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Short Paper

Shading Style Assessment for Vessel Wall and Lumen Visualization

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Abstract

Current blood vessel rendering usually depicts solely the surface of vascular structures and does not visualize any interior structures. While this approach is suitable for most applications, certain cardiovascular diseases, such as aortic dissection would benefit from a more comprehensive visualization. In this work, we investigate different shading styles for the visualization of the aortic inner and outer wall, including the dissection flap. Finding suitable shading algorithms, techniques, and appropriate parameters is time-consuming when practitioners fine-tune them manually. Therefore, we build a shading pipeline using well-known shading algorithms such as Blinn-Phong, Oren-Nayar, Cook-Torrance, Toon, and extended Lit-Sphere shading with techniques such as the Fresnel effect and screen space ambient occlusion. We interviewed six experts from various domains to find the best combination of shadings for preset combinations that maximize user experience and the applicability in clinical settings.

CCS Concepts

• ***Human-centered computing*** → ***Empirical studies in visualization;*** • ***Applied computing*** → ***Health informatics;*** • ***Computing methodologies*** → *Non-photorealistic rendering; Visibility; Reflectance modeling;*

1. Introduction

Surface representations of vascular structures are a well researched area. Algorithms for creating such surfaces are primarily divided into model-based and model-free and further into implicit and explicit [PO08]. Despite their different ways of modeling the surface, these approaches only generate a single surface layer. This may be sufficient for most visualization applications, but does not show a comprehensive picture of the underlying anatomy of blood vessels, as their wall consists of more than one layer [Rho80]. Modeling and visualizing multiple vessel wall layers is primarily important in large vessels and paramount for blood flow simulations [BVS*20] as well as rupture risk assessment of aneurysms [GLH*14].

Most currently used visualization techniques in applications such as aortic dissection or aneurysms are lacking an actual analysis of the style of wall visualization itself. In this work, we seek a holistic approach to visualize the outer vessel wall of vascular structures. We demonstrate our design assessment on aortic dissections, because they represent a comprehensive example case and comprise one of the most complex vascular anatomies. Aortic dissections are characterized by delamination of the media layer of the aortic vessel wall and formation of a second (false) lumen that is separated by a thin membrane (dissection flap) from the original (true) lumen [MHM*16]. Summarizing our contributions, we

- examine various combinations of shading styles and techniques to visualize the outer vessel wall, luminal surfaces, and the aortic dissection flap,
- provide a flexible tool that enables the adjustment of shading styles for all surfaces (inner, luminal, and outer), and
- give initial feedback from domain experts.

The remainder of this paper starts with discussing related work (Section 2), followed by the description of the investigated shading approaches (Section 3). In Section 4 we present and discuss our evaluation outcomes. Finally, we summarize our pilot study and provide potential future avenues for vessel wall rendering (Section 5).

2. Related Work

Previous vessel visualization techniques focused on modeling aspects, such as smooth continuation at bifurcations and accuracy. For rendering, mostly baseline techniques, such as Phong shading were employed [OP05]. Lawonn et al. [LGP14] analyzed different (illustrative) visualization techniques with respect to shape and depth perception of vascular structures in combination with flow data. However, they did not examine additional vessel wall layers, which is the focus of our work. Computational fluid dynamic simulations require depicting the complex interplay between physiological deformation, flow, pressure, and wall shear stress, as shown in the work of Bäumler et al. [BVS*20]. Burris et al. [BHKR17] introduced vascular deformation mapping to assess changes in aortic dimensions to quantify 3D changes in the aortic wall geometry. The results are superimposed on a 3D model using 3D color printing. Our work could help selecting suitable context visualizations of the vascular geometry when displaying blood flow.

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Glaßer et al. [GLH*14] combined wall shear stress data (color-coded on the inner wall) with wall thickness data (depicted by distance ribbons on the outer wall) in one visualization. To inspect the vessels' lumen, the transparency of the outer wall was modulated using the Fresnel effect by calculating the angle between the viewing vector and the surface normal leading to a ghosted view of the vessel wall. This approach is one customizable parameter for our shading pipeline. Lawonn et al. [LGV*16] visualized wall thickness data together with blood flow data. They combined dynamic cutaway surfaces with a glyph-based blood flow representation and mapped wall thickness color-coded onto the vessel surface. Mistelbauer et al. [MRB*21] implicitly modeled arbitrarily shaped cross-sections of aortic dissections including the outer vessel wall, rendered semi-transparently. Visualizing the difference between the true and false lumen with the outer vessel wall or how multiple lumina twist around each other is especially important in aortic dissections or stenotic regions.

