Transcatheter arterial embolization for the management of iatrogenic and blunt traumatic intercostal artery injuries

Andreas P. Chemelli, MD,[a] **Michael Thauerer, MD,**[b] **Franz Wiedermann, MD,**[c] **Alexander Strasak, PhD,**[d] **Josef Klocker, MD,**[e] and **Iris E. Chemelli-Steingruber, MD,**[a] *Innsbruck, Austria*

Objective: **The purpose of this retrospective study was to evaluate transcatheter arterial embolization (TAE) for the management of iatrogenic and blunt traumatic intercostal artery (ICA) injuries associated with hemothorax and clinical deterioration.**

Methods: **From May 1999 through April 2007, 24 consecutive patients (17 men, 7 women; mean age 53 years) presenting with active ICA hemorrhage underwent TAE mainly by means of coils combined with polyvinyl alcohol (PVA) particles. Eleven of them had blunt traumatic injuries (group A, n = 11) and 13 had iatrogenic injuries (group B, n = 13). In all patients, ICA injuries resulted in acute bleeding with clinical deterioration and hemothorax. Before discharge, all patients underwent clinical examination, laboratory tests, and chest x-ray. After discharge, no specific follow-up protocol was required, and the patients were questioned on their state of health at regular intervals and underwent CT or chest x-ray as needed.**

Results: **Primary technical success (PTS) was achieved in 21 of 24 patients (87.5%). In group A, it was achieved in all but one patient (90.9%) and in group B in 11 of 13 patients (84.6%). A total of three patients needed secondary interventions, which failed in one of them, amounting to a secondary technical success rate (STS) of 8.3%. The total cumulative mortality rate was 37.5% (n = 9). In group A, it was 9.1% (n = 1) and in group B, it was 61.5% (n = 8). 30-day-mortality was 9.1% in group A, where one patient died due to multiple severe associated injuries, and 30.8% (n = 4) in group B, where one patient died due to treatment failure and three patients due to severe comorbidities. During follow-up, no more deaths occurred in group A, while in group B, four more patients died due to severe comorbidities, amounting to a late mortality rate of 30.8%.**

No technical complications and no complications such as chest wall or spinal cord ischemia were observed. The mean observation period was 44.6 months in group A and 23.8 months in group B.

Conclusion: **TAE of ICAs is a minimally invasive, safe, and reliable treatment option to control massive intrathoracic hemorrhage, especially in patients with serious comorbidities and/or multiple injuries. However, it should be performed only by experienced interventionalists and exact knowledge of the anatomic features of the affected artery and of collateral pathways is mandatory to avoid complications. (J Vasc Surg 2009;49:1505-13.)**

Persistent intrathoracic hemorrhage and hemothorax are common diagnoses after chest trauma. For many years exploratory thoracotomy has been the treatment of choice in patients in whom conservative treatment including close observation, chest tube insertion, fluid resuscitation, pain control, and/or respiratory support failed. However, patients with severe associated injuries or serious medical comorbidities are poor candidates for surgical intervention. In these patients and in patients in whom thoracotomy is not successful, transcatheter arterial embolization (TAE) offers a less invasive and reliable therapeutic alternative for the management of hemorrhage from intercostal arteries (ICA)s.

From Department of Radiology,[a] Department of General and Transplant Surgery,[b] Department of Anaesthesiology and Critical Care Medicine,[c] Department of Medical Statistics, Informatics and Health Economics,[d] and Department of Vascular Surgery,[e] Innsbruck Medical University.

Competition of interest: none.

Reprint requests: Iris Chemelli-Steingruber, MD, Department of Radiology, Medical University Innsbruck, Anichstrasse 35, 6020 Innsbruck, Austria (e-mail: iris.steingruber@uki.at).

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The advent of selective and superselective angiography has made the detection of bleeding sources easier and TAE of ICAs safer. Several authors have reported successful TAE of ICAs with excellent technical success rates and encouraging short- and midterm-results.[1-11] However, most of these studies are case reports with relatively short observation periods, except for the series by Carillo at al, which included eight patients.[12]

The purpose of the present study was to confirm the advantages of this technique based on a larger patient population (n = 24) and over a longer observation period.

MATERIALS AND METHODS

Patients. From May 1999 through April 2007, 24 patients (17 men, 7 women) with a mean age of 53 years (range: 14-84 years) presenting with ongoing thoracic bleeding underwent TAE of ICAs mainly by means of coils combined with polyvinyl alcohol (PVA) particles. No patients treated for ICA lesions during this period underwent primary surgical intervention. The patients were divided into groups A (blunt traumatic injury, n = 11) and B (iatrogenic injury, n = 13) depending on the cause of the lesion. In group A, the hemorrhage was caused by rib

Table I. Patients, ASA criteria, primary technical success (PTS), secondary technical success (STS), failure, materials used, and number of arteries embolized in each patient

