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Foreign Intravascular Object Embolization and Migration: Bullets, Catheters, Wires, Stents, Filters, and More

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Additional information is available at the end of the chapter

Abstract

Foreign intravascular object embolization (FIOE) is an important, yet underreported occurrence that has been described in a variety of settings, from penetrating trauma to intravascular procedures. In this chapter, the authors will review the most common types of FIOEs, including bullet or "projectile" embolism (BPE), followed by intravascular catheter or wire embolization (ICWE), and conclude with intravascular noncatheter object (e.g., coil, gelatin, stent, and venous filter) migration (INCOM). In addition to detailed topic-based summaries, tables highlighting selected references and case scenarios are also presented to provide the reader with a resource for future research in this clinical area.

Keywords: intravascular emboli, iatrogenic injury, penetrating trauma, bullet injury, coil migration, intravascular device embolization, catheter or wire embolization

1. Introduction

Both traumatic and iatrogenic foreign intravascular object emboli (FIOE) have been described in the literature [1–3]. Traumatic bullet or "projectile" emboli (BPE) are mostly secondary to bullets or bullet fragments [1, 4, 5], with various types of shrapnel contributing to a smaller number of total cases [6]. In general, smaller caliber projectiles such as shot gun pellets are among the most common BPEs [8]. Iatrogenic FIOE are usually due to venous catheter dislodgement and retained guidewire migration [8, 9]. Such intravascular or wire embolization (ICWE) events continue to occur despite increased emphasis on patient safety and adverse event prevention [10]. As increasingly complex

endovascular procedures are becoming commonplace, reports of various types of intravascular objects (e.g., stents, coils, gelatin, and filters) migrating or embolizing to anatomically remote sites have been published [11–16]. Collectively, we have included the latter heterogeneous group of events under the umbrella term "intravascular noncatheter object migration" (INCOM).

The treatment of FIOE has evolved significantly over the last two decades, largely due to advances in endovascular therapeutics. Percutaneous intravascular techniques have become the gold standard in most situations, with surgery serving largely as a last-resort rescue option. Clinical management of FIOE is highly individualized and patient specific. Healthcare providers should be aware of major therapeutic options and any potential pitfalls. This chapter reviews FIOEs by type, specific complications, and clinical management. We will also discuss the most commonly encountered types of intravascular FIOEs, including BPEs, ICWEs and INCOMs associated with endovascular procedures.

2. Bullet or projectile embolism

Bullet or "projectile" embolism (BPE, **Figure 1** and **Table 1**) is a rare phenomenon in trauma, with approximately 300 published cases in the literature [17]. The first instance of a traumatic BPE was published by Thomas Davis in 1834, when he reported a case of a wooden fragment that embolized from the venous circulation to the right ventricle in a young boy [5]. A bullet embolism occurs when a small caliber, usually low velocity bullet, penetrates a single vessel wall and remains within the circulation [4]. Thus, the bullet must be of a smaller diameter than that of vessel, as well as of sufficiently low kinetic energy to traverse only one vessel wall and come to rest within the vascular lumen. In this context, shotgun pellets and 22-caliber bullets are the most commonly encountered projectiles [18]. Nearly all of the cases in literature involve bullets 0.38 caliber and smaller, with only one recorded case of a 0.40 caliber bullet embolism [18]. In rare cases, various fragments of shrapnel have been found to embolize as well [6, 19, 20].
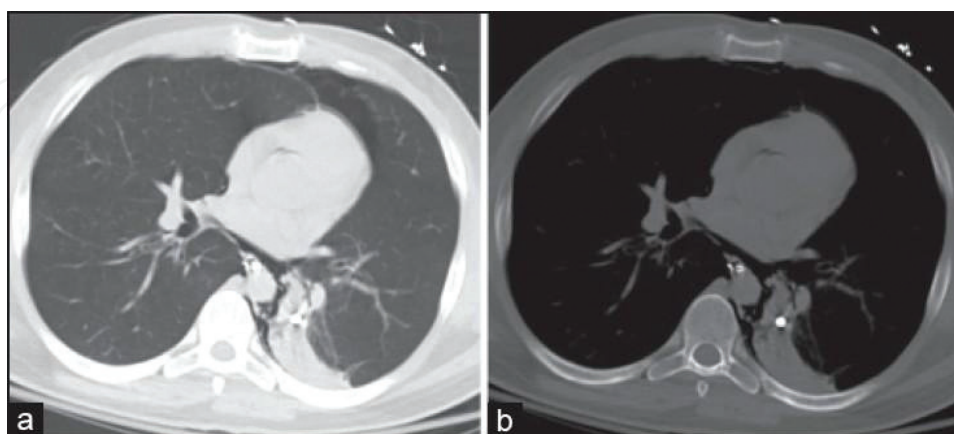

Figure 1. Computed tomography showing a 5 mm bullet that embolized to the left lower lobe pulmonary artery, causing a pulmonary infarction (a = lung window images; b = bone window images). *Source*: Duke et al. [1]. Images used under the terms of the *Creative Commons Attribution-NonCommercial-ShareAlike License (CC BY-NC-SA)*, which permits noncommercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

Author	Patient data	Course of projectile	Type of embolization	Intervention
Carter [4]	22-y/o M shot in the RLQ	Right external iliac vein to the left common iliac vein	Venous	Endovascular
Duke [1]	25-y/o M shot in the left face	Travelled from right jugular vein to the left lower pulmonary artery	Venous	Nonoperative
Huang [32]	19-y/o M, shot in the back	Abdominal aorta at the level of the celiac artery and travelled to the L popliteal artery	Arterial	Endovascular
Koirala [6]	36-y/o M who sustained hammer injury	Patient presented 9 days after a hammer injury left a piece of metal lodged in his R thigh. Following operative exploration of the wound in the Trendelenburg position, the object embolized to his mediastinum, lodging at the SVC-aygos junction	Venous	Sternotomy, with azygous venotomy and projectile retrieval
Lu [22]	20-y/o M shot in the right buttock	Right internal iliac vein to right middle lobe pulmonary artery	Venous	Open, after failure of endovascular
Manganas [20]	39-y/o M presented with massive hemoptysis 30 years after shrapnel blast injury to R chest	Patient sustained a remote shrapnel blast injury as a 9-y/o and presented with massive hemoptysis requiring emergency surgery	Traumatic arteriovenous malformation	Combined intervention; Emergency double lumen endobronchial intubation, arteriography with embolization, and R lower lobectomy
Miller [5]	22-y/o M shot in the left chest	Through the left hemidiaphragm into the external iliac vein, and was found in suprahepatic vena cava	Venous	Endovascular
Miller [5]	52-y/o M shot in midabdomen	IVC above bifurcation of iliac veins, was found in the right ventricle	Venous	Endovascular
Nolan [33]	46-y/o M shot in RUQ abdomen	Infrarenal IVC and travelled to the retrohepatic IVC, retracted into proximal R hepatic vein. It then migrated back to IVC and embolized retrograde to the left common iliac vein	Venous	Endovascular

