5ARIP10 Final Presentation Speaker Notes

Slide 1

Introduction to TACE for HCC

- **What is TACE?**
  - A treatment for advanced liver tumors, particularly hepatocellular carcinoma (HCC).
  - Used for tumors that cannot be removed with surgery.
  - HCC: Most frequent liver cancer, representing about 90% of primary liver cancers.
  - Third leading cause of cancer death worldwide in 2020.

Image: TACE Overview

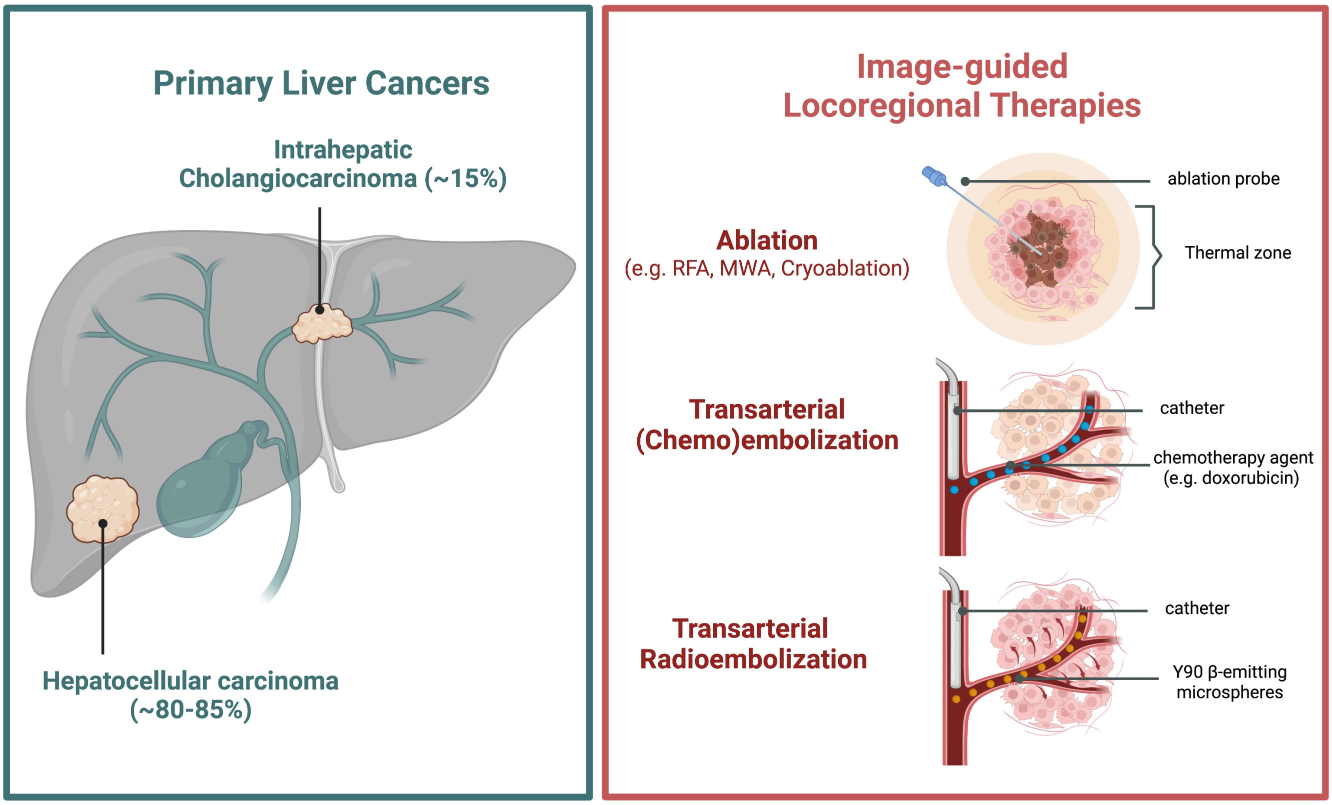

Figure 1: TACE intervention overview

Description:

- **Effectiveness of TACE:**
  - Based on selective blood flow manipulation.
  - Liver blood supply: Hepatic portal vein and hepatic artery.
  - Tumor blood supply: Mainly from the hepatic artery.
  - Catheter navigated to tumor site to block hepatic artery and inject chemotherapy.
- **Procedure:**
  - Catheter threaded through an artery in the groin.

