Pictorial essay: imaging findings following Y90 radiation segmentectomy for hepatocellular carcinoma

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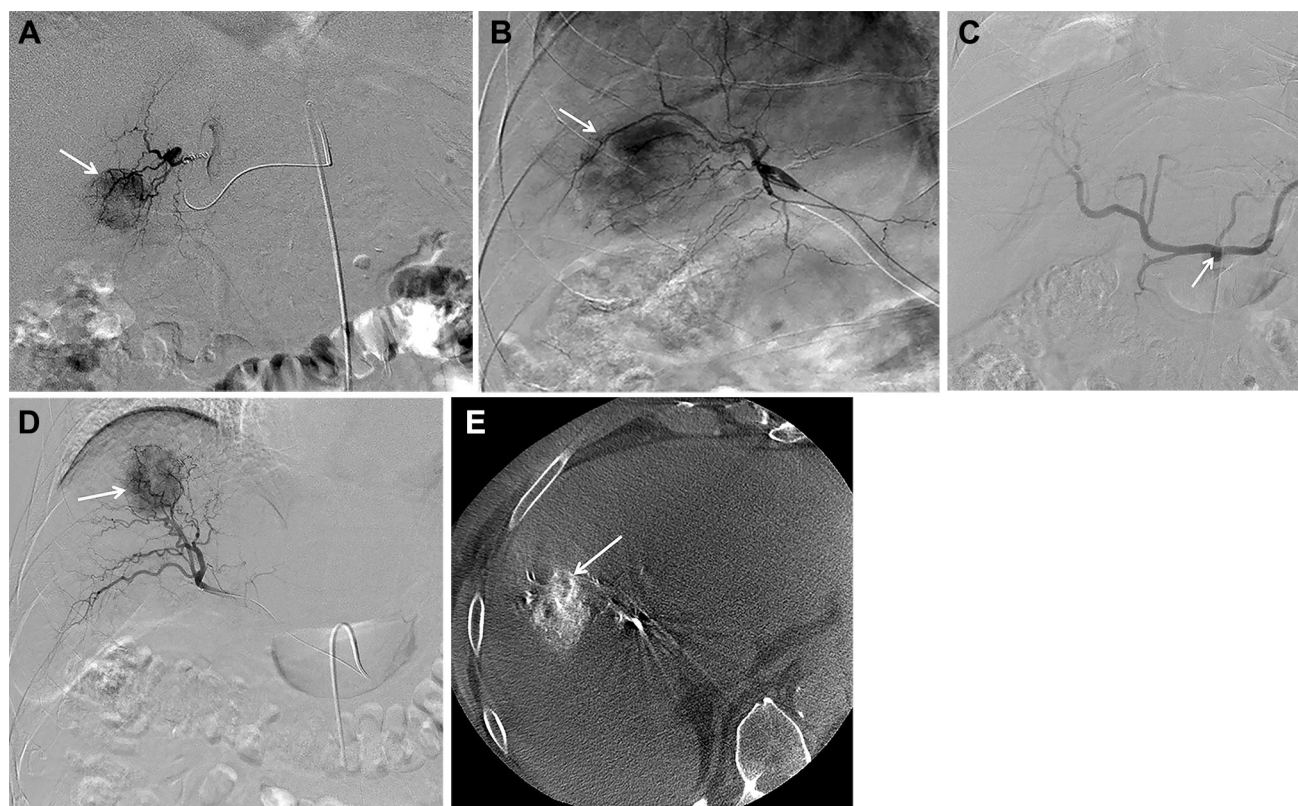
Abstract

Transarterial radioembolization is a novel therapy that has gained rapid clinical acceptance for the treatment of hepatocellular carcinoma (HCC). Segmental radioembolization [also termed radiation segmentectomy (RS)] is a technique that can deliver high doses (> 190 Gy) of radiation selectively to the hepatic segment(s) containing the tumor. The aim of this comprehensive review is to provide an illustrative summary of the most relevant imaging findings encountered after radiation segmentectomy. A 62-patient cohort of Child–Pugh A patients with solitary HCC < 5 cm in size was identified. A comprehensive retrospective imaging review was done by interventional radiology staff at our institution. Important imaging findings were reported and illustrated in a descriptive account. For the purposes of completeness, specific patients outside our initial cohort with unique educational imaging features that also underwent segmentectomy were included in this pictorial essay. This review shows that response assessment after RS requires a learning curve with common drawbacks that can lead to false-positive interpretations and secondary unnecessary treatments. It is important to recognize that treatment responses and pathological changes both are time dependent. Findings such as benign geographical enhancement and initial benign pathological enhancement can easily be misinterpreted. Capsular retraction and segmental atrophy are some other examples of unique post-RS response that are not seen in any other treatment.

