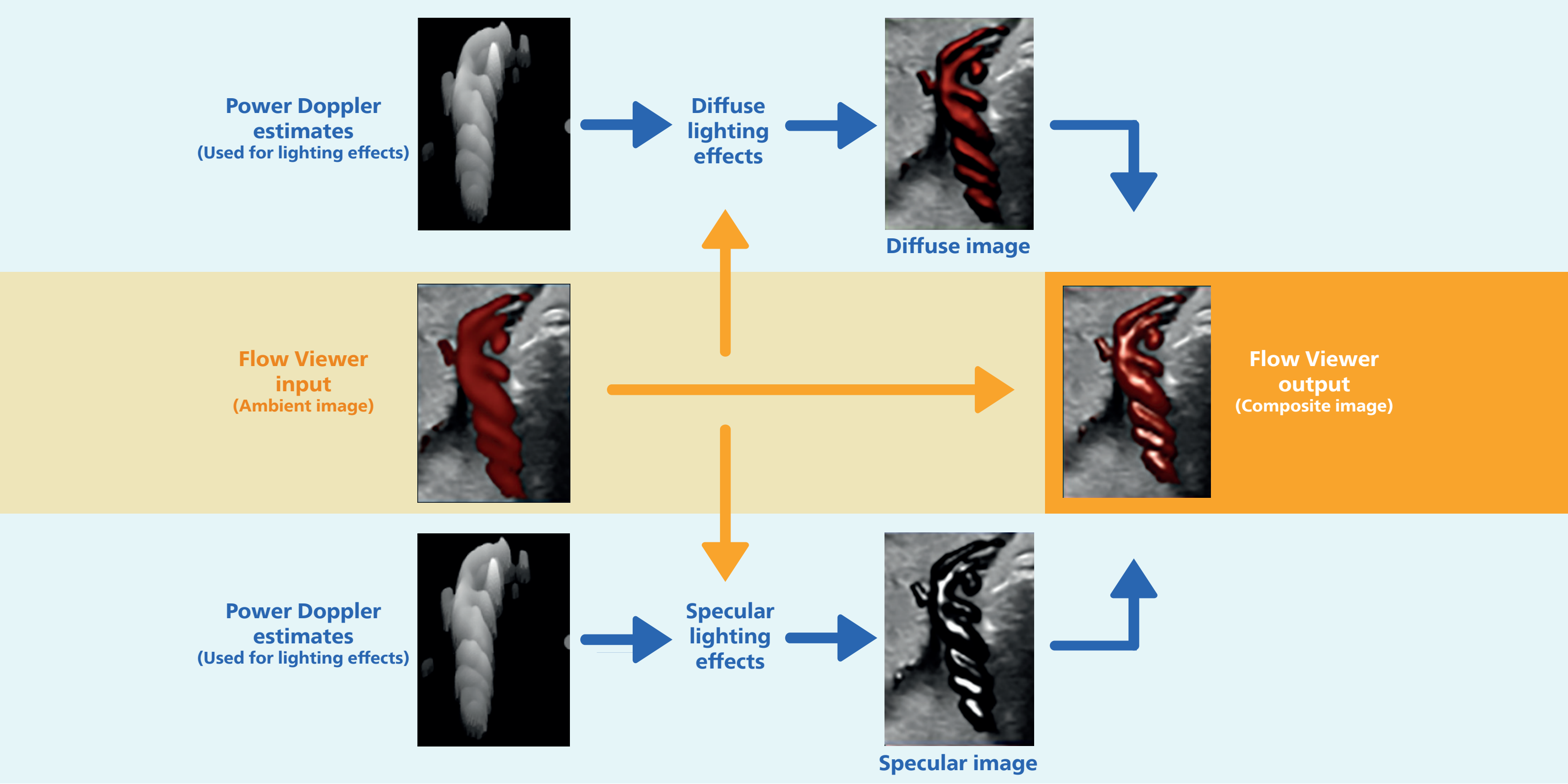

Figure 7
Schematic diagram illustrating the Flow Viewer principle of operation when processing image types containing Doppler Power estimates (CPA,DCPA, MFI, MFI-HD).

