Transradial Approach for Hepatic Radioembolization: Initial Results and Technique

Vivian L. Bishay[1]
Derek M. Biederman[1]
Thomas J. Ward[1]
Imramsjah Martijn J. van der Bom[2]
Rahul S. Patel[1]
Edward Kim[1]
Francis S. Nowakowski[1]
Robert A. Lookstein[1]
Aaron M. Fischman[1]

OBJECTIVE. The transradial approach (TRA) has been shown to reduce the morbidity and mortality associated with arterial coronary interventions. Selective internal radiation therapy (SIRT) performed via the TRA can enhance patient comfort, compared with the traditional transfemoral approach (TFA), by allowing immediate ambulation and precluding potential complications associated with the TFA, such as closure device injury or retroperitoneal hematoma. We report our initial experience with and technique for using the TRA for SIRT.

MATERIALS AND METHODS. Between May 1, 2012, and April 30, 2015, a total of 574 procedures, including planning angiograms ($n = 329$) and infusions of ^{90}Y ($n = 245$), were performed for 318 patients (mean age, 64.5 years). Of the 245 patients who received ^{90}Y infusions, 52 had SIRT performed with the use of a permanent single-use implant of ^{90}Y resin microspheres and 193 had SIRT performed with the use of millions of small glass microspheres containing radioactive ^{90}Y. Procedural details, technical success, the radial artery (RA) occlusion rate noted at 30 days (as assessed via pulse examination), and the major and minor adverse events noted at 30 days were evaluated.

RESULTS. Technical success was achieved in 561 of 574 cases (97.7%). The reasons for crossover to use of the TFA included an RA loop ($n = 2$), RA occlusion ($n = 9$), and type D response as determined by use of a Barbeau test ($n = 2$). Patients had undergone between zero and six previous TRA procedures. The mortality rate at 30 days was 0%. Superficial bruising occurred in 13 of 574 cases (2.3%). A grade 2 hematoma that required a second nonocclusive hemostasis cuff occurred in one case. Transient forearm numbness or pain occurred in two of 574 cases. One patient had a transient convulsive event occur after receiving intraarterial infusion of verapamil. RA occlusion occurred in nine of 574 cases (1.6%).

CONCLUSION. Use of the TRA for SIRT is safe, feasible, and well tolerated and is associated with high rates of technical success and rare complications.

Keywords: hepatocellular carcinoma, interventional oncology, selective internal radiation therapy, transradial access, yttrium-90

DOI:10.2214/AJR.15.15615

Received September 14, 2015; accepted after revision May 2, 2015.

I. M. J. van der Bom is an employee of Philips Healthcare. R. S. Patel is a consultant for Reverse Medical Corporation and Sirtex Medical Limited and a lecturer for St. Jude Medical, Inc., and Terumo Interventional Systems. E. Kim is on the scientific advisory board of and an industry-sponsored lecturer for BTG International, Limited. R. A. Lookstein is on the scientific advisory board of and a consultant for the Boston Scientific Corporation. A. M. Fischman is on the scientific advisory board of and is an industry-sponsored lecturer for Terumo Interventional Systems.

[1]Department of Interventional Radiology, Icahn School of Medicine at Mount Sinai, One Gustave L. Levy Pl, New York, NY 10029. Address correspondence to A. M. Fischman (aaronfischman@mountsinai.org).

[2]Image-Guided Therapy Systems, Philips Healthcare, Best, The Netherlands.

AJR 2016; 207:1112–1121

0361–803X/16/2075–1112

Since the appearance of the first reports of radial coronary angiography, published in 1989 by Lucian Campeau [1], and percutaneous coronary angioplasty, published in 1992 by Kiemeneij and Laarman [2], the interventional cardiology community has seen a rapid increase in the use of the radial artery (RA) for cardiac catheterization, so that it now surpasses use of the femoral artery in several parts of the world [3]. The rate of use of the transradial approach (TRA) continues to increase in countries like India and Japan. It is estimated that, in 2011, 32.5% of percutaneous coronary interventions (PCIs) performed in India were done via a radial route, and in Japan, the utilization rate reached approximately 60% [4]. Although use of the TRA in the United States has increased more slowly, data from the National Cardiovascular Registry on more than 2.8 million PCIs performed between 2007 and 2012 indicated that the rate of utilization of the TRA increased from 1.18% to 16.07% during that period [5].

Observational and randomized control trials comparing the use of the TRA with the use of the transfemoral approach (TFA) and the brachial artery approach for coronary angiography and PCI consistently showed a significant reduction in bleeding and access site complications when the TRA was used [6]. In addition, studies have shown an association between the TRA and both reduced cost and greater patient satisfaction [6–13]. Among patients who have undergone procedures performed via both the TRA and the TFA, there is a strong preference for use of

TABLE 1: Baseline Demographic Characteristics of 318 Patients

Characteristic	Value
Age (y), mean (range)	64.5 (59.3–70.9)
Sex	
Male	238 (74.8)
Female	80 (25.2)
Hepatic tumor cause	
Hepatocellular carcinoma	263 (82.7)
Neuroendocrine tumor	21 (6.6)
Colorectal carcinoma	9 (2.8)
Cholangiocarcinoma	7 (2.2)
Pancreatic carcinoma	9 (2.8)
Other	9 (2.8)

Note—Except where indicated otherwise, data are no. (%) of patients.

the TRA because it offers improved patient comfort and immediate functionality of the extremities after PCI [11]. Given the rapid increase in the use of TRA for PCI in the United Kingdom and concerns about a concomitant increase in the risk of neurologic complications, a retrospective search of the British Cardiovascular Interventional Society database for information from the period between 2006 and 2010 was performed, and no association was found between the choice of access site and an increased risk of clinically detected neurologic complications [14].

The disadvantages of the TRA that are relevant to the interventional radiologist include the limited availability of differing shapes and lengths of guiding and diagnostic catheters and increased exposure of the operator to radiation, particularly during the steepest part of the learning curve. In addition, the TRA involves manipulation at the aortic arch, and although minimized by an approach through the left arm, the risk of neurologic complication resulting from interventional procedures performed below the diaphragm is unknown. Given the current limitations regarding catheter lengths, a secondary advantage of the TRA from the left arm versus the right arm is the shorter distance to the target vessel.

In the interventional radiology community, the use of the RA as an access vessel for abdominal and pelvic angiography and intervention remains largely absent. With regard to interventional oncology, Shiozawa et al. [15] described use of the TRA for chemoembolization of hepatocellular carcinoma in 177 patients. In our practice, TRA has been adopted for a variety of abdominal and pelvic interventions. The purpose of this article is to report a single institution's experience with the use of the TRA for selective internal radiation therapy (SIRT), to assess the technical feasibility and safety of using the TRA during radioembolization procedures.

Materials and Methods

Between May 1, 2012, and April 30, 2015, a total of 318 patients with hepatocellular carcinoma or liver-dominant metastasis underwent one or both parts of the two-part session that consisted of a planning angiogram using ^{99m}Tc-labeled macroaggregated albumin (MAA) and ^{90}Y treatment via the TRA. Selection of the access site was based on operator preference and patient-specific characteristics noted at the time each procedure was performed; therefore, the TRA was not used for both sessions in all cases. The exclusion criteria included an RA diameter of less than 2 mm and the lack of a patent ulnopalmar arch in the left hand, as determined by the use of a Barbeau test as discussed in the Setup and Access subsection of this article). In addition, patients with end-stage renal disease who possessed a fistula for dialysis or who were close to needing dialysis were also excluded.

After approval was granted by the institutional review board at the Icahn School of Medicine at Mount Sinai, a comprehensive review of demographic characteristics, imaging features, and adverse events was performed. Electronic medical records were reviewed to identify patient demographic and clinical data, and angiographic images for each procedure were reviewed on the hospital's Centricity PACS (GE Healthcare) to determine the rate of technical success. We assessed technical failure resulting in crossover to use of the TFA and analyzed predictors of crossover. Data on the dose-area product and fluoroscopy time were collected for all cases reported from 2013 onward.