	Age	*Sex*	*ASA before bleeding of ICA*	*ASA after bleeding of ICA*	*PTS*	*STS*	*Failure*	*Coils*	*PVA*	*NBCA*	*Embolization*
Group A											
1	52	f	1	4	1	0	0	1			8. ICA right
2	40	m	2	4	1	0	0	1			10. ICA left
3	57	m	2	4	1	0	0	1	1		10. ICA left
4	3	m	1	4	1	0	0	1			4., 5. ICA link
5	84	m	3	4	1	0	0	1			3., 4., 6., 9. ICA left
6	55	m	2	4	0	1	0	1	1		8.-10. ICA left, musculophrenic artery, inferior phrenic artery
7	57	f	3	4	1	0	0		1		1.-5. ICA right
8	66	m	1	4	1	0	0	1	1		6., 8., 9. ICA left
9	63	f	3	4	1	0	0	1	1		1.-3. ICA left, thyrocervical trunc
10	52	m	1	4	1	0	0	1			4., 7. ICA left
11	75	f	3	4	1	0	0	1	1		3.-6. ICA left
Group B											
12	55	m	3	4	1	0	0	1	1		9. ICA left
13	37	m	2	4	1	0	0		1		5. ICA left
14	55	m	4	4	1	0	0	1	1		6., 7., 9. ICA right
15	71	w	3	4	1	0	0	1	1		9., 10. ICA left
16	14	f	4	5	1	0	0	1	1		5., 6. ICA left
17	57	f	3	4	1	0	0	1	1		8., 9., 10. ICA left
18	68	m	3	4	1	0	0	1	1		8., 9. ICA right
19	49	f	3	4	1	0	0	1	1		4. ICA right
20	63	m	3	4	1	0	0	1	1		9. ICA left
21	76	m	2	4	0	0	1	1	1	1	6., 7. ICA left
22	35	m	2	4	1	0	0	1			9. ICA right
23	23	m	2	4	0	1	0	1	1		11., 12. ICA left
24	59	m	3	4	1	0	0	1	1	1	6., 7., 10. ICA left

fractures in 10 patients and by a vertebral body and transverse process fracture in one patient. In group B, it was caused by chest tube insertion in four patients, by puncture or pigtail drainage of pleural effusion in five patients, by lung or lung tumor biopsy in three patients and by redon drainage insertion after renal tumor extirpation in one patient. The American Society of Anesthesiology (ASA) classification[13] of the patients before and after bleeding of the ICAs is shown in Table I and comorbidities in Table II.

In all patients, the hemorrhage was associated with hemothorax and hypotension. Computed tomography (CT) images performed on admission in 16 patients, showed extravasation of contrast agent into the pleural cavity in 13 and pseudoaneurysm in 2 of them. One patient showed both, extravasation and pseudoaneurysm (Fig 1). In all of them, the CT studies excluded other possible etiologies for the hemothorax such as aortic rupture or lung laceration. Chest x-ray performed in seven patients and ultrasound images in one patient demonstrated huge pleural effusions. As these eight patients had iatrogenic vessel lesions, the bleeding source was obvious and therefore, CT was not necessary.

The decision for TAE was made on the basis of clinical symptoms and laboratory findings combined with either CT imaging, chest x-ray or ultrasound, by an interdisciplinary team including anesthesiologists, trauma surgeons, thoracic surgeons, and interventionalists. It is our policy to consider TAE when a patient's hemoglobin level drops by more than 2 points compared with that on admission or when the patient shows signs of shock with hypotension or tachycardia.

Table II. Comorbidities in both patient groups

	Group A	*Group B*
Patients	11	13
Hypertension	1	2
Diabetes mellitus	2	1
Chronic obstructive pulmonary disease	4	0
Cardiovascular disease	3	4
Hepatobiliary disease	1	3
Nervous disease	3	0
Chronic renal failure	0	1
Malignancy	0	5
Transplantation	0	2
Total	14	17

In nine patients in group A and in six patients in group B, TAE was performed under general anesthesia with intubation, because they were in poor medical condition. In the remaining patients, the procedure was performed under local anesthesia with anesthesiological standby. All patients