    - Chemotherapeutic agents injected at tumor site.
    - Ensures concentrated chemotherapy and minimizes systemic exposure.
    - Embolization restricts tumor's access to nutrients and oxygen.

Ideal Candidates for TACE:

- Preserved liver function.
- Multinodular tumors or isolated large tumors (>3 cm).

Conclusion:

- TACE: Minimally invasive, effective approach for targeting liver cancer.
- Enhances therapeutic effect while minimizing damage to healthy tissue.

Slide 2

Current Challenges and Innovations in TACE Visualization

- **Single-Plane 2D X-Ray (Fluoroscopy)**
    - **Usage:**
        - Real-time X-ray images to guide catheter placement during TACE.
    - **Limitations:**
        - 2D perspective hampers understanding of 3D arterial structures.
        - Limited visibility of blood vessels due to similar densities with surrounding tissues.
        - **Impact:**
            - Precise catheter guidance is challenging.
            - Potential for suboptimal treatment outcomes.
            - Estimated failure rate up to 60%, leading to financial and emotional burdens.

Slide 3

Contrast Agents in TACE

- **Purpose:**
    - Enhance arterial visualization.
- **Challenges:**
    - **Contrast-Induced Nephrotoxicity:**
        - Risk of kidney damage, especially in patients with pre-existing kidney issues.
    - **Allergic Reactions:**
        - Range from mild discomfort to life-threatening complications.

Image: 2D Fluoroscopy with Contrast Agent

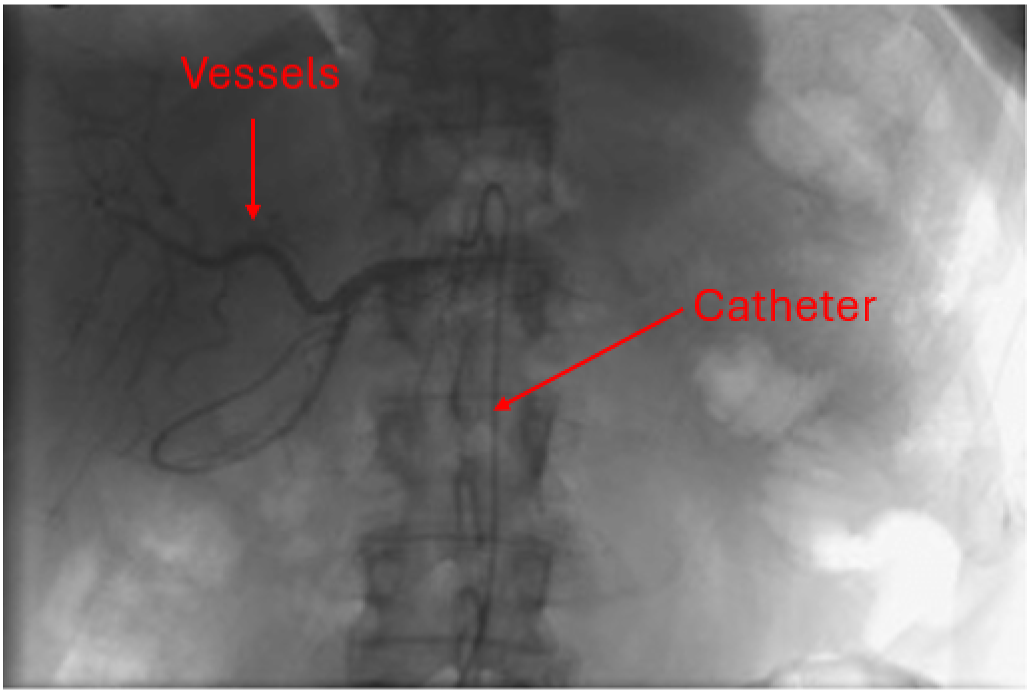

Figure 2: 2D Fluoroscopy example with contrast agent.

