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Etiology, Management, & Outcomes for Upper Extremity Arterial Iatrogenic Injury

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ABSTRACT

Objective: *Iatrogenic injuries, including pseudoaneurysm and thrombosis, are rare complications for upper extremity arterial interventions. Unrecognized, these complications lead to significant morbidity.*

Methods: *Retrospective review from January 2006 to January 2022. Radiology reports including key search terms associated with arterial injury were queried. Cases with clinical suspicion of an iatrogenic injury were included. Embolic causes of acute limb ischemia were excluded. Cases were reviewed for cause, chronicity, complications, treatment, and outcomes.*

Results: *A total of 323 upper extremity iatrogenic arterial injuries (IAIs) were identified, 171(53%) thrombosis, followed by pseudoaneurysm (85, 26%), extravasation/hematoma (39, 12%), and arterial stenosis (5, 6%). Computed tomography angiography (CTA) diagnosed 51% (163) of IAIs, while duplex ultrasound diagnosed 49% (159) of the injuries. The most injured artery was the radial artery (135, 42%), followed by the brachial (104, 32%), and axillary artery (40, 12%). Given the variety of clinical presentations, the underlying causes of injury were analyzed. Most common causes of upper extremity IAIs were arterial lines (76, 24%), cardiac procedures (66, 20%). Dialysis access complications accounted for 20% of cases, while trauma cases accounted for 12%, and vascular surgery procedures accounted for 9% of injuries.*

For the 150 patients who underwent intervention with 95% overall success. The majority underwent primary repair of the injured vessel (58, 39%), followed by endovascular interventions (30, 20%), including balloon angioplasty and/or stenting, and thrombin injection (19,13 %). Pseudoaneurysms were more likely to result as a complication of dialysis access rather than as a complication of thrombosis or extravasation IAIs (36% vs 11% vs 18%, p<0.001) and were more likely to undergo re-operation after initial intervention (18% vs 6% vs 5%, p=0.005), primarily due to necessity of further repair or dialysis access revision.

Arterial thrombosis was more likely to be caused by arterial lines than pseudoaneurysm or extravasation injuries (36% vs 11% vs 13%, p<0.001). Extravasation injuries were more likely caused by trauma, than pseudoaneurysm or thrombosis (36% vs 13% vs 4%) and were more likely to undergo hematoma evacuation (50% vs 4% vs 0%, p<0.001). Extravasation had significantly shorter days from cause of injury to diagnosis (4 days vs 215 days vs 150 days, p=0.002).

Conclusions: *Upper extremity iatrogenic injury occurs secondary to various causes. While operative management is often necessary to prevent long-term sequelae and morbidity, this study found that 54% of patients were successfully managed non-operatively, demonstrating the range of therapeutic approaches that can be used for upper extremity IAIs.*

Keywords
Upper Extremity, Iatrogenic Arterial Injury, Radial Artery, Brachial Artery, Axillary Artery, Pseudoaneurysm, Endovascular Repair.

Introduction
Iatrogenic arterial injuries (IAIs) may occur because of invasive diagnostic or therapeutic procedures that require arterial access or inadvertent arterial injury during a procedure on a surrounding structure. Common types of arterial injuries include hematomas, pseudoaneurysms, dissections, and thrombosis [1,2]. These injuries pose significant risks to patients, potentially leading to prolonged hospitalization, increased financial burden, lifelong disability, and even mortality [3]. It is estimated that about 0.6% of patients undergoing endovascular procedures experience IAIs [4], a number expected to rise with the increasing prevalence of percutaneous endovascular interventions [5]. Particularly, IAI of the upper extremity can be particularly morbid and debilitating to patients if complications are recognized and treated promptly.

Upper extremity IAIs are often associated with procedures across specialties that utilize percutaneous access to arteries, such as vascular surgery, interventional cardiology, interventional radiology, and neuro-endovascular surgery [6]. They may also result from placing or attempting to place arterial lines, central venous catheters, or peripheral intravenous lines [7-9]. The adverse effects of IAIs can be significantly reduced through prompt management and repair, highlighting the importance of their early detection and diagnosis. The clinical presentation of IAIs varies with the type and extent of the injury. These symptoms include pain, pallor, absence of pulses, numbness, bleeding, swelling, bruising, and the presence of a large or expanding hematoma [10]. The presence of such signs and symptoms warrants a diagnostic workup by healthcare providers, with duplex ultrasound (US) and computed tomography angiography (CTA) being common diagnostic approaches [11]. The treatment of IAIs depends on the type and extent of the injury. Some can be managed with medical treatment and close monitoring alone, while others may require surgical intervention, either through open or endovascular techniques.

Here, we present a retrospective study performed throughout multiple hospitals within a single healthcare system on incidence and management of upper extremity IAIs. The cause of the injury in addition to patient presentation, diagnosis, management, and over patient outcomes were explored over a period of 16 years. The goal of this study is to better understand incidence and causation of upper extremity IAI, in order to guide future practice and prevent additional injuries from occurring.