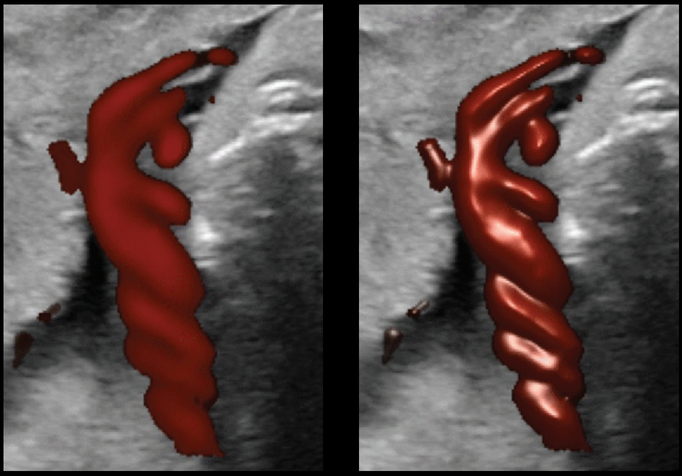

Figure 8
Magnified versions of the Flow Viewer input (left) and Flow Viewer output (right) images from Figure 7.

See **Figure 9** for a schematic representation of the Flow Viewer operation when processing image types containing Doppler Velocity estimates. As can be seen from this diagram, and in analogy with the Doppler Power case above, the input image (CPA) provides the ambient component, while the diffuse and specular components are derived by applying lighting effects to the underlying Doppler Power estimates, and the output image (composite component) is obtained by combining the ambient, diffuse and specular components.

