Scatter Correction of Vessel Dropout Behind Highly Attenuating Structures in 4D-DSA

James R. Hermus[a], Charles Mistretta[a,b,c], Timothy P. Szczykutowicz[b,c]
[a]Department of Biomedical Engineering, University of Wisconsin-Madison, WI 53706
[b]Department of Medical Physics, University of Wisconsin-Madison, WI 53705
[c]Department of Radiology, University of Wisconsin-Madison, WI 53792

Motivation

Today digital subtraction angiography (DSA), is the gold standard for vascular imaging. In this method a non-contrast mask projection is acquired, then contrast is injected into the vasculature and scanned to create a fill projection. Next, the mask is log subtracted from the fill creating an image with only the contrast filled vasculature. With implementation of multiple constraints on static 3D-DSA volumes, the ability to embed temporal information into a 3D-DSA volume, a 4D-DSA time frame, has become possible)[1, 2]. This imaging method requires an original 3D-DSA volume which is constrained by the temporal information in each projection. This is done by back projecting the temporal projections onto the 3D-DSA volume creating a 4D-DSA volume at a specific time frame. In contrast to 3D-DSA, in 4D-DSA the fill scan begins while contrast is filling the anatomy of interest, not when the vasculature is already filled. Therefore, the temporal dynamics of the contrast filling the vascular anatomy is embedded into the projection data. 4D-DSA allows the clinician to view images with only veins or only arteries at any angle. This technique allows for contrast dynamics to be visualized; different from 3D-DSA which only allows visualization of contrast at a single time point.

In 4D-DSA image reconstruction, vessel dropout was observed due to highly attenuating anatomy, such as large aneurysms (see Figure 1). Vessel drop out in this context is the drop in signal value of a vessel to near zero value that has no pathological explanation and is considered an artifact in 3D and 4D-DSA imaging. In a previous work we utilized forward projections in combination with Monte Carlo simulations and concluded the majority of contrast degradation results from scattering artifacts in cases of vessel dropout due to highly attenuating anatomy[3]. In this work we present a correction algorithm that can mitigate these artifacts.

