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CAS-GAN for Contrast-free Angiography Synthesis

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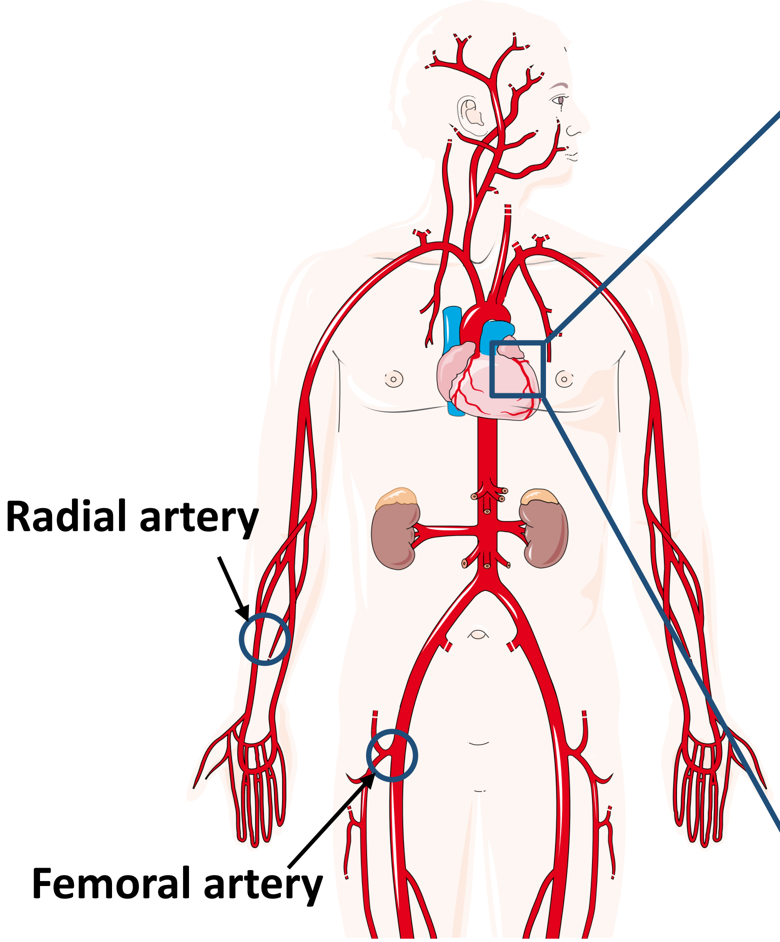
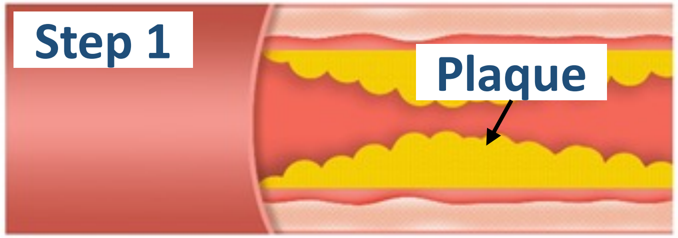
Background

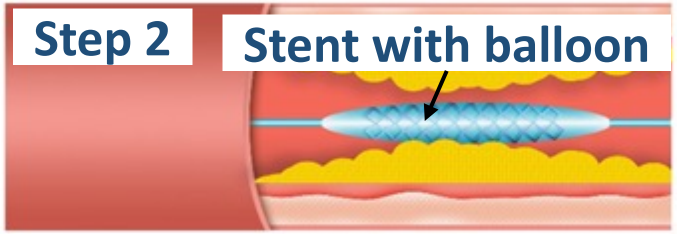
- **Vascular intervention** is a minimally invasive treatment of cardiovascular diseases.



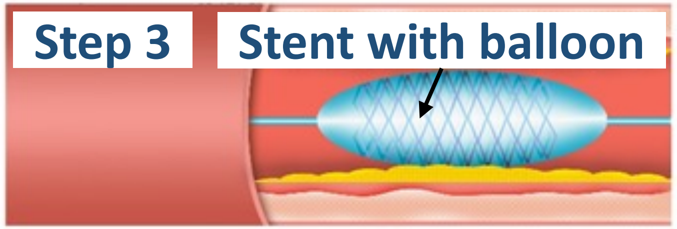
Steps of vascular intervention



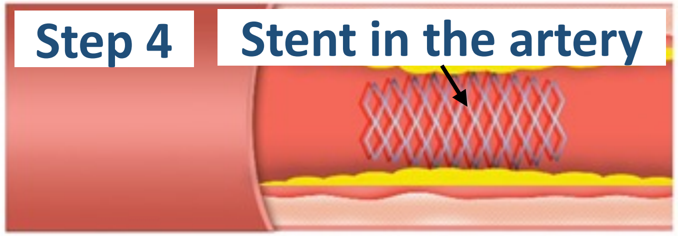
The blood flow are blocked by **plaque**.



Stent with balloon inserted into blocked artery.



Balloon **inflated** to expand stent.

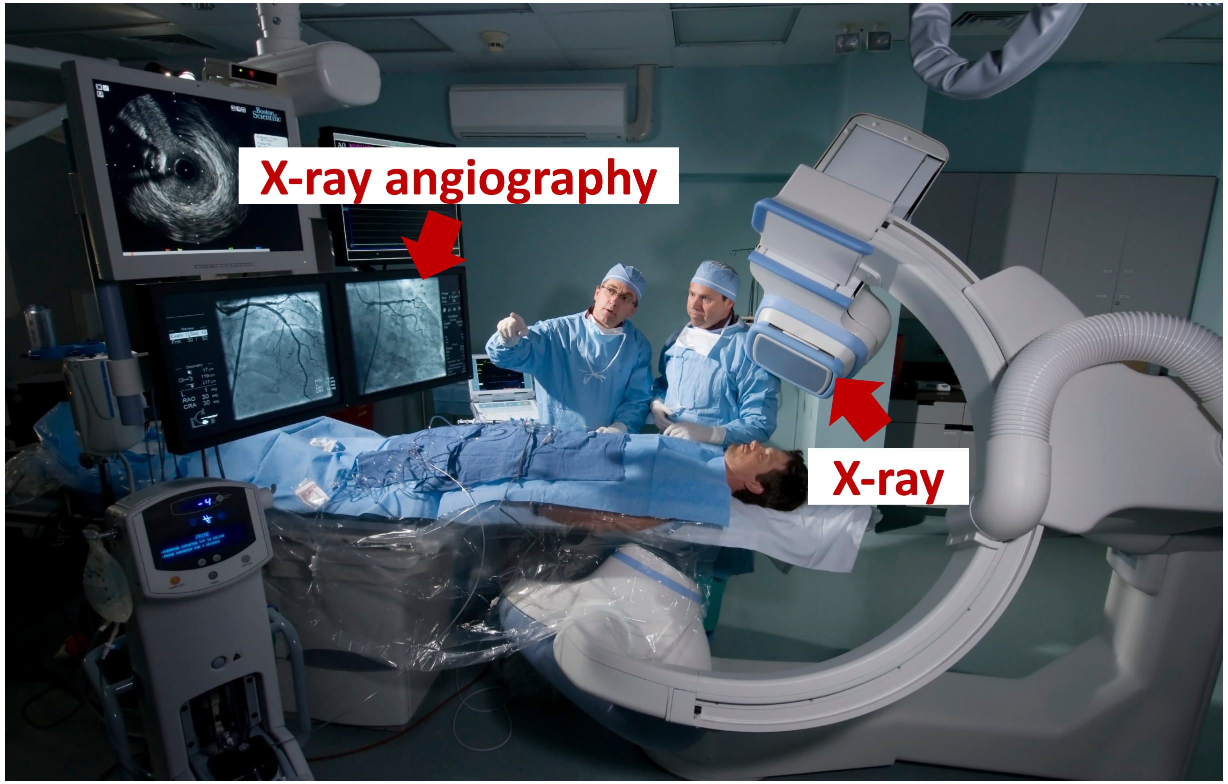


Balloon removed from expanded stent. **Improving blood flow**.

- R. A. Byrne *et al.*, “Vascular access and closure in coronary angiography and percutaneous intervention,” ***Nat. Rev. Cardiol.***, 10: 27-40, 2013.