Author	Patient data	Course of projectile	Type of embolization	Intervention
Padula [28]	32-y/o F who sustained abdominal GSW	Following gunshot wounding in 1952, the patient presented in 1966 with bullet embolism to the heart. Initially (1952) the bullet was lodged in the pelvis, and subsequently became fixated to the annulus of the tricuspid valve. In 1966, she developed acute cough and fevers	Venous	Cardiotomy under cardiopulmonary bypass was performed to retrieve the bullet
Pan [24]	19-y/o M shot in the LLQ of the abdomen	Abdominal aorta and gained access to the IVC through an aorto-caval fistula. It was found in the right ventricle	Paradoxical	Open approach
Ranvier [23]	20-y/o M shot in right buttock	Right internal iliac vein to the right middle lobe pulmonary artery	Venous	Nonoperative, after failure of endovascular
Schroeder [27]	19-y/o M shot in right chest	Right brachiocephalic vein, travelled to the left internal iliac vein	Venous	Endovascular
Stallings [18]	23-y/o M shot in the right shoulder	Bullet travelled from axillary vein to the right ventricle	Venous	Open, after failed endovascular
Yamanari [26]	39-y/o M shot in the left buttock	Left external iliac vein, travelling to the left pulmonary artery	Venous	Nonoperative, after failed endovascular
Yordanov [34]	14-y/o F shot in the right neck	External right jugular vein to superior vena cava to inferior vena cava and into the intrahepatic venous system	Venous	Open approach

Entries listed in alphabetical order, based on first author's name.

Table 1. Summary of selected literature reports involving bullet or projectile embolization.

Several diagnostic findings should prompt suspicion of a BPE. An inconsistent number of entry and exit wounds may be indicative of a retained bullet or projectile. The possibility of an intra-vascular location of this retained object should be considered when there is no clinical or radio-graphic evidence of the projectile at any place along the expected course, or if the bullet is found at a distant or inappropriate location based on this trajectory. Additionally, a "migrating projectile" found in different locations on serial or repeat imaging should prompt suspicion of BPE [5].

Most BPEs are arterial (80%) with only 20% being venous [5]. Arterial emboli travel in the direction of blood flow and eventually become lodged in distal vessels, with the potential for

resultant end-organ or extremity ischemia and thrombosis [21]. Approximately 80% of arterial emboli are symptomatic due to acute vessel occlusion. Consequently, arterial BPEs are more likely to have early and acute clinical presentation that requires urgent procedural intervention [22]. Surgical BPE removal is considered to be the gold standard, with both open and endovascular techniques described [23].

Venous emboli also generally travel in the direction of blood flow. However, exceptions to this rule do exist. In an estimated 15% of instances, a bullet in the venous system will embolize in retrograde fashion and travel in peripheral direction under the effects of gravity [24]. Even less common, a projectile may become a "paradoxical" embolus if it enters the venous system and subsequently gains access to the arterial circulation through a traumatic arteriovenous fistula or intra-cardiac communication, such as a patent foramen ovale or ventricular septal defect [22]. The incidence of paradoxical emboli was found to be 2.4% in a review by Springer et al. [17].

As previously stated, the vast majority of venous emboli migrate in the direction of blood flow and most commonly come to rest in the pulmonary arterial system or the right heart [17, 25, 26]. A 90-year review of 120 cases of venous missile emboli compiled by Schroder et al. [27] showed that 83% eventually travelled to the right heart or pulmonary artery, and only 4% remained in the peripheral venous system. Significantly delayed venous projectile embolization has also been reported [20, 28].

Clinical consequences of venous BPE migration include pulmonary artery embolism, cardiac valve dysfunction, endocarditis, abscess formation, sepsis, thrombosis, dysrhythmias, intraventricular communications, cardiac conduction defects, tissue erosion, hemorrhage, cardiac ischemia from erosion into coronary vessels, and thrombophlebitis [5]. However, venous emboli are only symptomatic in approximately one-third of the cases, and complications from the initial injury may not occur until months, years, and even decades later [5, 20]. Therefore, treatment of venous emboli has remained controversial.

Symptomatic cases undoubtedly warrant removal, with endovascular techniques being the first line management. The danger of BPE can be exemplified by a case of an abdominal shotgun wound where pellet embolization resulted in bilateral lower extremity amputations [7]. The advent and subsequent progress in the area of endovascular interventions resulted in increased procedural safety and greater BPE retrieval success rates, as exemplified in a report from the 1980s describing removal of embolized bullet from the right ventricle [25]. Aside from previously mentioned complications of venous emboli; symptoms such as fever, pericarditis, pleural effusions, arrhythmia, and thrombi seem to favor BPE removal [5]. It has been proposed that objects >5 mm in diameter, irregularly shaped, freely mobile, or only partially embedded within the myocardium should also be considered for extraction [5].

The management of asymptomatic venous emboli is not clearly defined. In asymptomatic cases, the risk of surgical intervention involving the pulmonary artery or right ventricle must be weighed against the risk of delayed embolic or infective complications. Some authors recommend that retrieval of asymptomatic emboli should be considered only if an endovascular technique can be used, as the risks associated with invasive surgery, up to and including median sternotomy or cardiopulmonary bypass may be too high to be considered

on an elective basis [5]. Moreover, existing evidence suggests that there is no significant outcome difference between patients managed operatively versus nonoperatively [29, 30]. In terms of nonoperative management approaches, it has been proposed that patients should undergo serial imaging during outpatient follow-up, with consideration of therapeutic anticoagulation and selective use of antibiotic prophylaxis [23, 31]. The treatment of BPE continues to evolve as endovascular techniques increase in popularity and become safer. BPEs are rare but well-documented occurrences in traumatology, and further studies are required to determine the most optimal clinical management strategies.

