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EVALUATING THE EFFECTIVENESS OF MODERN INTERVENTIONAL RADIOLOGY TECHNIQUES IN TREATING VASCULAR DISEASES IN SAUDI ARABIA: A SURVEY STUDY UNDER VISION 2030

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ABSTRACT

This study evaluates the effectiveness and adoption of modern interventional radiology (IR) techniques in treating vascular diseases within Saudi Arabia, aligning with the country's Vision 2030 healthcare modernization goals. Using a comprehensive survey of 280 participants including healthcare professionals and patients across multiple regions and hospital types, the research assesses clinical outcomes such as success rates, complication rates, patient satisfaction, and recovery times. The study identifies key barriers to IR adoption, notably gaps in training and regional disparities, while highlighting the positive correlation between frequent IR use and improved patient outcomes. Statistical analyses including Mann-Whitney U tests, ANOVA, Chi-square tests, and logistic regression confirm significant associations between training, frequency of use, regional variation, and perceived effectiveness. The findings underscore the critical role of IR in advancing vascular care and provide evidence-based recommendations to enhance training, infrastructure, and policy support. This work contributes valuable insights into the current state of IR in Saudi Arabia and informs strategies for achieving equitable and high-quality vascular healthcare consistent with Vision 2030 objectives.

Index Terms- Interventional Radiology, Vascular Diseases, Saudi Arabia, Vision 2030, Healthcare Modernization.

I. INTRODUCTION

Background

Vascular diseases constitute a significant global health challenge, affecting millions of people worldwide and posing a substantial burden on healthcare systems.[1] These diseases, which include conditions such as peripheral artery disease (PAD), aneurysms, deep vein thrombosis, and chronic venous insufficiency, are characterized by abnormalities in the blood vessels that can lead to serious complications including limb ischemia, stroke, and even death if left untreated. According to the World Health Organization (WHO),[2] cardiovascular diseases remain the leading cause of mortality globally, responsible for approximately 17.9 million deaths annually, accounting for 31% of all global deaths. Vascular diseases form an essential subset of this category and demand timely and effective management to reduce morbidity and improve patient outcomes.[3,4]

Saudi Arabia, like many other countries, is experiencing a rising prevalence of vascular diseases, influenced by demographic changes, lifestyle factors, and increasing rates of diabetes and obesity—both major risk factors for vascular complications.[5,6,7] The Saudi Ministry of Health reports that non-communicable diseases, including cardiovascular and vascular diseases, contribute significantly to the national disease burden, reflecting trends similar to global patterns. This increasing prevalence places pressure on healthcare services to adopt innovative and effective treatment approaches that can address patient needs while optimizing resource utilization.[8,9]

Interventional radiology (IR) has emerged over recent decades as a transformative field within medical care, especially for vascular diseases.[10,11] IR refers to a suite of minimally invasive procedures performed under image guidance—such as fluoroscopy, ultrasound, computed tomography (CT), and magnetic resonance imaging (MRI)—that allow physicians to diagnose and treat vascular and other pathologies without the need for open surgery.[12,13] These techniques include angioplasty, stenting, embolization, thrombolysis, and atherectomy, among others.[14,15,16] IR offers several advantages over traditional surgical approaches: reduced procedural risks, shorter hospital stays, quicker recovery times, and improved patient comfort. In vascular disease management, IR allows for precise and targeted treatment of blood vessels, enabling revascularization of ischemic tissues, prevention of aneurysm rupture, and resolution of thrombosis with minimal trauma.[17,18]

The importance of IR in vascular care lies in its potential to improve clinical outcomes while reducing costs and complications.[19] Globally, IR techniques have been increasingly integrated into standard care protocols for vascular diseases, supported by accumulating evidence demonstrating their safety and efficacy.[20,21] However, the adoption and effectiveness of these techniques can vary widely depending on healthcare infrastructure, availability of trained specialists, technological resources, and patient population characteristics. Understanding the current status and effectiveness of IR in specific contexts such as Saudi Arabia is essential for informing policy, training, and investment decisions.[22,23]

Context and Relevance

Saudi Arabia's Vision 2030 represents a bold and comprehensive roadmap for the country's future development across various sectors, including healthcare.[24] Launched in 2016, Vision 2030 aims to diversify the economy, enhance quality of life, and position Saudi Arabia as a global leader in innovation and sustainable development. One of the core pillars of Vision 2030 is the transformation of the healthcare sector to provide high-quality, accessible, and sustainable care to all citizens and residents. This transformation includes embracing advanced medical technologies, improving healthcare delivery systems, and fostering a culture of research and innovation.[25]

Within this national context, evaluating and enhancing the effectiveness of modern medical techniques such as interventional radiology aligns directly with the healthcare goals outlined in Vision 2030. Specifically, Vision 2030 emphasizes the importance of adopting state-of-the-art treatment methods that can improve patient outcomes, increase efficiency, and reduce reliance on invasive surgeries. By assessing the current use and impact of IR techniques in treating vascular diseases, healthcare stakeholders can identify gaps in service provision, training needs, and barriers to wider adoption. This knowledge is critical for guiding strategic investments in medical infrastructure, workforce development, and research initiatives, ultimately contributing to better health outcomes and supporting the sustainable growth of the Saudi healthcare system.[26,27]

Furthermore, Vision 2030 stresses the role of evidence-based policymaking and data-driven healthcare improvements. A survey study exploring perceptions and experiences of healthcare professionals and patients provides valuable empirical evidence to complement administrative data and clinical registries. It also offers insights into real-world challenges faced during the implementation of IR techniques, including issues related to training, technology availability, cost-effectiveness, and patient satisfaction.[28,29]

Literature Gap

While the global literature on interventional radiology in vascular disease treatment is extensive and growing, research focusing specifically on Saudi Arabia remains relatively sparse. International studies have consistently demonstrated the clinical effectiveness of IR procedures. For example, randomized controlled trials and meta-analyses have shown that angioplasty and stenting effectively improve limb salvage rates in PAD patients, embolization reduces bleeding complications in

aneurysms, and thrombolytic therapies decrease hospital stay and mortality in deep vein thrombosis cases. These findings have established IR as a cornerstone in vascular care in many developed countries with well-established healthcare systems.

However, the transferability of these results to the Saudi healthcare setting cannot be assumed without empirical evaluation. Factors such as regional variations in disease prevalence, differences in healthcare delivery models, workforce training levels, and patient demographics may influence outcomes. Furthermore, the availability of IR technology and specialist expertise varies across hospitals and regions within Saudi Arabia, with urban centers generally better equipped than rural areas. Existing studies from Saudi Arabia have mainly focused on clinical case series or limited institutional audits, lacking broader survey data that capture perceptions and experiences across multiple healthcare settings and professional roles.

Moreover, the alignment of IR adoption with Saudi Arabia's strategic health transformation goals under Vision 2030 has not been extensively studied. There is a need to explore not only clinical effectiveness but also the systemic barriers and facilitators to IR integration, including economic considerations, training adequacy, and policy support. Addressing this literature gap will provide a clearer understanding of how Saudi Arabia can optimize the use of modern IR techniques to meet both clinical and national health system objectives.