Qi et al. [QML*16] visualized the entry tear and intimal flap of aortic dissections using computed tomography virtual intravascular endoscopy. Rezk-Salma et al. [RSK06] employed opacity peeling for direct volume rendering to make outer layers transparent and reveal hidden information of internal structures. Straka et al. [SCLC*04] introduced *VesselGlyph*, a focus and context visualization for computed tomography angiography. They combine different rendering styles for focus and context, e.g., a curved planar reformation [KFW*02] of a vessel and its immediate neighborhood (focus) is combined with a direct volume rendering of the surrounding data. The combination of the different styles could improve spatial orientation, which is the reason why we investigate physically-based and stylistic rendering techniques.

Glaßer et al. [GOH*10] introduced an automatic 2D and 3D transfer function specification to visually emphasize coronary artery plaque. The transfer functions are calculated based on the mean intensity and standard deviation of the bloodpool and vessel wall.

There are several possibilities for enhancing depth perception of vascular structures. Ropinski et al. [RMSD*08] presented a method to render volumetric data sets with dynamic ambient occlusion and color bleeding. Lichtenberg et al. [LL19] studied the effects of different techniques on the depth perception of liver vascular structures. Among the analyzed methods are supporting lines, supporting anchors, concentric circle glyphs, and void space surfaces. They find that each technique improves depth perception. In our work, we use screen space ambient occlusion [Eng09].

3. Methodology

Our goal is to identify appropriate combinations of shading styles and techniques (Fig. 1) to visualize surface meshes of the inner and outer vessel wall together with the aortic dissection flap. For this reason, we use common and well-known physically-based and stylistic rendering approaches to highlight specific structures and focus the viewer's gaze on specific areas, while providing contextual information to maintain an overview of the surrounding anatomy. The outer vessel wall, the inner vessel wall, and the dissection flap can be rendered separately with different shading styles and techniques. Each of these styles has user-defined parameters, as summarized in Fig. 1 and demonstrated in Fig. 2.

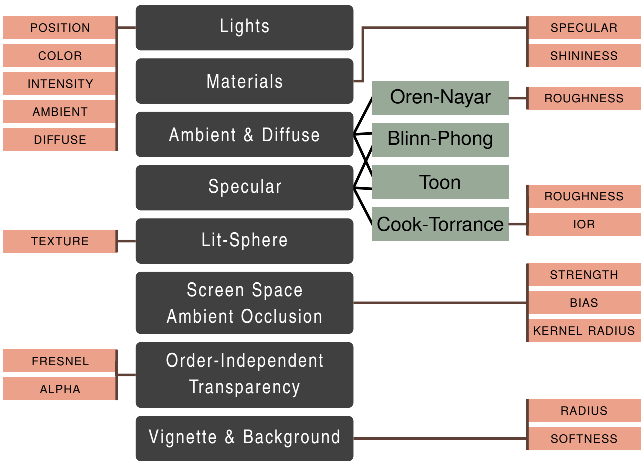


Figure 1: *Main steps (black boxes) of the shading pipeline, consisting of various lighting shaders (green boxes) and modifiable parameters (red boxes). Lit-Sphere is a separate step, as ambient, diffuse, and specular depend on the selected texture.*

For physically-based rendering, we use Blinn-Phong shading [Pho75] as it is one of the most well-known shading techniques, and we believe practitioners are used to this type of shading. Surfaces rendered with Blinn-Phong shading tend to appear glossy. To mimic rougher surfaces, we used Oren-Nayar shading [ON94] for ambient lighting and Cook-Torrance shading [CT82] for specular lighting. Both are based on the concept of micro facets to approximate light reflected from rough surfaces.

We use Toon shading [vPBB*10] as a stylistic rendering approach to emulate the look of cartoon art. This shading simplifies parts of a visualization while maintaining a cue for depth and still outlining the morphological structure [vPBB*10] as shown in image 15 in Fig. 2.