3. Intravascular catheter or wire embolization (ICWE)

Vascular access catheters are utilized for numerous indications including long-term antibiotic delivery, parenteral nutrition, hemodynamic monitoring, hemodialysis, infusion of chemotherapeutic agents, and administration of other medications [35, 36]. Complications of vascular access include bleeding, thrombosis, infection, pneumothorax, mechanical occlusion, and rarely, catheter dislodgement/fracture with subsequent distal embolization / migration [11, 35–37]. In a study of 1500 patients with implanted venous access devices, 87% patients had no reported complications, with infection occurring in 4.8%, thrombosis in 3.2%, and catheter fracture in 0.2% cases [38]. Other studies have reported catheter fracture rates of up to 4.1% [39–41]. The utilization of intravenous catheters continues to be high. Inherent to this trend is the growing number of mechanical catheter malfunctions. Therefore, it has become increasingly apparent that effective strategies for dealing with complications of mechanical malfunction, including intravascular catheter or wire embolization (ICWE) must be developed.

Early reports of ICWE date back to mid-1950s [42]. Turner and Sommers described the embolism of a polyethylene catheter that passed from the median cubital vein to the right atrium [42]. At autopsy, a large mural thrombus was discovered at the tip of the catheter with associated myocardial necrosis. In the early 1970s, Bernhardt et al. [43] reported on 28 patients with intracardiac ICWE. In that study, mortality rate was approximately 60% [43]. In 1978, Fisher published a collected series of 42 ICWE cases reporting adequate follow-up data, with associated mortality and rate of serious complications attributable to ICWE being 38 and 71%, respectively [44]. Among causes of death were cardiac tamponade secondary to myocardial perforation, thrombotic events, pulmonary embolism, sepsis, and arrhythmias. The authors emphasized the importance of early extraction of the ICWEs [44].

Several hypotheses have been proposed regarding the cause of catheter fracture. In one review of 215 cases, the so-called "pinch-off" syndrome was found to be responsible for nearly 41% of fractures (e.g., structural failures) [45]. It was thought that mechanical stress due to repetitive catheter compression and movement relative to surrounding anatomical structures (e.g., clavicle, first rib, sharp bend at the thoracic inlet, etc.) was an important factor [46]. When this "pinch-off" sign was present, physical fragmentation of the catheter was reported as many as 170–280 days after the initial placement procedure [37]. Other potential causes of fracture

included catheter damage during extraction (17.7%), separation of port and catheter (10.7%), proximal or distal catheter fracturing (11.6%), and unknown reason in 19.1% of the patients [45]. It is likely that within the latter subgroup, unintentional catheter injury during placement or manipulation resulted in fragmentation, without the primary event being clearly identified. In another review of 92 cases, the most common fracture site was found to be at the physical junction of the port and catheter (84%) [40]. Other potential causes of fracture and dislocation include improper connection between the port and catheter during implantation [47] and the use of small syringes leading to elevated pressures in the system [48].

When catheters become disconnected or fractured, they may migrate to the vena cava, right atrium, right ventricle, and ultimately the pulmonary artery. Because the majority of known ICWEs are associated with acute or chronic clinical symptoms, there are many potentially undiscovered and asymptomatic ICWE occurrences. In fact, it has been reported that asymptomatic ICWEs may be seen in as many as 24–36% of cases of embolization [40, 45]. Many patients present with nonspecific complaints of increased catheter "flow resistance" during infusion, localized pain or swelling. In a review of 42 previously published cases of ICWE, only two cases (4.8%) presented with chest pain. Thirty-six percent of cases were discovered incidentally and 29% cases had localized swelling or pain [49]. Less commonly, patients experienced cardiac dysrhythmias such as ventricular tachycardia [49, 50].

Management of ICWEs has traditionally relied on surgical or interventional extraction to prevent future risk of morbidity and mortality. Relatively recent data suggest that ICWE-related mortality has declined to <2% and prompted some to call into question the aggressiveness of ICWE retrieval strategies [45]. Indeed, there have been several reports of retained catheters in asymptomatic patients for prolonged periods of time (e.g., 10–20 years after the original device placement) [3, 51]. In one case, a chronically retained ICWE lodged in bilateral pulmonary arteries was managed without procedural extraction [52]. In another report, a retained catheter dilator was present in the right ventricle outflow tract for >20 years without clinical symptoms and was removed electively during a later coronary artery bypass and aortic valve replacement operation [3].

Prior to the emergence of advanced endovascular techniques, surgery was the only means of removing centrally located ICWEs. In the mid-1960s, it was reported that nonsurgical retrieval of ICWE from the right atrium was possible [53]. Percutaneous ICWE removal has now become the preferred technique due to its high rate of success and low rate of complications [54]. Numerous authors have reported successful ICWE retrieval using a variety of endovascular approaches [54–58]. In the majority of such cases, vascular access has been obtained through central veins (e.g., internal jugular, femoral, or subclavian). However, the use of peripheral intravenous access sites for retrieval has now also been reported [59]. In conclusion, if central embolization of a catheter or catheter fragment occurs and retrieval is indicated, removal should be attempted by percutaneous methods. In the event that these methods are unsuccessful, the decision to move forward with surgical removal should not be automatic. Indeed, if the catheter is unlikely to further migrate or its discovery has been purely incidental, observation with or without serial imaging may be a reasonable approach [3]. Summary of literature reports on the topic of ICWE is presented in **Table 2**.

Study	Study type	Embolic source	Comment
Bindraban [54]	Case report	Port-a-cath	Description of "lasso technique" for retrieval of broken, dislocated port-a-cath fragment
Biswas [50]	Case report	Central line	Percutaneous retrieval w/ triple loop snare
Cheng [40]	Case series	TIVAD	92 cases. Retrieval w/ loop snare
Choksy [59]	Case report	TIVAD	Peripheral percutaneous retrieval
Chow [9]	Case series	PICC	11 pediatric cases. Nonsurgical, percutaneous retrieval
Chuang [39]	Case series	TIVAD	23 dislodged catheters. Retrieval w/ pigtail and loop snare
Kalińczuk [58]	Case series	TIVAD, CVC, and Swan-Ganz catheter entanglement	14 cases. Retrieval w/ pigtail and loop snare
Kim [56]	Case report	TIVAD	Percutaneous retrieval w/ pigtail catheter and gooseneck snare
Kock [38]	Case series	TIVAD	1500 patients. 0.2% catheter fracture rate
Nakabayashi [55]	Case report	TIVAD	Percutaneous retrieval w/ pigtail catheter and gooseneck snare
Pande [57]	Case report	PICC	Nonsurgical removal w/ flexible biopsy forceps

Entries listed in alphabetical order, based on first author's name.
TIVAD, totally implantable venous access device; CVC, central venous catheter.