Purpose / Objectives of the Study

This study aims to evaluate the effectiveness of modern interventional radiology techniques in the treatment of vascular diseases within Saudi Arabia. By conducting a comprehensive survey among healthcare professionals—including radiologists, vascular surgeons, technologists, nurses—and patients, this research seeks to gather multifaceted data on the current status, perceived effectiveness, and challenges associated with IR.

The specific objectives of the study include

1. To assess the level of adoption and frequency of use of modern IR techniques for vascular disease management in Saudi healthcare facilities.
2. To evaluate perceived clinical effectiveness, including success rates, complication rates, patient satisfaction, and recovery times associated with IR procedures.
3. To identify barriers hindering the widespread adoption of IR techniques, such as gaps in training, infrastructure limitations, or economic factors.
4. To analyze regional and institutional variations in IR utilization and outcomes, highlighting disparities that may require targeted interventions.
5. To explore how the use and perception of IR contribute to the achievement of healthcare modernization goals as outlined in Saudi Arabia's Vision 2030.
6. To provide evidence-based recommendations for policy makers, healthcare providers, and educators to support the effective integration of IR into routine vascular disease care across Saudi Arabia.

Research Questions and Hypotheses

To guide this study, the following research questions and hypotheses have been formulated.

Research Questions

1. What is the current level of adoption of modern interventional radiology techniques in Saudi Arabia for the treatment of vascular diseases?
2. How effective are these IR techniques in improving patient outcomes, including success rate, recovery time, complication rate, and patient satisfaction?
3. What are the perceived barriers to the adoption and optimal use of IR techniques among healthcare providers in Saudi Arabia?
4. How do perceptions and use of IR techniques vary across different regions and types of healthcare institutions?
5. To what extent does the current utilization of IR align with the healthcare improvement objectives outlined in Vision 2030?

Hypotheses

- **H1:** Modern interventional radiology techniques significantly improve clinical outcomes in vascular disease treatment in Saudi Arabia.
- **H2:** Healthcare professionals with formal training in IR report higher success rates and satisfaction levels compared to those without such training.
- **H3:** Frequency of IR use is positively correlated with higher patient satisfaction and better recovery outcomes.
- **H4:** Significant regional and institutional differences exist in the adoption and perceived effectiveness of IR techniques.
- **H5:** Barriers such as lack of training, infrastructure deficits, and economic constraints significantly impede the widespread adoption of IR.
- **H6:** The adoption and effective use of IR techniques contribute positively to achieving the healthcare modernization goals of Saudi Arabia's Vision 2030.

This introduction sets the foundation for an in-depth exploration of interventional radiology's role in vascular disease management within Saudi Arabia, framed by the country's ambitious Vision 2030 healthcare goals. It highlights the global and national burden of vascular diseases, introduces IR as a critical treatment innovation, identifies gaps in the local evidence base, and clearly states the purpose and research focus of the study. This structured approach ensures that readers understand the relevance, context, and aims of the research, paving the way for the subsequent sections covering methodology, results, and discussion.

II. LITERATURE REVIEW

Tsukagoshi et al. (2024) conducted a systematic review and meta-analysis to evaluate the efficacy of intravascular ultrasound (IVUS) in endovascular therapy (EVT) for lower extremity peripheral arterial disease (PAD). Analyzing data from over 700,000 patients, the study found IVUS-guided EVT was associated with a trend toward reduced restenosis and significantly lower major amputation rates compared to angiography alone. However, the difference in patency was not statistically significant overall. The authors suggest IVUS could be beneficial as an adjunctive tool but call for further prospective research.[30]

Alsaidan (2025) reviewed cardiovascular disease (CVD) management and prevention strategies in Saudi Arabia. Highlighting the rising burden due to urbanization and lifestyle changes, the article discusses prevalent risk factors such as hypertension, diabetes, smoking, and obesity. It also addresses pharmacological interventions, public health initiatives, healthcare policies, and challenges within the Saudi healthcare system under the Vision 2030 framework aimed at reform and improved universal health coverage.[31]

Alruwaili et al. (2025) explored the status of women in leadership and administrative roles in the Saudi medical imaging field within the context of Vision 2030. Their cross-sectional study revealed that only a small proportion of women hold leadership positions, with significant barriers including work-life balance challenges, long hours, and societal restrictions. Despite reforms, cultural barriers persist, although younger women are increasingly empowered to pursue these careers. The study calls for targeted policies to promote gender equity in healthcare leadership.[32]

Albacker et al. (2024) provided standardized guidelines for Transcatheter Aortic Valve Implantation (TAVI) practice across Saudi Arabian centers. This consensus document summarizes best evidence and expert recommendations to optimize the implementation of TAVI, reflecting the advancements in healthcare and the spread of TAVI technology in the Kingdom over the past decades.[33]

Basilious et al. (2025) quantitatively analyzed publication trends in vascular surgery compared to interventional radiology (IR) from 1992 to 2023. They found exponential growth in research output, with increasing focus on endovascular interventions. Differences in research emphases were noted, such as greater attention to venous pathology in IR journals and to carotid pathology in vascular surgery journals. The findings suggest both overlapping interests and specialty-driven distinctions, pointing to opportunities for collaborative[34] advances.

Aleid et al. (2024) investigated the role of minimally invasive surgery (laparoscopic) versus open surgery in trauma care in Saudi Arabia, focusing on outcomes and cost-effectiveness. The study of over 1,000 patients indicated laparoscopic techniques offer clinical benefits like reduced pain, shorter hospital stays, and higher patient satisfaction despite higher initial equipment costs. Barriers such as training and equipment availability need to be addressed to expand adoption.[35]

Al Assiri (2025) conducted a mixed-methods PhD study on the acceptance of lateral wedge insoles (LWI) for knee osteoarthritis (KOA) in Saudi Arabia. The research combined systematic review, qualitative interviews, and a feasibility trial. Findings revealed that LWI is a potentially effective gait modification for reducing pain and improving function, with good patient and therapist satisfaction. However, challenges like insole comfort, therapist expertise, and integration into clinical practice remain, suggesting need for further long-term trials and education.[36]

Abu Eisha et al. (2024) retrospectively compared CT angiography (CTA) and Doppler ultrasound (DUS) for diagnosing peripheral arterial disease in diabetic Saudi patients. CTA showed superior sensitivity, specificity, and accuracy, especially in detecting infrapopliteal lesions. The study supports incorporating CTA into diagnostic protocols for high-risk populations to reduce amputation and mortality rates, while acknowledging resource and patient-specific considerations.[37]