Complications were reported in accordance with the guidelines of the Common Terminology Criteria for Adverse Events, version 4.03, and were categorized as minor or major [16]. Access site–related complications, such as hematoma, RA occlusion, and perforation, were assessed. RA occlusion was diagnosed by means of a combination of a physical examination performed at the clinic follow-up visit and a Doppler ultrasound examination performed before the intervention. Perforation was identified intraprocedurally by observation of extravasation on a radial arteriogram.

The number of prior TFA procedures related to ^{90}Y treatment was also calculated. The RA pulse was evaluated before the patient was discharged from the hospital and whenever any change in neurologic status occurred. All data were collected retrospectively.

A total of 318 patients underwent a pretreatment ^{99m}Tc-MAA planning angiogram, ^{90}Y treatment, or both during the aforementioned study period. Of the 574 cases that were undertaken, 329 (57.3%) involved a ^{99m}Tc-MAA planning angiogram. SIRT was performed with glass microspheres for 193 cases (33.6%) and with resin microspheres for the remaining 52 cases (9.1%). Patient demographic characteristics and tumor characteristics are presented in Table 1. The median patient age was 64.5 years (range, 59.3–70.9 years), with 263 patients (82.7%) presenting with unresectable hepatocellular carcinoma. The remainder of the patients presented with primary and metastatic liver malignancies.

Pretreatment Evaluation

Baseline laboratory tests and appropriate imaging examinations, including complete evaluation of hepatic vasculature with CT or MR angiography, were performed, and a clinical history was

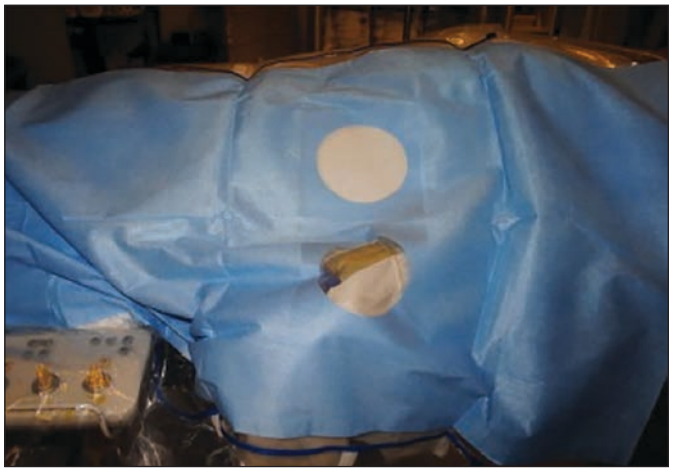

Fig. 1—Photograph of arm positioned parallel to table to allow use of standard femoral drapes and ergonomic positioning similar to that used for femoral access.

obtained. The angle of the first-order artery to the aorta and variation in the vascular anatomy were taken into account when planning to use the TRA. After initial assessment, the benefits and potential risks of using the TRA, including the possibility of converting to use of the TFA, were discussed with the patient. During preoperative assessment, the left wrist was palpated for the presence of an RA pulse, and a cream comprising 40 mg of lidocaine and 30 mg of nitroglycerin ointment (Nitro-Bid, Fougera) was applied to the volar aspect of the wrist. This preparation has previously been shown to effectively increase the cross-sectional area of the RA by a mean (± SD) of 16.5% ± 4.2% [17].

Setup and Access

All procedures were ambulatory same-day procedures performed by one of five interventional radiologists assisted by a fellow or resident in a single-plane angiography suite (Allura Xper FD20 or AlluraClarity FD20, Philips Healthcare). Patients were placed in a supine position on the angiography table. The left wrist was visually inspected, and a palpable RA pulse was again confirmed. For all cases, a standard RA access technique for noncoronary interventions, as described elsewhere by Fischman et al. [18], was used. A Barbeau test was performed to assess the patency of the ulnopalmar arch by placing a pulse oximeter on the left thumb of the patient and analyzing the arterial pulse waveform [19]. The morphologic features of the waveform were observed before and after manual compression of the RA. The response to compression was assigned a grade of A through D. A response grade of A, B, or C confirmed ulnopalmar arch patency. Patients with waveforms assigned a grade of A and B have uninterrupted arterial filling after compression. A type C waveform has initially interrupted arterial filling with recovery of the waveform within 2 minutes. A response grade of D, which was assigned when the pulse tracing was lost and was not recovered within 2 minutes, was considered a contraindication to the use of TRA. Sonographic examination of the left RA was then performed to again confirm vessel patency and to assess caliber before puncture.

In all cases, the left arm was placed parallel to the patient's body and close to the left groin, rather than in an abducted position, allowing easy placement of the catheter and wire over the patient's draped body and enabling operator and monitor positioning comparable to that noted with the use of the TFA. Standard femoral drapes were used for all TRA procedures (Fig. 1). The wrist was supinated and hyperextended on a long arm board, and a folded sheet was inserted under the distal forearm for support, with the hand taped to the board [20] (Fig. 2). Standard surgical preparation of the access site was performed. A pulse oximeter was maintained on the left thumb throughout the procedure because monitoring is, in general, necessary for all cases and because, for patients who undergo procedures performed via the TRA in particular, any change in pulse oximetry waveform from the left thumb might indicate injury to the brachial artery. All interventions were completed with the patient receiving moderate sedation, with intraprocedural monitoring performed by radiology nursing staff.

The left RA was exclusively accessed to minimize the catheter length requirement as well as to limit manipulation at the aortic arch. The RA was punctured using a short 21-gauge 38-mm needle (Radifocus Introducer Transradial Kit, Terumo Interventional Systems). The vascular needle was viewed entering the vessel, and pulsatile arterial blood return was visually confirmed before a 0.021-inch nitinol wire was advanced into the RA. If resistance was encountered, the microwire was retracted and readjusted. If the wire could not be advanced, then fluoroscopic visualization was used.

Once access was obtained, the needle was removed and a 0.021-inch tapered hydrophilic radial sheath (Glidesheath, Terumo Interventional Systems) was advanced into the RA. No dermatotomy was required for sheath insertion. The smallest feasible sheath size, which was 5 French in the majority of cases, was selected to minimize the risk of RA occlusion. A total of 3000 U of heparin, 200 μg of nitroglycerin, and 2.5 mg of verapamil was administered through the access sheath immediately after access was obtained, to reduce RA spasm and prevent thrombosis. Hemodilution and a slow injection rate of 1 mL/s were used to mitigate the burning sensation caused by verapamil. A saline side flush was subsequently started. A continuous saline infusion through the access sheath arm was subsequently started to prevent clot formation between sheath and catheter.

Catheter Selection

In most cases, a 110-cm diagnostic catheter (Sarah Radial Optitorque, Terumo Interventional Systems) and a standard 0.035-inch access wire were used to traverse the left arm and engage the descending aorta. Frequently, once the operator gained sufficient experience with RA access, navigation of the arm to the proximal axillary artery could be done quickly without fluoroscopic visualization as long as no resistance was felt, minimizing exposure to radiation for both the patient and the interventionalist. In the vast majority of cases, use of the Sarah Radial Optitorque catheter in combination with a standard 0.035-inch wire was the only catheter-and-wire combination needed to negotiate the transverse arch, direct the guidewire toward the descending aorta, and access the mesenteric arteries. A cobra 2–shaped catheter (Glidecath, Terumo Interventional Systems) was also used in a minority of cases. When the angle between the aorta and the left subclavian artery was very acute, a visceral catheter (SOS Omni 1, AngioDynamics) was useful for negotiating this turn. A 0.016-inch steerable guidewire (Fathom, Boston Scientific) also offered directionality down the descending aorta. Celiac and mesenteric angiography was performed in standard fashion. Microcatheters with lengths of 130 and 150 cm were then used to select second- and higher-order arteries.