Table 2. Summary of selected literature reports involving intravascular catheter or fragment embolization.

4. Intravascular guidewire migration or embolization

The use of guidewires in medical procedures to obtain safe vascular access began in the 1950s when the Swedish radiologist Sven-Ivar Seldinger introduced the practice of using flexible guidewires to place catheters into vessels [60]. Since then, the Seldinger technique has become the cornerstone of procedures such as angiography, percutaneous thoracostomy tube placement, certain PEG tube models, and lead insertion for artificial pacemakers or automatic implantable cardioverter-defibrillators [61–66].

One specific procedural approach that almost all medical and surgical trainees will encounter and use is the Seldinger technique for the insertion of central venous catheters (CVC) [67]. CVC placement is usually performed for hemodynamic monitoring, vascular access, or specific treatments that require central vein access. Commonly used points of access include the neck (internal jugular vein), chest (subclavian or axillary vein), groin (femoral vein), or arm (as a peripherally inserted central catheter or "PICC line") [35, 36].

Although there are many different types of CVCs available, the insertion process for all of them is similar. Due to limited scope of the current article, the reader is referred to other sources describing typical procedural steps of CVC placement [68, 69]. For the purposes of our discussion, there are two key safety messages: (a) if the catheter is adequately positioned, all lumens of the CVC should allow for the easy aspiration of blood from the vein and the flushing of saline (or heparin) into the vein; and (b) radiographs should be obtained as a final precaution to ensure that the CVC is not anatomically malpositioned, there is no evidence of pneumothorax or postprocedural bleeding, and to document that the guidewire has been removed [68, 69].

In addition to pneumothorax, central venous catheterization is associated with other, well-described risks, including infection, thrombosis, unintentional arterial puncture, malpositioning, nerve damage, bleeding, venous air embolism, and arrhythmias [35, 36]. It is estimated that between 15 and 33% of CVC attempts result in some sort of complication (including failure to place the CVC) [70, 71]. Specific recommendations exist regarding CVC placement and maintenance care to reduce complication rates, with special focus on eliminating catheter-associated infections [72].

One of the most unusual and poorly described complications of CVC placement is guidewire embolization (GWE, **Figure 2**). GWE is an iatrogenic complication estimated to occur roughly at a rate of 1–2 per several thousand CVC insertions [10, 73]. The event occurs when a guidewire migrates through the venous system causing complications such as arrhythmias, vascular injury, thrombosis, or infection. It is the direct result of a guidewire becoming lost during CVC placement by either not removing the guidewire after the procedure or failing to control the guidewire during the procedure [73].
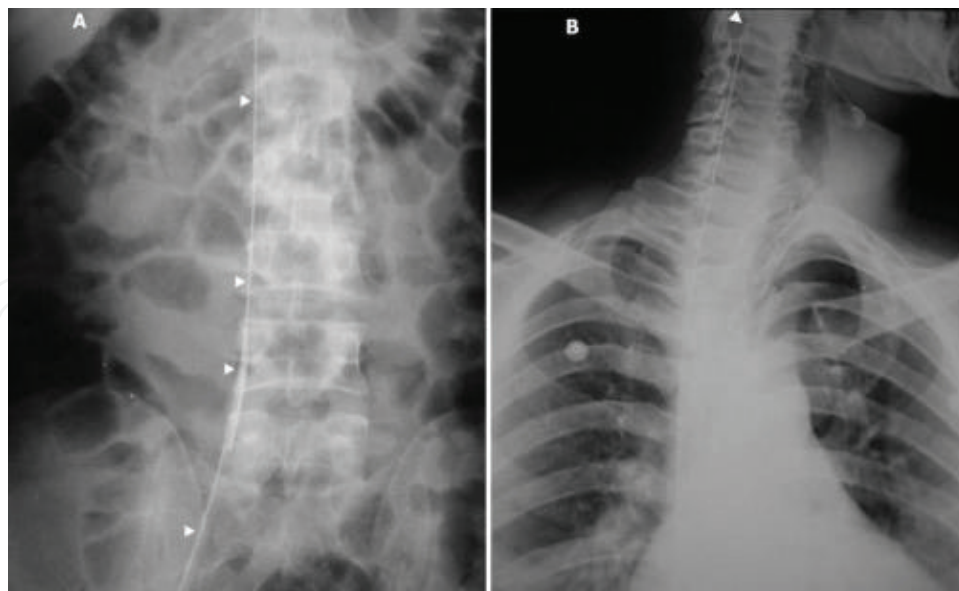

Figure 2. Radiographic images showing a retained guidewire spanning from the abdominal vena cava [A] to the right internal jugular vein [B]. *Source*: Taslimi R et al. [150]. Images used under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Inspect the wire for defects before insertion

If resistance is met during guidewire placement, remove and inspect the guidewire for damage and replace it if needed

Make sure that the guidewire is visible on the proximal and distal ends of the catheter before advancing the catheter

Advance the catheter over the guidewire and do advance the guidewire with the catheter

Hold onto the guidewire at all times until it is removed; if necessary, clamp the end of it while advancing the catheter

Inspect the wire for complete removal at the end of the procedure and document in medical record accordingly

Table 3. Recommendations for decreasing the chances of guidewire loss during CVC placement [77].

While data are lacking regarding the risk of GWE from losing a guidewire *per se*, guidewire loss is the only mechanism for GWE to occur and therefore key technical and procedural safety steps must be followed at all times when placing CVCs [10]. Risk factors for guidewire loss include CVCs placed by inexperienced providers, CVCs placed in emergent situations, operator inattention, inadequate supervision of trainees, and overburdened staff [10, 74–76]. Selected recommendations for decreasing the likelihood of guidewire loss are listed in **Table 3** [77]. All anatomic vascular access points are at risk for guidewire loss and GWE (**Table 4**). It is important to emphasize that GWEs may be discovered at various points in time, sometimes even years after the CVC placement procedure occurred. Listing of selected GWE cases is provided in **Table 4**.