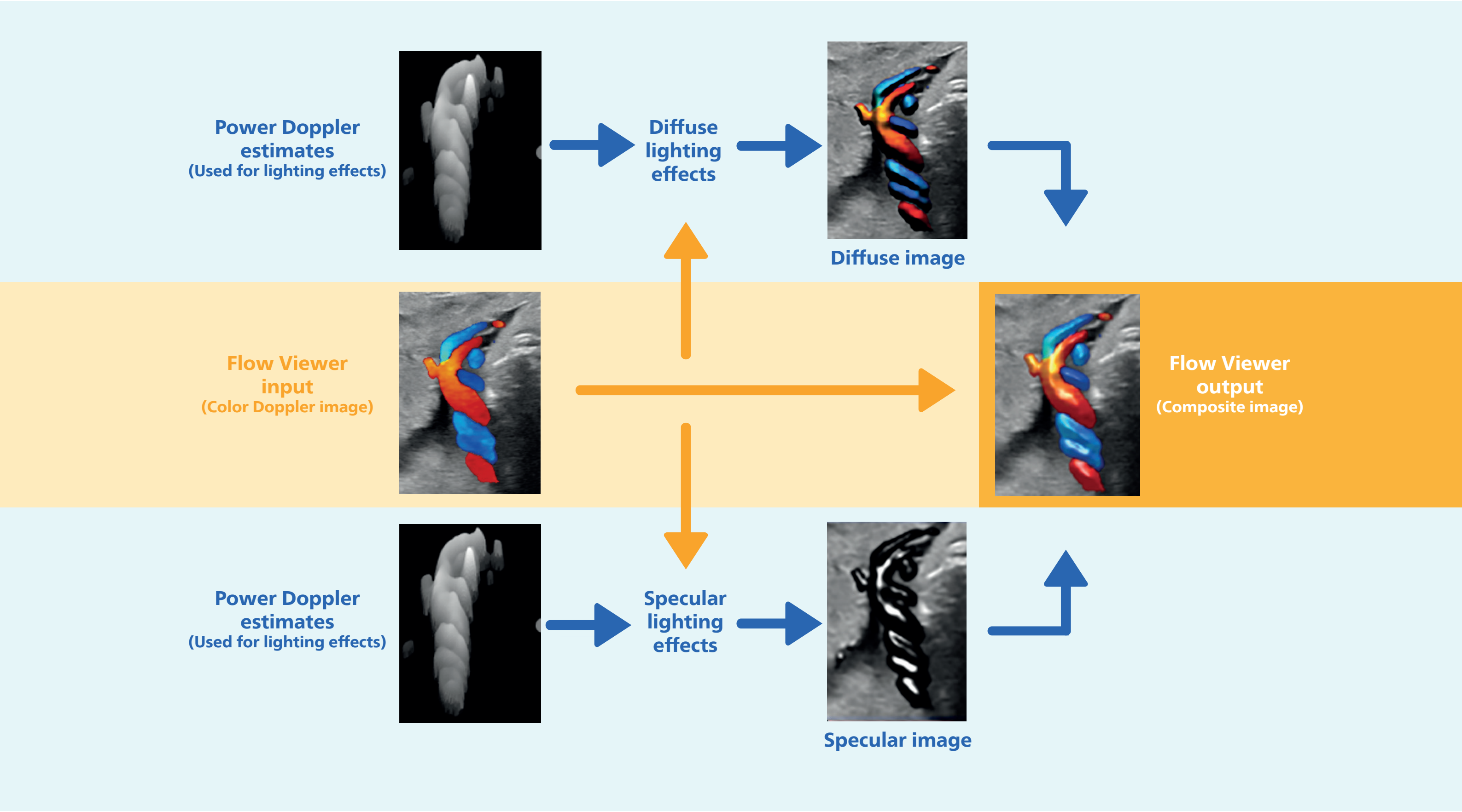

Figure 9
Schematic diagram illustrating the Flow Viewer principle of operation when processing image types containing Doppler Velocity estimates (i.e., Color Doppler).

2.1 Should lighting effects be derived from Doppler Power or Doppler Velocity estimates?

Comparison between the left and center images of **Figure 10** (especially the vessels inside the dotted white ellipses), which display magnified versions of the Color Doppler Flow Viewer input and output images from **Figure 9**, shows that the use of the underlying Doppler Power estimates to derive the diffuse and specular lighting effects offers noticeably improved detail enhancement, as was also the case with the CPA results of **Figure 8**. However, as can be seen from the right image of **Figure 10**, detail enhancement is much less prominent when applying Flow Viewer on Color Doppler images by deriving the diffuse and specular lighting effects from the underlying Doppler Velocity estimates (instead of the Doppler Power estimates). The reason for this discrepancy is that the Doppler Velocity and the corresponding Doppler Power estimates obtained when scanning a given vessel differ in a few important respects:

- Doppler Power estimates have lower amplitude close to the vessel walls, thereby generating more tapered flow profiles than Doppler Velocity
- Doppler Power estimates exhibit "valley-like" transitions in areas between vessels close to each other, which help to visually separate such vessels, as opposed to Doppler Velocity estimates, which tend to "merge" the vessels together when their flow directions are the same
- Doppler Power estimates suffer less from low-amplitude flash artifacts. Such artifacts are much more distracting in Doppler Velocity images since Color Doppler does not convey any amplitude-related information cues

Therefore, when applying Flow Viewer on Color Doppler images, the derivation of the diffuse and specular components from the underlying Doppler Power estimates provides a very effective technique to generate "hybrid" Color Doppler images which combine both velocity and amplitude information.

However, it is important to note that this approach, although much better than the alternative of deriving the diffuse and specular components from the underlying Doppler Velocity estimates, depends on the availability of raw Doppler Power estimates all the way to the end of the signal and image processing path where Flow Viewer is applied. This prerequisite is fully supported by the EPIQ and Affiniti Color Doppler signal and image processing paths, unlike with other less advanced ultrasound system architectures.