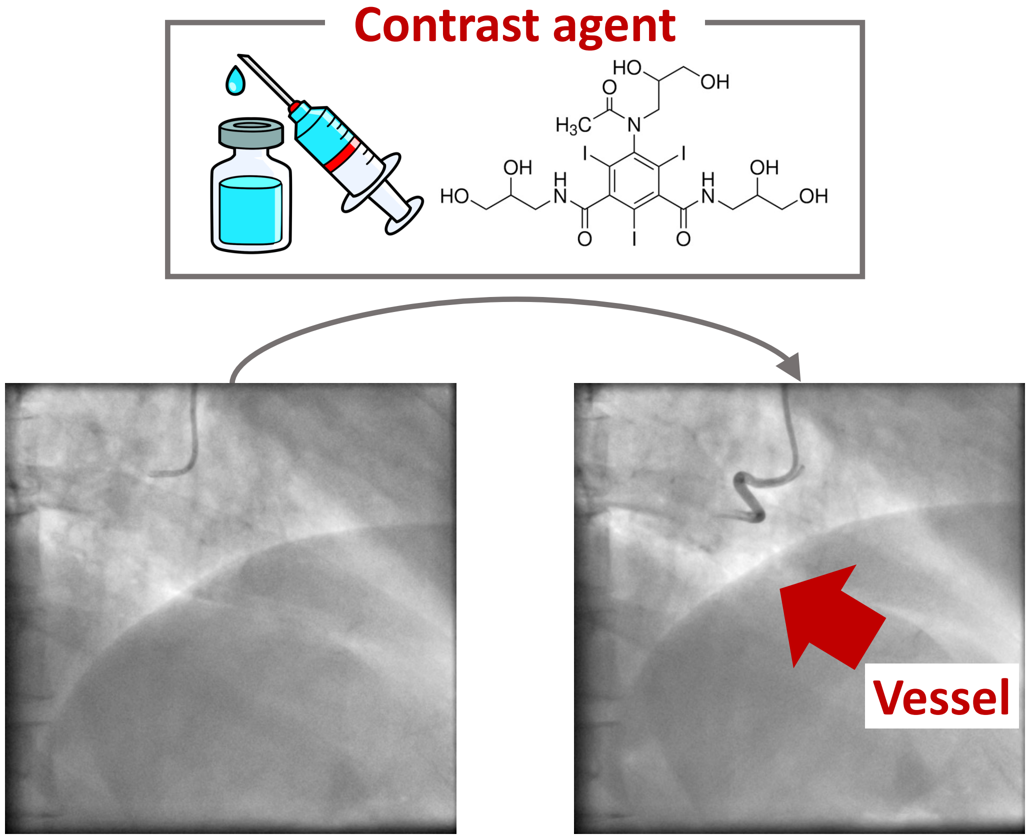
Background

- Currently, **X-ray angiography** is a **must** for guiding cardiologists to locate vascular lesions.



Vascular interventional procedures

(From: https://www.dicardiology.com/)

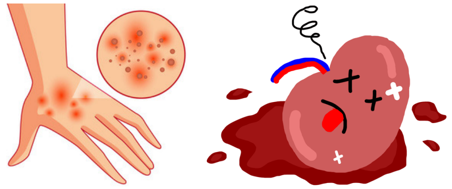


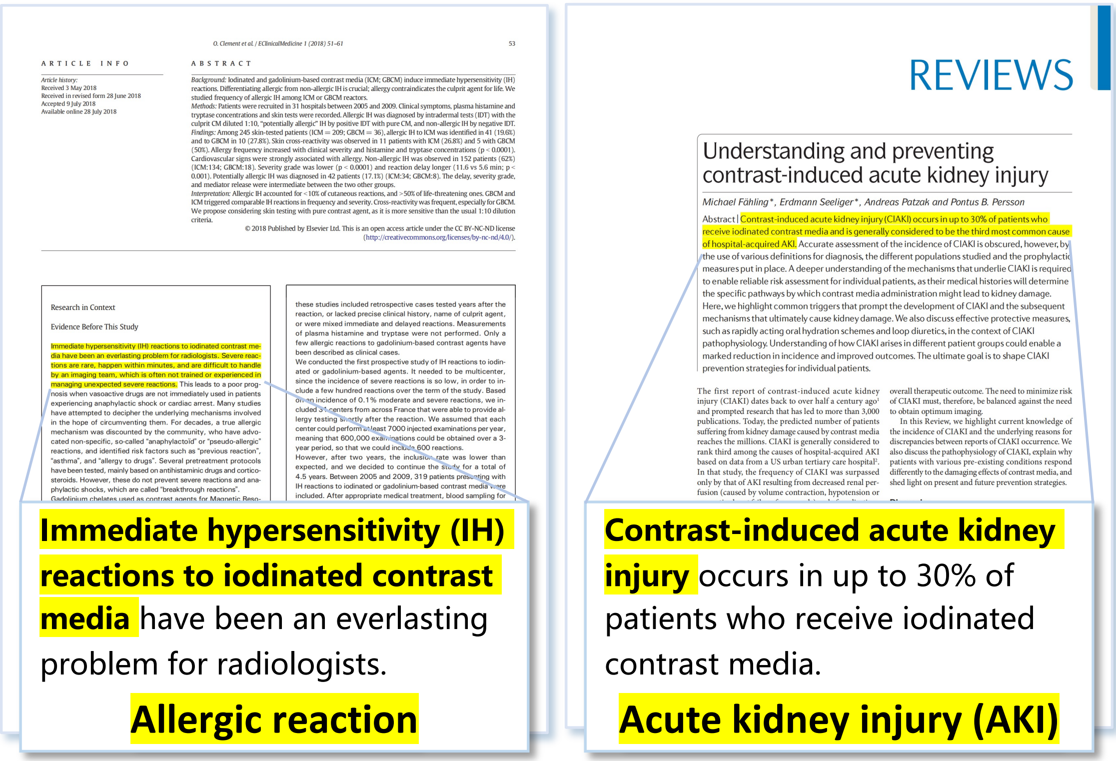
Non-contrast X-ray | **X-ray angiography**

- H. Zhao *et al.*, “Large-scale pretrained frame generative model enables real-time low-dose DSA imaging: An AI system development and multi-center validation study,” ***Med***, 6(1): 100497, 2025.

Motivation

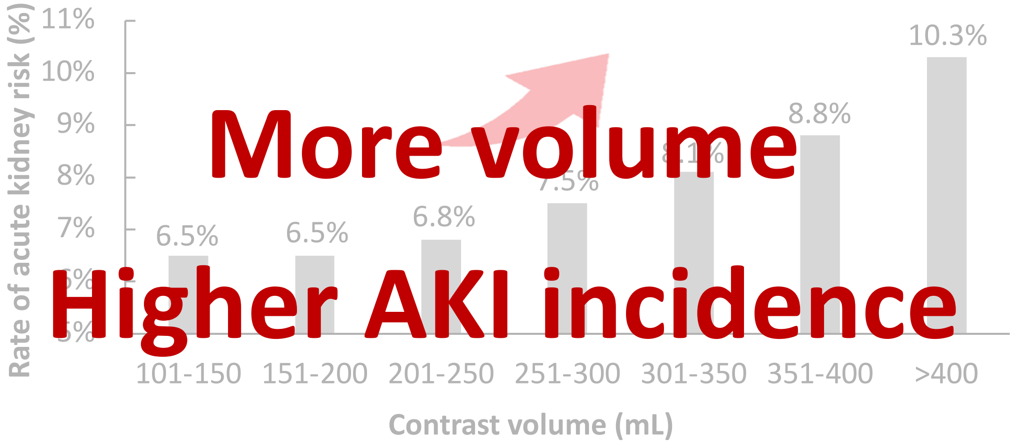
- Contrast agents pose **significant health risks** for patients.





Lancet Discovery Science, 1: 51-61, 2018.

Nature Reviews Nephrology, 13(3): 169-180, 2017.



- A. P. Amin *et al.*, "Association of variation in contrast volume with acute kidney injury in patients undergoing percutaneous coronary intervention," ***JAMA Cardiol.***, 2017, 2(9): 1007-1012.