Methods
Study Sample
Clinical and radiographic data were retrospectively reviewed and analyzed for patients who sustained iatrogenic arterial injuries to the upper extremities in a multihospital healthcare system between January 2006 and January 2022. To identify those cases, radiology reports across 5 different hospitals were examined using a predefined set of key search terms indicative of arterial injury. The search terms used were "occlusion", "occluded", "thrombosis", "extravasation", "hematoma", "dissection", "bleed", "aneurysm", and “pseudoaneurysm”. Imaging modalities included computed tomography angiography (CTA), duplex ultrasound, and magnetic resonance imaging (MRI). No cases were included via physical exam alone, since all cases were included via initial screening of radiology imaging reports. This study relied only upon de-identified data from patients and therefore was exempt from an ethics review.
All cases with identified radiologic evidence of upper extremity arterial injury underwent extensive chart review to confirm iatrogenic injury and relevant patient history. This included review of patient chief complaint, pertinent history and past interventions, physical exam, primary provider evaluation, specialty consultations, and when indicated, operative notes and post-intervention outcomes. Patients identified with a causative prior procedure/intervention to the upper extremity artery and subsequent arterial injury on presentation were identified as having an upper extremity IAI and included within the study.

Included and Excluded Cases
The study included all cases with a suspicion of iatrogenic injury of upper extremity arterial vessels. To ensure clarity in data interpretation, dialysis access-related IAIs were included in the analysis if they were specifically arterial injuries secondary to dialysis access creation, revision, or ligation. Venous outflow complications and dialysis synthetic graft pseudoaneurysms were specifically excluded from the dataset. Traumatic injuries, while not explicitly iatrogenic in nature, carry with them clinically significant similarities to iatrogenic arterial injury in the sense that most are penetrating injuries as well as the feared sequalae of these injuries including extravasation, thrombosis, and pseudoaneurysm formation. Lastly, the treatment between traumatic and iatrogenic injuries did not vary significantly and for this reason traumatic injuries were considered relevant to include within the dataset.

Variables and Outcomes
The variables examined in this study included the laterality and level of injury on the extremity, the specific artery affected, and the type and cause of the injury. The types of injuries were thrombosis, pseudoaneurysm, extravasation/hematoma, dissection, stenosis, and arteriovenous fistula. The causes of injuries encompassed arterial or intravenous line insertions, central line placements, complications related to hemodialysis (HD) access, infections, procedures performed by various specialties (including cardiology, interventional radiology (IR), vascular surgery, orthopedic surgery, and neurosurgery), and trauma. Additionally, data on patient characteristics (age, gender, BMI), the presence of comorbid medical conditions, presenting symptoms, subsequent complications, types of repairs, reoperation rates, time from the cause to diagnosis, time from diagnosis to operation, operative repair techniques, and outcomes in the operating room were collected and analyzed.

Statistical Analysis

Statistical analysis was carried out in Python 3.10.9 using several libraries including Pandas 1.5.3, scikit-learn 1.2.1, scipy 1.10, statsmodels 0.13.5 inside a Jupyter notebook. Baseline demographics were counted, normalized, and descriptive values calculated such as arithmetic mean, median, and mode using Pandas. Categorical to categorical comparisons were assessed for significant correlations by first constructing a contingency table and then using the chi-square contingency test from scipy to assess for differences in expected versus observed category assignments. Comparisons between numerical and categorical data were made using a one-way ANOVA test (with Welch correction for small distributions) from statsmodels. Tests for freedom from reintervention were made using the logistic regression model from statsmodels. The outcome variable of re-intervention was defined as "0" for no intervention and "1" if subsuquent intervention occurred. Independent variables analyzed were age, gender, and comorbidities including hypertension, diabetes, end-stage renal disease. Independent variables also were the type of arterial injury as defined above. Model assumptions included independence of observations, in that each data point was independent of the others, large sample size, and no multicollinearity. Statistical significance was defined as a=0.05.

Due to the use of de-identified data and information, this study was exempt from institutional board and ethics review. There were no major potential sources of bias within this study. This study followed the criteria outlined by the 22 point checklist within the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines for observational studies (Supplemental Figure 1).

In the preparation of this manuscript, artificial intelligence (AI) tools or assistance were not utilized.

Results

A total of 323 upper extremity iatrogenic arterial injuries (IAIs) were identified. The mean age of the cohort was 59 years old (+/- 18 years), 50% (162 patients) were female, and 33% identified as white race versus 23% black and 3% Hispanic. Comorbidities of the overall cohort are listed within Table 1. Overall, 58% of patients were diagnosed with their arterial injury in the emergency department followed by 21% as outpatients, 12% on inpatient floors, and 9% in the intensive care unit (ICU).

The most common upper extremity IAI was arterial thrombosis (171, 53%), followed by pseudoaneurysm (85, 26%). Extravasation injuries were observed in 12% of cases. Less common injuries included arterial stenosis (5, 6%), other injury (2, 0.6%), arterial kinking (1, 0.3%), and arteriovenous fistula (1, 0.3%). Most common causes of upper extremity IAIs were arterial lines (76, 24%), cardiac procedures (66, 20%), and dialysis access complications (63, 20%), followed by trauma (39, 12%), and vascular surgery procedures (28, 9%) as seen in Table 2. Within the 63 dialysis access complications specifically, 26 (41%) were due to arterial thrombosis in proximity of an old thrombosed or ligated arteriovenous fistula (AVF), 16 injuries (25%) occurred after AVF creation or revision, 10 (16%) during dialysis/cannulation, 7 (11%) fistulogram complications, and 5 (8%) arterial injuries after infected arteriovenous graft removal. For arterial line injuries, from available data, the majority were caused by 20-gauge access.