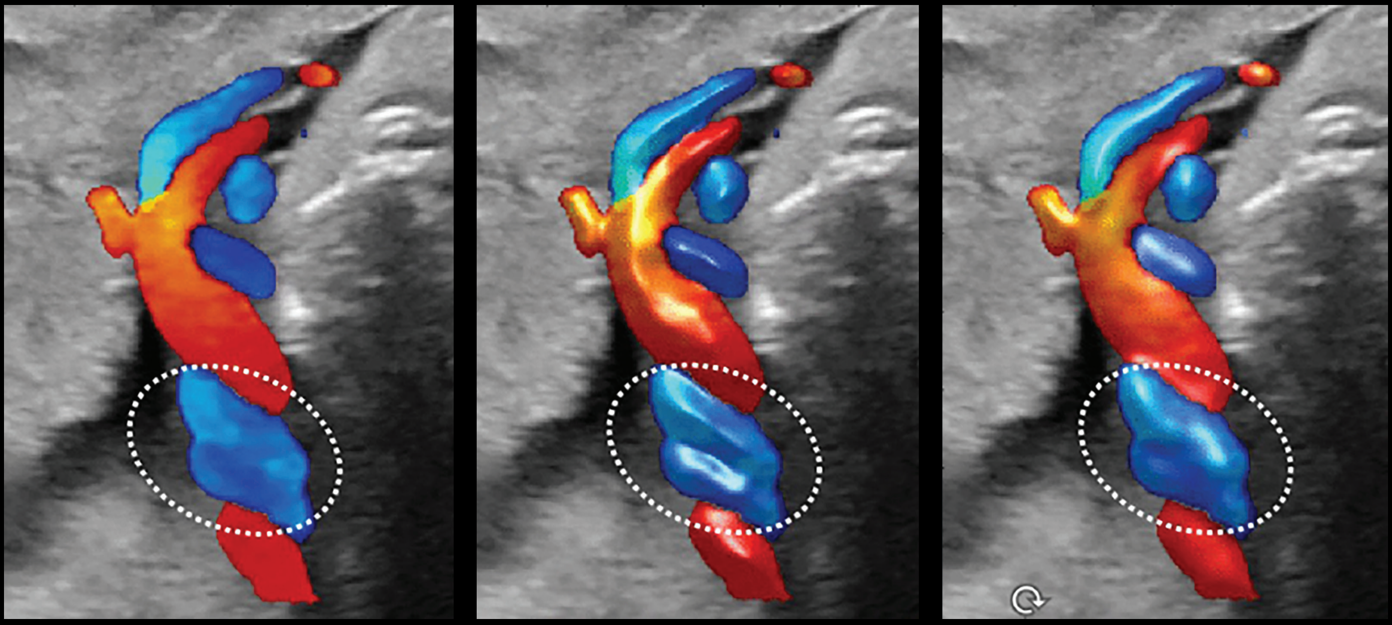

Figure 10
Magnified versions of the Flow Viewer input (left) and Flow Viewer output (center) from Figure 9 when the diffuse and specular components are derived from the Doppler Power estimates, plus the Flow Viewer output when the diffuse and specular components are derived from the Doppler Velocity estimates (right).

2.2 System implementation

Flow Viewer is available on multiple tissue-specific presets on the Philips EPIQ and Affiniti families of ultrasound systems.

Flow Viewer offers five user-selected processing settings (off, low, med, high, max), which can be stored as part of a custom preset.

Flow Viewer works both as a real-time and a post-processing feature which can be used:

A. During real-time flow imaging (Color Doppler, CPA, DCPA, MFI, MFI-HD)

B. After pressing the "freeze" button

C. In review, on single frames as well as video loops previously acquired on the same ultrasound system

D. On "native DICOM" files imported from a different Philips ultrasound system

Since Flow Viewer requires access to the "raw" Doppler Velocity and/or Power estimates, Option D is made possible by taking advantage of the "native DICOM" export option on the Philips EPIQ and Affiniti systems, which embeds the "raw" Doppler Velocity and/or Power estimates inside private tags of the exported DICOM files.

Regular DICOM exports include only the blended B-mode and flow imaging color-coded red/green/blue (RGB) values and are used primarily for visualization purposes. In contrast, native DICOM exports leverage the "raw" data stored in addition to the RGB images to support additional functionalities such as post-processing and quantification applications.

3 Clinical applications and benefits

Figure 11 and **Figure 12** display two Color Doppler images from scans of the portal vein and hepatic artery without and with Flow Viewer. Both figures illustrate the remarkable ability of Flow Viewer to resolve and separate vessels which are adjacent to each other and have the same flow direction, due to the fact that diffuse and specular lighting effects are derived from the underlying Doppler Power estimates.