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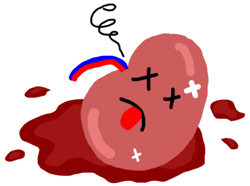
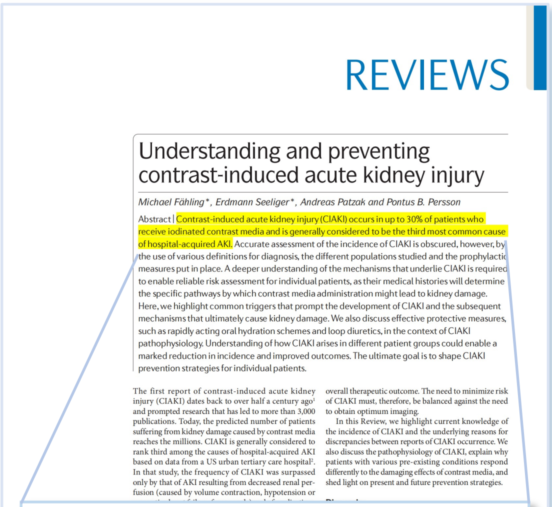




Immediate hypersensitivity (IH) reactions to iodinated contrast media have been an everlasting problem for radiologists.

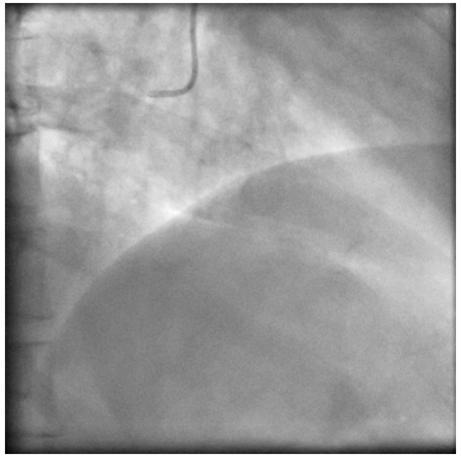
Allergic reaction

Contrast-induced acute kidney injury occurs in up to 30% of patients who receive iodinated contrast media.

Acute kidney injury (AKI)

Lancet Discovery Science, 1: 51-61, 2018.

Nature Reviews Nephrology, 13(3): 169-180, 2017.



Non-contrast X-ray

Vessels are invisible in non contrast X-ray!

Contrast-free X-ray angiography

- A. P. Amin *et al.*, “Association of variation in contrast volume with acute kidney injury in patients undergoing percutaneous coronary intervention,” ***JAMA Cardiol.***, 2017, 2(9): 1007-1012.

Solution

- Generative models can create **photorealistic images** based on specific constraints.

A photo of Bakklandet in Trondheim, 4k, photorealistic

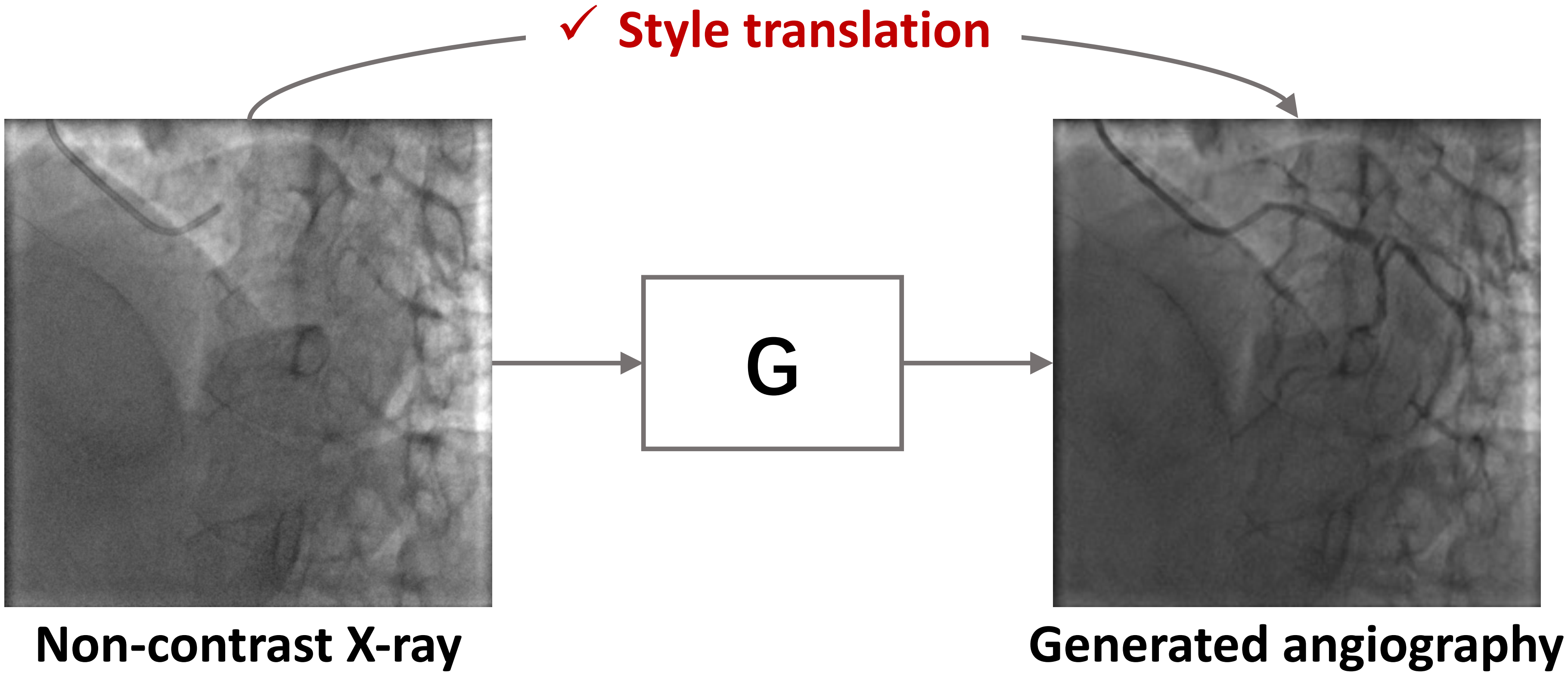
MRI: breast tumor with HER2 mutation from the view of T1c

Can we use generative models as "virtual contrast agent"?

- R. Rombach *et al.,* "High-resolution image synthesis with latent diffusion models," in ***Proc. CVPR***, 2022: 10684-10695.
- J. Wang *et al.,* "Self-improving generative foundation model for synthetic medical image generation and clinical applications," ***Nat. Med.***, 31, 609-617, 2025.

Challenge

- Current methods focus on **style translation** but fail to preserve **vessel fidelity**.



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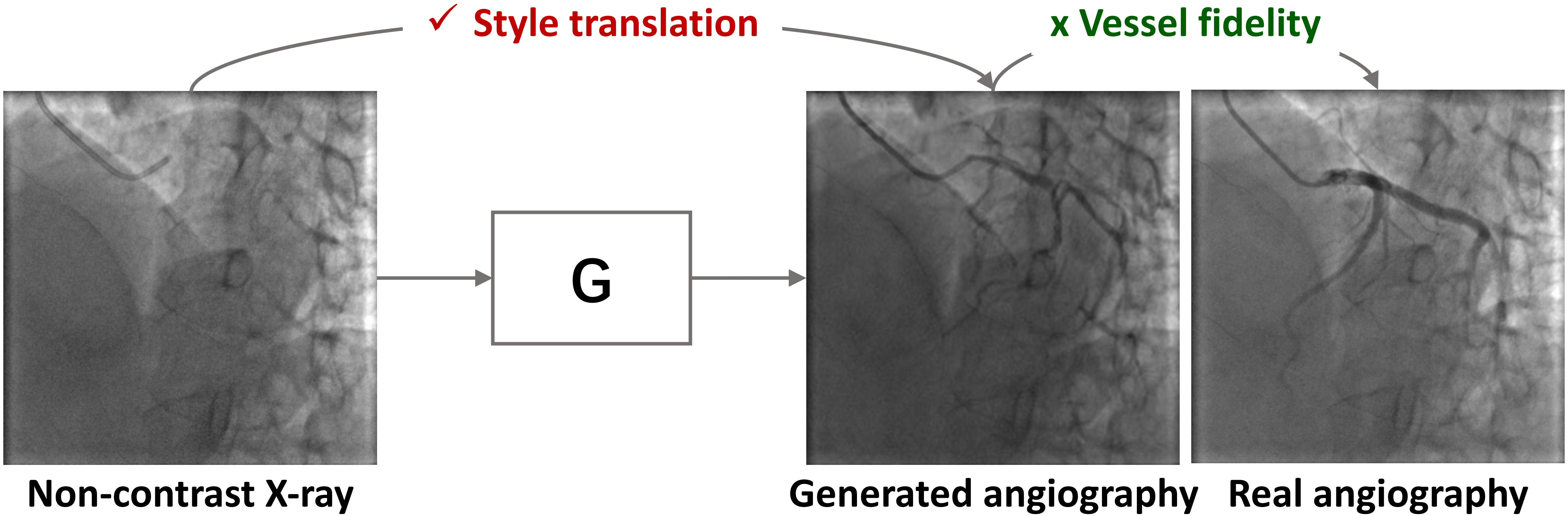