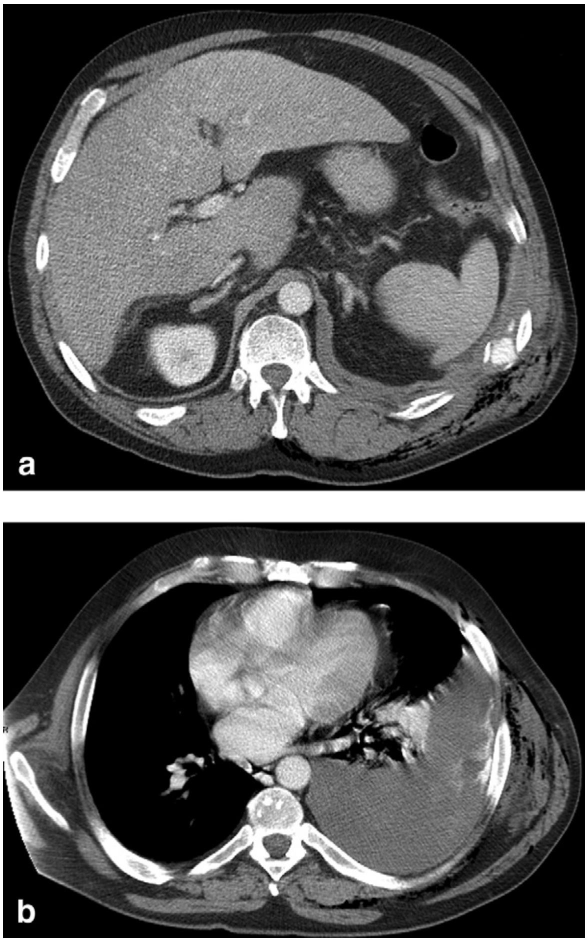


Fig 1. A 57-year-old patient (*patient 3*). **a**, Contrast enhanced computed tomography (*CT*) of the thorax reveals a fracture of the second to the tenth left ribs and a pseudoaneurysm within the chest wall, originating from the injured tenth intercostal artery (*ICA*). **b**, The same CT study shows a contrast extravasation into the pleural cavity in addition to the pseudoaneurysm seen above.

obtained hemodynamic support during the intervention, including blood and fluid transfusion and vasopressors.

A total of 57 ICAs were embolized, 27 in group A and 30 and in group B (median 2; interquartile range [IQR 1-3]). In addition, embolization of the thyrocervical trunk was performed in patient 9 and embolization of the musculophrenic and the left inferior phrenic arteries in patient 6. The number of ICAs embolized in each patient is shown in Table I.

Diagnostic work up. On admission, contrast-enhanced CT was obtained from 16 patients, chest x-ray from seven patients, and chest ultrasound from one patient. From May to December 1999, CT examinations were performed using a single-slice SDCT scanner. From December 1999 to June 2006, CT examinations were performed using a 4-row multi-slice scanner. Since June 2006, data have been acquired from a 64 detector-row MDCT scanner (VCT; GE Medical Systems, Milwaukee, Wis) using a slice thickness of 5 mm with pitch 0.98 in the standard reconstruction kernel. Scans were obtained using 100-150 mL of a nonionic contrast agent (Ultravist; Schering, Berlin, Germany) administered at a concentration of 300-370 mg I/mL and a flow rate of 3 mL/s.

Technique. All procedures were performed in an angiographic suite (Integris BV 3000; Phillips, Eindhoven, The Netherlands). In all patients, access was obtained using a right femoral approach. Selective angiography was performed using a sidewinder I catheter (Cordis, Miami, Fla) or a cobra catheter (Cordis). Superselective embolization was performed using a coaxial catheter technique by introducing a 0.018-in microcatheter (tracker-18, fast tracker; Target; Boston Scientific, Boston, Mass) through the angiographic catheter.

Various embolic agents were used either separately or in combination. The materials used in each patient are listed in Table I. Pushable microcoils (MWCE 18, 2 to 4 mm in diameter; Cook, Bloomington, Ind) were placed in 22 patients, in most of them in combination with PVA particles of different sizes (150 to 250 and/or 250 to 355 μm, and/or 350 to 500 Contour® Target, Boston Scientific; Boston, MA). Coils alone were used in six patients and PVA particles alone in two patients. In two patients with severely reduced coagulation, the coils were combined with a mixture of N-butyl-2-cyanoacrylate (NBCA; Histoacryl, B. Braun, Melsungen, Germany) and iodized oil (Lipiodol; Guerbet, Aulnay-sous-Bois, France) to achieve quick closure of the lesion. As NBCA is FDA-approved solely for use in the central nervous system arteriovenous malformation embolization, relatives were informed about the specific risks of this treatment before giving their consent.

The coils were inserted using a coilpusher (Coilpusher 16; Target, Boston Scientific; Boston, Mass). The PVAs were used to promote thrombosis or to treat small side branches of ICAs. They were inserted by slow manual injection to avoid backflow into the aorta and/or the radicular arteries. Small PVA particles (size 150-250 μm) were only injected after placing coils distal to the bleeding source to avoid soft tissue ischemia.

We used different strategies depending on the location of the bleeding source. If the bleeding source was in the main ICA itself, microcoils were first placed distal to the source to prevent retrograde bleeding and to protect the thoracic wall from embolization. This was followed by placement of further microcoils proximal to the bleeding source and intermittent injection of PVA particles in order to accelerate thrombosis.

If the source was in a small side branch of the ICA and could therefore, not be reached by the microcatheter, first, the part of the ICA distal to the origin of the side branch was occluded using microcoils, followed by injection of small PVA particles into the ICA in order to occlude the bleeding source and the entire side branch. Finally, the part of the ICA proximal to the side branch, close to its origin was occluded using microcoils.