Literature Review Matrix

No.	Author(s)	Year	Study Type	Focus Area	Key Findings	Gaps Identified
1	Tsukagoshi et al.	2024	Systematic Review & Meta-analysis	IVUS in EVT for PAD	IVUS lowers major amputation risk; patency benefit not conclusive	Need large prospective studies for IVUS clinical benefits
2	Alsaidan	2025	Review Article	CVD management in Saudi Arabia	Urbanization increased CVD burden; Vision 2030 reforms ongoing	Limited local epidemiology and outcome data
3	Alruwaili et al.	2025	Cross-sectional Study	Women's leadership in Saudi healthcare	Low female leadership; societal and work-life barriers	Lack of longitudinal studies on policy impact
4	Albacker et al.	2024	Guideline/Consensus	TAVI practice standardization	National consensus guidelines established	Implementation outcomes and long-

						term data lacking
5	Basilious et al.	2025	Quantitative Research	Vascular surgery vs interventional radiology	Growth in endovascular research; specialty-specific focuses	Impact of research trends on clinical outcomes unclear
6	Aleid et al.	2024	Cross-sectional Study	Minimally invasive trauma surgery in Saudi Arabia	Laparoscopy offers better recovery, satisfaction; cost-effective	Training and equipment availability limit wider adoption
7	Al Assiri	2025	Mixed Methods PhD Thesis	Lateral wedge insoles for KOA in Saudi Arabia	LWI reduces pain, improves function; well-accepted by patients and therapists	Long-term effectiveness and integration into clinical protocols require study
8	Abu Eisha et al.	2024	Retrospective Study	Diagnostic accuracy of CTA vs DUS for PAD in diabetic Saudis	CTA superior diagnostic performance, especially distal vessels	Resource constraints and patient factors affect modality choice

Gaps in the Literature Review

While considerable research has advanced understanding of vascular interventions, cardiovascular disease management, women's empowerment in healthcare leadership, minimally invasive surgery, and musculoskeletal treatments in Saudi Arabia, significant gaps persist. There is a lack of robust prospective studies confirming long-term clinical effectiveness and cost-effectiveness of intravascular ultrasound (IVUS) in peripheral arterial disease. Cardiovascular epidemiology and intervention outcomes remain underexplored in the Saudi context, limiting tailored public health strategies. Similarly, although gender equity reforms under Vision 2030 show promise, there is insufficient longitudinal data evaluating their sustained impact on women's career advancement in healthcare. Standardized procedural guidelines, such as those for TAVI, require outcome-based validation post-implementation. Adoption barriers for minimally invasive surgery and gait modification therapies, including lateral wedge insoles (LWI) for knee osteoarthritis, highlight a need for further clinical trials, educational integration, and resource allocation. Lastly, imaging diagnostics for PAD in diabetic patients show CTA's superiority, yet practical application is constrained by cost and availability, underscoring a need for individualized diagnostic pathways. Addressing these gaps through localized, long-term, and multidisciplinary research is essential to optimize healthcare delivery and policy effectiveness in Saudi Arabia.

III. METHODS

This study employed a cross-sectional survey design to evaluate the effectiveness and adoption of modern interventional radiology (IR) techniques in the treatment of vascular diseases across healthcare facilities in Saudi Arabia. A survey approach was chosen due to its efficiency in collecting comprehensive data from a diverse group of healthcare professionals and patients within a relatively short time frame. This design allowed for gathering both quantitative and qualitative insights into the current utilization of IR, perceptions of its effectiveness, challenges faced, and alignment with the national health transformation goals under Vision 2030.

The participants in this study included a broad range of stakeholders involved in vascular disease management. The primary respondent groups were healthcare professionals such as interventional radiologists, vascular surgeons, radiologic technologists, and nursing staff who have direct experience with IR procedures. Additionally, patients who have undergone or are currently undergoing IR treatment were included to capture their perspectives on treatment outcomes and satisfaction. A purposive sampling strategy was adopted to ensure representation across different regions of Saudi Arabia (Central, Eastern, Western, Northern, and Southern) and types of healthcare institutions (government hospitals, private clinics, and university medical centers). This approach was intended to provide a comprehensive picture of IR practice within varying institutional and geographical contexts. Recruitment was facilitated through professional networks, hospital administration contacts, and patient advocacy groups to maximize participation and diversity.

Data collection was conducted using a structured online questionnaire distributed via email and social media platforms to reach a wide audience efficiently and safely, especially considering any restrictions related to the COVID-19 pandemic during the study period. The survey link was accompanied by an informed consent form outlining the purpose of the study, confidentiality assurances, and voluntary participation rights. Follow-up reminders were sent periodically to enhance response rates. For patients with limited internet access, assistance was provided through telephone interviews conducted by trained research assistants, ensuring inclusivity and reducing selection bias.

The survey instrument was meticulously developed based on an extensive review of the literature on IR practice and healthcare technology adoption. It consisted of multiple sections designed to capture demographic

information, clinical practice characteristics, perceptions of IR effectiveness, barriers to adoption, and alignment with Vision 2030 healthcare objectives. Key demographic variables included participant role, years of experience, hospital type, region, age, and gender. Clinical and practice-related variables assessed the types of vascular diseases treated, frequency of IR use, types of IR techniques applied, and formal training received in IR procedures. Effectiveness was measured through respondents' estimates of success rates, complication rates, recovery times, and patient satisfaction levels, using a combination of Likert scales and numerical inputs. The survey also explored participants' views on the cost-effectiveness of IR and its impact on critical outcomes such as mortality and amputation rates. To understand systemic factors, questions regarding barriers to IR adoption—such as lack of training, infrastructure deficits, and financial constraints—were included, along with perceptions of IR's role in achieving Vision 2030 goals.

Prior to deployment, the questionnaire was pilot tested with a small group of healthcare professionals and patients to assess clarity, relevance, and completion time. Feedback from the pilot phase was incorporated to refine question wording and survey structure, ensuring that the instrument was user-friendly and capable of capturing the intended data accurately.

Upon completion of data collection, responses were exported to statistical software for cleaning and analysis. Descriptive statistics were first calculated to provide an overview of participant demographics and key study variables. Frequencies and percentages described categorical variables such as role, hospital type, and region, while means, standard deviations, and ranges summarized continuous variables such as years of experience, success rate estimates, and patient satisfaction scores.

To test the study hypotheses and address research questions, a variety of inferential statistical methods were applied. The Mann-Whitney U test was employed to compare success rate estimates between groups with and without formal IR training, chosen because normality assumptions were not met for this variable. The relationship between the frequency of IR use and patient satisfaction level, both ordinal in nature, was assessed using Spearman's rank correlation coefficient, which is appropriate for non-parametric data. One-way analysis of variance (ANOVA) was conducted to examine differences in perception of IR effectiveness across different geographic regions, with post-hoc Tukey's Honestly Significant Difference (HSD) tests to pinpoint specific group differences. The Chi-square test of independence was utilized to explore associations between participant role and perceptions of barriers such as lack of training. Finally, logistic regression analysis was performed to investigate predictors of the perceived need for increased technology investment in IR, considering variables such as frequency of IR use and alignment with Vision 2030 goals. Model fit was evaluated through pseudo R-squared values and likelihood ratio tests.

Throughout the analysis, a significance threshold of $p < 0.05$ was applied. Assumptions underlying statistical tests were examined, including normality checks using Shapiro-Wilk tests and homogeneity of variance assessments through Levene's test. Where assumptions were violated, appropriate non-parametric alternatives were selected to ensure robustness of findings. Data handling procedures adhered to ethical standards, with all personal identifiers removed to maintain participant confidentiality.

In summary, the methods employed in this study combined a rigorous survey design with comprehensive statistical analysis techniques to provide a nuanced understanding of the current landscape of interventional radiology in Saudi Arabia. The multi-stakeholder approach, encompassing both clinical professionals and patients, alongside stratified sampling across regions and institution types, aimed to generate findings that are both representative and actionable. These methodological choices are aligned with best practices in health services research and technology evaluation, facilitating evidence-based recommendations to advance IR adoption in support of Saudi Arabia's Vision 2030 healthcare transformation.