Slide 4

Current Image Guidance Techniques

- **2D-3D Registration Techniques:**
  - Used in cardiac, cranial, abdominal, and orthopedic interventions.
  - **Approaches:**
    - Extrinsic, intrinsic, and calibration-based methods.
  - **Challenges in Abdominal Procedures:**
    - Respiratory motion causing structure deformations.
    - Compounded reliance on contrast agents.

Dynamic Coronary Roadmaps (DCR)

- **Technology:**
  - Displays real-time blood vessel paths on live X-ray images.
  - Overlays coronary vessel shapes from angiographic frames.
- **Effectiveness:**
  - Deemed "fit for use" in the majority of cases by specialists.
  - 28.8% reduction in contrast agent usage.
- **Limitations:**
  - Lack of depth in vessel overlay.

Image 2: Dynamic Coronary Roadmaps (DCR)

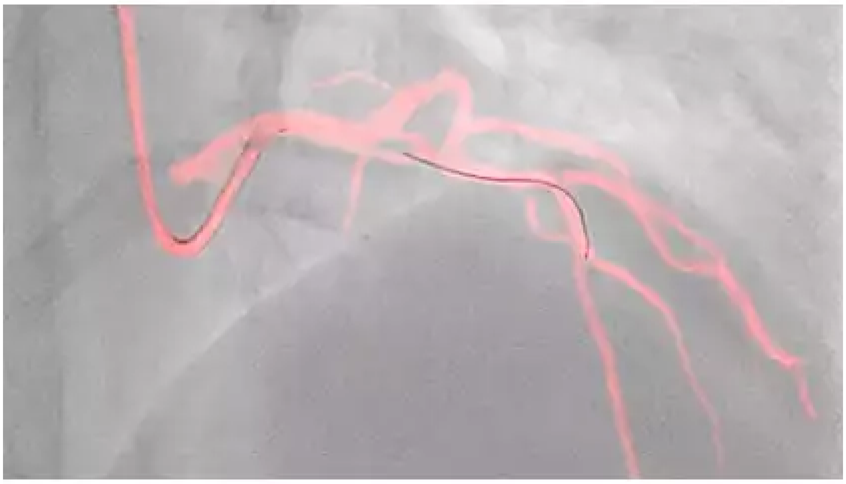

Figure 3: Dynamic Coronary Roadmaps (DCR) technology.

Slide 5

Project Aim: Deep Learning-Based System for TACE

- **Goals:**
  - Enhance arterial visibility for precise catheter placement.
  - Reduce reliance on contrast agents.
- **Benefits:**
  - Increased patient safety by mitigating risks associated with contrast agents.
  - Improved interventional oncology outcomes.
- **Objective:**
  - Develop an automatic, continuously updated roadmap during TACE procedures.
- **Focus:**
  - Enhance arterial visibility.
  - Ensure precise catheter placement even with anatomical rotations and deformations.
  - Reduce reliance on contrast agents.
- **Impact:**
  - Significant improvement in guidance for doctors.
  - Enhanced treatment outcomes for patients undergoing TACE.

Slide 6

Introduction to the Business Case

- **Objective:**
  - Establish a startup to commercialize advanced imaging technology for TACE interventions.
- **Focus:**
  - Target hospitals and collaborate with healthcare companies.
  - Provide a valuable tool for healthcare providers.

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Assumptions for Success

1. **Feasibility:**
   - AI-based medical technologies are feasible within reasonable time frames and budgets.
   - Significant advancements in AI frameworks enhance medical image analysis.
2. **Regulatory Compliance:**
   - Anticipate meeting medical device regulations and obtaining FDA and CE approvals.
   - Regulatory acceptance of AI-based medical tools is increasing.
3. **Demand for Improved Visualization Methods:**
   - Growing demand for advanced diagnostic tools to enhance patient care.
4. **Competitive Advantage:**
   - Proposed solution offers better visibility and reduced patient risk.
5. **Data Availability and Quality:**
   - Access to high-quality medical imaging datasets is assumed (e.g., TCIA).
6. **Respiratory Motion Compensation:**
   - AI-based TACE technology must robustly compensate for respiratory motions during the intervention.