Table 1: Overall Cohort Upper Extremity Iatrogenic Injury Patient Characteristics.

Characteristic		Number/Percentage
Age	Mean (SD)	59 (18)
Race	Black	74 (22)
	Hispanic	11 (3)
	Other/Non-Specified	120 (37)
	White	108 (33)
	Asian	9 (3)
Gender	F	162 (50)
	M	161 (50)
Body Mass Index	Mean (SD)	304 (6)
Coronary Artery Disease	No	202 (63)
	Yes	121 (37)
Congestive Heart Failure	No	240 (74)
	Yes	83 (26)
Hypertension	No	220 (68)
	Yes	103 (32)
Diabetes	No	208 (64)
	Yes	115 (35)
Chronic Kidney Disease	No	208 (64)
	Yes	115 (36)
End Stage Renal Disease	No	230 (71)
	Yes	93 (29)
Cerebral Vascular Accident	No	270 (84)
	Yes	53 (16)
Peripheral Artery Disease	No	268 (83)
	Yes	55 (17)
Anticoagulation	No	199 (62)
	Yes	124 (38)
Coagulopathy	No	307 (95)
	Yes	16 (5)
Location	Emergency Department	187 (58)
	Inpatient Floor	39 (12)
	Intensive Care Unit	29 (9)
	Outpatient	68 (21)

The most injured artery was the radial artery (135, 42%), followed by the brachial (104, 32%), and axillary artery (40, 12%) (Table 3). Less commonly injured vessels were the subclavian artery (27, 8%) and ulnar artery (15, 5%). The most frequent region of injury was the forearm (127, 39%), arm (125, 38%), axilla (33, 10%) and the wrist (29, 9%). The thoracic outlet was an infrequent location of IAIs (8, 3%). Overall, 51% (164) of upper extremity IAIs were on the right arm versus 49% (158) were left laterality.

For imaging, computed tomography angiography (CTA) imaging diagnosed 51% (163) of IAIs, while duplex ultrasound diagnosed 49% (159) of the injuries. Radial artery injuries were significantly more likely to be diagnosed via arterial duplex (114/135, 84%, p=0.04) (Figure 1) versus other upper extremity arteries, including the brachial artery (27/104, 26%) and axillary artery (5/40, 26%) (Table 4). Brachial artery injuries were diagnosed more often with CTA imaging (77/104, 75, p=0.02). The radial (94, 69%) and brachial arteries (43, 41%) had significantly higher diagnosis of thrombosis followed by pseudoaneurysm (Figure 2) (25, 19% and 43, 41% respectively, all p values < 0.05) compared to other injured arteries Table 4. Axillary artery injuries were most frequently extravasation/hematoma (13, 33%) (Figure 3), followed by pseudoaneurysm (12, 30%), and thrombosis (10, 25%). Most common presenting symptoms were upper extremity swelling (93, 29%), pain (90, 28%), and digital ischemia/embolization (54, 17%) (Table 5). Out of the cohort, 12 patients (4%) were asymptomatic at time of IAI diagnosis.

Table 2: Type and cause of upper extremity iatrogenic artery injuries.

		Number/Percentage
Type of Injury	Pseudoaneurysm	85 (26)
	Thrombosis	171 (53)
	Dissection	4 (1)
	Extravasation/Hematoma	39 (12)
	Stenosis	18 (6)
	Kinking	1 (0.3)
	Arteriovenous Fistula	1 (0.3)
	Other	2 (0.6)
Cause of Injury	Arterial line	76 (24)
	Cardiac Procedure	66 (20)
	Dialysis Access Complication	63 (19)
	Trauma	39 (12)
	Vascular Procedure	28 (9)
	Other	22 (7)
	Intravenous Line	10 (3)
	Interventional Radiology Procedure	5 (2)
	Neurosurgery Procedure	4 (1)
	Central Line	3 (1)
	Orthopedic Procedure	3 (1)
	Injection Drug Use	3 (1)

Table 3: Iatrogenic upper extremity arterial injury location, region, and laterality.

		Number/Percentage
Artery Injured	Radial Artery	135 (42)
	Brachial Artery	104 (32)
	Axillary Artery	40 (12)
	Subclavian Artery	27 (8)
	Ulnar Artery	15 (5)
Region of Injury	Forearm	127 (39)
	Arm	125 (38)
	Axilla	33 (10)
	Wrist	29 (9)
	Thoracic Outlet	8 (3)
Laterality of Injury	Left	164 (51)
	Right	158 (49)

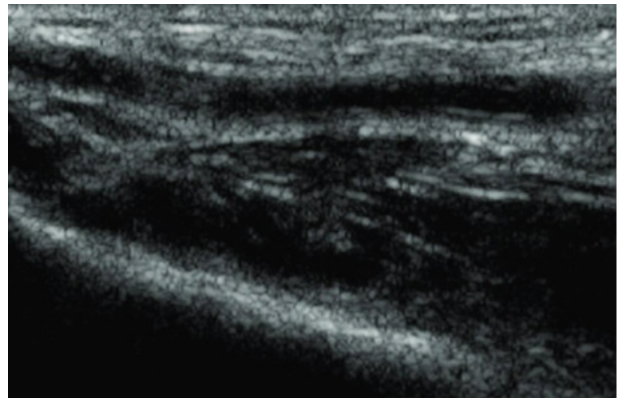

Figure 1: Longitudinal view on duplex ultrasound of a radial artery thrombosis after arterial line placement.