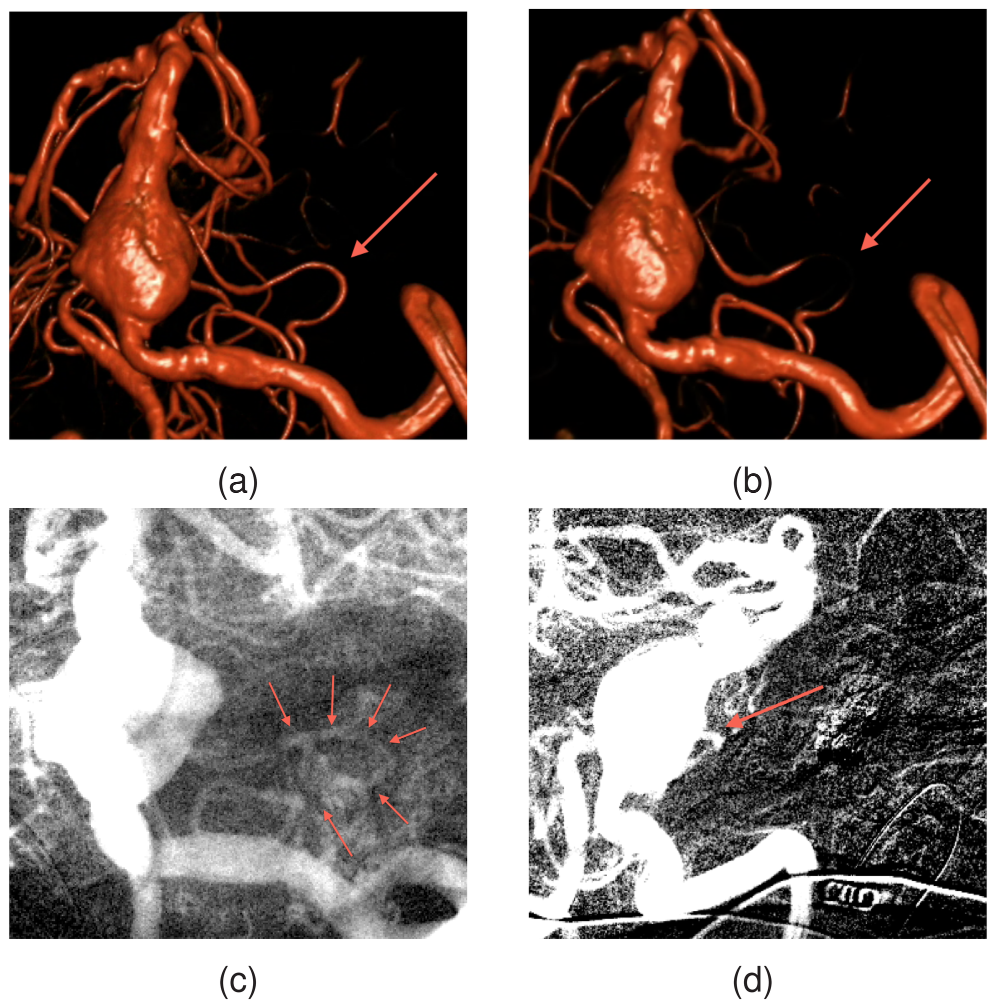

Figure 1: The red arrows point to the vessel that experiences signal loss. (a) and (b) are 4D-DSA reconstructions which correspond to the time frame of the DSA projections (c) and (d) respectively. There is no signal loss in the 4D-DSA in (a) as the aneurysm does not over lap the vessel at this angle as seen in the DSA projection data (c). Signal loss is clear in the 4D-DSA in (b) due to the angle dependent overlap from the aneurysm seen in the DSA projection data (d).

Methods

We have implemented a correction which uses a threshold to locate vasculature where signal loss will likely be observed and then increases the signal for those projections, correcting the vessel dropout. (Note: whenever the 4D-DSA volume is referred to in this correction we are referring to the 4D-DSA volume at the time frame where vessel dropout is observed.) Figure 2 provides an overview of the correction algorithm:

a) This correction algorithm uses a **3D-DSA** to create a **Correction Volume**. The correction volume contains values greater than one (white) where the 4D-DSA is effected by vessel dropout and contains ones (gray) where there is no dropout.

b) The correction volume and the **4D-DSA** are multiplied. The signal value in the 4D-DSA time frame is enhanced only where the dropout is likely to occur.

c) This multiplication produces the **Corrected 4D-DSA volume**. This correction could be applied to all 4D-DSA time frames, only modulating 4D-DSA values in regions where signal loss should occur.

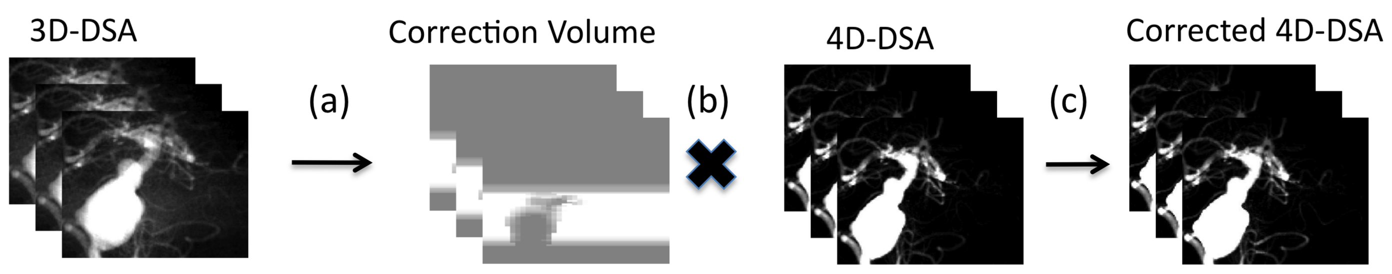

Figure 2: Flow chart of correction.