Study	Demographics	Access point	Complications	Resolution	Comments
Ghatak [74]	60-y/o female	Neck—Right internal jugular v.	Guidewire found crossing superior and inferior vena cava junction	Grasped catheter and wire together with forceps and removed both together	Guidewire lost when operator distracted by arrhythmia on monitor
Schummer [77]	63-y/o female	Neck—Right internal jugular v.	Guidewire found within internal jugular v. extending into superior and inferior vena cava	Guidewire removed via right internal jugular v. open surgical exploration	Unsupervised trainee encountered resistance while advancing the guidewire and after placing the catheter, did no know to remove the guidewire. Catheter withdrawn later while guidewire still remained in vein
Schummer [77]	62-y/o male	Neck—Right internal jugular v.	Guidewire found extending from right atrium to right internal jugular v.	Guidewire removed using Dormia basket	Distracted anesthesiologist failed to supervise trainee who never removed guidewire during catheter placement

Study	Demographics	Access point	Complications	Resolution	Comments
Schummer [77]	43-y/o male	Neck—Left internal jugular v.	Guidewire hidden within catheter of left internal jugular v.	Guidewire removed with catheter held in place by two clamps	Found incidentally on X-ray within catheter
Cheddie and Singh [9]	30-y/o male	Chest - Right subclavian v.	Migration to right external iliac v.	Retrieved under fluoroscopy from cannulated right common femoral v. using snare	Inexperienced operator did not hold onto guidewire after inserting it excessively
Ghatak [76]	40-y/o female	Chest – Right subclavian v.	Guidewire found within a pre-existing catheter during hospital admission	Grasped catheter and wire together with forceps and removed both together	Guidewire was never removed after procedure and had been advanced into vein with the catheter
Narendra and Baghavan [80]	64-y/o female	Chest – Right subclavian v.	Guidewire migrated down to right external iliac vein	Removed by open surgical retrieval	Guidewire advanced with catheter by accident
Cheddie and Singh [9]	31-y/o female	Groin - Right femoral v.	Migration to inferior vena cava and superior vena cava, and ultimately into right jugular v.	Retrieved under fluoroscopy through right common femoral v. with snare	Emergent trauma catheter placed where catheter accidentally advanced with guidewire
Schummer [79]	68-y/o male	Groin – Left femoral v.	Guidewire hidden within catheter of left femoral v.	Guidewire removed after catheter removed when it was found to still be sticking outside of skin	Post-procedure X-ray showed wire but it was not reported by radiologist, discovered incidentally when another catheter was placed one day later in a different body vessel
Reynen [54]	53-y/o male	Arm – Right cubital v.	Guidewire found 14 years later with one end at the junction of the left and right pulmonary arteries and the other end in the right ventricle	Guidewire flotation on fluoroscopy was absent. Wire was thought to adhered to vascular wall so extraction not attempted	Diagnosis delayed since patient had concomitant moderate chronic obstructive lung disease

Table 4. Case series of guidewire embolisms arranged by vascular access point.

Whenever there is concern that guidewire loss may have occurred, immediate identification and remedial action is required. As obvious as this occurrence may seem when examining events retrospectively, the fact that GWEs continue to happen suggests that our current approaches are not fail-proof [79, 80]. In this context, commonly reported "red flags" suggesting guidewire

loss may include: (a) the guidewire is missing at the end of case and not accounted for; (b) there is resistance to blood aspiration and saline flushing through the distal lumen; and (c) the guidewire is visible on postprocedure radiograph. In the event that guidewire loss occurs and it is not immediately retrievable at bedside, or it is discovered that GWE has occurred, it is recommended that the first basic steps in management is to anticoagulate the patient with intravenous heparin [78] and to initiate intravenous antibiotic therapy [8]. This is usually followed by procedural retrieval of the guidewire. It is critically important to honestly disclose any adverse events to the patient and his/her family.

The need for prompt procedural extraction is supported by the reports that embolic events related to guidewires are associated with complications in 49% of cases and can be fatal in up to 20% of cases [81]. In one unusual case, the guidewire disintegrated and emerged from the patient's neck [82]. Although not strictly a study of lost guidewires, in a series of 220 ICWEs, morbidity exceeded 70% and mortality approached 40% when a catheter fragment causing embolism was not removed [44]. Not infrequently, GWEs are found incidentally on imaging [83]. With more chronic cases of guidewire retention, the foreign object may become incorporated into the vessel wall. In such circumstance, the risk of extraction may exceed the risk of continued retention, especially if there are no clinical symptoms or other manifestations. If there is any question in that regard, fluoroscopy can be performed to help guide clinical decision making. If the retained guidewire fails to exhibit "flotation" within the vessel lumen on fluoroscopy, it has likely become incorporated into the vessel wall [84].

Once the decision to remove a retained guidewire is made, the extraction is preferably performed using percutaneous endovascular techniques. However, if the GWE is in the heart or central vasculature, or if percutaneous extraction fails for any reason, thoracotomy or video-assisted thorascopic surgery may be needed [81]. Devices which have been used successfully in GWE removal (percutaneous and open) include snares, Dormia baskets, bronchoscopy forceps, and surgical hooks [52]. It is critical to remember that as the utilization of endovascular procedures increased over time so did the number of associated complications. **Table 4** provides a detailed overview pertaining to the general area of GWE, including anatomic considerations, retrieval, and morbidity.

5. Foreign object embolization and/or migration during therapeutic procedures

This section of the chapter will discuss the uncommon yet potentially serious occurrence of FIOE associated with therapeutic interventional procedures. Various types of potential FIOEs, event types, clinical manifestations, and management options will be discussed. As previously outlined, we group this heterogeneous group of events under the umbrella term "intravascular noncatheter object migration" (INCOM). Events are categorized by general anatomic location. It is important to note that many of the reports reviewed involve device migration, and that the overlap between "migration" and "embolization" entails certain mechanistic similarities. **Table 5** provides a summary of major clinical events associated with endovascular therapeutic procedures.