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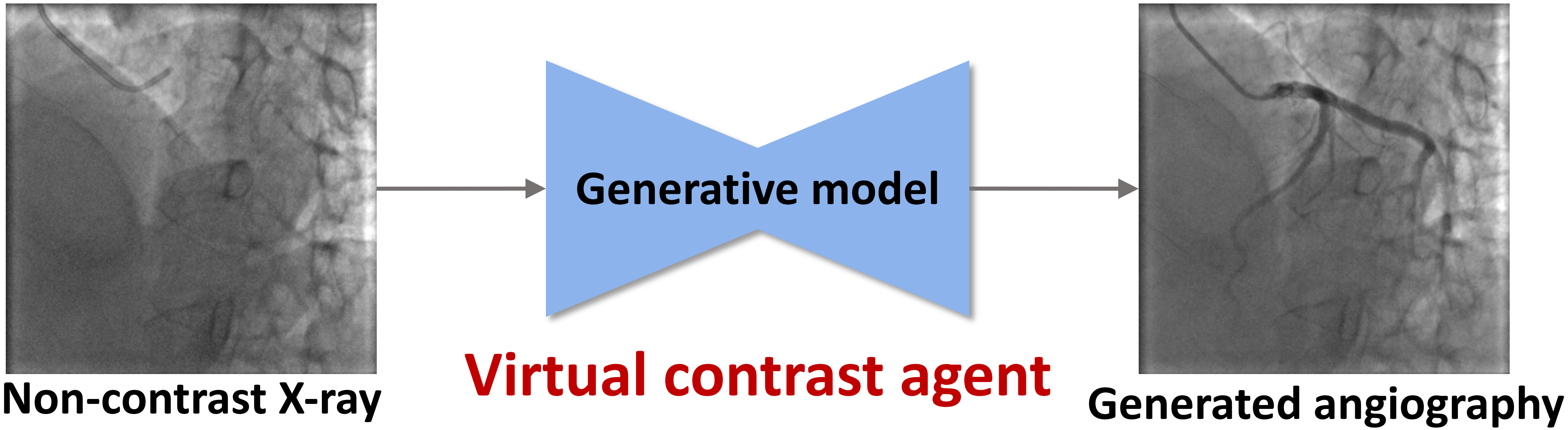
Contributions of this work

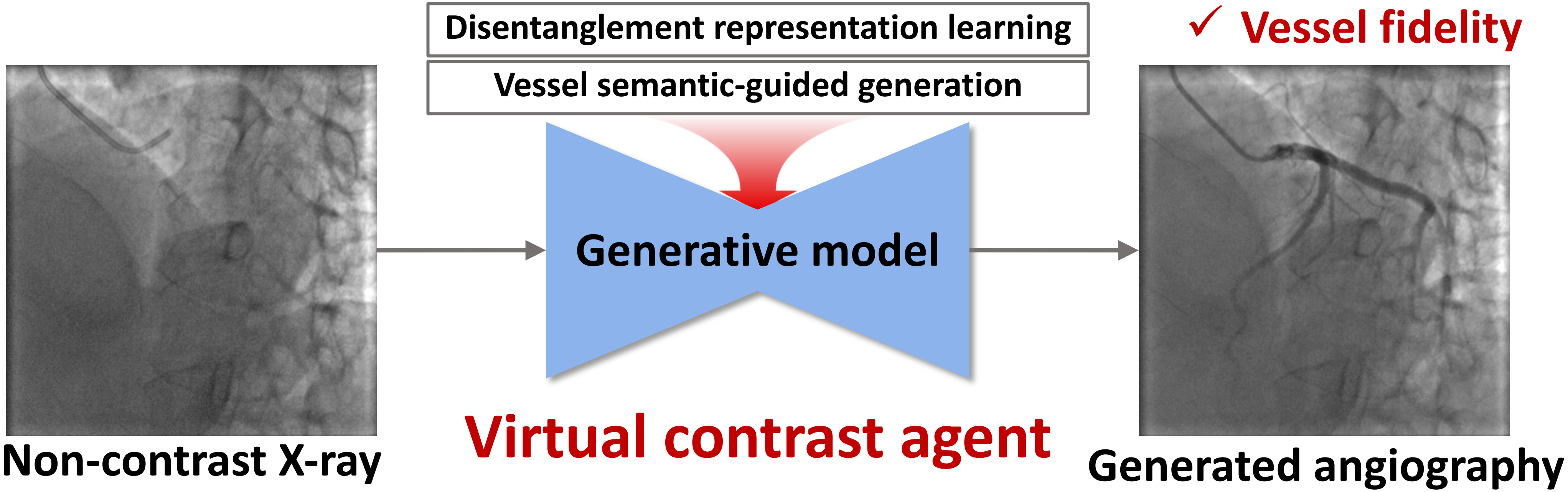
✓ Novel **generative model** for more accurate contrast-free X-ray angiography synthesis.



Contributions of this work

- ✓ Novel **generative model** for more accurate contrast-free X-ray angiography synthesis.
- ✓ Novel **disentanglement representation learning** approach for capturing relationships between anatomical and vessel features.
- ✓ Novel **vessel semantic-guided generation process** for X-ray angiography synthesis with enhanced attention mechanism and loss function.

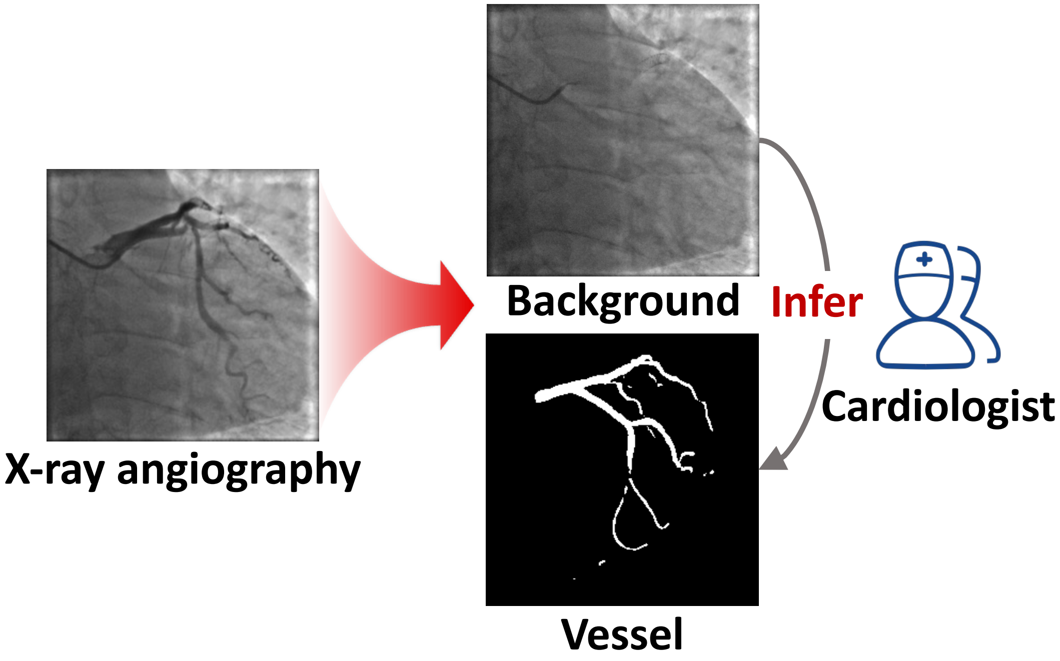
✓ **Style translation**
✓ **Vessel fidelity**