Creating the Correction Volume

The correction volume is created in four steps as depicted in Figure 3. (Note: In this correction, forward and back projections are preformed only at the angle of the projection used to temporally encode the 4D-DSA volume at the time frame where the vessel dropout is observed.):

a) The **3D-DSA** volume is forward projected, creating a single projection, **I**.

b) A correction function, **CF** is then applied to this projection (see Equation 1 for the form of the correction function). When creating the correction function we used a scaled logarithmic function to avoid a sharp increase in signal for projection values near the threshold. This functional form was empirically determined using three clinical cases. This form may not be extendible to all cases nor to other body regions.

$$CF = \begin{cases} I = m * log(I - Tr + 1) + 1 & : ifI > Tr \\ I = 1 & : ifI < Tr \end{cases} \qquad (1)$$

If the intensity at a pixel exceeds some threshold, Tr, the pixel value is multiplied by a factor greater than one determined by the threshold function. If the pixel does not exceed the threshold it is set to 1 in the projection.

c) The projection is back projected to create a volume.

d) As the aneurysm lies in the portion of the 4D-DSA volume which is enhanced by the **Correction Volume** and contains the locations with the highest attenuation values, without accounting for its position in this correction volume the intensity of the aneurysm would be significantly over enhanced by the correction volume. Therefore, the location of the aneurysm in the correction volume is set to 1.