Author	Device and location	Comment
Intracranial		
Standard (1994) [85]	Guglielmi detachable coil; anterior inferior cerebellar artery	Dual guidewire technique was used to retrieve the device
Watanabe (1995) [87]	Detachable coil; superior cerebellar artery	Snare type endovascular retrieval device was used during retrieval
Zoarski (1997) [98]	Fibered platinum microcoils; Posterior cerebral artery	Adjustable-size, nonangled microcatheter retrieval device was used
Prestigiacomo (1999) [99]	Guglielmi detachable coil; Posterior inferior cerebellar artery	Goose neck snare "twist" technique was used during retrieval
Raftopoulos (2002) [118]	Guglielmi detachable coil; anterior communicating artery	Minimal transarterial coil hooking procedure used during retrieval
Schutz (2005) [110]	Coil fracture; Siphon internal carotid artery; posterior communicating artery	Loose end of the fractured coil was fixed with a stent at the proximal parent vessel wall
Fiorella (2005) [111]	Stretched platinum coils; superior inferior cerebellar artery, middle cerebral artery	Monorail snare technique was used during the removal of platinum coils; goose neck microsnare
Henkes (2006) [119]	Endovascular coil; basilar bifurcation	Description of coil retrieval using the alligator retrieval device
Vora (2008) [91]	Detachable coil; vertebro-basilar system	Retrieval of displaced detachable coil and intracranial stent described using an L5 Merci device during intracranial aneurysm embolization
O'Hare (2009) [120]	Migrated coil; posterior communicating artery	Description of the use of X6 Merci Retrieval device for removing a migrated coil
Lee (2011) [121]	Displaced/stretched coils; Superior inferior cerebellar artery	Authors describe the use of wire as a snare for "rescue" endovascular recovery of displaced/stretched coils
Leslie-Mazwi (2013) [122]	Displaced coil management; various intracerebral locations	Authors describe the use of stent retriever for removal of displaced microcoils
Nas (2015) [123]	Dislocated coil; internal carotid artery	Description of the use of Solitaire® stent for retrieval of dislocated coil
Cardiovascular		
Chomyn (1991) [124]	Stainless Gianturco coil; right lower lobe pulmonary artery	The authors describe the retrieval of migrated Gianturco coil from the pulmonary artery using flexible intravascular forceps
Sanchez (1992) [125]	Wallstent; right atrium	Authors describe retrieval of a Wallstent misplaced during TIPS procedure using a loop snare
Berder (1993) [11]	Coronary stent; Descending aorta	Authors describe retrieval of a migrated coronary stent from the descending aorta utilizing biopsy forceps and PTCA balloon

Author	Device and location	Comment
Kamalesh (1994) [126]	Inferior vena cava stent; Left pulmonary artery	Authors describe retrieval of embolized inferior vena cava stent from the left pulmonary artery; balloon catheter was used with the aid of trans-esophageal echocardiography
Bartorelli (1995) [127]	Palmaz stent; right atrium	Authors describe transcatheter management of embolized Palmaz stent following superior vena cava stenting
Grosso (1995) [128]	Palmaz stent; left pulmonary artery	Description of the retrieval of dislodged Palmaz stent that occurred during TIPS procedure; the authors utilized an angioplastic balloon catheter with surgical venotomy extraction
Hoyer (1996) [129]	Palmaz stent; Right ventricle	The authors describe transcatheter retrieval of a Palmaz stent embolized from the pulmonary artery to the right ventricle in a child; Retrieval and repositioning procedure is presented
Prahlow (1997) [130]	Wallstent embolization; Right atrium and aorta	Authors describe a fatal complication of TIPS procedure. Embolization of Wallstent led to cardiac perforation with tamponade and death
Feghaly (1998) [2]	Venous stent migration: (a) Left common iliac vein to right ventricle; and (b) Left braciocephalic vein to pulmonary artery	Authors describe endovascular retrieval of two migrated venous stents; balloon catheter-based techniques were utilized; operative extraction from the iliac vein was performed
Marcy (2001) [131]	Strecker stent; right pulmonary artery	Authors describe long-term management of Strecker stent migration from left innominate vein to the right pulmonary artery using anticoagulation and "wait-and-see" approach
Ashar (2002) [132]	Wallstent; Pulmonary artery	Authors describe percutaneous retrieval of a wallstent from the pulmonary artery following migration from the original placement site in the iliac vein; Jugular and femoral approaches are utilized
Abdominal		
Takahashi (2001) [133]	Steel-wire coils; migration from splenic artery to gastric body	Report of steel-wire coil migration into the stomach following arterial embolization of a bleeding splenic artery aneurysm
Ozkan (2002) [134]	Guglielmi detachable coil; erosion from hepatic artery to CBD	Patient developed pancreatitis after erosion of Guglielmi coils into the CBD, 2 years after the original hepatic artery pseudoaneurysm embolization procedure
Turaga (2006) [135]	Embolization coil; Hepatic artery to CBD	Patient developed ascending cholangitis due to coil migration into the CBD; Surgical intervention was required
Dinter et al. (2007) [136]	Embolization coil; stomach	Fatal hematemesis due to coil migration into the stomach and the associated creation of aorto-gastric fistula

Author	Device and location	Comment
Reed (2007) [137]	Embolization coil; aorto-venous fistula involving branch of the renal artery	Embolization coil eroded into the collecting system and passed through patient's urinary tract 1 year after the index procedure
Shah (2007) [138]	Steel-wire coils; migration from splenic artery into the gastrointestinal tract	After migrating from embolized splenic artery pseudoaneurysm, steel-wire coils passed via rectum
Jurałowicz (2010) [139]	Embolization coil; Hepatic artery to common bile duct	Patient developed life-threatening obstructive jaundice after migration of embolization coils from hepatic artery aneurysm to the biliary tree; Endoscopic removal of coils was performed
Miscellaneous		
Cishek (1995) [140]	Coronary artery stent; Dislodgement from coronary balloon catheter to the iliac artery	Authors describe the use of a peripheral angioplasty balloon to withdraw the stent into the arterial sheath and then from the patient
Kiyosue (2004) [141]	Intravascular coils; Coil migration from the ICA to pharynx and the external auditory canal	Radiation necrosis was thought to be contributory to the observed coil migration
Chow (2002) [142]	Embolization coil; migration from internal carotid artery into the middle ear and auditory canal	Management consisted of cutting the coil wire (approximately 25 cm) flush to the tympanic membrane; Patient was doing well at 18 month follow-up
Dagain (2008) [143]	Endovascular coil; Erosion of a coil from ICA aneurysm into the right oculomotor nerve	The patient presented 5 years after the index procedure with progressive diplopia and ptosis; Surgical correction was performed
Choi (2016) [144]	Nitinol clip; Distal migration of the clip with tibial-popliteal artery occlusion	Patient developed critical ischemia of the right lower extremity following StarClose SE device deployment; Surgical embolectomy was performed to correct the problem

CBD, common bile duct; ICA, internal carotid artery.

Table 5. Selected reports of intravascular device/particle migration or embolization; within each anatomic location, reports are arranged alphabetically.