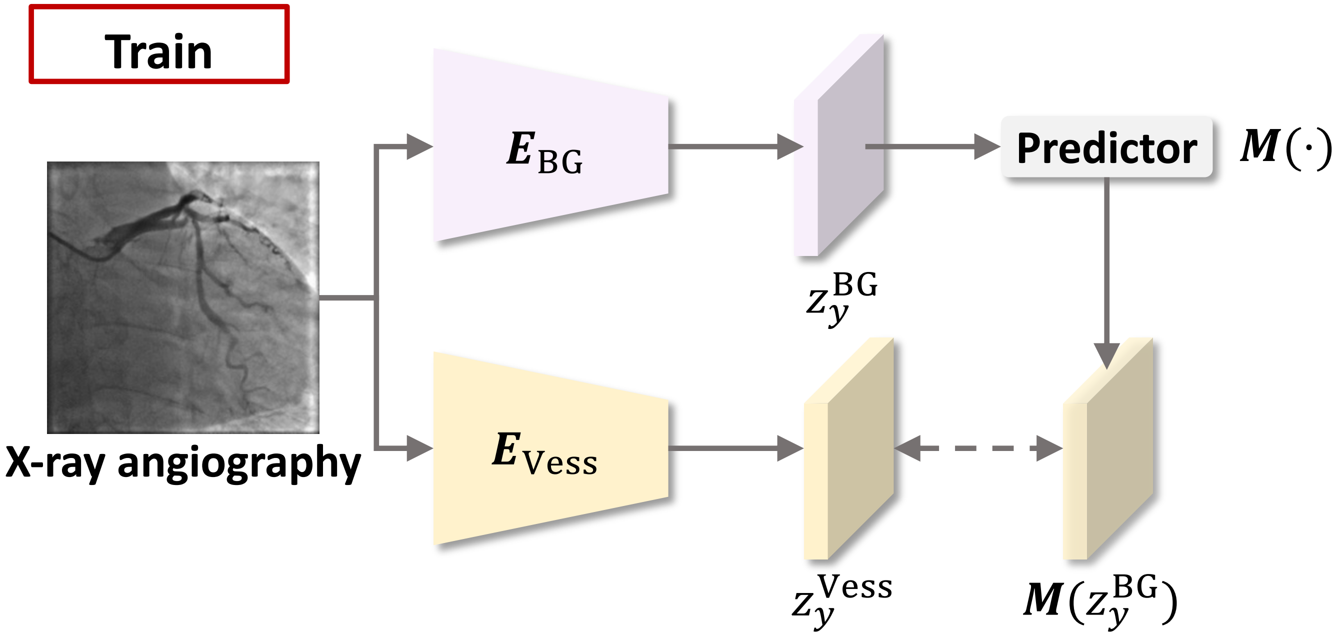


Part I: Disentanglement Representation Learning

Novel representation learning approach inspired by cardiologists

Part I: Disentanglement Representation Learning





- **Disentanglement encoding**

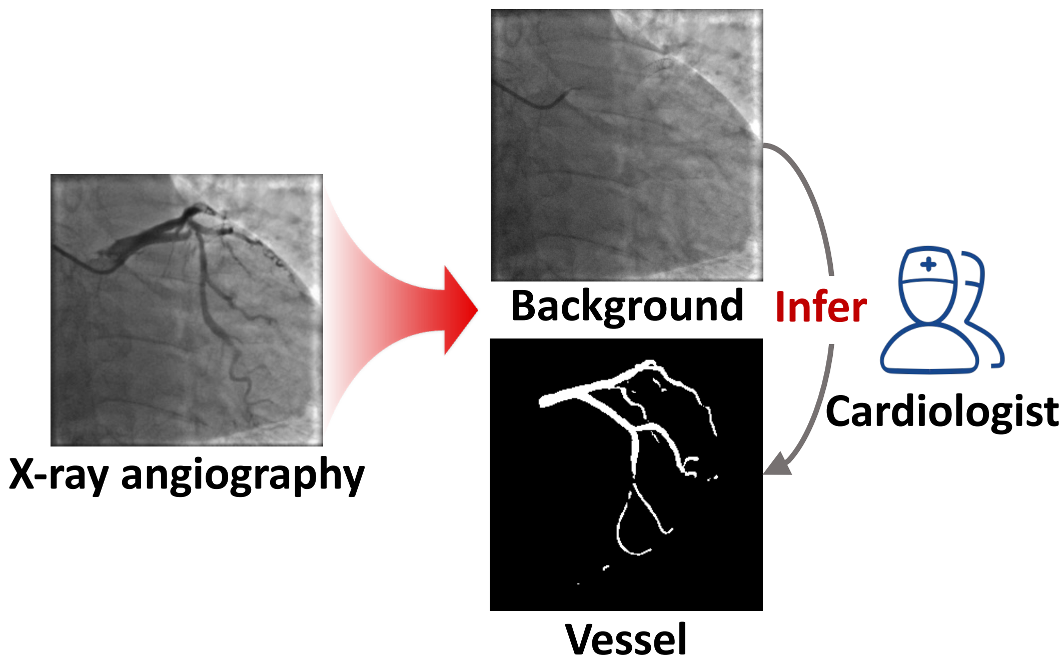
For an X-ray angiography (y), using the background encoder ($\boldsymbol{E}_{\text{BG}}$) and vessel encoder ($\boldsymbol{E}_{\text{Vess}}$) to extract its background (z_y^{BG}) and vessel (z_y^{Vess}) features.

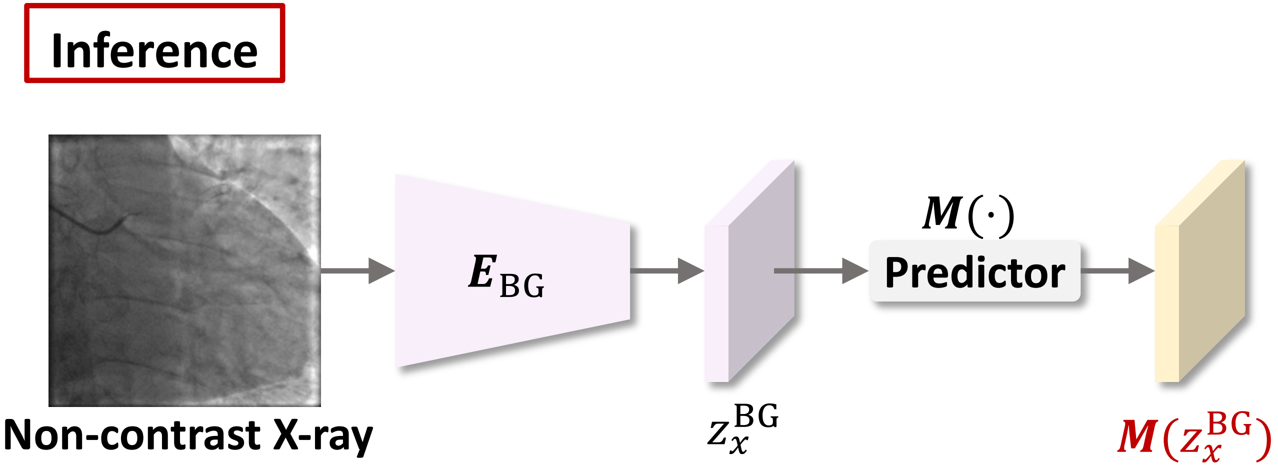
$$z_y^{\text{BG}} = \boldsymbol{E}_{\text{BG}}(y), z_y^{\text{Vess}} = \boldsymbol{E}_{\text{Vess}}(x)$$

- **Explicitly formulating the relationship between background (z_y^{BG}) and vessel (z_y^{Vess}) features**

$$\mathcal{L}_{\text{Pred}} = \mathbb{E}_{y \sim \mathcal{Y}}\left\{\left|M\left(z_y^{\text{BG}}\right) - z_y^{\text{Vess}}\right|_1\right\}$$

Part I: Disentanglement Representation Learning





Our model can infer vessel features like cardiologists!