If the source was in a very distal part of the ICA and could therefore, not be reached by the microcatheter,

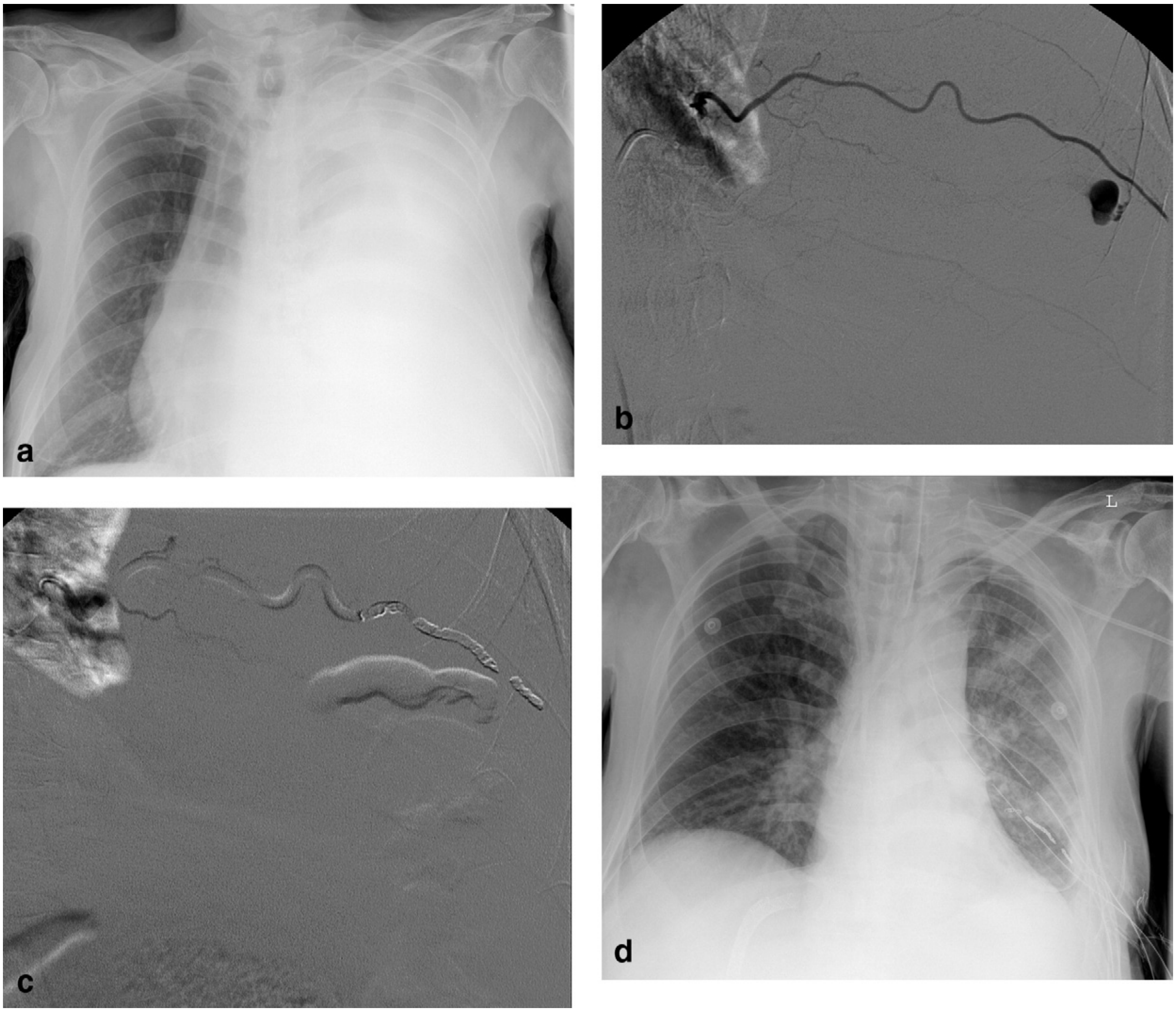


Fig 2. A 71-year-old patient (*patient 20*). **a**, Chest x-ray shows left-sided hemothorax after puncture of a pleural effusion. **b**, Selective angiography of the ninth intercostal artery (*ICA*) demonstrates a pseudoaneurysm of a small side branch of the ICA. **c**, Selective angiography shows successful closure of the bleeding source by means of microcoils and PVA particles. **d**, Chest x-ray after endovascular intervention and insertion of chest tubes shows disappearance of pleural effusion and hemothorax.

embolization was performed by first injecting PVA particles of a larger size (>250 μm) distal to the bleeding source and by placing coils proximal to it afterwards.

If the bleeding source was very close to the radicular arteries, as seen in patient 4, we used coils alone, without PVA particles to avoid reflux of particles into the radicular arteries.

In all patients, the vascular sheath for femoral access was left in place until coagulation time was within normal range and the patient was in stable condition. All procedures were performed within 3 hours after diagnosis.

Follow-up protocol. The follow-up protocol included clinical examination, laboratory tests, and chest x-ray before discharge. CT was performed as needed (Fig 2). After discharge, no specific follow-up protocol was required. The patients were questioned on their state of health at regular intervals and underwent CT or chest x-ray as needed.