Lit-Sphere shading, introduced by Sloan et al. [SMG01], can be used for realistic and stylistic rendering, depending on the selected texture. This texture resembled a hemisphere rendered with a specific shading and acts as a lookup for the final color, depending on the angle between the viewing direction and the surface normal of the rendered mesh. Todo et al. [TAY13] extended this approach by introducing a light space with the final color depending on the light direction and surface normal. For the evaluation we use extended Lit-Sphere shading with two different textures (Fig. 3), one with a gray shading and the other representing the natural colors of blood vessels, see images 12 and 13 in Fig. 2.

Because opaque visualization of both the outer and inner vessel walls does not provide adequate visibility of the dissection flap, we added weighted blended order-independent transparency (OIT) [MB13]. Optionally, the Fresnel effect can be used to adjust the transparency of the surface depending on the angle between viewing direction and surface normal, similar to the approach of Gasteiger et al. [GNKP10]. The strength of this effect is controlled by the edge falloff parameter. The effect is presented in image 29 in Fig. 2, while it is disabled in image 30.

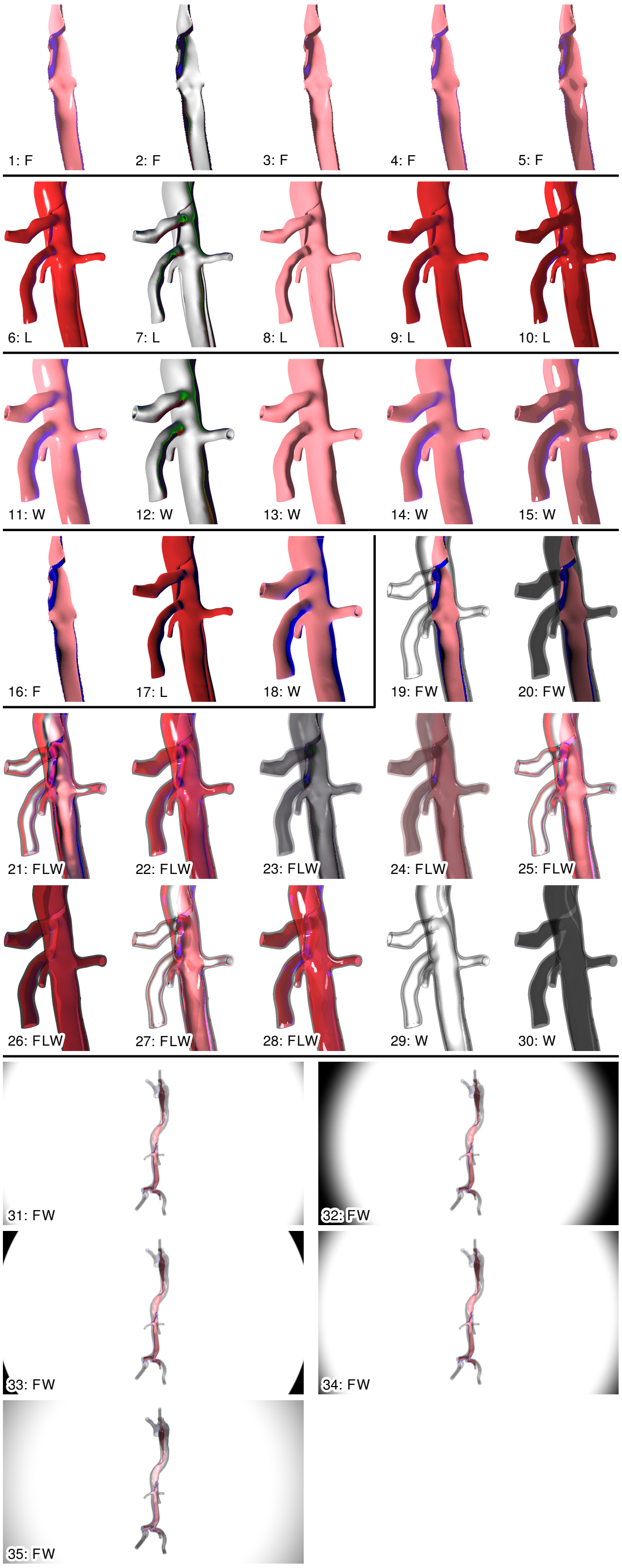


Figure 2: *Analyzed design space for rendering the aortic dissection flap (F), vessel lumen (L), and outer vessel wall (W). The corresponding styles and techniques of the images are given in Fig. 3.*