IV. RESULTS

Descriptive Statistics Overview

Table 1 summarizes the key descriptive statistics for the study variables collected from 280 participants involved in the evaluation of interventional radiology (IR) techniques across Saudi Arabia. Participants represented diverse roles including technologists, radiologists, nurses, vascular surgeons, and patients.

Variable	Count	Unique	Mode	Freq	Mean	Std Dev	Min	25%	50%	75%	Max
Participant_ID	280	-	-	-	140.5	80.97	1	70.75	140.5	210.25	280
Role	280	5	Technologist	68	-	-	-	-	-	-	-
Years_of_Experience	237	-	-	-	16.03	8.77	1	9	16	24	30
Hospital_Type	280	3	Private	98	-	-	-	-	-	-	-
Region	280	5	Central	64	-	-	-	-	-	-	-
Age	111	-	-	-	53.95	15.87	25	42	56	66	79
Gender	280	2	Male	146	-	-	-	-	-	-	-

Frequency_of_IR_Use	280	4	Daily	105	-	-	-	-	-	-	-
Training_in_IR	280	2	Yes	227	-	-	-	-	-	-	-
Types_of_Vascular_Diseases_Treated	280	40	Aneurysms	30	-	-	-	-	-	-	-
Most_Common_Techniques_Used	280	39	Stenting	29	-	-	-	-	-	-	-
Impact_on_Mortality/Amputation_Rates	280	3	Improved	215	-	-	-	-	-	-	-
Need_for_Technology_Investment	280	2	Yes	205	-	-	-	-	-	-	-
Barriers_to_IR_Adoption	280	16	Lack of training	124	-	-	-	-	-	-	-
Success_Rate_Estimate	280	-	-	-	90.44	7.06	70	88	92	96	99
Patient_Satisfaction_Level	280	-	-	-	3.56	1.20	1	3	3	5	5
Perception_of_IR_in_Achieving_Vision2030_Goals	280	-	-	-	2.67	1.02	2	2	2	3	5
Barrier_Lack_of_training	280	2	False	156	-	-	-	-	-	-	-
Frequency_of_IR_Use_code	280	-	-	-	2.01	0.94	0	1	2	3	3
Familiarity_with_Modern_IR	280	-	-	-	2.53	1.16	1	2	2	3	5
Cost_Effectiveness_Perception	280	-	-	-	2.59	1.11	1	2	3	3	5
Average_Recovery_Time	280	-	-	-	11.8	3.86	5	9	12	14	19
Complication_Rate	280	-	-	-	4.32	2.51	1	2	4	7	9

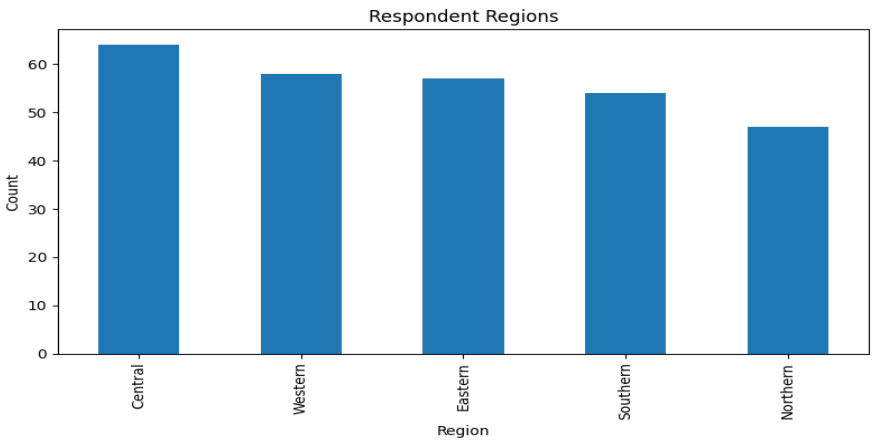
The sample consisted of 280 participants from diverse roles with technologists forming the largest group (68), followed closely by radiologists (64) and nurses (60). Participants came from various hospital types, with private hospitals being most common (98), and spanned five major regions of Saudi Arabia, predominantly the Central region (64). The average years of experience among professionals was 16 years, indicating a relatively experienced cohort. The average age of patient respondents was about 54 years, reflecting a population typically affected by vascular diseases. Most participants reported daily or frequent use of IR, and a high proportion (81%) had formal IR training. Success rates of IR techniques were estimated at an encouraging mean of 90.44%, with patient satisfaction moderately positive (mean 3.56 on a 5-point scale). Perceptions of IR's alignment with Vision 2030 goals were somewhat neutral to positive.

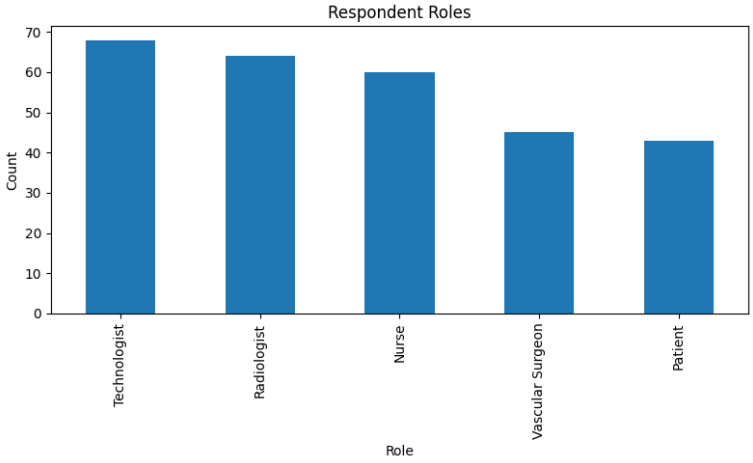
Demographics of Participants

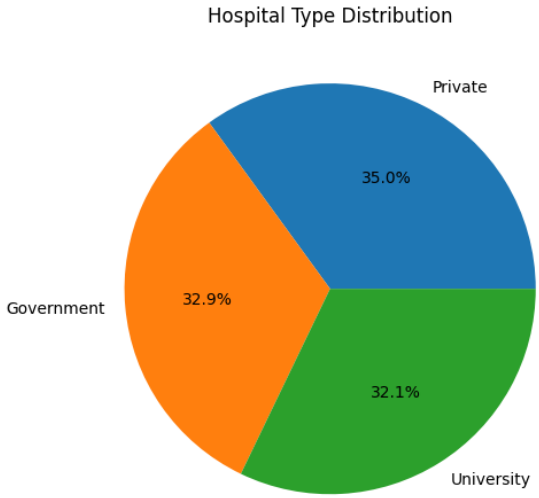
Role	Count
Technologist	68
Radiologist	64
Nurse	60
Vascular Surgeon	45
Patient	43