- **Infer vessel (z_x^{Vess}) features from background (z_x^{BG}) features**

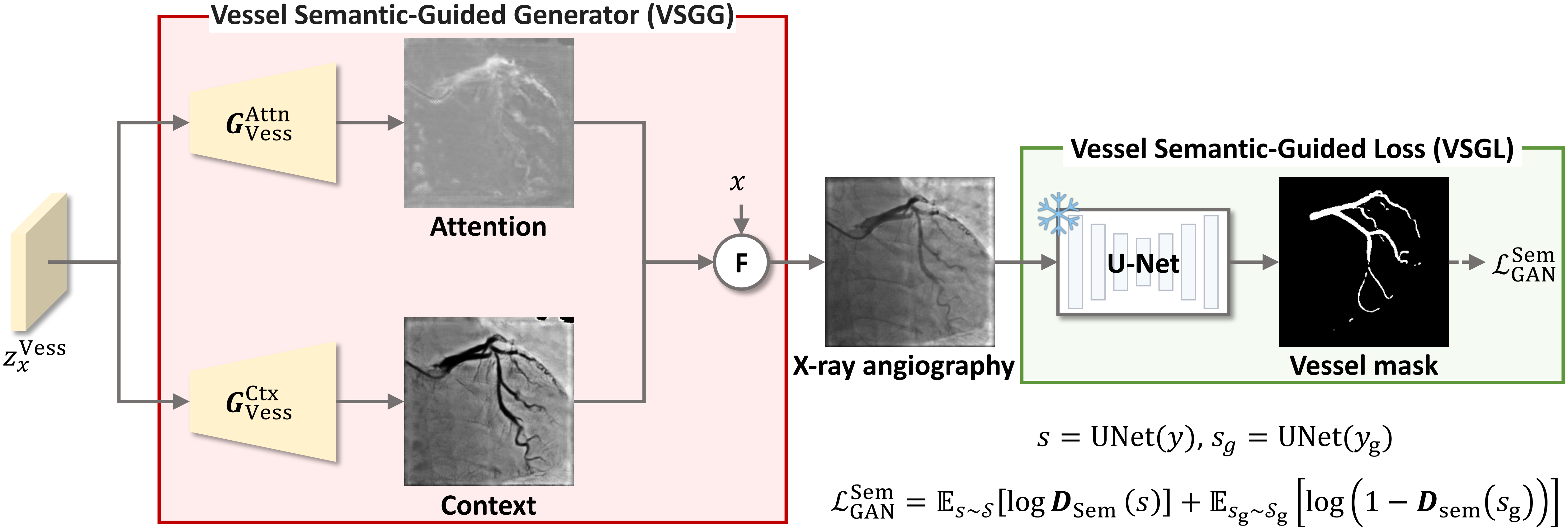
For a non-contrast X-ray (x), using the background encoder ($\boldsymbol{E}_{BG}$) to extract its background (z_x^{BG}) features. Then, the predictor is utilized infer vessel features (z_x^{Vess}) based on background (z_x^{BG}) features.

$$z_x^{BG} = \boldsymbol{E}_{BG}(x), z_x^{Vess} = \boldsymbol{M}(z_x^{BG})$$

Part II: Vessel Semantic-Guided Generation

Novel angiography generation process focuses on vascular details

Part II: Vessel Semantic-Guided Generation



$$s = \text{UNet}(y),\ s_g = \text{UNet}(y_g)$$

$$\mathcal{L}_{\text{GAN}}^{\text{Sem}} = \mathbb{E}_{s\sim\mathcal{S}}[\log \boldsymbol{D}_{\text{Sem}}(s)] + \mathbb{E}_{s_g\sim\mathcal{S}_g}\left[\log\left(1 - \boldsymbol{D}_{\text{sem}}(s_g)\right)\right]$$

$$A_g = \boldsymbol{G}_{\text{Vess}}^{\text{Attn}}\left[\boldsymbol{M}\left(z_x^{\text{BG}}\right)\right],\ C_g = \boldsymbol{G}_{\text{Vess}}^{\text{Ctx}}\left[\boldsymbol{M}\left(z_x^{\text{BG}}\right)\right]$$

$$y_g = x \odot (1 - A_g) + C_g \odot A_g$$

- H. Tang *et al.*, "AttentionGAN: Unpaired image-to-image translation using attention-guided generative adversarial networks," ***IEEE Trans. Neural Networks Learn. Syst.***, 34(4): 1972-1987, 2021.
- O. Ronneberger *et al.*, "U-Net: Convolutional networks for biomedical image segmentation," in ***Proc. MICCAI***, 2015: 234-241.

Main Results – Comparisons with SOTAs

- The proposed CAS-GAN significantly outperforms baselines in both FID and MMD.

Evaluation metrics

- **Frechet Inception Distance (FID)**

$$\mathrm{FID} = |\mu - \hat{\mu}|_2^2 + \mathrm{Tr}\left\{\Sigma + \hat{\Sigma} - 2\left(\Sigma\hat{\Sigma}\right)^{\frac{1}{2}}\right\}$$

- **Maximum Mean Discrepancy (MMD)**

$$\mathrm{MMD} = \frac{1}{n(n-1)}\sum_{i\neq j} k\left(f_i^{\mathrm{R}}, f_j^{\mathrm{R}}\right) + \frac{1}{m(m-1)}\sum_{i\neq j} k\left(f_i^{\mathrm{G}}, f_j^{\mathrm{G}}\right) - \frac{2}{mn}\sum_{i=1}^{n}\sum_{j=1}^{m} k\left(f_i^{\mathrm{R}}, f_j^{\mathrm{G}}\right)$$

Table I. Quantitative comparisons with SOTAs.

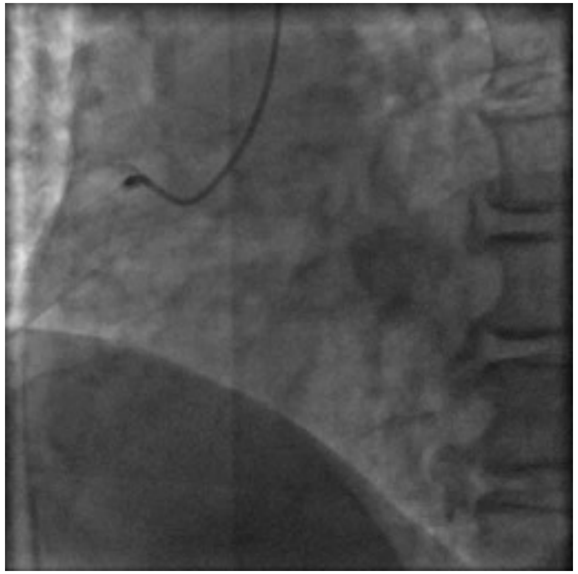
Method	**FID** ↓	**MMD** (×10) ↓
CycleGAN *[ICCV' 17]*	6.54	0.28
UNIT *[NeurIPS' 17]*	9.99	<u>0.22</u>
MUNIT *[ECCV' 18]*	8.87	0.33
CUT *[ECCV' 20]*	7.09	0.26
AttentionGAN *[TNNLS' 21]*	<u>6.34</u>	0.31
QS-Attn *[CVPR' 22]*	7.20	0.24
StegoGAN *[CVPR' 24]*	10.80	2.26
CAS-GAN **[Ours]**	**5.87**	**0.16**

- Best results are highlighted in **bold** and second best are <u>underlined</u>.

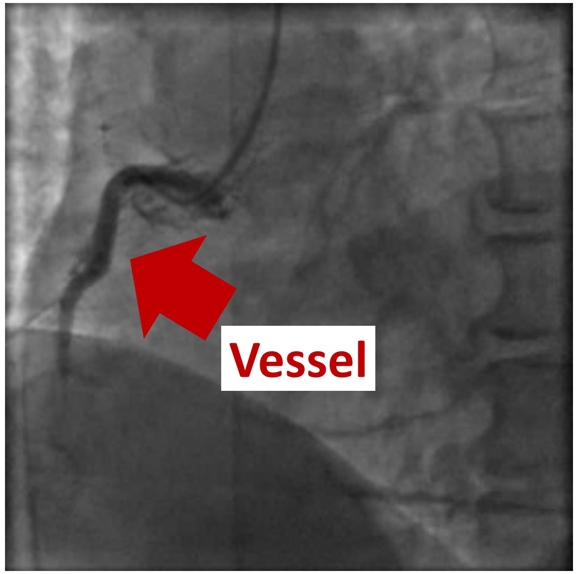
- M. Heusel *et al.*, "GANs trained by a two time-scale update rule converge to a local Nash equilibrium," in ***Proc. NeurIPS***, 2017.
- A. Gretton *et al.*, "A kernel two-sample test," ***J. Mach. Learn. Res.***, 13(1): 723-773, 2012.

Main Results – Comparisons with SOTAs

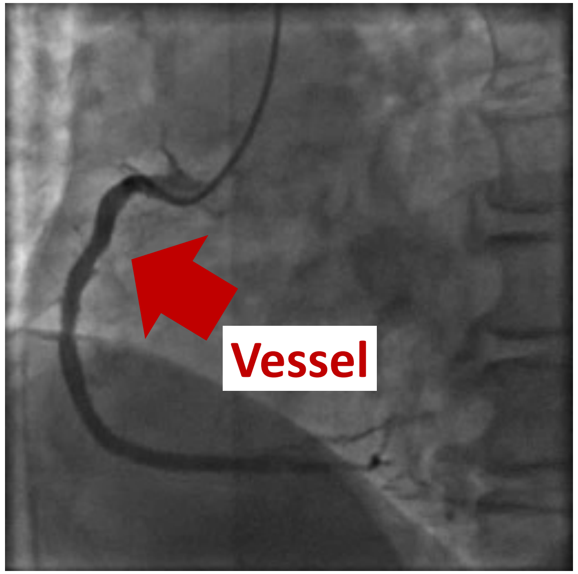
- Case 1: CAS-GAN can effectively **preserve structural consistency** of vessels.