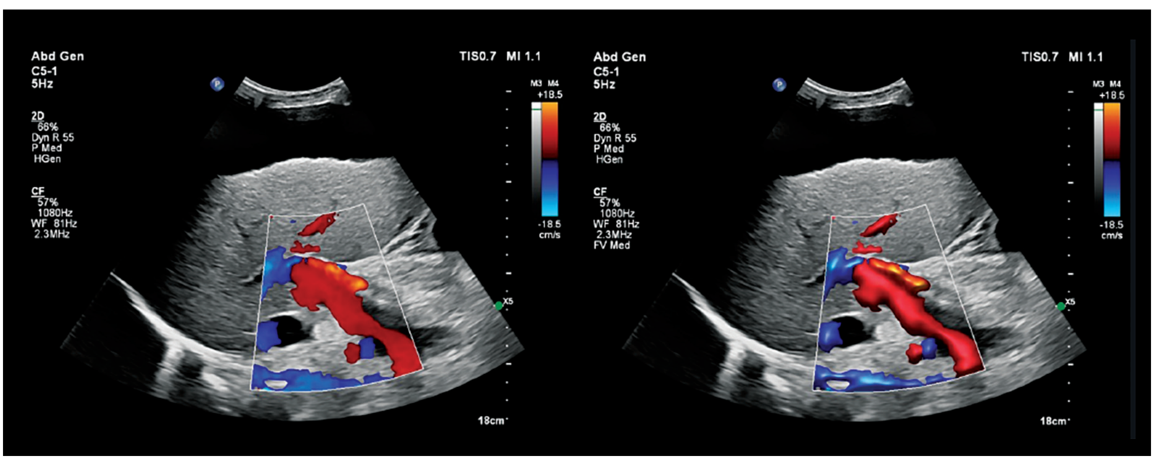

Figure 11
Left: Color Doppler image of the portal vein and hepatic artery. Right: Flow Viewer version of the image on the left (applied in post-processing).

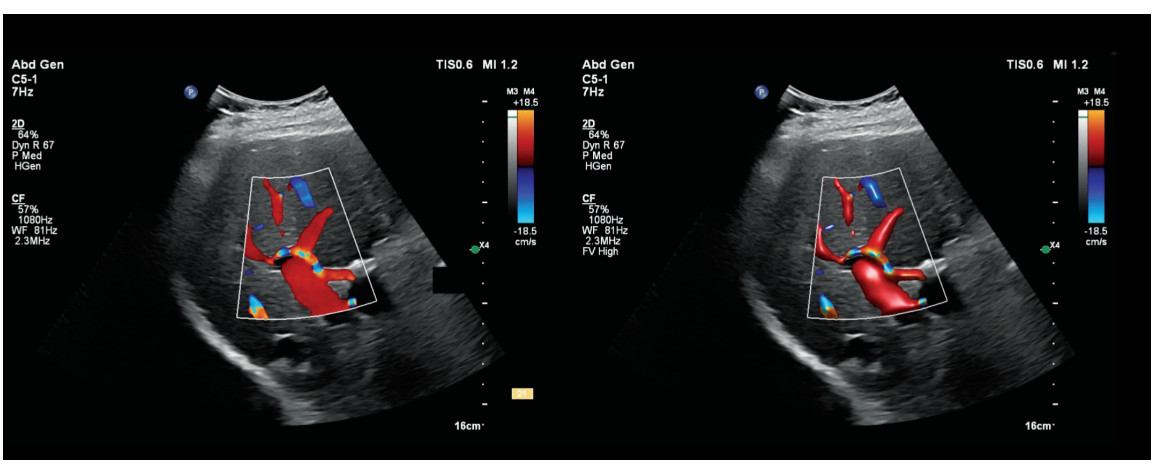

Figure 12
Left: Color Doppler image of the portal vein and hepatic artery (different patient than shown in Figure 11). Right: Flow Viewer version of the image on the left (applied in post-processing).

Figure 13 displays two different MFI frames from the same renal scan. Both frames were acquired with the Flow Viewer feature turned on, but the MFI data has been blended with the B-mode image on the left frame, whereas the right frame is displayed without MFI blending (solid background). These two examples illustrate the ability of Flow Viewer to enhance the visual conspicuity of small vascular structures. In addition, the frame on the right highlights the flow sensitivity improvements offered by applying Flow Viewer on MFI data with a solid background.