We provide additional depth cues by using screen space ambient occlusion (SSAO) [Eng09]. It approximates shadows that occur when the scattering of ambient light is obstructed by surrounding geometry. Finally, we added a vignette effect that surrounds the rendering with a customizable transition from white to black at the image border, see images 31-35 in Fig. 2. This effect could support patient communication by visually highlighting certain structures and bringing them into focus.

We positioned two light sources in our scene, a white frontlight and, motivated by the work of Lawonn et al. [LGV*16], a blue backlight. Both lights use an inverse-squared distance falloff. The position of the lights can be freely changed by the users, but for the evaluation they are kept at a fixed position to ensure a common baseline among participants.

4. Evaluation and Discussion

We performed an assessment of multiple visualizations of the aortic dissection surface in the form of an online survey that included different shading styles and techniques. Each question of the survey consisted of two still images, a close-up view as shown in Fig. 2 and the corresponding full image, as shown in the bottom row. The images were selected by the authors, who did not participate in the study, to cover a wide range of shading style combinations but could be evaluated within a two-hour time frame. We then asked six experts to rate their agreement regarding the utility and clinical applicability of the presented shading styles on a 7-point Likert scale, ranging from strongly agree (1), to agree (2), more or less agree (3), undecided (4), more or less disagree (5), disagree (6), and strongly disagree (7), and to provide justification and comments below. Participants, all coauthors, included three radiologists, a clinical scientist, a computational fluid simulation expert, and a medical image processing expert. The outcome of this pilot study is presented in Fig. 3 and all subsequent descriptive statistics are reported below as median and interquartile range.

All participants *more or less disagreed* and *disagreed* with rendering the dissection flap alone (Fig. 2, images 1-5). Toon shading received most disagreement (image 5, 6.5 (5.25-7)). Participants justified that showing the aortic dissection flap alone does not provide complete visualization of dissection anatomy, i.e., the location of branches and fenestrations or which side of the flap is displayed.

Participants more or less agreed to display the true and false lumen surface (Fig. 2, images 6-10). They preferred *Oren-Nayar and Cook-Torrance* (image 9, 2.5 (2-3.75)) due to the more natural coloring and the good true and false lumen contours. One participant mentioned, however, that less surface details are apparent, compared to image 7. Participants were undecided with *Lit-Sphere (Texture 1) and Cook Torrance* (image 7, 4 (3-5)) and Toon shading (image 10, 4 (3.25-4.75)). One participant suggested that the *metallic look* of image 7 could visualize stent grafts.

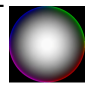
Generally, participants more or less disagreed with displaying only the outer vessel wall (Fig. 2, images 11-15). They were particularly clear about *Lit-Sphere (Texture 1) and Cook Torrance* (image 12, 5 (4.25-5)), mainly because the texture does not reflect the expected colors of a vessel. This is also reflected by the better score, when using the second texture (image 13, 3 (3-3.75)).

To assess the effect of screen space ambient occlusion, we decided to use Oren-Nayar and Cook-Torrance (Fig. 2, images 16-18). Although participants were generally undecided to more or less disagree, they more or less agreed to display true and false lumen with ambient occlusion (image 17, 2.5 (2-3.75)).

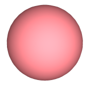
When combining the dissection flap, true and false lumen, and the outer vessel wall (Fig. 2, images 19-30), participants were generally undecided to more or less disagree with the presented styles. However, they agreed with a transparent outer vessel wall and the flap rendered with *Oren-Nayar and Cook-Torrance with Fresnel* (image 19, 2 (2-4.25)). They mentioned the good contrast between the flap and the outer vessel wall in relation to the branch vessels. However, the extent of the flap into branch vessels was not fully apparent yet, neither from which lumen branches originate.