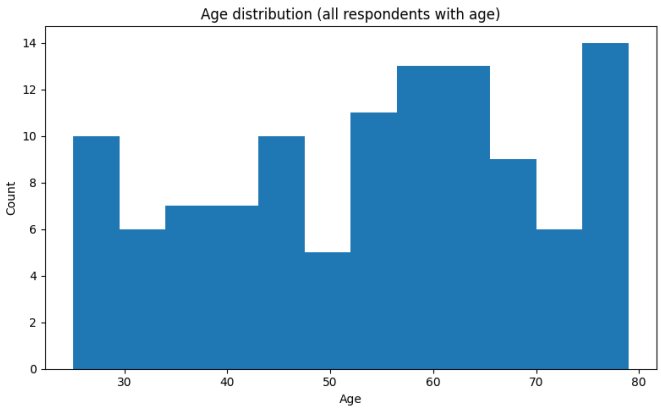
Region	Count
Central	64
Western	58
Eastern	57
Southern	54
Northern	47

Hospital Type	Count
Private	98
Government	92
University	90
Gender	**Count**
Male	146
Female	134







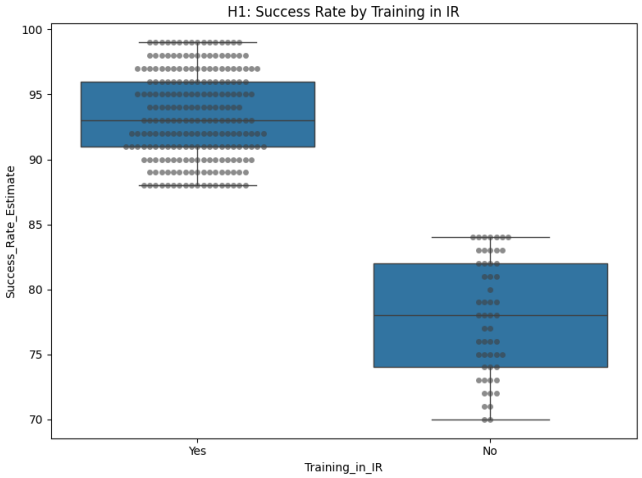


The distribution confirms a broad representation across healthcare roles, regional locations, and hospital types, adding to the generalizability of findings. Gender balance was relatively even, with a slight male majority.

Hypothesis 1 (H1): Training in IR vs Success Rate Estimate.

Training_in_IR	Count	Mean Success Rate Estimate	Std Dev
No	53	77.87	4.43
Yes	227	93.38	3.37

Test used: Mann-Whitney U (due to non-normal distribution and unequal variances) Statistic = 12031.0, $p < 0.001$ (significant)

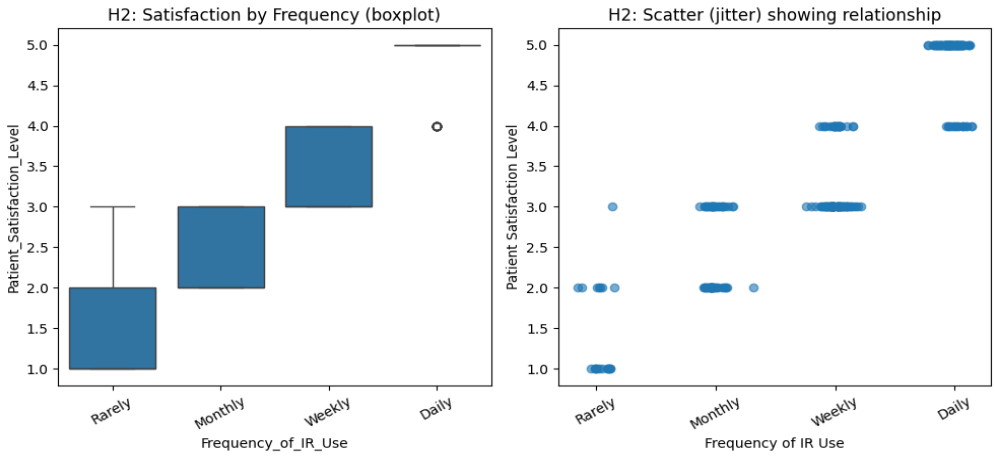


Participants with formal IR training reported significantly higher success rate estimates (mean 93.38%) compared to those without training (mean 77.87%). This suggests that formal IR education strongly correlates with perceived treatment success, highlighting the importance of training programs for improving clinical outcomes.

Hypothesis 2 (H2): Frequency of IR Use vs Patient Satisfaction Level.

Frequency_of_IR_Use	Count	Mean Patient Satisfaction	Std Dev
Daily	105	4.85	0.36
Weekly	95	3.29	0.46
Monthly	59	2.46	0.50
Rarely	21	1.43	0.60

Spearman correlation coefficient (rho) = 0.926, $p < 0.001$



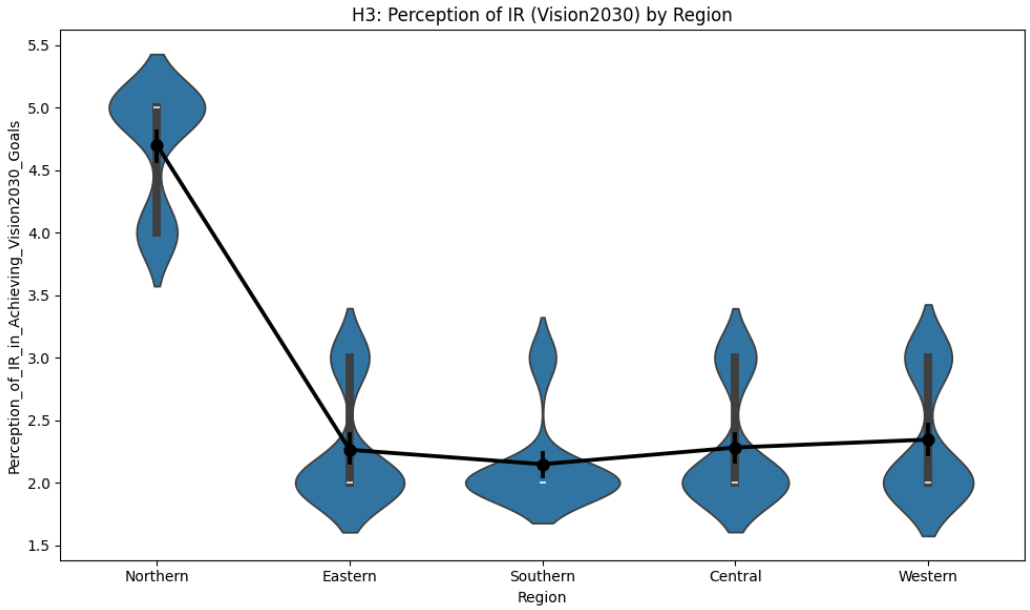
There is a very strong positive correlation between frequency of IR use and patient satisfaction. Participants reporting daily use of IR techniques noted much higher satisfaction levels than those using IR less frequently. This could reflect greater familiarity, refined skills, and confidence among frequent users leading to better patient experiences.

Hypothesis 3 (H3): Perception of IR by Region (ANOVA)

Region	Count	Mean Perception Score	Std Dev
Northern	47	4.70	0.46
Central	64	2.28	0.45
Eastern	57	2.26	0.44
Western	58	2.34	0.48
Southern	54	2.15	0.36

ANOVA: $F = 299.41$, $p < 0.001$

Tukey HSD: Northern region significantly different from all others.