Neurovascular procedures. Endovascular occlusion of intracranial aneurysms is commonly performed; however, coil displacement and migration remains a problem and carries the risk of thromboembolic complications [84]. The reported rates of coil migration (**Figure 3**) range from 2 to 6% [85]. Coils seal the aneurysm from blood flow by inducing thrombosis within the lumen of the aneurysm. Thromboembolic complications represent the greatest risk during the endovascular treatment of an aneurysm, with displaced coil material posing significant additional risks. Protrusion, stretching, fracture or migration of a coil may occlude proximal large-caliber vessels or migrate into smaller distal vessels [86]. Moreover, the coil may migrate with blood flow into smaller-branch vessels or lodge at the bifurcation of a vessel, resulting in limitation of flow and potentially tissue hypoperfusion. Occlusion of either the main artery or distal vessel may result in a variable size territory infarct—a disabling or even fatal event [85].

The risk for coil displacement and migration is influenced by a combination of anatomic and technical factors. Both undersized and/or unstable long coils can result in distal coil migration, especially in wide-neck aneurysms [87]. Tortuous vessels and high flow velocities are thought to increase the potential for coil migration [88, 90]. The use of balloon or stent assistance reduces the risk of coil displacement and migration.

The risk of coil prolapse, in addition to migration, is also a significant concern in endovascular treatment of cerebral aneurysms. When improperly positioned, coils may protrude out of the aneurysm neck, narrowing or occluding the parent artery. Stenting can provide further structural support when placing the coils within a specific location, but also runs the risk associated with additional instrumentation. If the coils do not completely fill the aneurysm, residual blood can enter the neck and cause the aneurysm to refill. Meticulous delivery of coils to avoid catheter tip prolapse and deployment of new coils within a stable coil basket may further minimize the risk for coil displacement [39]. Derdeyn et al. [90], found that aneurysm size and coil protrusion were the most important variables associated with postprocedure ischemic events. Systemic
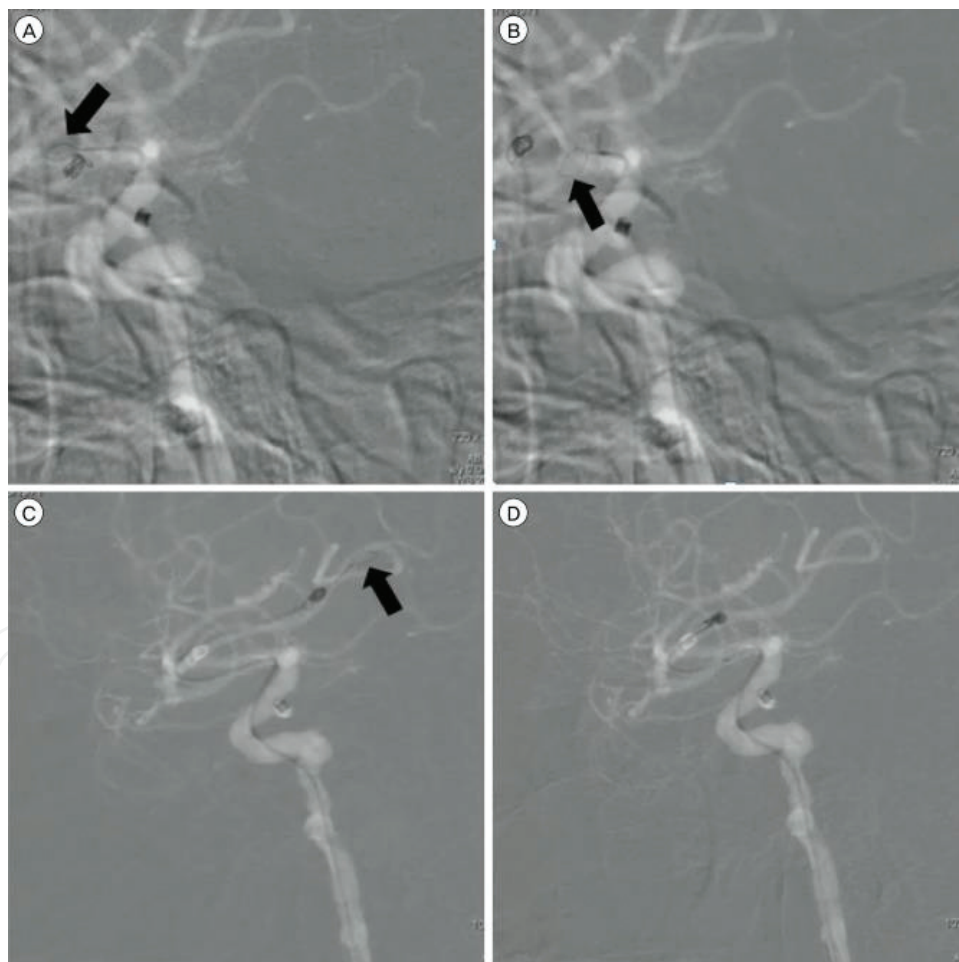

Figure 3. Angiographic images obtained during the coiling of a posterior communicating artery aneurysm. One of the coils migrated into the distal middle cerebral artery (A), requiring the use of a Goose Neck Snare ® (black arrow, A-C) for its retrieval. The right lower image shows the coil being removed after its capture using the snare device (D). *Source*: Oh et al. [151]. Images used under the terms of the Creative Commons Attribution Non-Commercial License (http://creativecommons.org/licenses/by-nc/3.0/) which permits unrestricted noncommercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

heparinization during coil placements may help reduce the risk of thromboembolism; however, definitive treatment is removal of the protruded or migrated coil [89]. Significant coil displacement may necessitate prompt intervention to avoid significant neurological morbidity and mortality [86]. Successful endovascular strategies for retrieval of migrated coils include utilization of wire techniques, snares, retriever devices, and stent retrievers. Microsnares are usually best used during coil retrieval in vessels over 3 mm in diameter, with some risk of vessel dissection or perforation [88, 89]. Among established approaches to coil recovery is the so-called coil stretching with gentle retraction; however, this is only helpful when a coil is not entangled with another device [91]. The L5 Merci Retriever was designed as a device for thrombectomy in the intracranial circulation. However, this particular retriever also carries an indication for foreign body recovery based on trials with earlier models [91, 92]. Intrinsic to the design of the L5 Merci Retriever device is a nontapering helical coil with distally attached arcading suture filaments to ensnare loose particles [91]. These modifications may offer another possible approach for recovery of misplaced coils or stents. Occasionally, endovascular approaches fail and salvage approaches such as microsurgical removal and stent fixation of fractured coil fragments may be employed [86, 93, 94].