In addition to the shading styles and techniques, we also assessed different strengths of a vignette effect (Fig. 2, images 31-35) using image 19, *Oren-Nayar and Cook-Torrance with Fresnel*. Participants only agreed to a rather small (image 31, 2.5 (2-4.5)) or smooth (image 35, 3.5 (1.5-4)) vignette effect.

Concerning other aspects, one participant mentioned that a differentiation between true and false lumen could be valuable information. Also, different front- and backlights could emphasize the tortuosity of the flap. Furthermore, a visual depiction of entry and exit tear or other fenestrations would be helpful.



Texture 1



Texture 2

	Blinn-Phong Diffuse	Blinn-Phong Specular	Oren-Nayar Diffuse	Cook-Torrance Specular	Toon Diffuse	Toon Specular	Lit-Sphere Shading	Fresnel Effect	SSAO	Flap	Lumen	Wall	Radiologist	Radiologist	Radiologist	Clinical Scientist	Simulation Expert	Image Processing Expert
1:	×	×								×			3	5	6	6	5	3
2:				×			T1			×			4	6	6	7	5	5
3:				×			T2			×			4	3	6	7	5	2
4:			×	×						×			4	5	6	6	5	2
5:					×	×				×			6	4	7	7	5	7
6:	×	×									×		2	1	4	4	4	3
7:				×			T1				×		6	5	3	5	3	2
8:				×			T2				×		3	2	4	5	4	1
9:			×	×							×		2	1	4	5	3	2
10:					×	×					×		6	1	4	5	4	3
11:	×	×										×	2	5	4	6	3	6
12:				×			T1					×	5	5	3	6	4	5
13:				×			T2					×	3	3	4	6	3	2
14:			×	×								×	5	5	4	6	3	3
15:					×	×						×	6	4	5	6	3	6
16:			×	×					×	×			4	6	6	6	5	1
17:			×	×					×		×		2	1	3	5	4	2
18:			×	×					×			×	6	4	5	6	3	4
19:			×	×				×		×		[×]	5	5	2	2	2	1
20:			×	×						×		[×]	7	5	5	4	3	3
21:	×	×						×		×	[×]	[×]	7	3	3	5	3	4
22:	×	×								×	[×]	[×]	7	3	5	5	3	3
23:				×			T1			×	[×]	[×]	7	6	4	6	2	5
24:				×			T2			×	[×]	[×]	5	4	4	4	4	5
25:			×	×				×		×	[×]	[×]	7	3	3	5	2	4
26:			×	×						×	[×]	[×]	7	5	5	5	4	5
27:					×	×		×		×	[×]	[×]	7	5	5	5	2	2
28:					×	×				×	[×]	[×]	7	2	6	5	4	5
29:			×	×				×				[×]	7	6	3	5	4	6
30:			×	×								[×]	7	6	6	6	4	6
31:			×	×				×		×		[×]	3	5	7	2	2	2
32:			×	×				×		×		[×]	4	5	7	2	2	3
33:			×	×				×		×		[×]	4	5	7	2	3	6
34:			×	×				×		×		[×]	4	5	6	2	2	4
35:			×	×				×		×		[×]	4	5	4	3	1	1

Figure 3: *Results of our evaluation. The numbers on the left side indicate the corresponding image of Fig. 2. An empty box ☐ represents 'not selected', whereas × indicates that the technique or effect was used. A dashed border [×] denotes transparent rendering, whereas a solid border ☒ means opaque rendering.*

5. Conclusion and Future Work

In this work, we performed a preliminary evaluation of different combinations of shading styles and techniques to render vascular surface meshes of the outer vessel wall and lumen simultaneously. We combined Blinn-Phong shading, Oren-Nayar shading, Cook-Torrance shading, Toon shading and extended Lit-Sphere shading with effects such as transparency with or without Fresnel and screen space ambient occlusion on aortic dissections to identify a parameter combination that is favored by the interviewed experts.