Definitions. Primary technical success (PTS) was defined on an intent-to-treat basis as successful embolization of the ICA with complete occlusion of the bleeding source during the first procedure. Secondary technical success (STS) was defined as successful embolization by a second or by further procedures.

Statistical analysis. Cumulative survival rates were evaluated by means of Kaplan-Meier estimates. Independent predictors for death due to ICA bleeding were evaluated by means of multivariate cox proportional hazards regression analyses. Two-sided *P* values of <.05 were considered statistically significant. All statistical analyses were conducted using SPSS 16.00 statistical software.

RESULTS

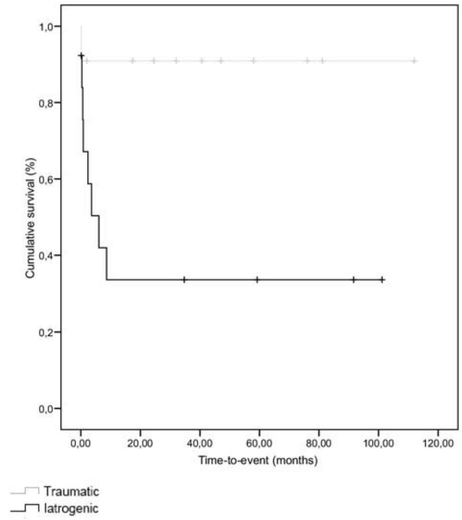
The mean procedure time was 75.2 minutes (range, 25-210 minutes). The mean amount of contrast agent used during the procedures was 199.2 mL (range, 80-390 mL). The patients required on average 8.1 units (range, 2-22 units) of blood transfusion before TAE and on average 3.2 units (range, 0-20 units) of blood transfusion after TAE.

After the procedure, all patients were routinely transferred to the surgical intensive care unit. The mean length of stay in the intensive care unit (ICU) was 28 days (range, 1-182 days), followed by a mean stay on the ward of 18.1 days (range, 0-63 days). Six patients died during hospitalization (five patients within 30 days, one patient after 182 days), and 18 patients were discharged (17 of them went home and one went to a rehabilitation center).

Observation time. Mean observation time was 44.6 months (range, 0.1-111.9 months; standard deviation (SD) 34.8; 95% confidence interval (CI) 17.4-76.1) in group A and 23.8 months (range, 0.0-101.2 months; SD 36.6; 95% CI 5.0-46.9) in group B. Five patients died within 30 days, and two were lost to follow-up, which leaves a total of 17 patients who were observed for more than 30 days.

Survival rates and independent predictors for death due to ICA bleeding. In group A, cumulative survival rates were 90.9% (standard error 8.7) at 1 year, at 2 years, and at 5 years (Fig 3). In group B, they were 33.6% (standard error 13.7%) at 1 year, at 2 years, and at 5 years (Fig 3). Neither age (P = .85), nor sex (P = .32) were independent predictors for death due to ICA bleeding. Odds ratios (OR) (95% CI) obtained for both, age (OR 0.996, 95% CI 0.96-1.04, P = .85) and sex (OR 2.03, 95% CI 0.50-8.21, P = .32) were not significant.

Mortality. The total cumulative morality rate was 37.5% (n = 9). In group A, cumulative mortality was 9.1% and in group B it was 61.5%. The total 30-day-mortality rate was 20.8% (n = 5). In group A, 30-day-mortality was 9.1%. One patient (patient 7) died due to multiple severe associated injuries. In group B, it was 30.8% (n = 4) due to treatment failure. He had sustained multiple severe injuries in a car accident. Contrast enhanced CT showed complex pelvic fractures with extravasation of contrast medium from the left superior gluteal artery and the right internal pudendal artery. In addition, he had multiple left-sided rib fractures, involving ribs 2 to 12. There was no thoracic extravasation of contrast medium, but a small hemorrhagic pleural effusion. The patient underwent successful TAE of the proximal part of the superior gluteal and the distal part of the internal pudendal arteries. After the procedure, he was stable and increasing bilateral pleural effusions were successfully treated by placing chest tubes. After 21 days, a pigtail drainage was inserted under ultrasonic guidance in order to relieve a new increasing left-sided pleural effusion. After the intervention, the patient recovered and the pleural effusion resolved. Four days later, the drainage was removed. However, the patient rapidly deteriorated showing signs of hemorrhagic shock necessitating fluid resuscitation, blood transfusions, and intubation. A chest x-ray revealed a large pleural effusion. TAE was performed to occlude the sixth and seventh ICAs, which had been injured by the pigtail catheter. However, due to the severe bleedings, the patient developed consumption coagulopathy and hemorrhage from the rib fractures evolved. During two further TAE procedures the fourth, fifth, and eighth ICA s were embolized. However, the bleeding could not be stopped and unfortunately the patient died.



Patient at risk	1 year	2 years	3 years	4 years	5 years
Group A	9	7	6	4	5
Group B	4	4	3	3	2

Fig 3. Kaplan-Meier estimates of cumulative survival in group A (*blunt traumatic injuries*) and group B (*iatrogenic injuries*).