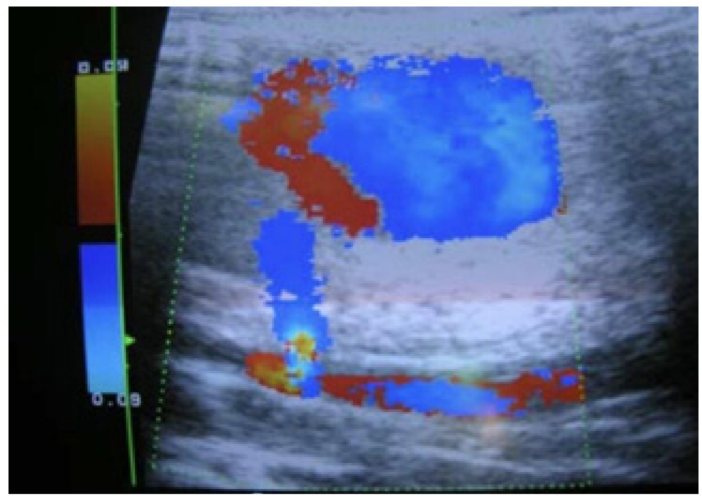

Figure 2: Longitudinal view on color duplex ultrasound of a brachial artery pseudoaneurysm.

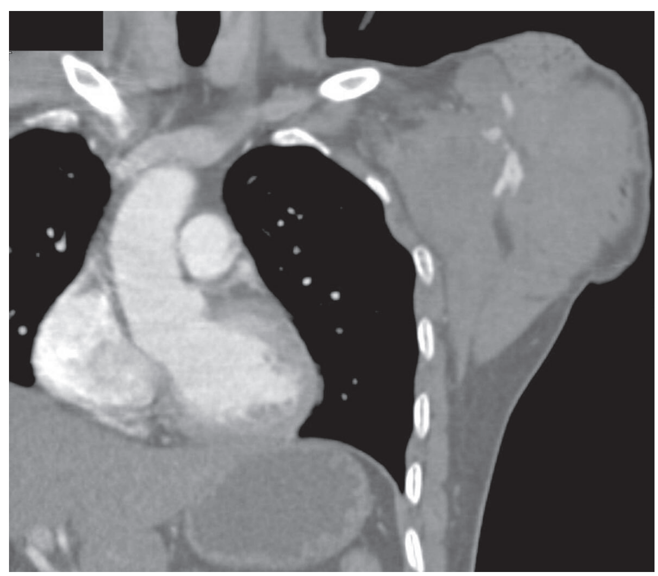

Figure 3: Coronal view of computed tomography angiography of a left axillary artery injury with active extravasation and surrounding hematoma.

Table 4: Method of imaging for diagnosing upper extremity iatrogenic artery injuries based on location and type of arterial injury.

Artery Injured	Axillary Artery	Brachial Artery	Radial Artery	Ulnar Artery	Subclavian Artery
Imaging Method for Diagnosis					
Computed Tomography Angiography	35 (88)	77 (74)	21 (16)	9 (60)	20 (74)
Duplex Ultrasound	5 (12)	27 (26)	114 (84)	6 (40)	7 (26)
Imaging Method for Diagnosis					
Pseudoaneurysm	12 (30)	43 (41)	25 (19)	3 (20)	2 (7)
Thrombosis	10 (25)	43 (41)	94 (70)	11 (73)	13 (48)
Dissection	1 (2)	0	2 (1)	0	1 (4)
Extravasation/Bleed	13 (33)	11 (11)	11 (8)	1 (7)	3 (11)
Stenosis	3 (8)	5 (5)	2 (1)	0	8 (30)
Kinking	1 (2)	0	0	0	0
Arteriovenous Fistula	0	0	1 (1)	0	0
Other	0	2 (2)	0	0	0

Table 5: Presenting symptoms for patients with upper extremity iatrogenic artery injuries.

Presenting Symptoms	Number/Percentage
Upper Extremity Swelling	93 (29)
Upper Extremity Pain	90 (28)
Digit Ischemia/Embolization	54 (17)
Bruising	44 (14)
Acute Limb Ischemia	38 (12)
Upper Extremity Paresthesia	39 (12)
Enlarging Mass	28 (9)
Hematoma	22 (7)
Asymptomatic	24 (7)
Bleeding	12 (4)
Necrotic Digit/Extremity	11 (3)
Compartment Syndrome	7 (2)