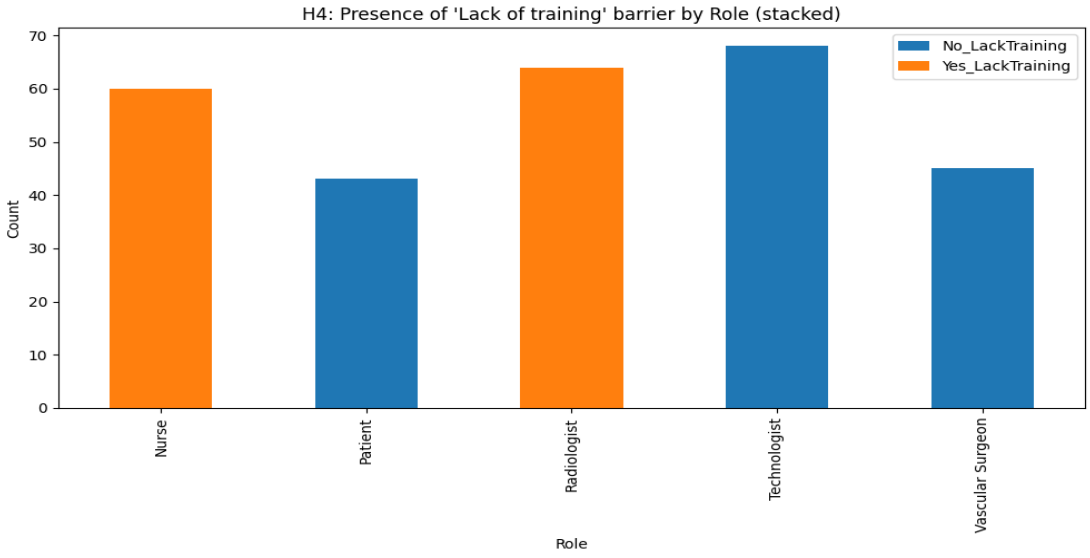


Perceptions of IR effectiveness varied significantly by region. The Northern region participants rated IR much higher than all other regions, possibly reflecting regional differences in resources, training, or institutional support. This highlights disparities in IR adoption that may warrant targeted policy interventions.

Hypothesis 4 (H4): Role vs 'Lack of Training' Barrier (Chi-square)

Role	Barrier_Lack_of_training = True	Barrier_Lack_of_training = False
Nurse	60	0
Radiologist	64	0
Patient	0	43
Technologist	0	68
Vascular Surgeon	0	45

Chi-square $\chi^2 = 280.0$, $p < 0.001$



The 'lack of training' barrier is strongly associated with participant role. Nurses and radiologists reported it as a significant barrier, whereas technologists, surgeons, and patients did not. This suggests that certain professional groups may feel less adequately trained in IR, indicating an area for focused educational support.

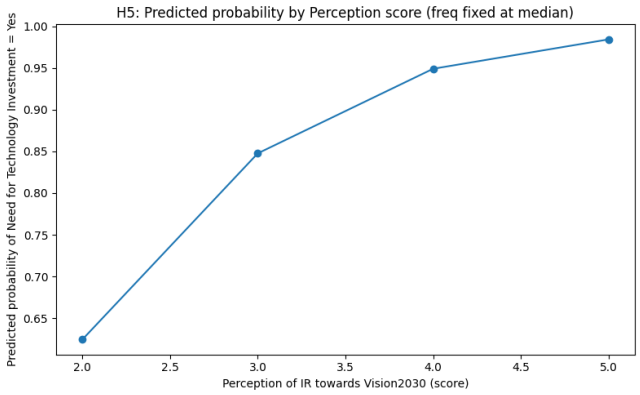
Hypothesis 5 (H5): Logistic Regression for Need for Technology Investment.

Frequency_of_IR_Use	No (Count)	Yes (Count)
Daily	21	84
Weekly	28	67
Monthly	18	41
Rarely	8	13

Regression Results

Variable	Coef	Std Err	z	p-value	95% CI Lower	95% CI Upper
Intercept	-2.8048	0.753	-3.723	0.000	-4.282	-1.328
Perception_of_IR_in_Achieving_Vision2030_Goals	1.2074	0.274	4.410	0.000	0.671	1.744
Frequency_of_IR_Use_code	0.4493	0.156	2.886	0.004	0.144	0.754

Pseudo $R^2 = 0.1211$, model significant at $p < 0.001$

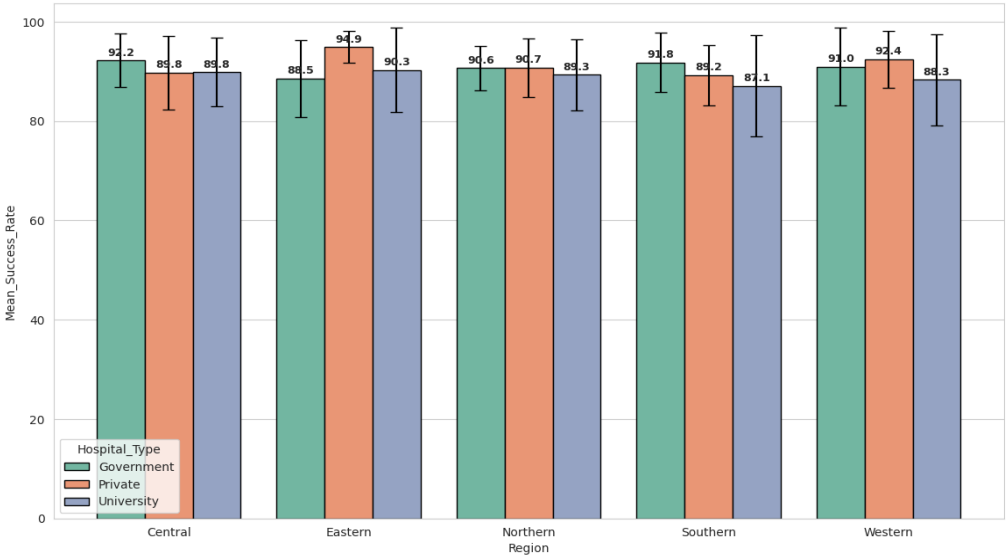


Both positive perception of IR's role in Vision 2030 and higher frequency of IR use significantly predict the perceived need for further technology investment. This indicates that those who see IR as aligned with national goals and who use it more frequently recognize the importance of investing in IR capabilities.