Patient 24 had a lung metastasis and bleeding started after a tumor biopsy. An injured ICA was successfully embolized, but ongoing bleeding from the metastasis necessitated wedge resection of the tumor. However, the hemorrhage could not be stopped, because the patient developed consumption coagulopathy. He died 19 days after the biopsy.

The total late mortality rate was 16.7% (n = 4). In group A, no more deaths occurred during follow-up. In group B, four more deaths occurred during follow-up amounting to a late mortality rate of 30.8%. Patients 15, 19, and 22 died of sepsis and multiorgan failure 3.6, 6.1, and 8.7 months after the intervention, respectively, and patient 20 died of acute cardiac infarction 2.4 months after the intervention.

Success rates. PTS was achieved in 21 of 24 patients (87.5%) and STS in two of 24 patients (8.33%). In group A (n = 11), PTS was achieved in 90.9%. In one patient (patient 6) (Fig 4), three embolization sessions were necessary in order to occlude the bleeding source. This patient had a car accident and was transferred to our department from a peripheral hospital, where he was intubated and treated by placement of a chest tube in order to drain his left sided pleural effusion. The patient had sustained left-sided

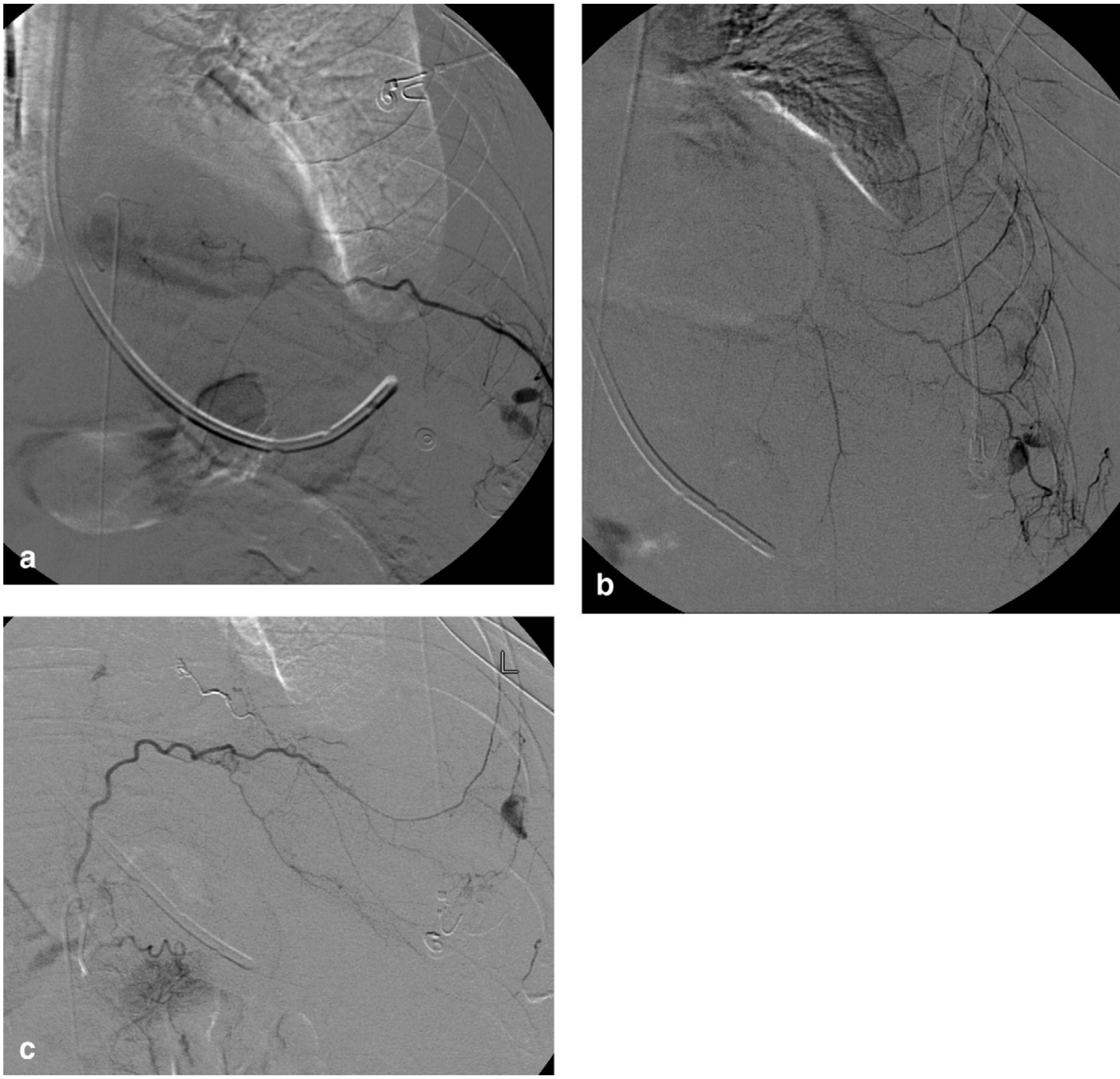


Fig 4. A 58-year-old patient (*patient 6*). **a**, Selective angiography demonstrates a pseudoaneurysm, which arises from the ninth intercostal artery (*ICA*). **b**, Selective angiography shows that the pseudoaneurysm is also fed by the musculophrenic artery (*via the internal mammary artery*). **c**, Selective angiography reveals a third route of blood supply to the pseudoaneurysm via the inferior phrenic artery.