Average time from injury to diagnosis of upper extremity IAIs was 145 days (+/- 673 days), with significant variability across injury types. This long length of time from injury to diagnosis was driven by subclinical pseudoaneurysms (215 days) and asymptomatic radial artery occlusions/thromboses (150 days). Most were medically managed and presented later from the date of injury. Extravasation injuries were diagnosed more rapidly (4 days on average, median 2, IQR 1-5), while pseudoaneurysms and thromboses had longer delays [215 days (median 217, IQR 103-250) and 150 days (median 137, IQR 95-173), respectively]. Average day from diagnosis of the IAI to operation, if indicated, was 14 days (+/- 43 days) (Table 6). A total of 173 patients (54%) did not have a surgical intervention, while 150 patients (46%) underwent intervention. Patients with asymptomatic radial and ulnar artery occlusions underwent observation, with little clinical sequela to this cohort. Rationale for this management, was risk outweighed benefit for an asymptomatic radial artery occlusion. Out of the patients who did not undergo a procedure, 86 (50%) were initially placed on either a heparin drip or anticoagulation, particularly in the inpatient setting for patients with new diagnosis of arterial thrombosis. Of patients with non-operative management of pseudoaneurysms, 5% underwent US guided compression successfully and 95% underwent thrombin injection. Pseudoaneurysms with long, small necks were eligible for thrombin injection, while those with short necks or very small pseudoaneurysms were eligible for compression. Following thrombin injection 87% had initial success on repeat duplex, with 13% requiring subsequent ultrasound guided thrombin injection.

Table 6: Repair type, need for reoperation, and timing from cause to diagnosis and operation for patients with upper extremity iatrogenic artery injuries.

		Number/Percentage
Repair Type	**Primary Repair**	58(39)
	Endovascular Balloon / Stent	30 (20)
	Thrombin Injection	19 (13)
	Hematoma evacuation	13 (8)
	Bypass	10 (6)
	Ligation	10 (6)
	Patch Repair	7 (5)
	Embolization	2 (1)
	Pressure / Compression	1 (1)
Reoperation?	**No**	116 (77)
	Yes	34 (23)
Days From Cause to Diagnosis	Mean (SD)	142 (673)
Days From Diagnosis to Operation	Mean (SD)	14 (43)
Estimated Blood Loss	Mean (SD)	129 (172)

For the 150 patients who underwent intervention, the majority underwent primary repair of the injured vessel (58, 39%), followed by endovascular interventions (30, 20%), including balloon angioplasty and/or stenting, and thrombin injection (19,13 %). Ten patients (6%) required arterial bypasses, while 10 (6%) arterial injuries underwent ligation. For arteries undergoing bypass, they were specifically axillary (5) and brachial artery (5) injuries, where reversed GSV was utilized for bypass in all patients. For the 10 arterial ligations, all of patients underwent radial artery ligation, secondary to non-salvageable artery and ulnar dominant flow to the hand. Associated procedures performed with open repair included 37 embolectomies and 7 fasciotomies. Four of the endovascular interventions utilized tissue plasminogen activator (tPA) during the procedure. Most interventions had good outcomes with 143/150 (95%) successful repairs, as defined by resolution of symptoms that did not require subsequent intervention during that admission. 34 patients (23%) required reoperation on the ipsilateral extremity. However, majority of these cases (32/34) were dialysis access procedures, including dialysis access creation, revision, or fistulogram. These were unrelated to the initial upper extremity IAI repair. 2 patients who had underwent brachial artery bypass, underwent upper extremity angiogram with balloon angioplasty for mid graft stenosis and one for stenosis at the distal anastomosis. Both were successful.

Overall mortality in the cohort was 72 deaths (22%) with an average of 520 days (+/- 822 days) from presentation of IAI to death. The causes of death were not explicitly categorized in this study; however, there were no deaths directly related to the procedure. The prolonged time frame suggests that many deaths were likely related to underlying comorbidities. No cases of limb or digital amputation were documented in this study. Mean follow up time for this study was 1,002 days.

Subgroup analysis of the three most common upper extremity IAIs, pseudoaneurysm, thrombosis, and extravasation, was performed as seen in Table 7. Patients with extravasation IAIs were more likely to have coronary artery disease (80%) than pseudoaneurysm (55%) or thrombosis (63%) patients (p=0.035). Meanwhile, thrombosis IAI patients were significantly more likely to have chronic kidney disease (70%, p=0.012) and end-stage renal disease (78%, p<0.001). Extravasation IAI patients were more likely to be diagnosed in the emergency department than pseudoaneurysm or thrombosis injuries (67% vs 42% vs 23%, p<0.001).

Pseudoaneurysms were more likely to result as a dialysis access complication than thrombosis or extravasation IAIs (36% vs 11% vs 18%, p<0.001) (Table 8). Arterial thrombosis was more likely to be caused by arterial lines than pseudoaneurysm or extravasation injuries (36% vs 11% vs 13%, p<0.001). Meanwhile extravasation injuries were more likely caused by trauma, than pseudoaneurysm or thrombosis (36% vs 13% vs 4%). Extravasation injuries had significantly shorter days from cause of injury to diagnosis (4 days vs 215 days vs 150 days, p=0.002) and higher estimated blood loss in the operating room (121 cc, p<0.001).

Extravasation IAIs were more likely to undergo hematoma evacuation than pseudoaneurysm or thrombosis interventions

Table 7: Patient demographics and location of diagnosis compared between types of upper extremity iatrogenic arterial injury.