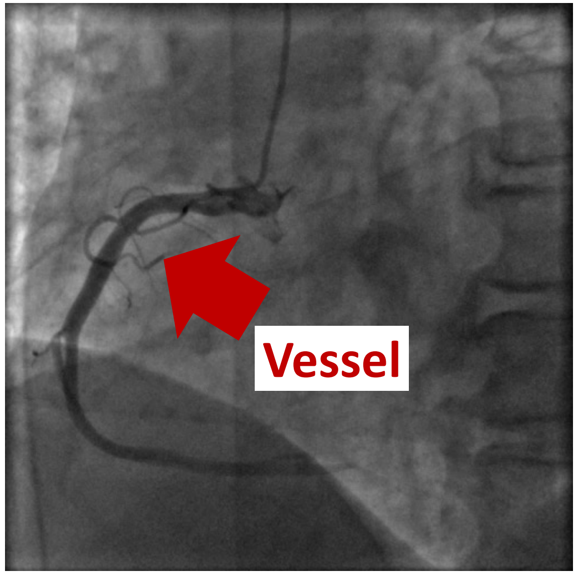
Non-contrast X-ray



AttentionGAN (*TNNLS*' 21)



CAS-GAN (Ours)



Real angiography

Main Results – Comparisons with SOTAs

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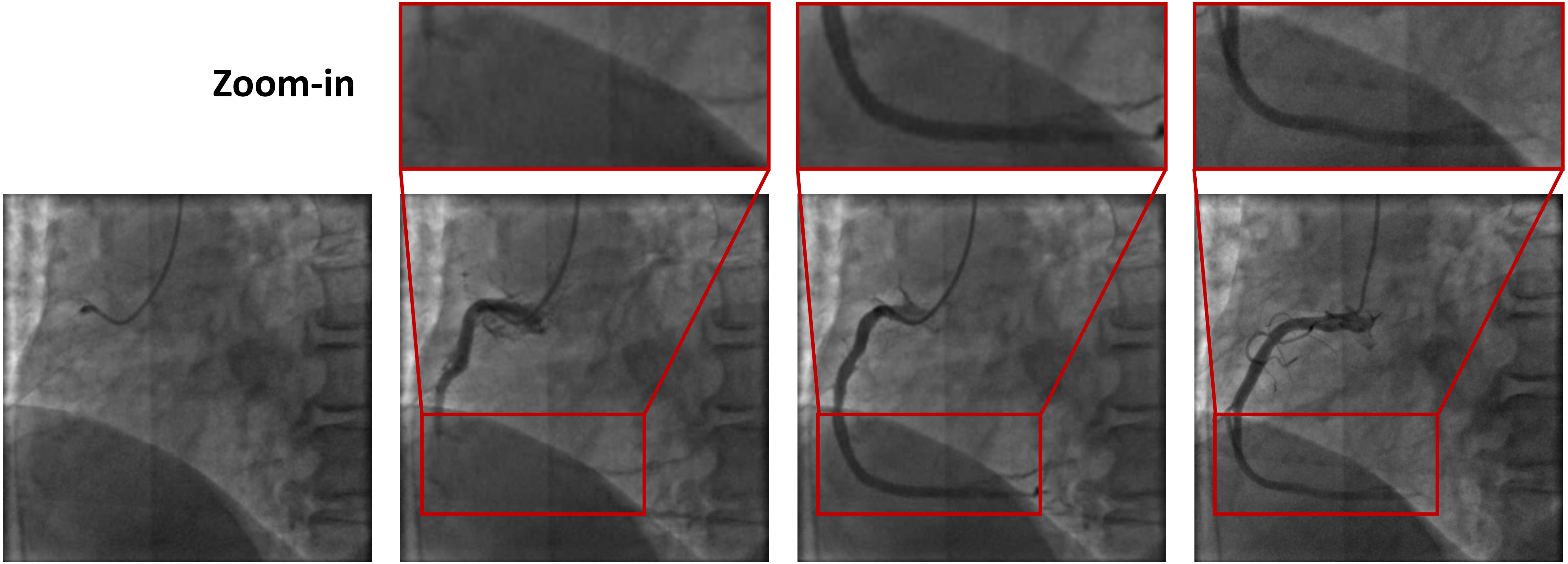
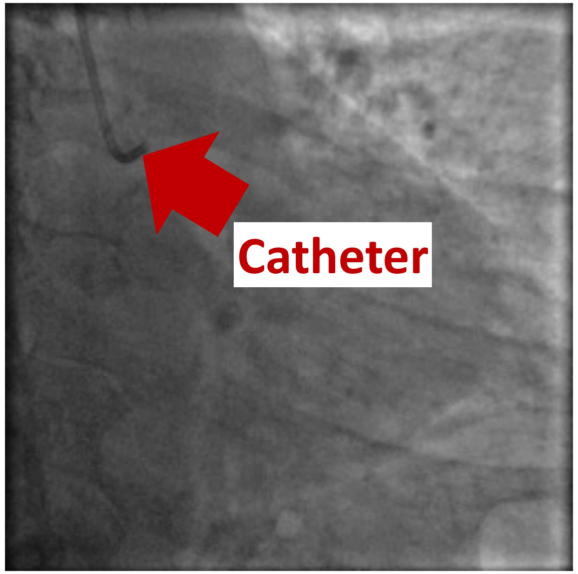


Non-contrast X-ray | **AttentionGAN (*TNNLS*’ 21)** | **CAS-GAN (Ours)** | **Real angiography**

Main Results – Comparisons with SOTAs

- Case 2: CAS-GAN can **accurately synthesis critical vessel bifurcations**.



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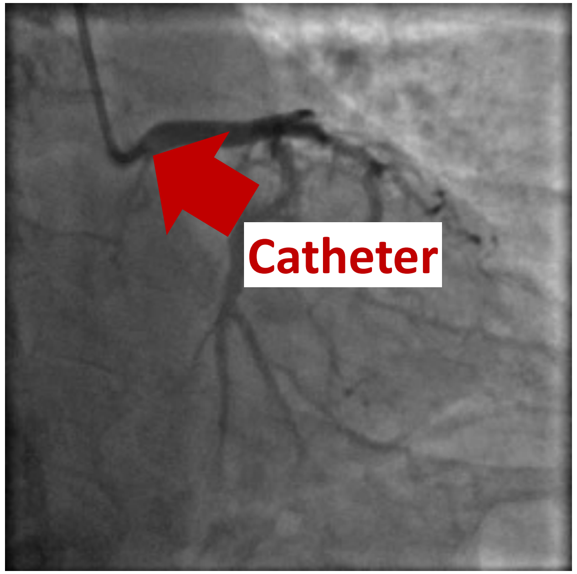

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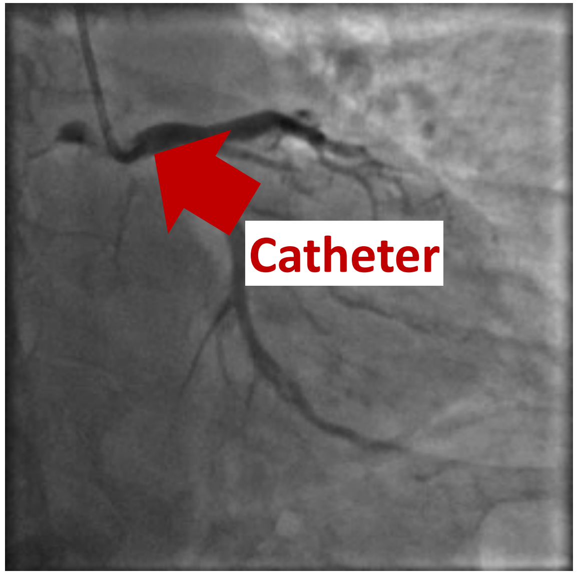