eighth and ninth rib fractures. Laboratory tests performed at the emergency room (ER) of our department showed declining hematocrit levels and persistent bleeding from the chest tube was noted. Therefore, the patient underwent selective angiography, which revealed a bleeding source from a small side branch of the eighth ICA. The hemorrhage persisted despite embolization of the eighth, ninth, and tenth ICAs. The patient could not be stabilized, and therefore, a minithoracotomy was performed. Unfortunately, it was not possible to localize the bleeding source. Two chest tubes were inserted through the thoracotomy and the patient was transferred to the ICU and kept under close surveillance. Hours later, persistent bleeding from the chest tubes was noted and angiography revealed collateralization of the blood supply to the source of bleeding via the musculophrenic artery (the distal part of the left internal mammary artery). Despite occlusion of this new route by embolization, the bleeding persisted and contrast-enhanced CT showed intrapleural extravasation of contrast agent documenting treatment failure. Therefore, a third selective angiography was performed, which showed that the bleeding source was now fed from the inferior phrenic artery. After successful embolization of this artery, the problem was solved. The patient is doing well 58 months after the procedure.

In group B (n = 13), PTS was achieved in 84.6%. Two patients needed further TAE procedures, which failed in

Table III. Review of reports on ICA embolization

Pub. date	*Author*	*Number of patients*	*Cause*	*Number of injured arteries*	*Findings at presentation*	*Therapy*	*Technical success*	*Comments*
1977	Barbaric	1	rib fractures	1	hemothorax	gelfoam	yes	
1993	Muthuswamy	1	chest tube	1	hemothorax	gelfoam	yes	
1997	Casas	1	iatrogenic after percutaneous biliary procedure	1	hematoma	PVA particles	yes	
1998	Matsumoto	1	rib fractures	2	hemothorax	gelfoam	yes	
1998	Carrillo	5	blunt and penetrating thorax injury	5	hemothorax	gelfoam and microcoils	yes	
2002	Bluebond-Langner	1	iatrogenic after nephrectomy	1	thoracoabdominal hematoma	conservative	yes	
2003	Aoki	1	blunt thoracic trauma	1	retroperitoneal hematoma	embolization	no	surgery
2004	Kessel	1	trauma	1	hemothorax	embosphere	yes	
2005	Yu	1	violent coughing	1	thoracoabdominal hematoma	gelfoam	yes	
2005	Sekino	1	stab wound with a knife	1	hemothorax and thoracic hematoma	microcoils	yes	rebleeding after 2 weeks
2008	Hagiwara	5	blunt thoracic trauma	5	hemathorax	gelfoam	yes	
2008	Hagiwara	1	vertebral fracture	1	hemathorax	gelfoam	yes	

one of them (patient 21). This patient has been described above. He is the only patient who died due to treatment failure. In the other patient (patient 23), an adjacent ICA, which fed the primary source of bleeding, was successfully embolized 13 days after the first TAE.

No technical complications occurred during the procedures and none of the patients developed complications such as chest wall or spinal cord ischemia.

DISCUSSION

There is widespread agreement that transcatheter arterial embolization is a reliable and feasible therapeutic alternative to thoracotomy to stop intrathoracic arterial hemorrhage. Carrillo at al stated that the morbidity associated with a thoracotomy, coupled with the frustratingly low yield of finding the source of the hemorrhage in some patients, makes selective angiography and transcatheter embolization (SATE) a less invasive, more accurate, and reliable method to treat these patients.[12] The advantages of TAE for the management of ICA hemorrhage have been documented by several reports, which were summarized in Table III.[1-7,9-12,14] However, only the series by Carrillo et al from 1998 included a larger patient population (five patients with ICA and three with internal mammary artery injuries).[12] In his series, SATE was successful in all patients. In three of them, who had previously undergone unsuccessful thoracotomy, the bleeding could be stopped by SATE. In our study, including 11 patients with blunt traumatic and 13 with iatrogenic ICA lesions, only three patients needed further TAE procedures (patients 6, 21, and 23), which failed only in one of them (patient 21). This patient was the only one who died due to treatment failure.

In patients with traumatic lesions and hemorrhagic pleural effusion, who may have multiple bleeding sources, contrast-enhanced CT is a valuable diagnostic tool to identify the bleeding source, to document its anatomic relationships, and to detect extravasation of contrast agent or pseudoaneurysm. Angiography alone would be too time-consuming in these patients considering their serious medical condition. In patients with iatrogenic lesions, CT is usually not necessary, because the bleeding source is obvious. In most of these patients chest x-ray or ultrasound is sufficient.