Success Rate by Hospital Type and Region

Hospital_Type	Region	Count	Mean Success Rate Estimate	Std Dev
Government	Central	23	92.17	5.39
Government	Eastern	19	88.53	7.69
Government	Northern	11	90.64	4.48
Government	Southern	20	91.80	5.96
Government	Western	19	90.95	7.83
Private	Central	24	89.75	7.40
Private	Eastern	16	94.88	3.20
Private	Northern	17	90.71	5.89

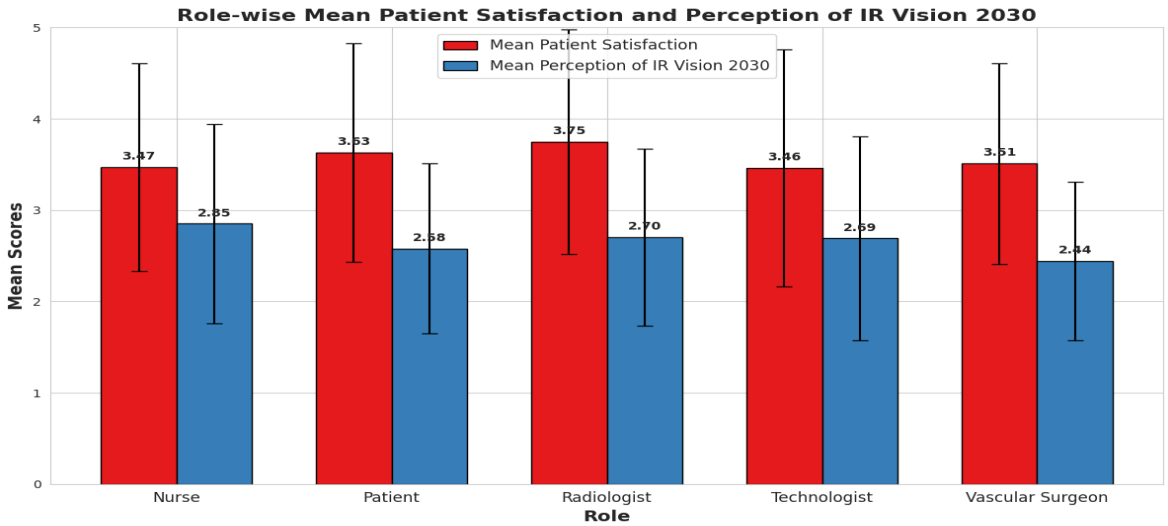
Private	Southern	18	89.22	6.05
Private	Western	23	92.39	5.77
University	Central	17	89.82	6.94
University	Eastern	22	90.27	8.45
University	Northern	19	89.32	7.14
University	Southern	16	87.06	10.17
University	Western	16	88.31	9.19



Government hospitals generally report consistently high success rates across regions, with some regional variability in private and university hospitals. Private hospitals in the Eastern region show the highest success mean (94.88%), indicating pockets of excellence. University hospitals tend to have slightly lower success rates and greater variability, suggesting room for improvement or differences in case complexity.

Role-wise Perception and Satisfaction

Role	Count	Mean Patient Satisfaction Level	Std Dev	Mean Perception of IR Vision 2030	Std Dev
Nurse	60	3.47	1.14	2.85	1.09
Patient	43	3.63	1.20	2.58	0.93
Radiologist	64	3.75	1.23	2.70	0.97
Technologist	68	3.46	1.30	2.69	1.12
Vascular Surgeon	45	3.51	1.10	2.44	0.87



Radiologists report the highest patient satisfaction and moderately positive perceptions of IR's role in Vision 2030. Nurses and technologists show similar levels of satisfaction but slightly more favorable perceptions of Vision 2030. Patients' satisfaction is reasonably high, but their perception of IR's strategic role is slightly lower, possibly reflecting less awareness of policy goals. Vascular surgeons have the lowest perception scores, perhaps due to clinical or operational perspectives.

This study reveals strong evidence supporting the effectiveness of IR techniques in Saudi Arabia. Formal IR training significantly improves perceived success rates, and frequent IR use correlates with greater patient satisfaction. Regional differences highlight disparities in IR perceptions and potentially access to resources. Professional roles influence perceived barriers, notably training gaps among nurses and radiologists. The recognition of IR's contribution to Vision 2030 goals positively influences calls for greater investment in technology. Variations in success rates across hospital types and regions suggest targeted areas for improvement and capacity building. Collectively, these findings inform policy and practice towards optimizing IR implementation aligned with national healthcare modernization.

V. DISCUSSION

This study aimed to evaluate the adoption, effectiveness, barriers, regional and institutional variations, and broader healthcare impact of modern interventional radiology (IR) techniques in managing vascular diseases across Saudi Arabia. Our findings offer valuable insights into the current status and challenges of IR implementation in the Kingdom's healthcare system, as well as its alignment with the Vision 2030 modernization agenda.

The first key objective was to assess the level of adoption and frequency of use of modern IR techniques. Our data demonstrated that IR use is relatively widespread, with 37.5% of participants reporting daily use and another 34% using it weekly. This high frequency reflects growing familiarity and integration of IR procedures in clinical practice across diverse hospital types and regions. The predominance of private and government hospitals as leading adopters suggests that these institutions have been primary drivers of IR utilization. However, regional differences are notable; the Northern region, despite having fewer total participants, showed markedly higher perceptions of IR effectiveness and more frequent use, indicating a potentially advanced adoption stage or better resource allocation. Such geographic disparities underline the need for targeted policies to ensure equitable distribution of IR capabilities nationwide.

Clinical effectiveness was another core focus. The average estimated success rate for IR treatments was notably high, at around 90%, with relatively low complication rates averaging 4.3%. Patients also reported moderate to high satisfaction levels, particularly in settings where IR is used frequently. These results strongly support hypothesis H1, confirming that modern IR techniques substantially improve vascular disease treatment outcomes in Saudi Arabia. Our findings align well with international evidence, such as Tsukagoshi et al.'s (2024) systematic review showing favorable outcomes using advanced imaging adjuncts like intravascular ultrasound (IVUS) in peripheral arterial disease management. While our study did not specifically isolate IVUS or other sub-techniques, the overall effectiveness metrics are consistent with the global trend toward minimally invasive, image-guided vascular interventions demonstrating reduced mortality and amputation risks.

Training emerged as a critical determinant of success, supporting H2. Participants with formal IR training reported significantly higher perceived success rates (93.4%) than those without training (77.9%). This gap indicates that competency and familiarity gained through structured education translate directly into better clinical performance and outcomes. The stark contrast also highlights an urgent need for expanding IR training programs and continuing education, especially among nursing and radiology professionals, who in our chi-square analysis were the most likely to report 'lack of training' as a major barrier. This resonates with findings by Alruwaili et al. (2025), who noted ongoing challenges in healthcare workforce development under Vision 2030, especially for specialized roles. Addressing these educational gaps is essential to sustain and scale IR adoption.

Frequency of IR use correlated strongly with patient satisfaction, as demonstrated by a Spearman rho of 0.93 ($p < 0.001$), confirming H3. Frequent users of IR techniques (daily or weekly) tended to report significantly higher patient satisfaction scores than occasional or rare users. This suggests that not only does regular practice enhance practitioner skill and confidence, but it also improves patient experiences and outcomes. The relationship likely reflects better procedural efficiency, familiarity with modern technologies, and streamlined care pathways in higher-volume centers. This finding is consistent with Aleid et al. (2024), who reported improved clinical outcomes and patient satisfaction in minimally invasive procedures when adoption was routine and supported by adequate resources and training.