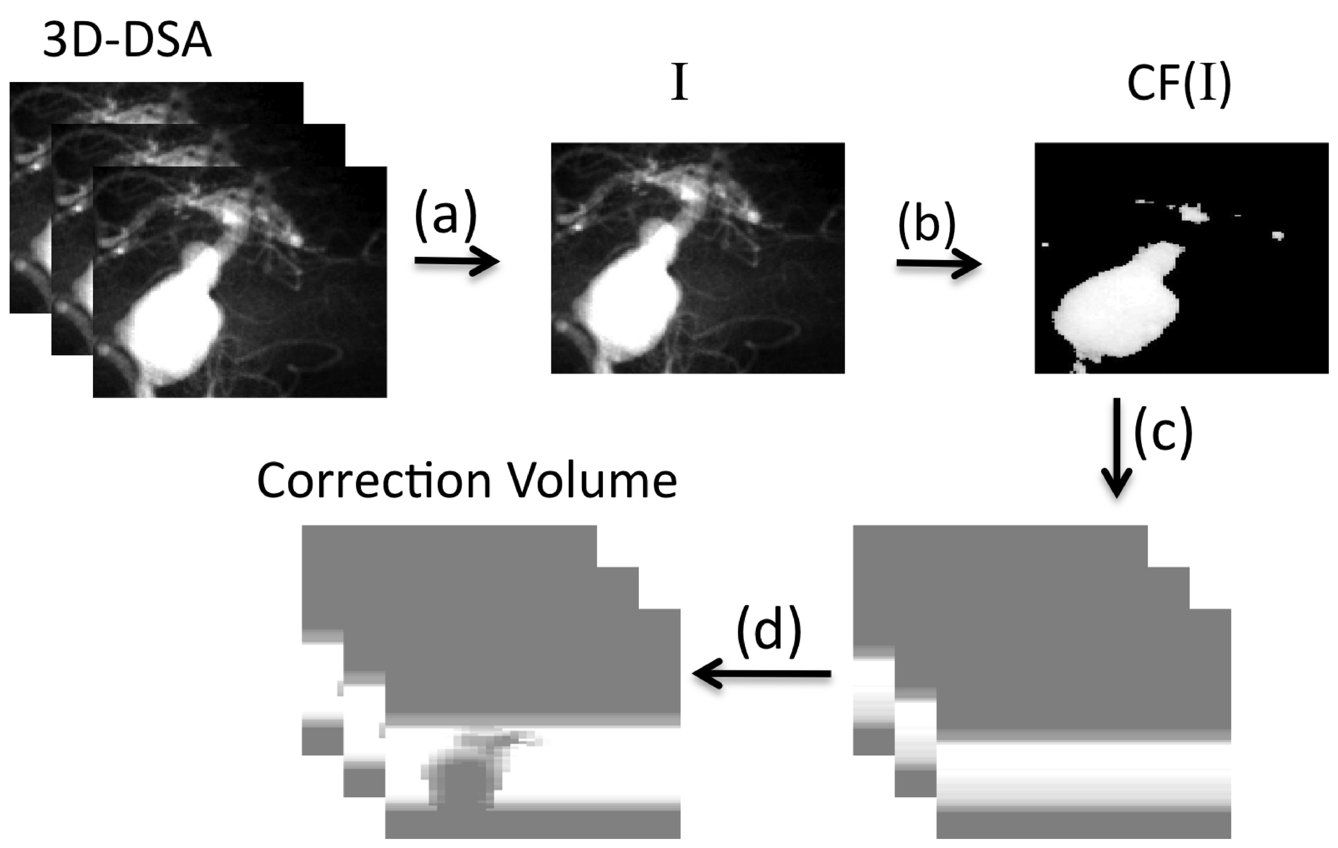

Figure 3: Flowchart of the correction function.

A threshold of 1.8×10^5 a.u. was used in this work. The projection images on which the CF function was applied, ranged in value from 0 to 3.66×10^5 a.u.. This range depends on the units of the 3D-DSA volume, but should not affect the methodology presented in this work (i.e. 3D-DSA images reconstructed in linear attenuation coefficient or HU units could also be used in this methodology, albeit some scaling and the addition of an offset may be required).

Plotting the reconstructed image value within the vessel from maximum intensity projections (MIP) of the 4D-DSA allows one to see if the correction returns the contrast in the vessel to values similar to surrounding vasculature of the same size which are not degraded by the aneurysm. It is a valid clinical assumption to assume the contrast dynamics along a vessel are similar and local minimum along a given vessel are clinically unlikely. Using this metric one can also ensure the vasculature that has not experienced signal loss is not over enhanced by this correction. When we refer to surrounding vasculature, we are referring to the vasculature immediately surrounding the dropout region, which should exhibit the same temporal dynamics as the dropout region. In other words, a vessel adjacent to the dropout vessel could have vastly different temporal contrast dynamics as it could originate from a different point in the vascular tree and should not be used to compare the effectiveness of our method.

The algorithm described above can only be used to correct for artifacts caused by contrast as it uses the 3D-DSA volume to isolate the areas where signal loss will be observed. To correct for highly attenuating material (i.e. metal from dental implants) not within the 3D-DSA volume, a similar correction can be applied using a thresholded fill volume. In such a volume, only highly attenuating dental or other metal implants would remain. This masked volume could then be fed into the scheme outlined in Figure 3. To implement the correction scheme algorithm the only change is in step (a) from Figure 3.

Results and Discussion

We have implemented the correction algorithm on a clinical case where vessel dropout is observed due to the attenuation of a large aneurysm. To quantitatively illustrate the signal increase the intensity of the vessel can be plotted as seen in the Figure 4. One can clearly see that the signal is enhanced by the correction to the same intensity as nearby portions of the same vessel that did not experience contrast degradation. Most importantly, when looking at the yellow portion of the plot one can see the correction did not enhance the signal in the nearby vasculature. This is important because the nearby vasculature was not adversely effected by the dropout artifact.