The use of coils combined with a mixture of N-butyl-2-cyanoacrylate and iodized oil can be a valuable tool in the hands of an experienced interventionalist.[15,16] The mixture works like glue and lesions can be closed quickly and effectively, even in the absence of coagulation. However, the lesion has to be closed by one single shot, and the catheter has to be withdrawn immediately after the procedure so as not to get stuck to the artery. Moreover, success also depends on the correct ratio of N-butyl-2-cyanoacrylate to iodized oil. Therefore, we do not use this technique routinely, but only in patients with severe coagulopathy and/or when the lesion has to be closed very quickly. In our series, it was used in patients 21 and 24.

Spinal cord ischemia is a serious potential complication related to embolization of ICAs and has been reported by several authors.[17,18] This may be explained by the fact that in an early period microcatheters were not available and, therefore, the tip of the catheter, could only reach the orifice of the ICA or its proximal part. Embolization from this position is associated with the risk of displacement of embolic material into the radicular arteries and further into the spinal cord arteries.[18] However, advances in technology such as steerable guide wires and coaxial microcatheters now allow a superselective approach to the bleeding source and accurate embolization distal to the orifice of the radicular arteries thus minimizing the risk of spinal cord complications. If the bleeding source is very close to the origin of the radicular arteries, we prefer the use of coils alone, without PVA particles, to avoid reflux of particles into the radicular arteries. This is mandatory, when the artery of Adamkiewicz arises from the affected ICA. Inadvertent displacement of material into the artery of Adamkiewicz and as a consequence into the anterior spinal artery can cause spinal cord infarction as was reported after tumor embolization of a vertebral body.[17] Carrillo et al and Vujic et al stated that embolization of an ICA is contraindicated if it gives rise to any important spinal cord branch.[12,18] However, none of our patients developed spinal cord ischemia, although in patient 4, the bleeding source was very close to the origin of the radicular arteries.

Another major point is exact knowledge of the anatomic features of the affected ICA and collateral pathways. In patient 6, two embolization procedures failed, because collateral pathways could not be clearly identified. If side branches are embolized, the adjacent ICAs should also be occluded in order to prevent ongoing bleeding from collateral pathways.[11] However, the bleeding source may not only be fed by adjacent ICAs, but also by other vessels such as the musculophrenic artery,[11] which arises from the internal mammary artery. In patient 6, angiography revealed a further collateral pathway arising from the left inferior phrenic artery (LIPA) and anastomosing with its descending branch to the left lower posterior ICA. This collateral pathway was also described by Loukas et al in a study on cadavers.[19] Anastomosis of the inferior phrenic artery (IPA) with branches of the inferior intercostal, internal thoracic and/or musculophrenic arteries at the parietal pleura have been reported in inflammatory disease. Rupture of the visceral pleura with rupture of these collateral pathways leads to hemoptysis.[20]

There may also be very small collateral vessels, which are invisible at the first angiography, as seen in patient 23. Therefore, patients have to be kept under close surveillance after the procedure. Based on our experience with patients 6 and 23, we have changed our strategy and now additionally examine the IMA and the IPA in all patients in whom the bleeding source is in the ventral part of the ICA or in a very inferior ICA, in order to detect possible collateral pathways.

Another problem is disorder of the clotting system, which is generally induced by massive hemorrhage and may develop into consumption coagulopathy in patients with multiple bleeding sources. This potentially lethal disorder is difficult to treat and results in uncontrollable diffuse bleeding, as seen in patients 21 and 24.

In our series, neither age ($P = .85$), nor sex ($P = .32$) were independent predictors for death due to ICA bleeding. However, early and late mortality rates were higher in group B (30.8% and 30.8%, respectively) than in group A (9.1% and 0% respectively). The higher mortality rates in group B, may be due to the fact that most patients in this group suffered from serious comorbidities, which were the primary reason for treatment, except for patient 21, who was admitted after a car accident. Patients in poor medical condition will certainly have more problems in coping with arterial injury and intervention, than otherwise healthy individuals. However, there is no alternative to TAE in these patients, despite possible associated risks.

CONCLUSION

In conclusion, our study shows, that TAE of ICAs is a minimally invasive, safe and reliable alternative to thoracotomy in patients with active intrathoracic hemorrhage, especially in those with serious comorbidities and/or multiple associated injuries. New technologies, such as steerable guide wires, coaxial microcatheters, and various embolic agents allow a superselective approach and contribute to avoiding complications. However, TAE is not without risks and therefore, it should be performed only by experienced interventionalists who are familiar with the technique. In addition, exact knowledge of the anatomical features of the ICAs and possible collateral pathways is mandatory.

AUTHOR CONTRIBUTIONS

Conception and design: AC, IC
Analysis and interpretation: AC, MT, JK
Data collection: AC, MT, JK, FW
Writing the article: AC
Critical revision of the article: AC, IC
Final approval of the article: IC
Statistical analysis: AS
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Overall responsibility: AC

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