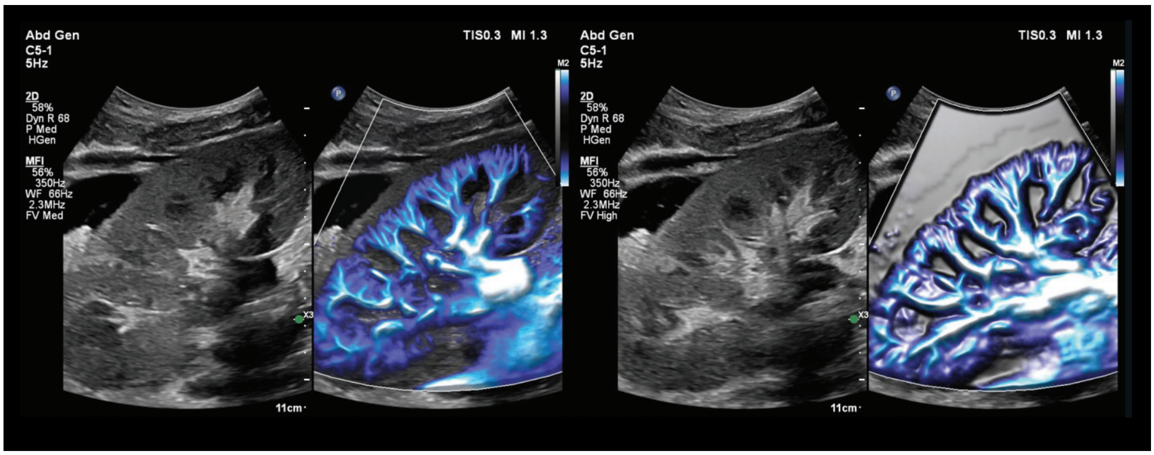

Figure 13
Left: MFI frame from a renal scan, with Flow Viewer turned on and blending between the MFI and B-mode data. Right: Different MFI frame from the same renal scan, with Flow Viewer again turned on but without blending between the MFI and B-mode data (solid MFI background).

Finally, **Figure 14** displays two examples of applying Flow Viewer to vascular carotid Color Doppler images and illustrates the ability of Flow Viewer to offer excellent color containment within the vessel lumen (i.e., reduced color "blooming") because the underlying Doppler Power estimates used to derive the diffuse and specular lighting effects generate more tapered flow profiles vs. the corresponding Doppler Velocity estimates.

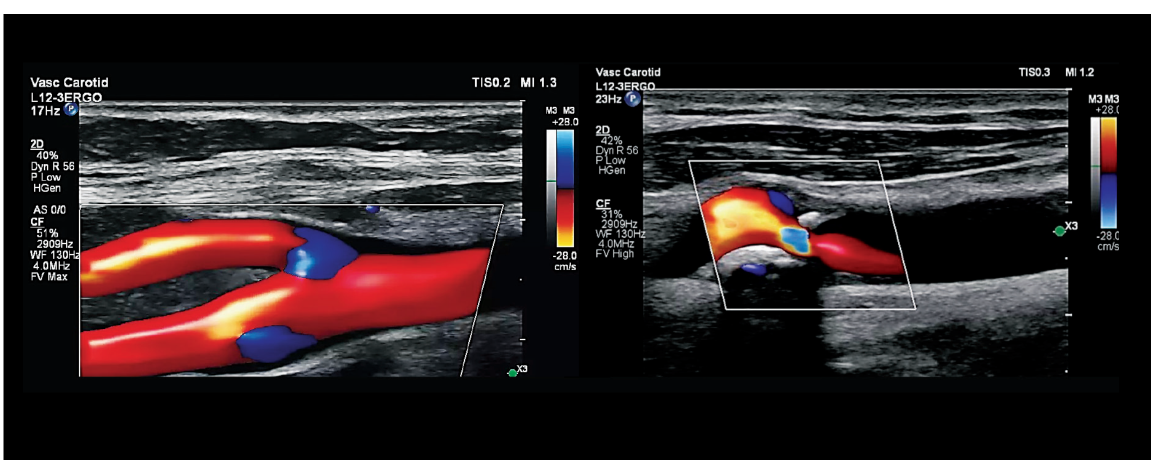

Figure 14
Two Color Doppler vascular carotid images illustrating the 3D-like visualization and excellent color containment with the vessel lumen offered by Flow Viewer.