		Pseudoaneurysm	Thrombosis	Extravasation/Hematoma	p
Total Patients		**85**	**171**	**39**	
Age	**Mean (SD)**	58 (17)	58 (18)	59 (20)	0.958
Race	Black	28 (33)	29 (17)	12 (31)	0.13
	Hispanic	4 (5)	4 (2)	2 (5)	
	Other/Non-Specified	30 (35)	72 (42)	9 (23)	
	White	21 (25)	61 (36)	15 (39)	
	Asian	2 (2)	4 (2)	1 (2)	
Gender					0.071
	F	34 (40)	94 (55)	18 (46)	
	M	51 (60)	77 (45)	21 (54)	
Body Mass Index	Mean (SD)	25 (5)	28 (6)	27 (7)	**0.005**
Coronary Artery Disease	No	47 (55)	108 (63)	31 (80)	**0.035**
	Yes	38 (45)	63 (37)	8 (20)	
Congestive Heart Failure	No	63 (74)	126 (74)	28 (72)	0.962
	Yes	22 (26)	45 (26)	11 (28)	
Hypertension	No	22 (26)	59 (35)	14 (36)	0.331
	Yes	63 (74)	112 (65)	25 (64)	
Diabetes	No	50 (59)	113 (66)	27 (69)	0.414
	Yes	35 (41)	58 (34)	12 (31)	
Chronic Kidney Disease	No	44 (52)	119 (70)	28 (72)	**0.012**
	Yes	41 (48)	52 (30)	11 (28)	
End Stage Renal Disease	No	46 (54)	133 (78)	31 (90)	**0.0002**
	Yes	39 (46)	38 (22)	8 (20)	
Cerebral Vascular Accident	No	68 (80)	143 (84)	34 (87)	0.584
	Yes	17 (20)	28 (16)	5 (13)	
Peripheral Artery Disease	No	69 (81)	146 (85)	34 (87)	0.599
	Yes	16 (19)	25 (15)	5 (13)	
Anticoagulation	No	51 (60)	102 (60)	28 (72)	0.355
	Yes	34 (40)	69 (40)	11 (28)	
Coagulopathy	No	81 (95)	165 (97)	34 (87)	0.057
	Yes	4 (5)	6 (3)	5 (13)	
Location	Emergency Department	36 (42)	39 (23)	26 (67)	**1.30E-07**
	Floor	16 (19)	32 (19)	3 (8)	
	Intensive Care Unit	10 (12)	58 (34)	6 (15)	
	Outpatient	23 (27)	42 (24)	4 (10)	

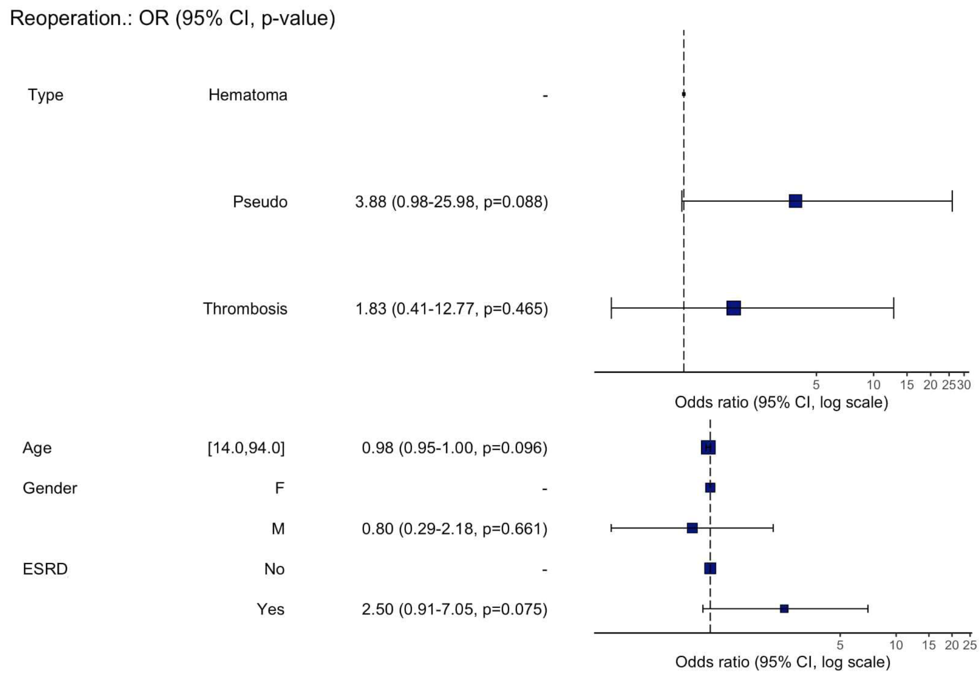

Figure 4: Odds ratios for reintervention after repair of iatrogenic arterial injury based on type of arterial injury and patient demographics.

(50% vs 4% vs 0%, p<0.001). Pseudoaneurysm patients were more likely to undergo re-operation after initial intervention (18% vs 6% vs 5%, p=0.005). This suggests that pseudoaneurysm management may require closer post-procedural monitoring and alternative intervention strategies to reduce recurrence risk. While open repair remains an option in many cases, early thrombin injection when indicated and close post-intervention follow up may help reduce reintervention rates, particularly in high-risk populations such as dialysis patients, who had disproportionately high rates of arterial pseudoaneurysms (36%). As shown in Table 8, pseudoaneurysm patients had an odds ratio of 3.88 for re-operation compared to those with extravasation injuries. Figure 4 further illustrates these differences in re-intervention rates across injury types. End stage renal disease trended towards higher rates of reintervention (Odds ratio 2.50, p=0.075). There was no significant difference between males and females and odds of re-intervention (Figure 4).