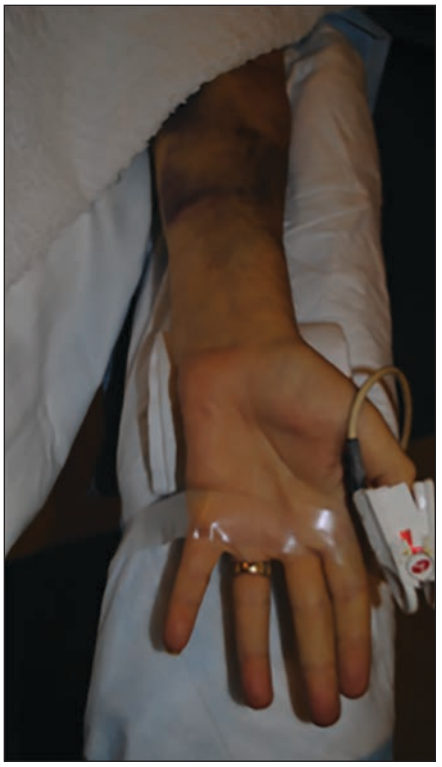

Fig. 2—Photograph of left arm of patient positioned parallel to body with wrist supinated and hyperextended on long arm board and with folded sheet inserted under distal forearm for support.

Treatment Planning

For patients who underwent planning ^{99m}Tc-MAA angiography via the TRA, hepatic digital subtraction angiography and ^{99m}Tc-MAA scinitigraphy were performed to evaluate gastrointestinal flow and lung shunting. Accessory arteries and hepatoenteric anastomoses identified during digital subtraction angiography were prophylactically embolized to avoid ^{90}Y deposition in nontargets and resultant injury [21]. The gastroduodenal artery, right gastric artery, superior pancreatic duodenal artery, cystic artery, and other nontarget arteries were embolized with the use

of coils or vascular plugs. In some instances, embolization of vessels to create flow redistribution was performed.

Appropriate positioning of the treatment catheter was also determined during this session. Cone-beam CT was used in combination with digital subtraction angiography to optimize catheter placement planning when the vascular supply to the tumor was unclear [21] (Fig. 3). Cone-beam CT data were obtained using an angiographic flat-detector C-arm–based system (AlluraClarity FD20, Philips Healthcare) with the use of an abdominal fast low-dose CT protocol (XperCT, Philips Healthcare). To acquire images, the C-arm–based system performed a rotational sweep of approximately 240° around the patient; during this sweep, 320 images were acquired at 60 frames per second. Volumetric reconstructions with a FOV of 250 × 250 × 198 mm and an isotropic resolution of 0.97 mm^3 were generated on a dedicated workstation. During cone-beam CT acquisition, the right arm was abducted and positioned above the level of the shoulder. For patients with a large body habitus or a tumor in the far lateral left hepatic lobe, the left arm was repositioned under the drape to an overhead position before cone-beam CT was performed, to allow detector clearance and optimal imaging of tumor vascularity. For all other patients, the left arm remained positioned at the side of the body. Images from cone-beam CT were reviewed for the presence of beam-hardening artifact that obscured tumor vascularity.

Depending on disease presentation, patients received treatment on a whole-liver or segmental basis with the use of glass (TheraSphere, BTG) or resin (SIR-Spheres, Sirtex) microspheres. Calculation of the therapy dose was based on the partition model, for TheraSphere, and a body surface area model, for SIR-Spheres, per the consensus panel report. For patients treated with TheraSphere, a minimally embolic brachytherapy, the entire vial was administered during the treatment session. SIR-Spheres, a moderately embolic therapy, were administered until near stasis was reached [22]. After receiving treatment, all patients underwent planar CT and SPECT/CT to assess for adequacy of coverage [23]. No unexpected extrahepatic uptake was identified on postprocedure scanning.

Hemostasis

After ^{90}Y infusion, wires and catheters were removed and a compression device (TR Band,

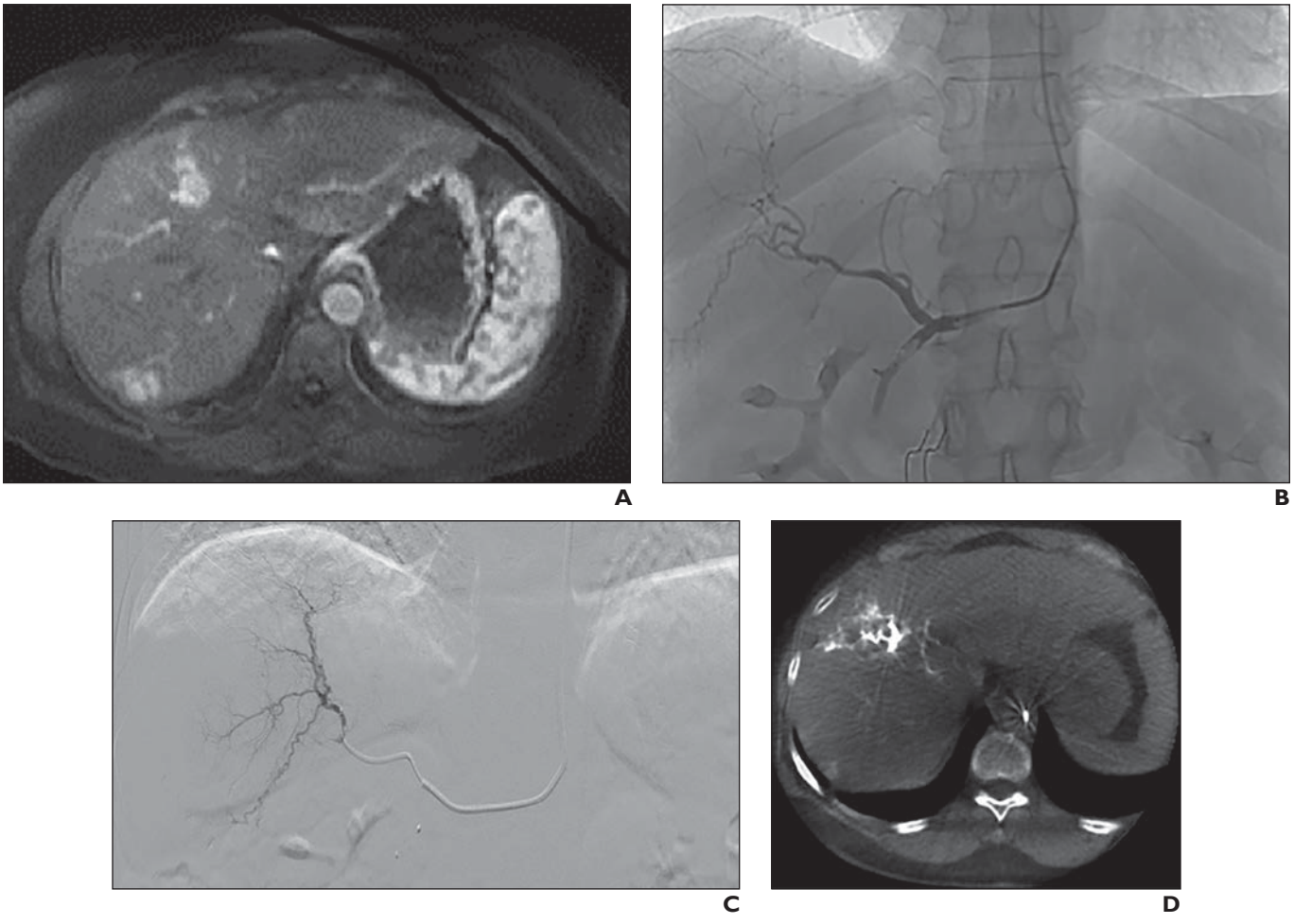

Fig. 3—61-year-old woman with hepatocellular carcinoma treated with right lobar selective internal radiation therapy via transradial approach.
A, Preplanning MR image shows two arterially enhancing lesions in liver segments IVA and VII.
B, Common hepatic arteriogram obtained after placement of microvascular plug (MVP, Medtronic-Covidien) in gastroduodenal artery shows occlusion of gastroduodenal artery.
C, Right hepatic arteriogram obtained during treatment planning shows position of catheter for cone-beam CT acquisition. No definite tumor blush is seen on digital subtraction angiography.
D, Axial slice of arterial contrast-enhanced cone-beam CT scan obtained from same catheter location shows tumor enhancement that confirms appropriate catheter position.