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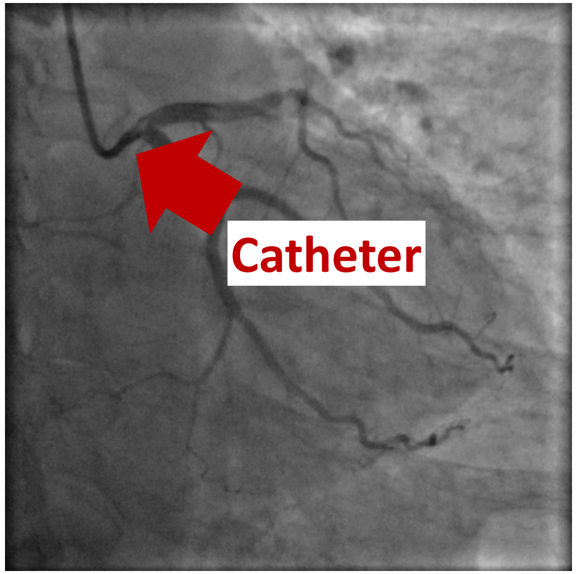

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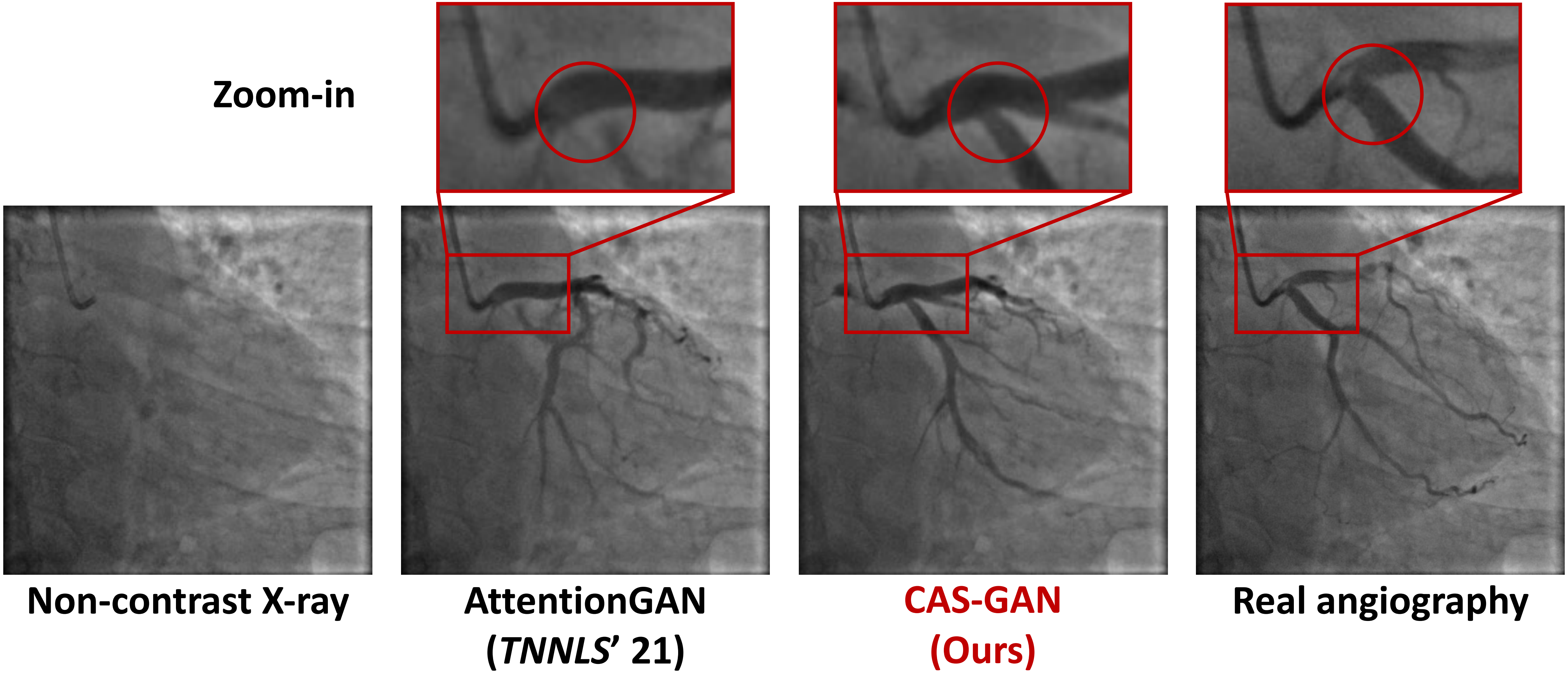
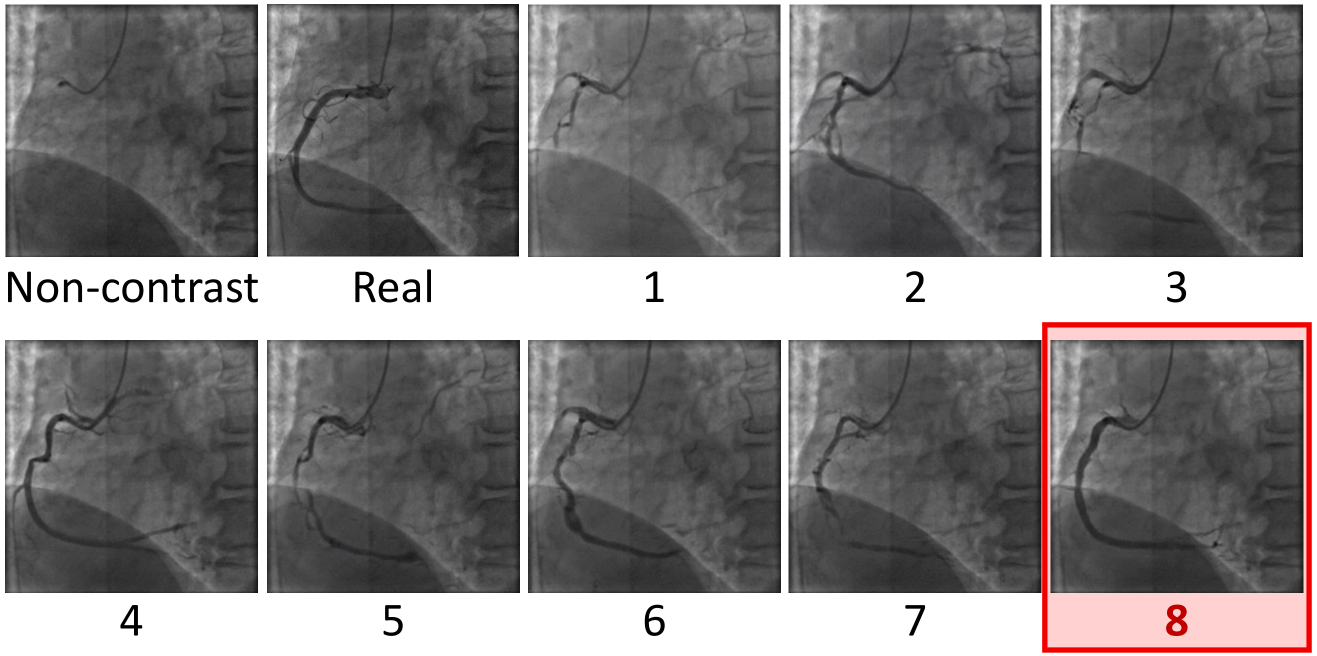


Main Results – Ablation Studies

Table II. Effects of several designs.

Index	DRL	VSGG	VSGL	FID ↓	Δ
1				7.14	+1.27
2			✓	8.59	+2.72
3		✓		6.57	+0.70
4		✓	✓	5.98	+0.11
5	✓			6.87	+1.00
6	✓		✓	6.70	+0.83
7	✓	✓		5.93	+0.06
8	✓	✓	✓	5.87	–

- DRL: Disentanglement representation learning
- VSGG: Vessel semantic-guided generator
- VSGL: Vessel semantic-guided loss



Each module within the CAS-GAN plays an integral role in precisely generating vascular structures

Summary

- ✓ This is the **first attempt** to utilize a generative model for **contrast-free angiography synthesis**, offering a promising way to reduce reliance on contrast agents.
- ✓ The **disentanglement representation learning approach** and **vessel semantic-guided generation process** can ensure high fidelity of generated images.
- ✓ In future works, CAS-GAN will be validated on a **large-scale dataset**, and **downstream applications** will be conducted in vivo animal experiments.

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Thanks! & QA

Email: huangdexing2022@ia.ac.cn

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