Our preliminary assessment shows that there is a lot of disagreement, especially between clinical and technical experts. We see this observation as motivation for several future avenues. We plan to explore how combinations of different diffuse and specular parts can be used to achieve focus and context visualizations sufficient for clinical practice and the visualization of computational fluid dynamics simulations. This also includes rendering parts of the dissection mesh with a combination of physically-based and stylistic shading styles. We also plan to extend our framework to include a gallery, similarly to the work of Bruckner et al. [BM10], from which users can interactively select shading styles, techniques, and parameters from preview images to iteratively create a desired design of a 3D surface mesh. Such a system would also allow experts to interactively explore the design space and develop shading styles for a particular task, which could then be incorporated into radiology workstations as presets. We also aim to explore how these styles behave when viewing larger vascular systems and from a greater distance, as the wall appears thinner and the vessel boundary may appear fuzzy and blurred as a result. Possibly, level-of-detail approaches could be useful here. Since we only evaluated the effects of still images, we want to investigate how these shadings are received when interacting with the vascular structures, e.g., when rotating, zooming, and panning. In addition, different red tones or even other colors should be considered for the representation of the blood vessels, as well as the effects of different light positions and colors on the overall perception.

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References

[BHKR17] Burris N. S., Hoff B. A., Kazerooni E. A., Ross B. D.: Vascular deformation mapping (VDM) of thoracic aortic enlargement in aneurysmal disease and dissection. *Tomography 3*, 3 (2017), 163–173. doi:10.18383/j.tom.2017.00015. 1

[BM10] Bruckner S., Möller T.: Result-driven exploration of simulation parameter spaces forvisual effects design. *IEEE Transactions on Visualization and Computer Graphics 16*, 6 (2010), 1468–1476. doi:10.1109/TVCG.2010.190. 4

[BVS*20] Bäumler K., Vedula V., Sailer A. M., Seo J., Chiu P., Mistelbauer G., Chan F. P., Fischbein M. P., Marsden A. L., Fleischmann D.: Fluid–structure interaction simulations of patient-specific aortic dissection. *Biomechanics and Modeling in Mechanobiology 19*, 5 (2020), 1607–1628. doi:10.1007/s10237-020-01294-8. 1

[CT82] Cook R. L., Torrance K. E.: A Reflectance Model for Computer Graphics. *ACM Transactions on Graphics 1*, 1 (1982), 7–24. doi:10.1145/357290.357293. 2

[Eng09] Engel W.: *ShaderX7 : Advanced Rendering Techniques*. Course Technology/Cengage Learning, Australia, 2009. 2, 3

[GLH*14] Glasser S., Lawonn K., Hoffmann T., Skalej M., Preim B.: Combined visualization of wall thickness and wall shear stress for the evaluation of aneurysms. *IEEE Transactions on Visualization and Computer Graphics 20*, 12 (2014), 2506–2515. doi:10.1109/tvcg.2014.2346406. 1, 2

[GNKP10] Gasteiger R., Neugebauer M., Kubisch C., Preim B.: Adapted Surface Visualization of Cerebral Aneurysms with Embedded Blood Flow Information. In *Eurographics Workshop on Visual Computing for Biology and Medicine* (2010), The Eurographics Association. doi:10.2312/VCBM/VCBM10/025-032. 2

[GOH*10] Glasser S., Oeltze S., Hennemuth A., Kubisch C., Mahnken A., Wilhelmsen S., Preim B.: Automatic transfer function specification for visual emphasis of coronary artery plaque. *Computer Graphics Forum 29*, 1 (2010), 191–201. doi:10.1111/j.1467-8659.2009.01590.x. 2

[KFW*02] Kanitsar A., Fleischmann D., Wegenkittl R., Felkel P., Gröller M. E.: Cpr – curved planar reformation. In *Proceedings of IEEE Visualization* (2002), pp. 37–44. doi:10.1109/VISUAL.2002.1183754. 2

[LGP14] Lawonn K., Gasteiger R., Preim B.: Adaptive surface visualization of vessels with animated blood flow. *Compututer Graphics Forum 33*, 8 (2014), 16–27. doi:10.1111/cgf.12355. 1

[LGV*16] Lawonn K., Glasser S., Vilanova A., Preim B., Isenberg T.: Occlusion-free blood flow animation with wall thickness visualization. *IEEE Transactions on Visualization and Computer Graphics 22*, 1 (2016), 728–737. doi:10.1109/tvcg.2015.2467961. 2, 3