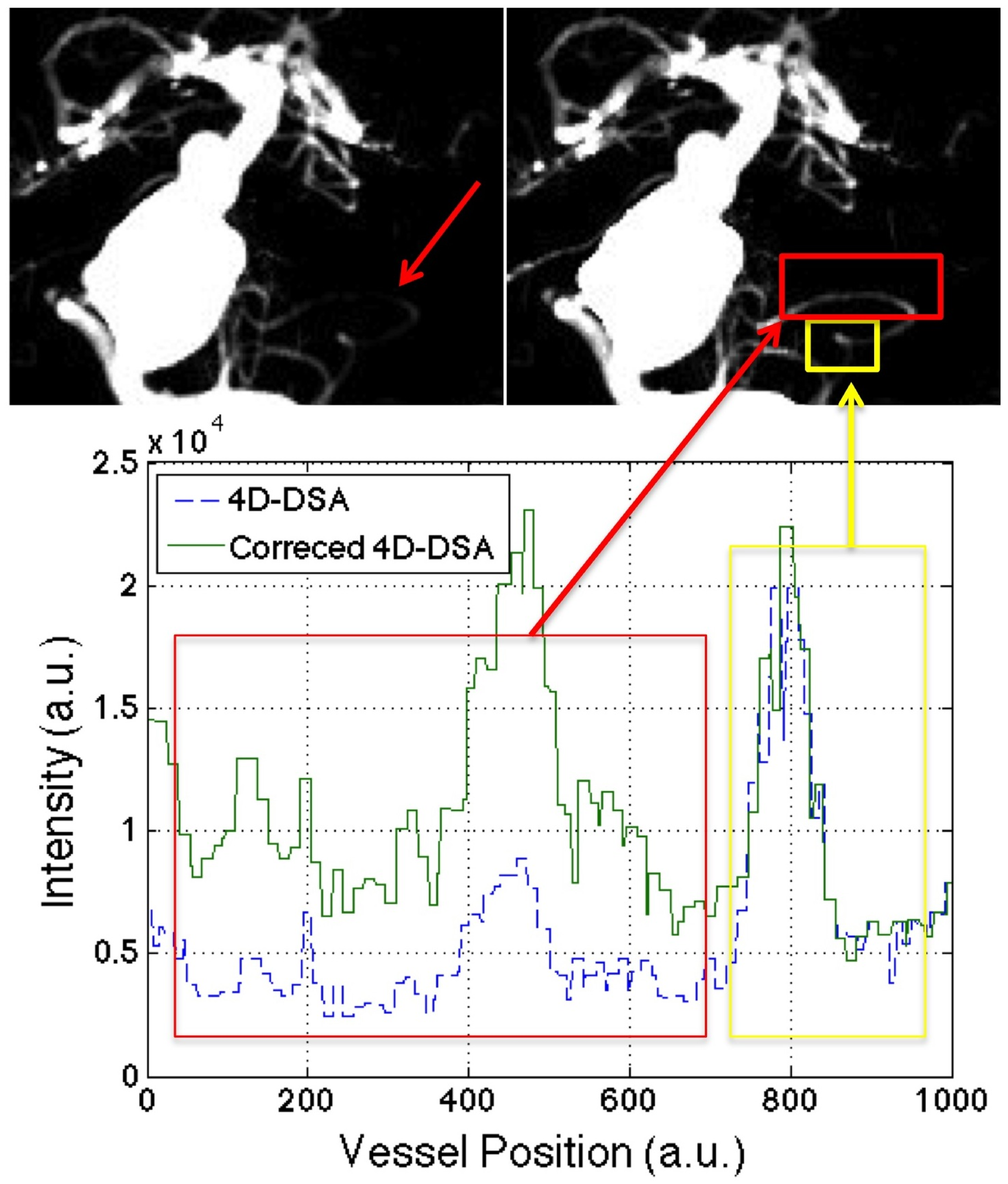

Figure 4: The image in the upper left displays a MIP of the 4D-DSA at a time frame where the signal in the vessel is lost. The image in the upper right shows the same 4D-DSA time frame after multiplication with the correction volume. In the plot below the images display the intensity with in the vessel. The red and yellow boxes correspond to the corrected and non-corrected portions of the vessel respectively. Note how the signal values in the corrected volume match the 4D-DSA volume where there is no dropout (yellow arrow) and the corrected volume shows an elevated signal over the dropout region.

New Work

- Correction for vessel dropout in 4D-DSA due to highly attenuating material in the fill volume.

Conclusions

We have demonstrated that this scatter correction algorithm acts to correct vessel dropout in areas with highly attenuating materials. In the future, work will be performed using Monte Carlo experiments and phantom measurements to better determine the optimal CF functional form and evaluate the applicability of this methodology to regions outside of the head.

Acknowledgments

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