Terumo Interventional Systems) was placed over the arteriotomy site on the left wrist. The cuff was maximally insufflated with the use of an accompanying syringe with 15 mL of air, and the sheath was removed. Air was then slowly removed from the cuff in 1-mL increments until bleeding was observed at the access site, at which time 1 mL of air was added back to the cuff to prevent bleeding.

With the pulse oximeter maintained on the left thumb, presence of a strong RA pulse distal to the cuff and stability of the arterial waveform were confirmed with the cuff inflated, thereby ensuring patency of the RA as well as nonocclusive patent hemostasis at the completion of the procedure. The compression device was left in place for 90 minutes, and arterial hemostasis was reconfirmed as the cuff was incrementally deflated. At the time of cuff removal, patency of the RA was confirmed by pulse palpation, and a sterile dressing was applied to the skin.

All patients ambulated on arrival to the recovery room, where they were directly monitored and were administered analgesics by nursing staff until they were discharged from the hospital. The RA pulse was documented at time of discharge. Patients were contacted by telephone 24 hours after discharge from the hospital, to identify signs of bleeding and vascular complication. One month after treatment, all patients were seen in the clinic, where they underwent a focused physical examination that included inspection of the left wrist and pulse examination.

Statistical Analysis

Descriptive data are presented as the mean (± SD) or the median (interquartile range), as appropriate. Categoric data are presented as percentages and counts. Crossover analysis was performed using logistic regression. Statistical analyses were performed using statistical software (SPSS, version 20.0, SPSS-IBM).

Results

For 574 cases, procedures were performed using the TRA for SIRT. Technical success was achieved for 97.8% of cases. Crossover to the TFA occurred in 13 cases. The results of TRA crossover analysis are presented in Table 2. Of the patients for whom crossover to a TFA occurred, two had their procedures switched from a TRA to a TFA before arterial access was achieved after perioperative palmar arch assessment revealed a type D response as determined by use of a Barbeau test. Two instances of radial loop could not be traversed. RA occlusion accounted for the remaining nine cases for which crossover occurred. No conversions to TFA resulted from inadequate device length or an inability to cannulate the access artery of interest. Female sex ($p = 0.001$) and use of catheters other than Sarah Radial Optitorque or cobra 2–shaped catheters ($p < 0.001$) were found to be statistically significant predictors of crossover to use of a TFA (Table 2).

TABLE 2: Analysis of Crossover from Use of the Transradial Approach to Use of the Transfemoral Approach

Predictor, Category	Odds Ratio (95% CI)	*p*
Age (y)		0.96
< 65	1.00	
≥ 65	0.97 (0.32–2.93)	
Sex		0.001[a]
Male	1.00	
Female	7.1 (2.15–23.4)	
Body weight (kg)		0.80
< 75	1.00	
≥ 75	1.16 (0.36–3.70)	
Height (m)		
< 1.6	1.00	—
1.6–1.8	0.34 (0.09–1.23)	0.10
> 1.8	0.52 (0.09–2.90)	0.45
Pathologic finding		0.051
HCC	1.00	
Other	3.10 (0.99–9.70)	
Intervention		
^{99m}Tc-MAA angiography	1.00	—
TheraSphere[b]	0.97 (0.28–3.37)	1.00
SIR-Spheres[c]	1.84 (0.37–9.11)	0.45
Prior procedure(s) using TRA		
0	1.00	—
1	2.23 (0.70–7.13)	0.18
≥ 2	0.65 (0.08–5.65)	0.65
Catheter used		
Sarah Radial Optitorque[d]	1.00	—
Cobra 2 shaped[d]	2.71 (0.31–23.78)	0.370
Other	17.9 (5.44–59.23)	< 0.001[a]

Note—Dash (—) denotes no value calculated. HCC = hepatocellular carcinoma, MAA = macroaggregated albumin, TRA = transradial access.
[a]Statistically significant.
[b]Millions of small glass microspheres that contain radioactive ^{90}Y (Biocompatibles).
[c]Permanent single-use implant of ^{90}Y resin microspheres (Sirtex Medical).
[d]Diagnostic catheter (Terumo Interventional Systems).

Complete characteristics of the 564 procedures performed are presented in Table 3. Most cases involved a ^{99m}Tc-MAA planning session or infusion of ^{90}Y in a lobar distribution ($n = 440$), some involved segmental planning or treatment ($n = 81$), and the remainder consisted of whole-liver treatment ($n = 40$). A mean dose of 2.2 GBq of ^{90}Y (range, 0.3–10.9 GBq) was delivered during treatments. Most of these procedures (98.6%) were performed with the use of a 5-French hydrophilic sheath. The remainder were performed with 4-French ($n = 6$) and 6-French ($n = 2$) sheaths. A 110-cm Sarah Radial Optitorque catheter was used to engage the first-order artery of interest in 84.4% of cases. A 100-cm cobra 2–shaped catheter was used for 6.3% of cases, and a variety of other catheters were used for the

TABLE 3: Characteristics of the 574 Procedures Performed

Characteristic	Value
Intervention	
^{99m}Tc-MAA angiography	319 (57.3)
^{90}Y therapy	
Therasphere[a]	193 (33.6)
SIR-Spheres[b]	52 (9.1)
Barbeau test response	
A	121 (21.1)
B	428 (74.6)
C	23 (4)
D	2 (0.3)
Prior procedure using left TRA	
0	295 (51.4)
1	189 (32.9)
2	53 (9.2)
> 2	37 (6.4)
Crossover to transfemoral approach	13 (2.3)
Sheath size[c]	
4 French	6 (1.1)
5 French	559 (98.6)
6 French	2 (0.4)
Infusion selectivity[d]	
Segmental	81 (14.4)
Lobar	440 (78.4)
Whole liver	40 (7.1)

Note—Data are no. (%) of procedures. MAA = macroaggregated albumin, TRA = transradial access.
[a]Millions of small glass microspheres that contain radioactive ^{90}Y (Biocompatibles).
[b]Permanent single-use implant of ^{90}Y resin microspheres (Sirtex Medical).
[c]Data are calculated on the basis of the number of cases for which sheaths were successfully placed via TRA (567/574 [98.8%]).
[d]Data are calculated on the basis of the number of cases successfully completed via TRA (561/574 [98.0%]).

TABLE 4: Embolizations Performed During Pretreatment ^{99m}Tc–Macroaggregated Albumin (MAA) Planning

Target Vessel	Total[a]	Coils	MVP Plug[b]	Amplatzer Vascular Plug 4[c]	Other
Gastroduodenal artery	113 (36.1)	81 (71.7)	14 (12.4)	18 (15.9)	—
Right gastric artery	38 (12.1)	28 (73.7)	8 (21.1)	2 (5.3)	—
Cystic artery	16 (5.1)	12 (75)	4 (25)	—	—
Phrenic artery	7 (2.2)	4 (57.1)	1 (14.3)	—	2 (28.6)
Left hepatic artery	6 (1.9)	3 (50)	1 (16.7)	1 (16.7)	1 (16.7)
SPDA	9 (2.9)	8 (88.9)	—	1 (11.1)	—
Other	7 (2.2)	6 (85.7)	—	—	1 (14.3)

Note—Data are number (%) of procedures. Dash (—) denotes no value calculated. SPDA = superior pancreatic duodenal artery.
[a]Percentages were calculated on the basis of the total number of MAA interventions (n = 313) successfully performed via the radial artery.
[b]Microvascular plug (Medtronic-Covidien).
[c]Vascular plug (St. Jude Medical).

remainder. The median dose-area product for available cases was 155,458.5 mGy · cm^2 (interquartile range [IQR], 62,369.0–313,436.0 mGy · cm^2), and the median fluoroscopy time was 9.8 minutes (IQR, 5.5–15.1 minutes).