[LL19] Lichtenberg N., Lawonn K.: Auxiliary Tools for Enhanced Depth Perception in Vascular Structures. In *Advances in Experimental Medicine and Biology*. Springer International Publishing, 2019, pp. 103–113. doi:10.1007/978-3-030-14227-8_8. 2

[MB13] McGuire M., Bavoil L.: Weighted blended order-independent transparency. *Journal of Computer Graphics Techniques 2*, 2 (2013), 122–141. 2

[MHM*16] Mussa F. F., Horton J. D., Moridzadeh R., Nicholson J., Trimarchi S., Eagle K. A.: Acute aortic dissection and intramural hematoma: A systematic review. *JAMA 316*, 7 (2016), 754–763. doi:10.1001/jama.2016.10026. 1

[MRB*21] Mistelbauer G., Rössl C., Bäumler K., Preim B., Fleischmann D.: Implicit modeling of patient-specific aortic dissections with elliptic fourier descriptors. *Computer Graphics Forum 40*, 3 (2021), 423–434. doi:10.1111/cgf.14318. 2

[ON94] Oren M., Nayar S.: Generalization of lambert's reflectance model. In *Computer graphics and interactive techniques* (New York, NY, 1994), Schweitzer D., (Ed.), ACM Press, pp. 239–246. doi:10.1007/BF01679684. 2

[OP05] Oeltze S., Preim B.: Visualization of vasculature with convolution surfaces: Method, validation and evaluation. *IEEE Transactions on Medical Imaging 24*, 4 (2005), 540–548. doi:10.1109/TMI.2004.843196. 1

[Pho75] Phong B. T.: Illumination for computer generated pictures. *Communications of the ACM 18*, 6 (1975), 311–317. doi:10.1145/360825.360839. 2

[PO08] Preim B., Oeltze S.: 3D visualization of vasculature: An overview. In *Visualization in Medicine and Life Sciences*, Linsen L., Hagen H., Hamann B., (Eds.), Mathematics and Visualization. Springer, 2008, pp. 39–59. doi:10.1007/978-3-540-72630-2_3. 1

[QML*16] Qi Y., Ma X., Li G., Ma X., Wang Q., Yu D.: Three-dimensional visualization and imaging of the entry tear and intimal flap of aortic dissection using CT virtual intravascular endoscopy. *PLOS ONE 11*, 10 (2016), e0164750. doi:10.1371/journal.pone.0164750. 2

[Rho80] Rhodin J. A. G.: Architecture of the vessel wall. *Comprehensive Physiology* (1980), 1–31. doi:10.1002/cphy.cp020201. 1

[RMSD*08] Ropinski T., Meyer-Spradow J., Diepenbrock S., Mensmann J., Hinrichs K.: Interactive volume rendering with dynamic ambient occlusion and color bleeding. *Computer Graphics Forum 27*, 2 (2008), 567–576. doi:10.1111/j.1467-8659.2008.01154.x. 2

[RSK06] Rezk-Salama C., Kolb A.: Opacity peeling for direct volume rendering. *Computer Graphics Forum 25*, 3 (2006), 597–606. doi:10.1111/j.1467-8659.2006.00979.x. 2

[SCLC*04] Straka M., Cervenansky M., La Cruz A., Köchl A., Sramek M., Gröller E., Fleischmann D.: The VesselGlyph: focus & context visualization in CT-angiography. In *IEEE Visualization* (2004), IEEE Comput. Soc. doi:10.1109/visual.2004.104. 2

[SMG01] Sloan P., Martin W., Gooch A.: The lit sphere: A model for capturing NPR shading from art. In *Proceedings of Graphics Interface* (2001), pp. 143–150. doi:10.20380/GI2001.17. 2

[TAY13] Todo H., Anjyo K., Yokoyama S.: Lit-sphere Extension for Artistic Rendering. *The Visual Computer 29*, 6-8 (2013), 473–480. doi:10.1007/s00371-013-0811-7. 2

[vPBB*10] van Pelt R., Bescós J. O., Breeuwer M., Clough R. E., Gröller M. E., ter Haar Romenij B., Vilanova A.: Exploration of 4d MRI Blood Flow Using Stylistic Visualization. *IEEE Transactions on Visualization and Computer Graphics 16*, 6 (2010), 1339–1347. doi:10.1109/tvcg.2010.153. 2