Slide 8

Stakeholder Identification

- **Patients:**
  - Safer procedures and reduced side effects.
- **Interventional Radiologists:**
  - Improved procedural outcomes and efficiency.
- **Hospitals and Clinics:**
  - Enhanced service quality and reduced complication costs.
- **Investors:**
  - Opportunity to support innovative technology with potential high returns.
- **Regulatory Bodies:**
  - Ensure safety and efficacy standards.
- **Insurance Companies:**
  - Lower costs due to shorter hospital stays and fewer complications.

Slide 9

Market Assessment

- **Total Addressable Market (TAM):**
  - Global market size for TACE projected to reach $25.9 billion by 2031.
- **Serviceable Available Market (SAM):**
  - Focus on regions with advanced healthcare infrastructures (North America, Europe, parts of Asia).
  - Estimated 60-70% of TAM.
- **Serviceable Obtainable Market (SOM):**
  - Target early adopters and top-tier hospitals and clinics.
  - Estimated 10-15% of SAM.

Image: Liver Cancer Map

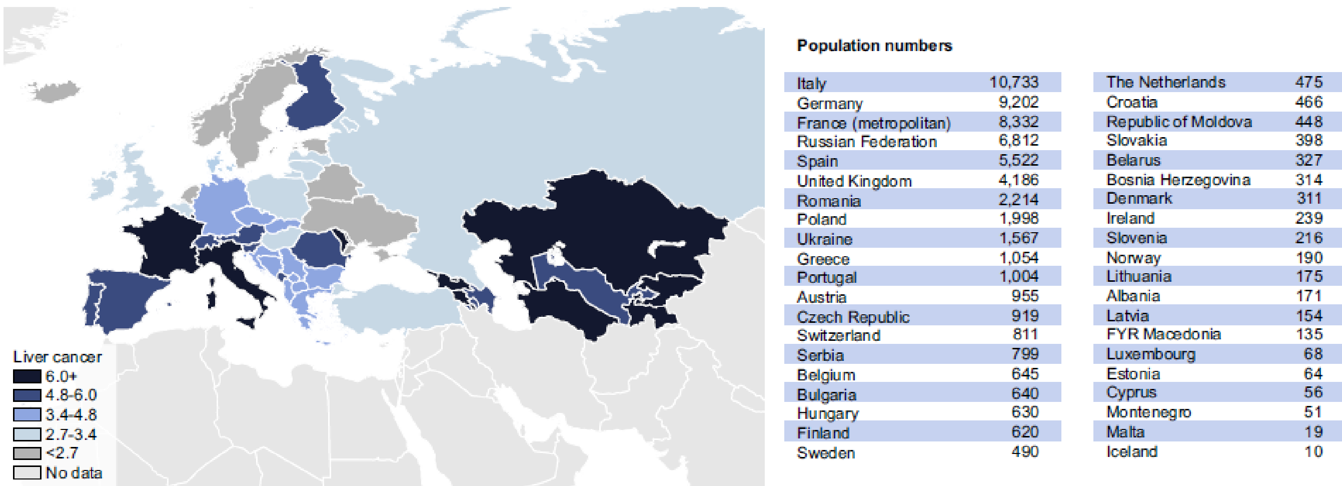

Figure **4**: Incidence rates of primary liver cancer according to geographical distribution in Europe.

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Strategic Approach

- **Advantages:**
  - Enhanced precision through improved arterial visibility.
  - Reduced reliance on contrast agents.
  - Cost efficiencies through minimized complications and shorter recovery times.
- **Revenue Model:**
  - Direct sales of software licenses to hospitals and clinics.
  - Maintenance and service contracts.
  - Potential for technology licensing.
- **Go-to-Market Strategy:**
  - Pilot programs in leading hospitals.
  - Strategic partnerships with medical device companies and healthcare providers.
  - Robust marketing strategy to educate stakeholders.

- **Financial Projections:**
    - Short-term focus on R&D, regulatory approvals, and market entry.
    - Long-term goals of scaling production, expanding market reach, and achieving significant market penetration.
- **Risk Analysis and Mitigation:**
    - Address technological challenges through continuous R&D.
    - Engage regulatory bodies early to manage approval delays.
    - Mitigate market risks through targeted education and marketing campaigns.