Cardiovascular procedures. Indwelling objects, including catheters, wires, and stents may embolize to the heart or the pulmonary artery when utilized in the venous system. Inadequate adhesion to the vessel wall, with subsequent stent dislodgment may be one factor for migration [55]. Within the venous circulation, migrating objects may come to rest at different anatomic levels depending on the location of placement and object size [55, 95]. For venous stents, meticulous procedural planning and selection of the correct device size are both critical. To avoid migration, stent diameter should be optimized to the size and location of the target vein [96, 97]. Stents that migrate from the lower extremities primarily lodge in the right side of the heart and the inferior vena cava, with the superior vena cava and the hepatic veins involved less commonly [98]. In terms of cardiac locations, migrating stents lodge between the inflow area of the right atrium and the inferior atrial or ventricular wall followed by the pulmonary arterial system [99].

Arterial stents may also undergo distal migration [100]. Prevention of such occurrences involves careful procedural planning, including detailed anatomic review of target vessel size and tortuosity [101]. Due to substantial risk of distal complications in such cases, immediate recognition and correction is indicated [102]. Various intravascular and open techniques have been described and successfully utilized to retrieve migrated arterial stents [100, 102, 103]. Operative removal of migrated intravascular stents is associated with high morbidity [104]. For that reason, percutaneous transluminal retrieval must be considered a primary option for the removal of a migrated stent. Exact technique and technical approach depends on stent length and diameter, area of migration, retrieval instruments available, operator experience, and anatomy of the vasculature.

Abdominal procedures. Endovascular interventions have been utilized in a variety of abdominal disease states, from chronic mesenteric ischemia to management of aneurysmal disease [105, 106]. Stent placement for mesenteric ischemia, much like in peripheral vascular disease, can be complicated by distal device migration [107]. Technical considerations are generally similar to those in peripheral vascular disease. Various abdominal aneurysms and pseudoaneurysms have been treated with endovascular embolization, stent insertion, and particle injection [105, 108]. Distal migration of aortic stents, as well as the presence of endoleaks, mandates the use of corrective endovascular techniques [108, 109]. Metallic coils,

gelfoam, hydrogel particles, or acrylic glue may be used for embolization [110]. Vascular pseudoaneurysms or aneurysms with a narrow neck benefit greatly from coil embolization and wide-neck, large diameter structures are best treated with a stent [111].

More selective visceral artery embolizations may be also associated with INCOM and significant postprocedural complications. Udd et al. [112] reported a morbidity rate of 17% in a series of embolizations for bleeding pseudoaneurysms due to chronic pancreatitis. In that study, endovascular complications included one localized coil migration requiring procedural retrieval and one distal coil embolization to the iliac artery necessitating operative intervention [112].

Unintended therapeutic particle embolization. Injectable particles used to embolize tumors or to achieve hemostasis in cases of traumatic hemorrhage can unintentionally embolize outside of the intended target area and cause remote end-organ injury [113, 114]. In one case, a stainless steel coil originally placed in the left renal artery migrated into the distal left common femoral artery [113]. In another study, bile duct necrosis occurred at high rates following transcatheter hepatic arterial embolization using Gelfoam powder potentially due to an unintended particle dispersion pattern [115]. Particle INCOM has also been described following intracranial tumor embolization procedures, although the mechanism behind this phenomenon is not fully understood [114]. Finally, Mehta et al. [116], discuss the potential risk of hydrophilic polymer emboli introduced into the vasculature during interventional procedures (e.g., cardiac catheterization, diagnostic, and therapeutic angiography). Associated clinical sequelae may include pulmonary infarct, stroke, and distal hypoperfusion reported days to weeks following suspected INCOM events [116]. In addition to listing cases of intravascular embolization and/or migration of various iatrogenic objects, **Table 5** also includes a number of instances where intravascular devices have migrated and eroded out of the vascular tree.

Complications of particulate foreign body embolization with cerebral angiography have also been described since the 1960s [117]. Shannon et al. [117], reviewed 5 years of autopsies related to postangiogram complications, looking at histological specimens from surgically resected cerebral arteriovenous malformations (AVMs). The results revealed three patients with cerebrovascular events likely related to particulate cotton fiber, gelfoam or polyvinyl alcohol embolization during diagnostic and therapeutic angiography. Possible theories include that the cotton fibers from guazepads, sponges, surgical drapes, etc. carry loosely woven synthetic fibers. These fibers may also be attracted to the glue utilized in AVM repair and travel with the liquid adhesive during the procedure. AVM embolization is typically a much longer procedure than conventional angiography alone, and this greater duration of "at risk" time may help facilitate catheter or guidewire contamination from these extraneous particles. Another comorbid factor includes difficult vascular access due to proximal atherosclerosis in affected patients, as noted during the procedure and by pathology sampling [117].

6. IVC filter migration and embolization

Although relatively rare, intravascular IVC filter migration and filter fragment embolization have been described [145]. Tam et al. [146] reported that the incidence of filter device fracture was relatively high (7.2%) and involved 5.5% of recipients of the Bard Recovery Filter. This

incidence rate has been corroborated by others [15]. Certain anatomic factors may lead to the formation of concentrated stress points and thus may cause predisposition for device failure. Specific risk factors include deployment in a tortuous vena cava, deployment over renal ostia, and placement adjacent to a vertebral osteophyte [15]. In descending order, the most common sites for filter fragment embolization were pulmonary arteries (31%), iliac/femoral veins (27%), and the right ventricle and renal vein (3.8% each) [146]. Factors that increase the risk of filter migration and embolization include the so-called "mega-IVC" (e.g., IVC diameter ≥28mm), filter malpositioning, and a large embolus creating a "sail effect" that then dislodges the filter from the IVC, with subsequent embolization to the heart [147–149]. A fracture-free survival model described by Tam et al., predicted a fracture rate of 40% at 5.5 years [146]. In one case, a broken IVC filter strut embolized to the heart, causing cardiac tamponade with hemodynamic collapse approximately 6 years after original placement procedure [149].

7. Conclusions

Foreign body embolism is a relatively heterogeneous grouping of rare but well-known complications. In aggregate, a vast majority of these events are iatrogenic in nature and involve retained catheters, wires, and various types of intravascular particles. Traumatic projectile fragments are well documented but far less common. Depending on the symptomatology, these unusual embolic events may go unnoticed for a period of time and may or may not require surgical intervention. The type and location of the emboli will dictate clinical approaches, with preference for endovascular retrieval with open surgical options reserved for the occasional case of unsuccessful minimally invasive intervention.

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