A recent clinical evaluation study of Flow Viewer[4] has confirmed the benefits of Flow Viewer mentioned above. More specifically, Color Doppler video clips from 40 liver transplant patients, retrospectively acquired with the Philips EPIQ Elite ultrasound system, were post-processed to generate multiple versions of each clip, with or without Flow Viewer. The resulting video clips were blindly evaluated by two readers, who were asked to express their opinion regarding various performance attributes using the Likert 1-5 scale[5] (1: Very negative 2: Negative 3: Neutral 4: Positive 5: Very positive). The findings of this study are summarized below:

- The portal vein and hepatic artery could be resolved in 75% of the Flow Viewer clips vs. 36% in regular Color, i.e., Flow Viewer offered a 2.1 times improvement
- The hepatic artery could be confidently visualized in 80% of the Flow Viewer clips vs. 29% in regular Color, i.e., Flow Viewer offered a 2.8 times improvement
- On a subset analysis which included the most challenging cases, the hepatic artery could be confidently visualized in 71% of the Flow Viewer clips vs. 11% in regular Color, i.e., Flow Viewer offered a 6.5 times improvement
- The portal vein and hepatic artery exhibited satisfactory color containment within the vessel lumen (i.e., acceptable color "blooming") in 55% of the Flow Viewer clips vs. 17% in regular Color, i.e., Flow Viewer offered a 3.2 times improvement
- Satisfactory depiction of aliasing was observed in 55% of the Flow Viewer clips vs. 23% in regular Color, i.e., Flow Viewer offered a 2.4 times improvement

Also, a recent marketing study conducted by Philips evaluated the performance of Flow Viewer in Obstetrics.[6] The study involved 20 second-trimester routine OB exams performed by 20 different sonographers, and Color video clips acquired with and without Flow Viewer were evaluated by the scanning sonographer using the Likert 1-5 scale. The findings of this study are summarized below:

- 100% of the scanning sonographers agreed that Flow Viewer enables sharper delineation of vascular flow margins compared to regular Color Doppler, with 85% of the sonographers expressing strong agreement (score 5) and 15% expressing agreement (score 4)
- 100% of the scanning sonographers agreed that Flow Viewer enables more definitive fetal cardiac chamber and outflow tract identification compared to regular Color Doppler, with 85% of the sonographers expressing strong agreement (score 5) and 15% expressing agreement (score 4)
- 100% of the scanning sonographers agreed that Flow Viewer enables more definitive ductus venosus identification in the second trimester compared to regular Color Doppler, with 79% of the sonographers expressing strong agreement (score 5) and 21% expressing agreement (score 4)
- 100% of the scanning sonographers agreed that Flow Viewer enables more definitive umbilical cord 3-vessel identification compared to regular Color Doppler, with 89% of the sonographers expressing strong agreement (score 5) and 11% expressing agreement (score 4)

4 Summary

This white paper provided the background, principles, as well as clinical applications and benefits related to Flow Viewer, an advanced rendering technique which leverages diffuse and specular lighting effects to offer 3D-like visualization of 2D ("flat") blood flow images.

Flow Viewer is available on the Philips EPIQ and Affiniti ultrasound platforms and works in real-time and/or post-processing for all Flow Imaging modes (Color Doppler, CPA, DCPA, MFI, MFI-HD).

Flow Viewer leverages both the raw Doppler Velocity and Doppler Power estimates to provide:

- Improved ability to resolve adjacent vessels
- Better color containment within the vessel lumen
- Increased conspicuity of small vascular structures

In recent years, photorealistic rendering has proven valuable in clinical settings across various 3D imaging modalities, including computed tomography (CT)[7] and 3D echocardiography[8,9] because it offers improved visualization of intricate three-dimensional anatomy with enhanced depth and shape perception.

Initially limited to 3D applications, advanced 3D rendering techniques are also emerging for 2D applications, such as blood flow ultrasound imaging with Flow Viewer. By incorporating an extra dimension, we can display different types of information such as Doppler Velocity and Doppler Power on a single image. Advanced rendering techniques can leverage our natural perception of depth cues to provide clearer visual differentiation and separation of anatomical structures. Therefore, we expect that the impact of advanced rendering techniques in ultrasound will continue to grow.

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