Summary

- The business case presents a strategic approach to launch and scale an innovative TACE visualization solution.
- Emphasis on patient safety, procedural efficiency, and cost-effectiveness.
- A robust methodology supports the technical innovation driving the business strategy.

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Overview of Methodology

- Introduction to the goal: Developing a deep learning-based system to enhance vessel architecture visibility during TACE.
- Brief mention of key components: data acquisition, preprocessing, algorithm approach, network architecture, X-ray simulation, and training procedure.
- Visual: Flowchart of the methodology steps.

Slide 12

Data Acquisition & Preprocessing

- **Data Source**: "Multimodality Annotated Hepatocellular Carcinoma" dataset.
- **Details**:
    - 105 HCC patients, pre- and post-procedure CT scans.
    - Includes multiphasic contrast-enhanced CT scans and manually curated segmentations.
- **Preprocessing Steps**:
    - Resizing all samples to [512, 512, 96].
    - Isolating vessel segmentation maps.
    - Controlling intensity values and applying augmentation techniques.
- Visual: Example images of raw CT data and preprocessed vessel segmentation maps.

Slide 13

Algorithm Approach

- **Objective**: Combine pre-operative 3D CT data with intra-operative 2D X-ray images.
- **Methodology**:
  - Using a conditional deep learning architecture.
  - Extracting latent embeddings from 3D CT data.
  - Real-time fusion with 2D DRR images.
  - Generating continuously updated roadmaps.
- Visual: Diagram illustrating the integration of 3D CT and 2D X-ray images.

Slide 14

Network Architecture - Encoding 3D CT Information

- **Encoding Module**:
  - Extract latent embeddings from 3D CT data.
  - Use of 3D max pooling and convolutional layers.
  - Dimensionality reduction to 2D latent embeddings.
  - Application of ReLU activation function.
- Visual: Schematic of the encoding module with convolutional layers and pooling.