In a subset of cases, embolization was performed during a pretreatment ^{99m}Tc-MAA planning angiogram on a prophylactic basis, to prevent ^{90}Y from reaching nontargets or for the purposes of redistribution. Details regarding embolization are presented in Table 4. The gastroduodenal artery was embolized in 113 cases that underwent MAA angiogram (36.1%), with detachable coils used in 81 cases, one vascular plug (MVP, Medtronic-Covidien) used in 14 cases, and another vascular plug (Amplatzer Vascular Plug 4, St. Jude Medical) used in 18 cases. Right gastric artery embolization was performed in 38 (12.1%) of the MMA mapping procedures successfully performed via the radial artery. Coils were used as the embolic in 28 cases, a vascular plug (MVP, Meditronic Covidien) was used in eight cases, and an Amplatzer Vascular Plug 4 plug was used in two cases. The left hepatic, cystic, phrenic, and superior pancreatic duodenal arteries were also embolized.

Patients had undergone 0–6 previous left TRA procedures. In most cases (295/574 [51.4%]), patients were TRA naive. In 189 cases (32.9%), patients had undergone one previous TRA, whereas in 53 cases (9.2%), patients had undergone two previous TRA procedures, and in 37 cases (6.4%), patients had undergone more than two previous TRA interventions (percentages do not total 100% because of rounding). For patients who had undergone at least one prior procedure via the TRA, the median interval between the current procedure and the most recent prior procedure performed using the TRA was 21 days (range, 15.0–56.8 days). Of the 295 patients who had not undergone any procedure involving the TRA, 112 patients had undergone a previous ^{99m}Tc-labeled MAA angiogram via the TRA or ^{90}Y treatment that involved a range of one to four procedures, for a total of 209 procedures performed (123 MAA treatment procedures [58.9%], 60 TheraSphere procedures [28.7%], and 26 procedures involving the use of SIR-Spheres [12.4%]).

The global access site complication rate was 3.8% (22 of 574 cases). These complications included one grade 2 hematoma that required the addition of a second hemostasis cuff, nine cases of asymptomatic RA occlusion, three cases of acute intraprocedural RA thrombosis, three intraprocedural RA perforations, two instances of RA spasm, three instances of forearm pain or numbness, and one seizure related to intraarterial infusion of the antispasmodic cocktail (which is discussed in detail later in this article). Superficial bruising of the wrist was observed in 13 cases (2.3%). RA thrombosis resolved spontaneously in all cases, as noted on follow-up ultrasound examination. Intraprocedural perforation identified by visualization of arterial extravasation on an arteriogram was asymptomatic in all cases and did not preclude successful completion of the case or repeat RA access. Forearm pain or numbness was treated with the use of nonsteroidal antiinflammatory drugs alone in all cases. The overall frequency of RA occlusion was 1.6% (nine of 574 cases).

No deaths had occurred at 30 days after the procedure was performed, no limb ischemia events were identified at the time of discharge from the hospital, and no significant bleeding complications were noted. Complications unrelated to the access site included migration of a gastroduodenal artery coil into the common hepatic artery, which was successfully snared, and a right hepatic artery dissection that required stenting, which was completed using the same TRA. Another patient who was found to have an arterioportal fistula had a non-ST segment elevation

myocardial infarction develop after closure was attempted with embolic particles.

Discussion

The TRA to coronary angiography and intervention was pioneered more than 2 decades ago and has since emerged as the preferred alternative to the traditional TFA in many parts of the world [24]. Multiple randomized trials have shown important advantages of the TRA over the TFA, including reduction of major bleeding and other access site–related complications [6–13, 25–30]. In a meta-analysis of randomized trials, Jolly et al. [6] found that use of the TRA for PCIs reduced the rate of major bleeding episodes by 73% when compared with the TFA. A large retrospective review of more than 400,000 coronary interventions performed using either the TRA or the TFA showed that the TRA was associated with reduced bleeding, fewer access site complications, and improved outcomes compared with use of the TFA with a vascular closure device [31]. Recently, the MATRIX Access (Minimizing Adverse Hemorrhagic Events by Transradial Access Sites and Systemic Implementation of AngioX) trial, which, to our knowledge, is the largest randomized control trial comparing femoral and radial access to date, included 8404 patients and showed that a TRA significantly reduces both the risk of clinically adverse events and the rate of death due to all causes [32]. It also suggested that the RA should become the default means of access for patients with acute coronary syndrome who are undergoing invasive management [32]. Access site–specific complications, including access artery occlusion, dissection, peripheral embolization, arterial pseudoaneurysm, or arteriovenous fistula, are also reduced with use of the TRA compared with the TFA [8].

Other studies have shown an association between use of the RA approach and reduced costs, a decreased length of hospital stay, and improved patient satisfaction [10]. In a randomized control trial, Cooper et al. [11] noted a strong patient preference, improved quality-of-life metrics, and decreased hospital costs associated with TRA, compared with TFA, for cardiac catheterization. We have observed that patients tolerate the hemostasis cuff well and enjoy free mobility of the left arm and immediate ambulation after the procedure. This is a particular advantage for patients undergoing SIRT, who, in most centers across the world, have their procedures performed as outpatients in an ambulatory setting. Certain patient populations may derive particular benefit from use of the TRA, including obese patients, those with a bleeding diathesis, and elderly patients [9, 12, 33]. Particular anatomic limitations may preclude the use of the TFA or may make the TRA a better option for use in some patients.

We noted a high technical success rate (97.8%) for SIRT performed via the TRA, with an associated global access site complication rate of 3.8%. Grade 1 hematoma (characterized by superficial bruising) occurred in 2.3% of cases. This complication rate is reported separately because there is significant variability in the reporting of superficial bruising in the literature. When combined, grade 1 and grade 2 hematomas occurred in 2.4% of cases, a rate that is much lower than the 5% frequency reported for radial PCI [34].

In this series, acute RA thrombosis was identified by ultrasound in three cases and presumably occurred secondary to vessel manipulation in the setting of an initial unsuccessful access attempt. Thrombosis did not preclude completion of the case via the TRA, and, in all cases, an ultrasound examination performed immediately after the procedure showed interval thrombosis resolution. We have used several approaches for achieving access in the setting of acute intraprocedural thrombosis or spasm. These include waiting 30–60 minutes and performing a second Doppler ultrasound examination to determine whether the spasm or thrombosis has resolved, repuncturing at a more proximal location of the RA, and repuncturing through the arterial thrombosis. RA occlusion was identified by physical examination at the follow-up visit and by ultrasound examination of patients who underwent repeat intervention. RA occlusion was asymptomatic in all cases identified. Perforation was identified if resistance was felt while navigating the RA, and it was confirmed by the ap-