Discussion

Iatrogenic upper extremity arterial injuries (IAIs) remain a significant yet underrecognized complication of medical interventions, impacting patient morbidity, procedural risk assessment, and long-term vascular health [12]. Our findings emphasize the need for heightened clinical awareness in procedural planning and postoperative surveillance. Undiagnosed thromboses or arterial bleeding can lead to serious morbidity, including potential limb loss or dysfunction.

Our study highlights that extravasation injuries were diagnosed and treated most rapidly (4 days), whereas pseudoaneurysms (215 days) and thromboses (150 days) had significantly longer delays (p=0.002). Given their subacute or chronic presentations, pseudoaneurysms and thromboses warrant a lower threshold for vascular assessment to avoid missed or late diagnoses. A timely work-up with appropriate vascular imaging is essential to prevent irreversible ischemic damage and improve patient outcomes, even in patients who are months to years from their index upper extremity vascular procedure. The authors recommend that in order to avoid this delay, either a lower clinical index of suspicion regarding any upper extremity symptoms post-procedure be utilized for non-invasive testing. Alternatively, a protocol be developed where every patient with upper extremity access undergo non-invasive duplex imaging prior to discharge in facilities with these imaging capabilities.

This study also has direct procedural implications. The high frequency of radial artery injuries (42%) underscores the importance of careful access site selection and routine post-procedural vascular assessments. While radial access is preferred for percutaneous interventions due to its lower bleeding risk [13,14], it still accounted for a substantial portion of iatrogenic complications. Since radial artery injuries were more often diagnosed by duplex ultrasound (84%) than CTA, this reinforces the need for ultrasound utilization for both procedural guidance and complication detection with trained technicians [15]. In contrast, brachial artery injuries were more frequently diagnosed via CTA (75%), emphasizing the need for site-specific imaging strategies. Given this, surgeons and interventionalists may be more inclined to utilize radial access when possible over brachial given the less expensive, more readily available, and renal-sparing ultrasound imaging utilized to adequately evaluate iatrogenic injury.
In addition to the site of injury, the cause is also important and carries with it clinical implications. Arterial line placement (24%)

Table 8: Cause of injury, repair type, need for reoperation, and timing of diagnosis and repair compared between types of upper extremity iatrogenic arterial injury.

		Pseudoaneurysm	Thrombosis	Extravasation/Hematoma	p
Total Patients		**85**	**171**	**39**	
Cause	**Arterial Line**	9 (11)	61 (36)	5 (13)	**5.20E-09**
	Cardiac Procedure	15 (18)	42 (25)	4 (10)	
	Dialysis Access Complication	31 (36)	19 (11)	7 (18)	
	Injection Drug Use	1 (1)	0	1 (2)	
	Orthopedic Procedure	0 (0.0)	2 (1)	1 (2)	
	Other	4 (5)	12 (7)	5 (13)	
	Trauma	11 (13)	7 (4)	14 (36)	
	Vascular Procedure	6 (7)	16 (9)	1 (2)	
	Intravenous Line	6 (7)	3 (2)	1 (2)	
	Central Line	1 (1)	2 (1)	0	
	Interventional Radiology Procedure	0	4 (2)	0	
Repair Type	**Primary Repair**	23 (40)	29 (55)	4 (20)	**<0.001**
	Endovascular Balloon / Stent	7 (12)	11 (21)	1 (5)	
	Thrombin Injection	14 (25)	0	2 (10)	
	Hematoma Evacuation	2 (4)	0	10 (50)	
	Bypass	3 (5)	6 (11)	0	
	Ligation	6 (10)	2 (4)	1 (5)	
	Patch Repair	2 (4)	3 (6)	1 (5)	
	Embolization	0	0	1 (5)	
	Pressure / Compression	0	1 (2)	0	
Reoperation?	**No**	70 (82)	161 (94)	37 (95)	**0.0055**
	Yes	15 (18)	10 (6)	2 (5)	
Days from Cause to Diagnosis	Mean (SD)	215 (656)	150 (766)	4 (7)	**0.0029**
Days from Diagnosis to Operation	Mean (SD)	24 (64)	7 (18)	5 (20)	0.165
Estimated Blood Loss	Mean (SD)	1 (0)	2 (0)	121 (116)	**<0.001**

was the leading cause of upper extremity IAIs, highlighting the importance of standardized catheterization protocols. Although arterial lines are widely used in the ED, ICU, and operating room, they pose a high risk for thrombosis and pseudoaneurysm formation, particularly in patients with small-caliber vessels [16]. Risk factors include female sex, multiple punctures, and prolonged catheter dwell time (>48–72 hours) [17].