TACENet Architecture

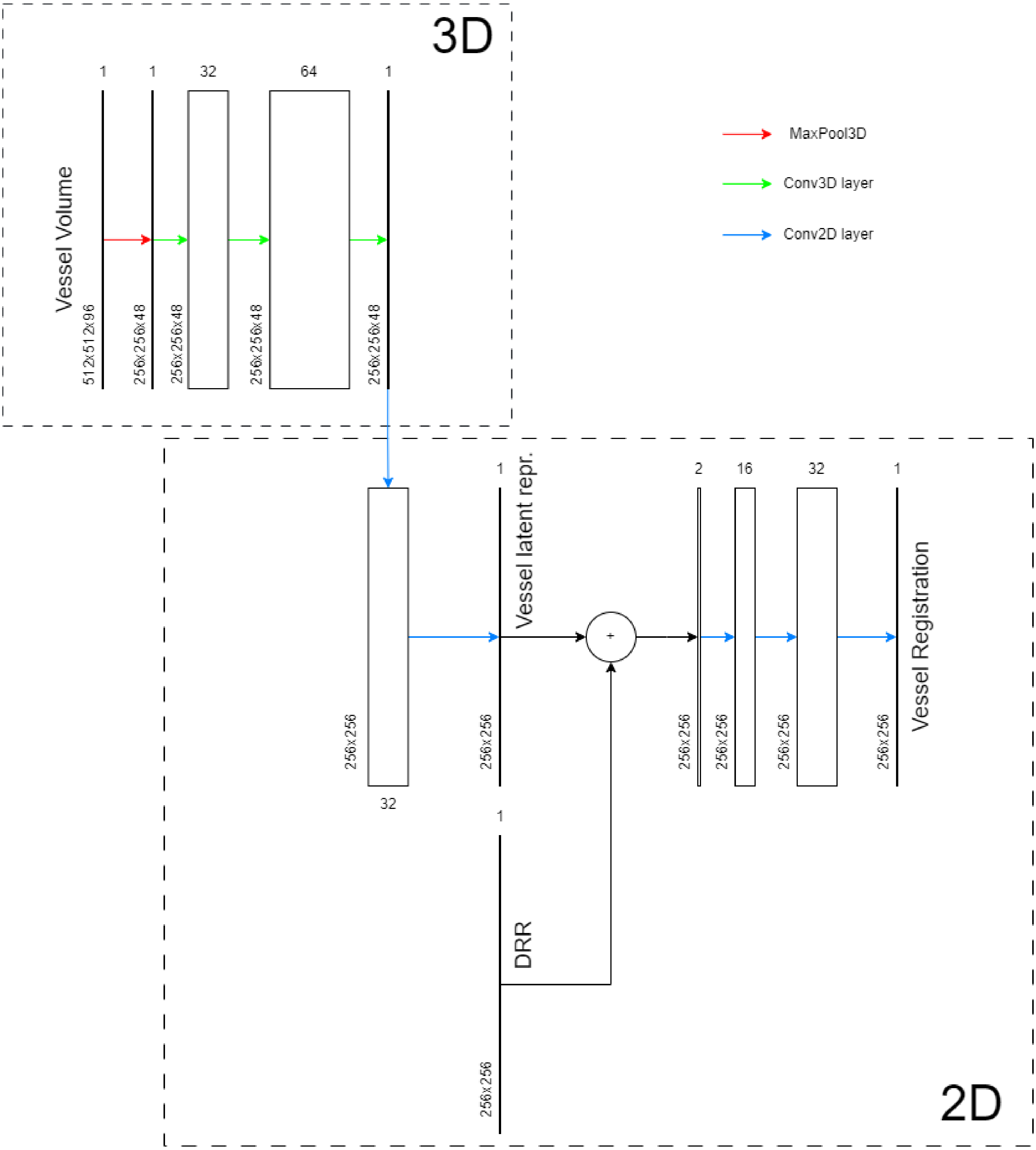

Figure 5: TACENet Architecture

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Network Architecture - Data Fusion for Vessel Enhancement

- **Data Fusion Process**:
  - Combining 3D CT latent embeddings with 2D DRR images.
  - Conv3DTo2D module for dimensional compatibility.
  - ConvNet for refining and enhancing vessel network.
- **Mathematical Representation**:

    - Bayesian inference notation: (p(DRR*e|DRR_r, CT*{embed})).
- Visual: Diagram showing the data fusion process and ConvNet.

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X-ray Simulation with Digitally Reconstructed Radiographs

- **Data Generation Technique**:
    - Use of DiffDRR for generating 2D DRR images from 3D CT volumes.
    - Advantages: variability in camera poses, controlled vessel enhancement.
- **Impact on Training**:
    - Training on diverse poses and enhancement levels.
    - Improved model generalization to real-world scenarios.
- Visual: Example of simulated DRR images with varying enhancement levels.

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Training Procedure

- **Optimization Details**:
    - Loss function: Mean Squared Error (MSE).
    - Optimizer: Adam with learning rate of 0.001.
    - Batch size: 1 (due to VRAM limitations).
    - Weight decay: (1 \times 10^{-5}).
- **Training Environment**:
    - Hardware: Ryzen 5 5600X CPU, Nvidia RTX 4080 GPU, 32GB RAM.
    - Training duration: 8 hours.
- Visual: Graph showing training loss over time.

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Summary & Key Visuals

- Recap of key points from each section.
- Visual: Combined flowchart summarizing the entire methodology from data acquisition to model training.

Slide 19

Overview of Results

- Introduction to the results section.
- Overview of key areas: Vessel enhancement, initial model performance, deformation robustness, and inference time.
- Visual: Diagram summarizing the results covered.

Slide 20

Vessel Enhancement and Initial Model Performance

- Presentation of the initial outcomes.
- Importance of enhancing vessel visibility during TACE procedures.
- Visual: Figure showing latent representation of the vessel volume.

Slide 21

Visualization of Latent Representation

- **Figure Explanation**: Visualization of the model including latent representation.
- **Outcome**: Improved visibility and contrast enhancement.
- Visual: Figure showing the latent representation (Fig. 6).