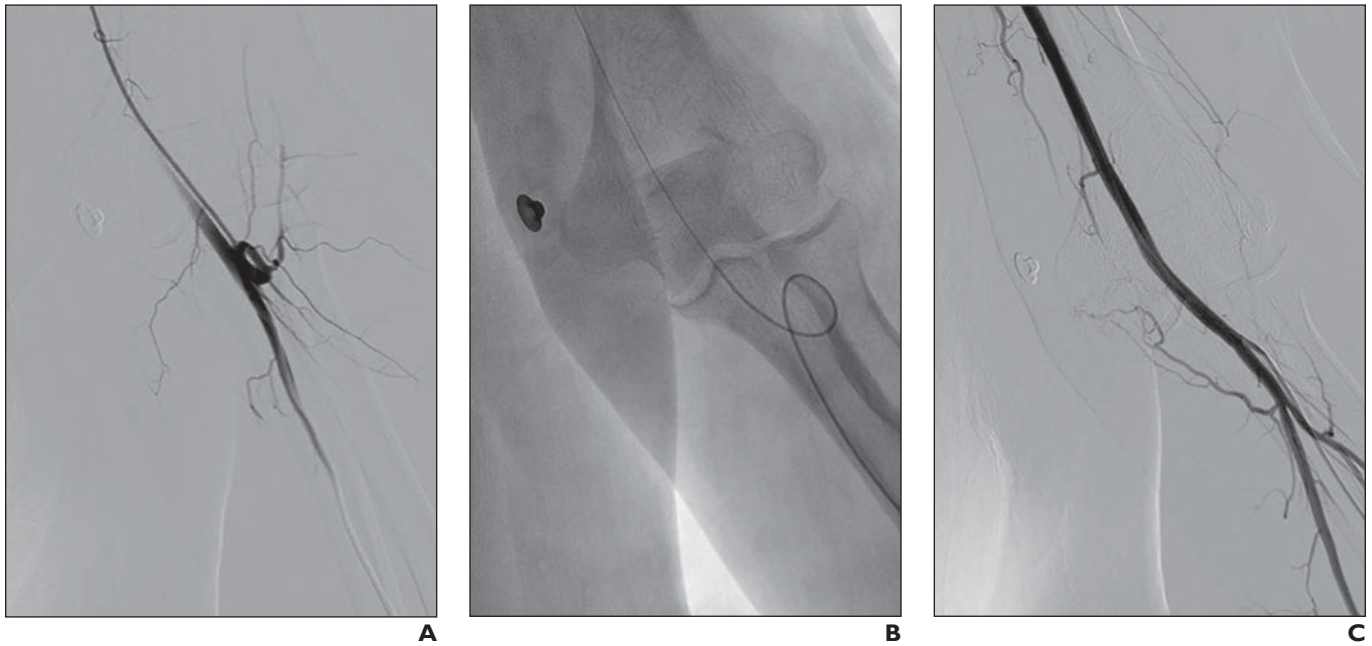

Fig. 4—62-year-old man with hepatocellular carcinoma undergoing pretreatment ^{99m}Tc-labeled macroaggregated albumin planning via transradial approach. **A–C,** Angiograms of forearm reveal 360° loop in distal brachial artery just above radial ulnar bifurcation before (**A**), during (**B**), and after (**C**) arterial loop reduction.

pearance of extravasation on the arteriogram. The wire was then retracted and readvanced under fluoroscopic guidance. Perforations all resolved spontaneously, requiring no further intervention, and did not result in termination of the procedure. A forearm arterial loop was rarely encountered. Once carefully crossed, the loop often reduced spontaneously, becoming anatomically straight (Fig. 4).

Despite the use of such maneuvers, crossover to use of the TFA was sometimes unavoidable. In this series, two forearm arterial loops could not be reduced and required conversion two femoral access. Female sex was found to be a statistically significant predictor of crossover to the TFA, possibly in relation to the smaller RA caliber noted in women. Use of catheters other than a Sarah Radial Optitorque or cobra 2–shaped catheter was also found to be a statistically significant predictor of crossover to the TFA. Possible explanations for this finding include the use of alternative catheters when met with challenging arterial anatomy or other technical factors precluding access from above the artery.

A significant complication noted in this series was a seizure that developed after infusion of the antispasmodic cocktail via the radial sheath immediately after sheath placement. No wire or catheter was introduced into the sheath before the event. The patient had a 3- to 5-minute convulsive event and subsequently had transient antegrade amnesia and confusion develop. The patient was admitted for observation, the neurology department was consulted, and head CT and brain MRI examinations were obtained, both of which revealed unremarkable findings. The patient's symptoms resolved, and he was discharged from the hospital the following day. It was hypothesized that the event was the result of intraarterial administration of verapamil, a rare cause of seizures reported in the literature [35]. No instances of digital ischemia, an exceedingly rare complication reported in patients without a patent ulnopalmar arch, were noted [36].

The ability to readily identify and treat access site–related bleeding and the dual blood supply of the hand no doubt contribute to the reduced risk of significant bleeding and access site–related complication reflected in large studies of PCI. No serious bleeding complications were noted in our series. The fact that the RA is more superficial than the femoral artery and does not have surrounding structures that are susceptible to injury makes it an ideal access vessel. Furthermore, inadvertent injury to the artery is rarely detrimental to the hand when a patent ulnopalmar arch is present [1]. The TRA certainly precludes the risk of retroperitoneal hematoma associated with TFA. Several steps were used in an attempt to maintain a rate of access site–related complications that is as low as possible. The role of preprocedure testing for dual circulation of the hand and whether it is necessary at all is an area of controversy in the interventional cardiology literature. Although use of the Allen test has been almost entirely abandoned in routine coronary interventional practice because of subjectivity, oximetry assessment with the use of the Barbeau test is still recommended by the European Association of Percutaneous Cardiovascular Interventions and is used for all cases for which procedures are performed using the TRA at the Department of Radiology at the Icahn School of Medicine at Mount Sinai [3, 6].

Use of a single-wall puncture technique and placement of the smallest-diameter hydrophilic sheath available to successfully complete the procedure are meant to minimize trauma to the access artery. Saito et al. [37] found that severe reduction in the RA flow after transradial coronary intervention was significantly higher if the ratio of the inner diameter of the RA to the outer diameter of the sheath is less than 1.0. Patients with an RA of less than 2 mm are therefore precluded from undergoing procedures performed using the TRA. The most frequently used access sheath size in this series was 5 French. In cases in which a more complex intervention, such as delivery of a large vascular plug, was needed, a 6-French sheath was used. For these cases, 6-French guiding catheters ranging in length from 90 to 125 cm were used. In addition, anticoagulation, vasodilator, and antispasmodic agents were administered, and a patent hemostasis technique was used to minimize thrombosis [3]. The PROPHET (Prevention of Radial Artery Occlusion–Patent Hemostasis Evaluation Trial) trial showed the superiority of nonocclusive pressure in maintaining patency of the RA [38]. An added benefit of using a patent hemostasis technique is the avoidance of vascular closure devices and the added risk and cost that these can incur. In our practice, the cost of a compression device

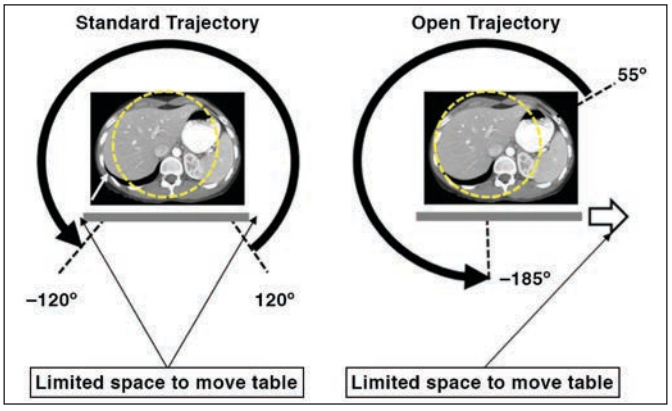

Fig. 5—Philips Healthcare schematic diagram for standard (*left*) and new (*right*) trajectory for cone-beam CT. Adjustment of uncovered part of trajectory from underneath patient to left side of patient allows positioning of liver in center of FOV without causing collision between patient and C-arm–based system. Dashed yellow circle denotes center of FOV.