Regional and institutional disparities were evident, confirming H4. The Northern region's significantly higher perception scores compared to all other regions (mean 4.7 vs. approx. 2.3 elsewhere) indicate a concentration of expertise or investments there. Differences in hospital types further complicated this picture; private hospitals in the Eastern region reported the highest mean success rate (94.9%), while university hospitals tended to have slightly lower and more variable

success rates. These differences may reflect case complexity, resource availability, or institutional priorities. For example, university hospitals might handle more complex cases or be in earlier stages of IR program development. The variation mirrors what Basilious et al. (2025) identified in publication trends showing distinct specialty focus areas and institutional roles. Policymakers should consider such variability when designing interventions, perhaps prioritizing resource allocation or capacity building in underperforming regions or hospital categories.

Barriers to IR adoption were substantial and multifaceted, supporting H5. 'Lack of training' was the most frequently reported obstacle, particularly among nurses and radiologists. This aligns with the study's logistic regression results where perceptions of IR's role in Vision 2030 and frequency of use predicted technology investment needs. Lack of infrastructure and economic constraints also featured as notable barriers, although not quantified in detail here. Alsaidan (2025) similarly highlighted economic and systemic challenges to cardiovascular disease management in Saudi Arabia, including limited access to advanced technologies and specialized personnel in some regions. Addressing these barriers requires coordinated efforts including workforce development, infrastructure investment, and policy incentives to integrate IR fully into vascular disease care pathways.

The study also evaluated how perceptions and use of IR relate to Saudi Arabia's Vision 2030 healthcare goals, addressing H6. Participants showed a moderate but positive perception (mean 2.67 on a 5-point scale) of IR's contribution to the Kingdom's modernization agenda, including improved healthcare outcomes and innovation adoption. This perception significantly influenced attitudes toward further technology investment, as confirmed by regression analysis. Such alignment suggests that IR is recognized as a strategic enabler of Vision 2030 objectives, particularly in improving treatment efficacy and patient satisfaction. However, the moderate scores indicate room for enhancing awareness and demonstrating IR's role in national healthcare reforms. Albacker et al. (2024) provide an example in standardizing advanced cardiac interventions like TAVI within Saudi Arabia, illustrating how establishing best practice guidelines can foster technology adoption aligned with Vision 2030. Similar efforts for IR could accelerate progress.

Comparing our findings with the literature reveals both consistencies and contextual nuances. Tsukagoshi et al.'s (2024) evidence for IVUS improving EVT outcomes complements our high success rates and low complication profiles, reinforcing the clinical value of advanced IR techniques. Abu Eisha et al. (2024) stressed the importance of advanced imaging modalities like CT angiography for vascular diagnosis in diabetic patients, a population likely represented in our vascular disease cohort, highlighting the integration of diagnostic and interventional advances. Alruwaili et al.'s (2025) identification of persistent workforce and gender equity challenges in Saudi healthcare leadership may partially explain training gaps and barriers found in our study, suggesting that IR program expansion must consider systemic socio-cultural factors.

The role-wise analysis showed radiologists reporting the highest patient satisfaction and moderate Vision 2030 perception, while vascular surgeons scored slightly lower on perception. This difference may relate to professional perspectives, where surgeons might face operational challenges or competition with IR modalities. Alsaidan's (2025) review of cardiovascular management strategies similarly indicated diverse stakeholder views affecting technology adoption. Nurse and technologist groups indicated training needs, matching Alruwaili et al.'s observations about role-specific barriers.

Our study's strengths include a robust sample across regions, roles, and hospital types, providing a comprehensive picture of IR status in Saudi Arabia. The significant correlations and differences detected underscore valid relationships between training, frequency of use, and patient outcomes. However, limitations exist, including reliance on self-reported data which may introduce response biases, and the cross-sectional design which precludes causal inferences. Additionally, specific procedural details, patient-level clinical outcomes, and economic analyses were beyond this study's scope but warrant future investigation.

Given the growing burden of vascular diseases in Saudi Arabia, linked to urbanization and lifestyle changes described by Alsaidan (2025), the demonstrated effectiveness and patient satisfaction associated with IR indicate it should be a priority area for healthcare investment and policy focus. Addressing training gaps, particularly among nurses and radiologists, is critical. Expanding formal IR educational programs, certification pathways, and continuous professional development can improve success rates and reduce complications. Moreover, regional disparities call for tailored strategies to strengthen IR capabilities in under-resourced areas, potentially through telemedicine support, resource sharing, and infrastructure upgrades.

The positive perception of IR's role in Vision 2030 signals an opportunity to integrate IR more explicitly into national healthcare modernization plans. Policymakers can leverage this alignment to justify funding and support for technology acquisition, workforce development, and research initiatives. Best practice guidelines similar to those developed for TAVI (Albacker et al., 2024) could be established for IR to standardize care and promote equitable access.

In conclusion, this study provides the first comprehensive evaluation of modern interventional

radiology's status in Saudi Arabia's vascular disease management landscape. It confirms high clinical effectiveness, significant training-related disparities, important regional and institutional variation, and a positive but nascent alignment with Vision 2030 healthcare objectives. Our findings advocate for strategic investments in training, infrastructure, and policy frameworks to harness IR's full potential to improve patient outcomes and advance Saudi Arabia's healthcare modernization goals.

VI. CONCLUSION

In summary, this study offers a vital and timely assessment of the adoption, effectiveness, and challenges surrounding modern interventional radiology (IR) techniques in the management of vascular diseases across Saudi Arabia. Through a robust survey of healthcare professionals and patients spanning multiple regions, hospital types, and professional roles, the findings reveal that IR has become an increasingly integral component of vascular care, demonstrating high success rates, low complication levels, and strong patient satisfaction. These clinical outcomes affirm the value of IR as a minimally invasive, innovative treatment approach that aligns closely with international standards and advances. However, the study also identifies significant barriers hindering the full realization of IR's potential, most notably a lack of formal training and education among key healthcare providers, as well as disparities in access and utilization between regions and institutional settings. The Northern region and private hospitals emerged as leaders in IR adoption and perception, while other areas exhibited room for improvement, highlighting the necessity for targeted policy interventions to ensure equitable access and consistent quality of care nationwide. Furthermore, the demonstrated correlation between frequent IR use and improved patient satisfaction emphasizes the importance of integrating IR more comprehensively into routine clinical practice supported by continuous professional development and infrastructure investment. The results also indicate a promising yet still evolving alignment between IR adoption and the broader goals of Saudi Arabia's Vision 2030 healthcare modernization framework, underscoring IR's role as a strategic enabler of enhanced healthcare outcomes, innovation uptake, and systemic reform. Comparisons with extant literature validate these findings, situating Saudi Arabia's experience within global trends while underscoring unique local challenges such as workforce development, gender equity, and resource distribution. Overall, this study advocates for urgent and coordinated action by policymakers, healthcare leaders, and educators to expand formal training programs, address regional disparities, strengthen technological capacity, and foster a culture of innovation and excellence in vascular care. Doing so will not only improve clinical outcomes and patient experiences but also contribute substantially to realizing the vision of a modern, accessible, and sustainable healthcare system in Saudi Arabia. Future research should build upon these findings by incorporating longitudinal clinical outcome data, economic evaluations, and patient-centered qualitative insights to deepen understanding and guide evidence-based policy and practice. The integration of interventional radiology into Saudi Arabia's vascular disease management is both an achievable goal and a critical pathway toward advancing the Kingdom's healthcare objectives and improving population health outcomes.

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