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Model Performance Metrics

- **Evaluation Metric**: Mean MSE over rotation range for different enhancement factors.
- **Optimal Performance**: Highlighting the best performance at 0.6 enhancement factor.
- **Clinical Significance**: 40% reduction in contrast fluid usage.
- Visual: Table showing Mean MSE for different enhancement factors (Table 1).

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Enhanced Vessel Visibility

- **Visualization**: AI-enhanced images for different levels of contrast fluid.
- **Observation**: Best reconstruction and visibility at 40% reduction.
- Visual: Figure showing AI-enhanced images with varying contrast fluid levels (Fig. 5).

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Real-Time Inference Performance

- **Inference Time**: Average inference time for TACEnet and ConvNet module.
- **Real-Time Suitability**: 221 fps theoretical maximum frame rate.
- **Application**: Ensuring suitability for real-time enhancements.
- Visual: Chart showing inference times and frame rates.

Slide 25

Deformation Robustness

- **Evaluation Focus**: Model's robustness against deformations.
- **Constant Parameters**: Enhancement factor at 0.6, no rotation.
- Visual: Figure showing AI-enhanced image and latent representation for deformed CT volume (Fig. 7).

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Quantitative Evaluation of Deformation Robustness

- **Performance Metric**: MSE across 20 different deformations.
- **Robustness**: Average MSE demonstrating robust performance.
- Visual: Figure showing MSE for different deformations (Fig. 8).

Slide 27

Summary & Final Observations

- **Recap of Results**: Key findings from vessel enhancement, performance metrics, and robustness evaluations.
- **Implications**: Potential impact on TACE procedures and clinical practice.
- Visual: Comprehensive summary diagram.

Slide 28

Overview of Discussion

- Introduction to the discussion of results and their significance.
- Overview of key points: effectiveness, findings, performance, limitations, and future work.
- Visual: Summary diagram highlighting the main discussion points.

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Effectiveness of TACEnet

- **Key Achievements**:
  - Enhanced visibility of vascular networks in real-time X-ray images.
  - Significant improvements using advanced deep learning techniques.
  - Effective data generation and augmentation with DRRs.
- **Clinical Impact**:
  - Reduced contrast fluid requirements.
  - Improved vessel enhancement with minimal side effects.
- Visual: Before and after images showing enhanced vessel visibility.

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Key Findings

- **Optimal Performance**:
  - Enhancement factor of 0.6 (60% of normal contrast fluid dose).
  - Lowest mean squared error (MSE) over rotation range.
  - 40% reduction in contrast fluid usage.
- **Comparison with State-of-the-Art**:
  - Outperformed current standards in contrast fluid reduction.
  - Reference to Philips DCR technology.
- Visual: Graph showing MSE versus enhancement factor.

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Model Learning and Generalization

- **Training Insights**:
  - Controlled enhancement allowed learning of intricate relationships between raw and enhanced DRR images.
  - Effective generalization to different poses and deformations.
- **Training Data Variability**:
  - Inclusion of different rotations and enhancement factors.
  - Enhanced model robustness.
- Visual: Diagram illustrating training process with various poses and enhancements.

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Limitations of the Study

- **Enhancement Levels**:
  - Limited dramatic differences in all cases.
  - Need for refinement in enhancement techniques.
- **Scope of Current Study**:
  - Focus on vascular structures only.
  - Potential for integrating other anatomical features.
- Visual: Example images showing varying levels of enhancement success.

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Future Work

- **Enhancement Techniques**:
  - Refining current techniques.
  - Exploring additional data augmentation methods.
- **Model Architecture**:
  - Investigating alternative model architectures.
- **Clinical Validation**:
  - Further validation across diverse patient populations.
  - Ensuring efficacy and safety in clinical settings.

- Visual: Flowchart of proposed future research directions.

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Summary & Conclusion

- **Recap of Key Points**:
  - Effectiveness and key findings.
  - Performance and limitations.
  - Future research directions.
- **Final Thoughts**:
  - Importance of TACEnet in enhancing TACE procedures.
  - Potential for further improvements and clinical applications.
- Visual: Comprehensive summary diagram.