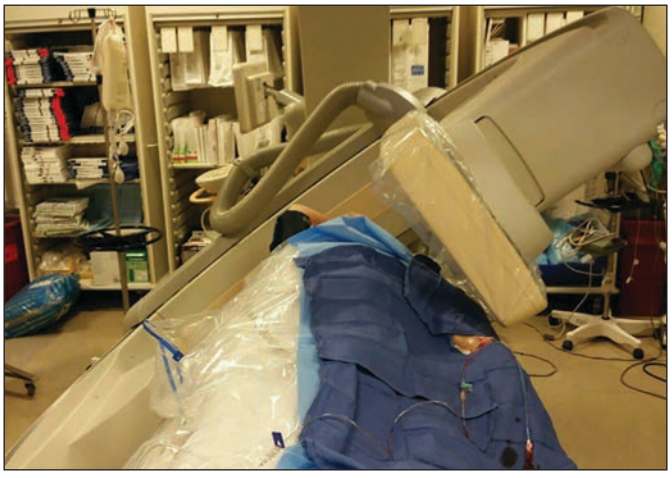

Fig. 6—Photograph of Philips Healthcare right trajectory for cone-beam CT imaging procedures performed via transradial approach shows clearance of left arm without repositioning.

(TR Band, Terumo Interventional Systems) is significantly less than that of typical femoral closure devices used by many operators.

A clear drawback of the use of the TRA for SIRT and, arguably, for all subdiaphragmatic interventions performed via the TRA, is the risk of embolic stroke resulting from manipulation of the aortic arch—a risk that is often avoided with use of the TFA. However, some operators form reverse curve catheters in the aortic arch via the use of a TFA approach, which can also potentially create a risk for neurologic complication. A retrospective analysis of the British Cardiovascular Intervention Society's database of PCIs, which included 124,616 radial procedures and 223,476 femoral procedures, found no statistically significant association between use of the TRA and the occurrence of neurologic complications, with a frequency of 0.11% noted in each cohort [14]. A study by Hamon et al. [39] in which 41 consecutive patients underwent DWI after a procedure was performed using the TRA concluded that the frequency of procedure-related ischemic lesions was lower when the TRA was used compared with the TFA. However, the applicability of this evidence to noncoronary interventions is limited, making it difficult to quantify the risk of adverse neurologic events associated with subdiaphragmatic procedures. This risk must be frankly discussed with the patient and should be balanced, along with the other disadvantages of TRA, against the benefits of using the TRA for the individual patient.

Several additional limitations of using the TRA for radioembolization include a steep operator learning curve, which potentially leads to increased exposure to radiation for both the operator and the patient, compared with the TFA. Although the left radial approach relative to right radial approach minimizes the fluoroscopy time, one of the largest studies to assess radiation exposure during diagnostic cardiac catheterization procedures performed by multiple operators found that the TRA was associated with a 23% increase in radiation exposure, compared with the TFA, when evaluated across operators with varying experience in performing procedures with use of the radial approach [3, 40]. Before the operator gains sufficient experience using the TRA, which, in our estimation, occurs after approximately 20 cases have been treated, navigation of the aortic arch is arguably the most time-consuming aspect of the TRA. Still, absolute increases in fluoroscopy time and the dose-area product resulting from the use of the TRA compared with the TFA are small, likely representing minimal risk to the patient, and they are further minimized in centers where a large volume of procedures are performed using the TRA [3].

Jolly et al. [41] evaluated air kerma or the dose-area product in more than 3500 patients randomized to undergo treatment via radial or femoral access as part of the RIVAL (Radial vs. Femoral) trial. No difference was noted in the dose-area product of the two access types. Air kerma was nominally higher in cases treated via radial access, but this difference persisted only in centers belonging to the lowest tertile when results were stratified according to the volume of TRA procedures performed [41]. Furthermore, whether this is borne out with SIRT and other below-the-diaphragm procedures is unclear and merits further study.

The technical difficulties associated with performing cone-beam CT are another important consideration for radioembolization planning and treatment via the TRA. The standard starting point and endpoint of the detector trajectory involves rotation between –120° and 120°, with the uncovered part of the trajectory below the patient. For SIRT, this trajectory leaves limited space to center the liver in the FOV, which is predominantly located on the right side of the patient. A newer protocol involves a detector trajectory involving rotation from 55° to –185°, with the uncovered portion to the left of the patient allowing full coverage of the liver in the FOV and clearance of the left arm without the need for repositioning [42] (Figs. 5 and 6).

The important advantages of using the TRA include patient preference and a reduced risk of bleeding and access site complications. These advantages must be balanced against the disadvantages associated with the TRA, which included a steep operator learning curve, increased radiation exposure, and the rare but profound possibility of digital ischemia and neurologic complications occurring.

The present study has limitations. First, the study is retrospective in nature and does not have a comparative cohort. One particular limitation of the data is that RA occlusion was assessed by physical examination at the follow-up clinic visit and by ultrasound examination performed at the time of repeat intervention. The use of tests of varying sensitivity may have resulted in an underestimation of the true occlusion rate. In addition, access site selection was based on operator preference and patient-specific characteristics at the time of each procedure. The purpose of the present article is not to show superiority of the safety or efficacy of the TRA compared with those of the TFA but, rather, to show that the TRA is safe and effective for SIRT. As such, the authors do not think that a comparative cohort of TFA cases is necessary. Furthermore, because access site selection was predominantly based on operator preference, with patients not randomized to undergo the TRA or the TFA, any results observed would likely be affected by selection bias. Finally, the observed results may not be generalizable to all institutions. The institution where the procedures were performed is a high-volume center with considerable experience in the use of the TRA for interventional oncology procedures. As such, observed results may be affected by the level of experience of the operator and the volume of such procedures performed.

In conclusion, hepatic radioembolization appears to be well suited for the TRA. The present study shows that the TRA is a safe and feasible access option for radioembolization and that it is associated with a low complication rate.

References

1. Campeau L. Percutaneous radial artery approach for coronary angiography. *Cathet Cardiovasc Diagn* 1989; 16:3–7
2. Kiemeneij F, Laarman GJ. Percutaneous transradial artery approach for coronary stent implantation. *Cathet Cardiovasc Diagn* 1993; 30:173–178
3. Caputo RP, Tremmel JA, Rao S, et al. Transradial arterial access for coronary and peripheral procedures: executive summary by the transradial committee of the SCAI. *Catheter Cardiovasc Interv* 2011; 78:823–839
4. Ramakrishnan S, Mishra S, Chakraborty R, Chandra KS, Mardikar HM. The report on the Indian coronary intervention data for the year 2011: National Interventional Council. *Indian Heart J* 2013; 65:518–521
5. Feldman DN, Swaminathan RV, Kaltenbach LA, et al. Adoption of radial access and comparison of outcomes to femoral access in percutaneous coronary intervention: an updated report from the national cardiovascular data registry (2007–2012). *Circulation* 2013; 127:2295–2306
6. Jolly SS, Amlani S, Hamon M, Yusuf S, Mehta SR. Radial versus femoral access for coronary angiography or intervention and the impact on major bleeding and ischemic events: a systematic review and meta-analysis of randomized trials. *Am Heart J* 2009; 157:132–140
7. Achenbach S, Ropers D, Kallert L, et al. Transradial versus transfemoral approach for coronary angiography and intervention in patients