Regarding the etiology of the injuries, extravasation injuries were more frequently caused by trauma compared to pseudoaneurysms or thrombosis and had a significantly shorter time from injury to both diagnosis and intervention (Table 8). This underscores the critical need for a rapid and decisive response in cases of upper extremity arterial bleeding or trauma to ensure timely hemostasis, prevent ischemic complications, and improve overall limb salvage rates [18-20]. Unlike extravasation injuries, which present acutely with active bleeding, thrombosis and pseudoaneurysms often exhibit more subtle physical exam findings, making delayed diagnosis a concern. A high index of suspicion remains essential for diagnosing upper extremity arterial thrombosis or pseudoaneurysms, particularly in post-procedural patients with non-specific ischemic symptoms.

Within the study cohort, about half of the patients with IAIs underwent surgical intervention, while the remainder were managed medically. Given the predominance of radial artery injuries, it is possible that many cases of thrombosis or occlusion were safely observed due to dual arterial supply or ulnar artery dominance in most patients [21]. However, for patients requiring surgical repair, primary vessel repair was the most frequently utilized intervention, demonstrating high rates of technical success. Whenever feasible, repairing the artery in a transverse orientation remains critical to prevent vessel narrowing and ensure optimal perfusion [22]. In cases where vessel damage was too extensive for primary repair, bypass procedures were required. The increasing role of endovascular interventions was also evident, particularly with covered stent placement for axillary and subclavian artery injuries, which are often difficult to expose surgically. Endovascular repair offers advantages such as shorter procedural time and reduced intraoperative blood loss [23], highlighting its evolving role in vascular trauma management.

Despite high success rates, pseudoaneurysms had the highest reoperation rate (18%) among upper extremity IAIs (compared to 6% for thrombosis and 5% for extravasation, p=0.005). This emphasizes the need for improved repair strategies. Given their higher recurrence rates, early thrombin intervention when feasible, open intervention when not possible, and stricter post-procedural surveillance may reduce the need for reoperation, particularly in dialysis-related pseudoaneurysms. The management of upper extremity pseudoaneurysms is reflected in the literature at other institutions examining pseudoaneurysms of the common femoral artery [24]. Clinicians should also consider individualized follow-up schedules for high-risk patients, incorporating serial duplex ultrasound assessments to monitor for persistent arterial abnormalities.

This study describes the incidence, causes, and outcomes of upper extremity IAIs, offering valuable insights for improving procedural safety and patient care. Despite being underrecognized, IAIs remain a significant complication of medical interventions, necessitating a data-driven approach to risk stratification, diagnosis, and management. However, our findings are not without limitations.

First, as a retrospective study, our ability to assess long-term functional outcomes and exact symptom onset is inherently limited. Additionally, while our data spans multiple hospitals, the findings reflect a single healthcare system, which may limit generalizability to broader patient populations.

Another key limitation is the potential for missing data and misclassification. Since patient data were extracted from electronic medical records (EMRs) and imaging reports, it is possible that some IAIs were not documented, particularly milder cases that did not warrant imaging or surgical intervention. Additionally, misclassification bias may have occurred if certain injuries were coded incorrectly or misattributed to another cause. Despite efforts to standardize data collection, variability in documentation practices and diagnostic criteria across different institutions may have influenced our findings. Furthermore, trauma was included as a mechanism of injury, but the authors acknowledge that trauma is technically not an iatrogenic injury. However, it adds for good analysis of upper extremity arterial injury and comparison of presenting and artery injured to other iatrogenic causes. This is even more true given the outcomes from the traumatic injury cohort did not differ significantly from the other groups, showing that when appropriately managed traumatic arterial injuries of the upper extremity can fare as well as atraumatic injuries.

The study's power is also constrained by sample size, raising the possibility that some cases of upper extremity IAIs may have been missed, particularly those not identified via imaging. Furthermore, clinically silent cases, such as arterial stenosis, may be underrepresented, as they often go undiagnosed unless symptomatic or incidentally detected on imaging. Additionally, while the mean follow-up period of 1,002 days is substantial, the absence of long-term functional outcomes or late complications limits the study's impact. Follow up noted at this length was primarily from non-vascular surgery clinical providers and there unfortunately was not data given on upper extremity function. This information was instead, used for calculating overall cohort mortality.

In conclusion, upper extremity iatrogenic arterial injuries occur due to a variety of procedural factors and require a nuanced approach to management. This study identifies arterial lines and cardiac procedures as the leading causes of upper extremity IAIs, with pseudoaneurysm and thrombosis being the most common injury types. While operative intervention remains a key treatment, 54% of cases were successfully managed non-operatively, emphasizing the importance of individualized management strategies. A heightened awareness of high-risk procedures and earlier intervention may help prevent complications, reduce reoperation rates, and improve patient outcomes. The radial and brachial arteries are the most commonly injured upper extremity vessels, necessitating procedural caution during percutaneous access. Ultimately, our findings can help inform future risk-reduction strategies and best practices for proceduralists across specialties to minimize iatrogenic vascular complications

Conclusion

Upper extremity IAIs can often be managed successfully with both operative and non-operative approaches, depending on the type and timing of injury. Arterial lines and cardiac procedures were the leading causes of upper extremity IAIs, with pseudoaneurysm and thrombosis as the most common injuries. The radial artery, followed by the brachial artery, were the most injured upper extremity arteries. 54% of cases were successfully managed non-operatively while operative interventions, when needed, had high rates of success. A high clinical index of suspicion and prompt work up of upper extremity IAI should be employed to achieve accurate diagnosis and optimize outcomes for patients.

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