above 75 years of age. *Catheter Cardiovasc Interv* 2008; 72:629–635

8. Agostoni P, Biondi-Zoccai GG, de Benedictis ML, et al. Radial versus femoral approach for percutaneous coronary diagnostic and interventional procedures: systematic overview and meta-analysis of randomized trials. *J Am Coll Cardiol* 2004; 44:349–356
9. Caputo RP, Simons A, Giambartolomei A, et al. Transradial cardiac catheterization in elderly patients. *Catheter Cardiovasc Interv* 2000; 51:287–290
10. Chase AJ, Fretz EB, Warburton WP, et al. Association of the arterial access site at angioplasty with transfusion and mortality: the M.O.R.T.A.L study (Mortality benefit Of Reduced Transfusion after percutaneous coronary intervention via the Arm or Leg). *Heart* 2008; 94:1019–1025
11. Cooper CJ, El-Shiekh RA, Cohen DJ, et al. Effect of transradial access on quality of life and cost of cardiac catheterization: a randomized comparison. *Am Heart J* 1999; 138:430–436
12. Cox N, Resnic FS, Popma JJ, Simon DI, Eisenhauer AC, Rogers C. Comparison of the risk of vascular complications associated with femoral and radial access coronary catheterization procedures in obese versus nonobese patients. *Am J Cardiol* 2004; 94:1174–1177
13. Sciahbasi A, Pristipino C, Ambrosio G, et al. Arterial access-site-related outcomes of patients undergoing invasive coronary procedures for acute coronary syndromes (from the ComPaRison of Early Invasive and Conservative Treatment in Patients With Non-ST-ElevatiOn Acute Coronary Syndromes [PRESTO-ACS] Vascular Substudy). *Am J Cardiol* 2009; 103:796–800
14. Ratib K, Mamas MA, Routledge HC, Ludman PF, Fraser D, Nolan J. Influence of access site choice on incidence of neurologic complications after percutaneous coronary intervention. *Am Heart J* 2013; 165:317–324
15. Shiozawa S, Tsuchiya A, Endo S, Kumazawa K, Ogawa K. Transradial approach for transcatheter arterial chemoembolization in patients with hepatocellular carcinoma [in Japanese]. *Nihon Shokakibyo Gakkai Zasshi* 2002; 99:1450–1454
16. National Cancer Institute, National Institutes of Health. Common terminology criteria for adverse events (CTCAE), version 4.03. National Cancer Institute Enterprise Vocabulary Services website. evs.nci.nih.gov/ftp1/CTCAE/CTCAE_4.03_2010-06-14_QuickReference_8.5x11.pdf. Published June 14, 2010. Accessed July 6, 2016
17. Beyer AT, Ng R, Singh A, et al. Topical nitroglycerin and lidocaine to dilate the radial artery prior to transradial cardiac catheterization: a randomized, placebo-controlled, double-blind clinical trial: the PRE-DILATE Study. *Int J Cardiol* 2013; 168:2575–2578
18. Fischman AM, Swinburne NC, Patel RS. A technical guide describing the use of transradial access technique for endovascular interventions. *Tech Vasc Interv Radiol* 2015; 18:58–65
19. Barbeau GR, Arsenault F, Dugas L, Simard S, Larivière MM. Evaluation of the ulnopalmar arterial arches with pulse oximetry and plethysmography: comparison with the Allen's test in 1010 patients. *Am Heart J* 2004; 147:489–493
20. Resnick NJ, Kim E, Patel RS, Lookstein RA, Nowakowski FS, Fischman AM. Uterine artery embolization using a transradial approach: initial experience and technique. *J Vasc Interv Radiol* 2014; 25:443–447
21. Louie JD, Kothary N, Kuo WT, et al. Incorporating cone-beam CT into the treatment planning for yttrium-90 radioembolization. *J Vasc Interv Radiol* 2009; 20:606–613
22. Kennedy A, Nag S, Salem R, et al. Recommendations for radioembolization of hepatic malignancies using yttrium-90 microsphere brachytherapy: a consensus panel report from the radioembolization brachytherapy oncology consortium. *Int J Radiat Oncol Biol Phys* 2007; 68:13–23
23. Hamami ME, Poeppel TD, Müller S, et al. SPECT/CT with 99mTc-MAA in radioembolization with 90Y microspheres in patients with hepatocellular cancer. *J Nucl Med* 2009; 50:688–692
24. Rao SV, Tremmel JA, Gilchrist IC, et al. Best practices for transradial angiography and intervention: a consensus statement from the society for cardiovascular angiography and intervention's transradial working group. *Catheter Cardiovasc Interv* 2014; 83:228–236
25. Hamon M, Pristipino C, Di Mario C, et al. Consensus document on the radial approach in percutaneous cardiovascular interventions: position paper by the European Association of Percutaneous Cardiovascular Interventions and Working Groups on Acute Cardiac Care** and Thrombosis of the European Society of Cardiology. *EuroIntervention* 2013; 8:1242–1251
26. Pristipino C, Pelliccia F, Granatelli A, et al. Comparison of access-related bleeding complications in women versus men undergoing percutaneous coronary catheterization using the radial versus femoral artery. *Am J Cardiol* 2007; 99:1216–1221
27. Romagnoli E, Biondi-Zoccai G, Sciahbasi A, et al. Radial versus femoral randomized investigation in ST-segment elevation acute coronary syndrome: the RIFLE-STEACS (Radial Versus Femoral Randomized Investigation in ST-Elevation Acute Coronary Syndrome) study. *J Am Coll Cardiol* 2012; 60:2481–2489
28. Slagboom T, Kiemeneij F, Laarman GJ, van der Wieken R. Outpatient coronary angioplasty: feasible and safe. *Catheter Cardiovasc Interv* 2005; 64:421–427
29. Kiemeneij F, Laarman GJ, Odekerken D, Slagboom T, van der Wieken R. A randomized comparison of percutaneous transluminal coronary angioplasty by the radial, brachial and femoral approaches: the access study. *J Am Coll Cardiol* 1997; 29:1269–1275
30. Santas E, Bodi V, Sanchis J, et al. The left radial approach in daily practice: a randomized study comparing femoral and right and left radial approaches [in English, Spanish]. *Rev Esp Cardiol* 2009; 62:482–490
31. Ratib K, Mamas MA, Anderson SG, et al. Access site practice and procedural outcomes in relation to clinical presentation in 439,947 patients undergoing percutaneous coronary intervention in the United kingdom. *JACC Cardiovasc Interv* 2015; 8:20–29
32. Valgimigli M, Gagnor A, Calabro P, et al. Radial versus femoral access in patients with acute coronary syndromes undergoing invasive management: a randomised multicentre trial. *Lancet* 2015; 385:2465–2476
33. Titano JJ, Biederman DM, Marinelli BS, et al. Safety and feasibility of transradial access for visceral interventions in patients with thrombocytopenia. *Cardiovasc Intervent Radiol* 2016; 39:676–682
34. Bertrand OF, Larose E, Rodés-Cabau J, et al. Incidence, predictors, and clinical impact of bleeding after transradial coronary stenting and maximal antiplatelet therapy. *Am Heart J* 2009; 157:164–169
35. Westhout FD, Nwagwu CI. Intra-arterial verapamil-induced seizures: case report and review of the literature. *Surg Neurol* 2007; 67:483–486; discussion, 486
36. de Bucourt M, Teichgräber U. Digital ischemia and consecutive amputation after emergency transradial cardiac catheter examination. *Cardiovasc Intervent Radiol* 2012; 35:1242–1244
37. Saito S, Ikei H, Hosokawa G, Tanaka S. Influence of the ratio between radial artery inner diameter and sheath outer diameter on radial artery flow after transradial coronary intervention. *Catheter Cardiovasc Interv* 1999; 46:173–178
38. Pancholy S, Coppola J, Patel T, Roke-Thomas M. Prevention of radial artery occlusion-patent hemostasis evaluation trial (PROPHET study): a randomized comparison of traditional versus patency documented hemostasis after transradial catheterization. *Catheter Cardiovasc Interv* 2008; 72:335–340
39. Hamon M, Gomes S, Clergeau MR, Fradin S, Morello R, Hamon M. Risk of acute brain injury related to cerebral microembolism during cardiac catheterization performed by right upper limb arterial access. *Stroke* 2007; 38:2176–2179
40. Neill J, Douglas H, Richardson G, et al. Comparison of radiation dose and the effect of operator experience in femoral and radial arterial access for coronary procedures. *Am J Cardiol* 2010; 106:936–940
41. Jolly SS, Cairns J, Niemela K, et al. Effect of radial versus femoral access on radiation dose and the importance of procedural volume: a substudy of the multicenter randomized RIVAL trial. *JACC Cardiovasc Interv* 2013; 6:258–266
42. Schernthaner RE, Chapiro J, Sahu S, et al. Feasibility of a modified cone-beam CT rotation trajectory to improve liver periphery visualization during transarterial chemoembolization. *Radiology* 2015; 277:833–841