Key words: Radioembolization—Radiation segmentectomy—Hepatocellular carcinoma (HCC)—World Health Organization (WHO)—European Association for the Study of the Liver (EASL)

Hepatocellular carcinoma (HCC) is the most common primary liver cancer. Despite improvements in treatment, it remains the second most common cause of cancer-related mortality [1]. Treatment modalities vary and include liver transplantation, resection, and ablation; these are still regarded as the treatments of choice with prolonged survival [2].

Other options include liver-directed therapies, such as transarterial chemoembolization (TACE) and radioembolization with yttrium-90 (Y90). Treatment choice will depend on many factors, the most important being the patient's disease stage, tumor burden, and liver functional reserve.

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Fig. 1. A Superselective angiogram showing hypervascular segment IV lesion (arrow). B Superselective angiogram showing hypervascular right lobe lesion (arrow). C Celiac artery as part of mapping angiography (arrow). D Superselective angiogram showing hypervascular dome lesion (arrow). E Cone-beam CT showing wedge enhancement corresponding to target segment in Figure 1B (arrow).

Y90 is a novel therapy that has gained rapid clinical acceptance for the treatment of (HCC) [3]. Segmental radioembolization [also termed radiation segmentectomy (RS)] is a technique which can deliver high doses of radiation selectively to the hepatic segment(s) containing the tumor [4–6], sparing the rest of the liver, providing a safe and effective method to target HCC. Patients with lower liver functions that cannot tolerate more extensive and taxing treatments like lobar therapies, TACE, or external beam radiations can be treated safely by reducing the overall radiation burden on the liver. We have observed unique and time-dependent changes in the hepatic parenchyma that affect clinical management and decision making.

Sixty-two patients with HCC who underwent treatment with radiation segmentectomy Y90 over an 11-year period (Dec 2003–Dec 2016) were included in this imaging finding review.

The aim of this pictorial essay is to provide a descriptive account of the most common radiologic imaging findings, from benign to pathologic, encountered after radiation segmentectomy. A review of these imaging findings has not been previously published. This information is of importance for clinical teams including oncologists and radiologists to be aware of these findings as they play a direct role in clinical management and treatment decision making.

Radiation segmentectomy technical considerations

Y90 is a pure beta emitter that decays into stable zirconium. It can be loaded either on a resin (SIR-Spheres®) or on glass [TheraSphere® (BTG)] microspheres [7, 8]. TheraSphere® was used for all patients in this review. Each microsphere ranges from 20 to 30 μm in size. The technical details of Y90 glass microspheres and dosage calculation for radiation segmentectomy have been previously discussed in detail [4].

Pre-treatment planning

Angiography is performed in every patient undergoing RS to assess the abdominal and liver vasculature anatomy, identification of tumor's blood supply, recognition of any anatomical variants [9, 10] that could lead to non-target deposition of Y90 microspheres, and prophylactic embolization of these vessels [11–13]. A technetium-99m macroaggregated albumin (^{99m}Tc-MAA) scan is also

performed to determine the lung shunt fraction (LSF) and identify any shunting to the gastrointestinal tract [14].

Cone-beam CT is another valuable tool during pre-treatment planning that allows confirmation of complete tumor targeting; the scan is performed during the pre-treatment angiography or before Y90 to collect additional information. It allows improved visualization of the tumor and its supplying arteries which may not be entirely evident with angiography alone [15–18] (Fig. 1).

Radiation segmentectomy patient selection criteria

Patients have to meet the following criteria to be selected as candidates for RS: (1) solitary HCC ≤ 5 cm; (2) liver-only disease (no metastasis and/or vascular invasion); (3) tumor can be isolated angiographically such that no more than two hepatic segments are perfused at the selected treatment location for the segmentectomy to be possible. Baseline characteristics of patients in this review are presented in Table 1.

Follow-up intervals and imaging studies

A universally accepted post-therapeutic imaging follow-up protocol has not been established. These continue to vary by center [19–21]; this may in part be due to limited consensus regarding surveillance for each treatment and disease [22, 23]. Imaging follow-up was performed following our institutional standard protocol at 1 month post-treatment and at 3-month intervals after the first evaluation for all patients. Follow-up median time for this pictorial essay was 17 months (range 2–120 months).
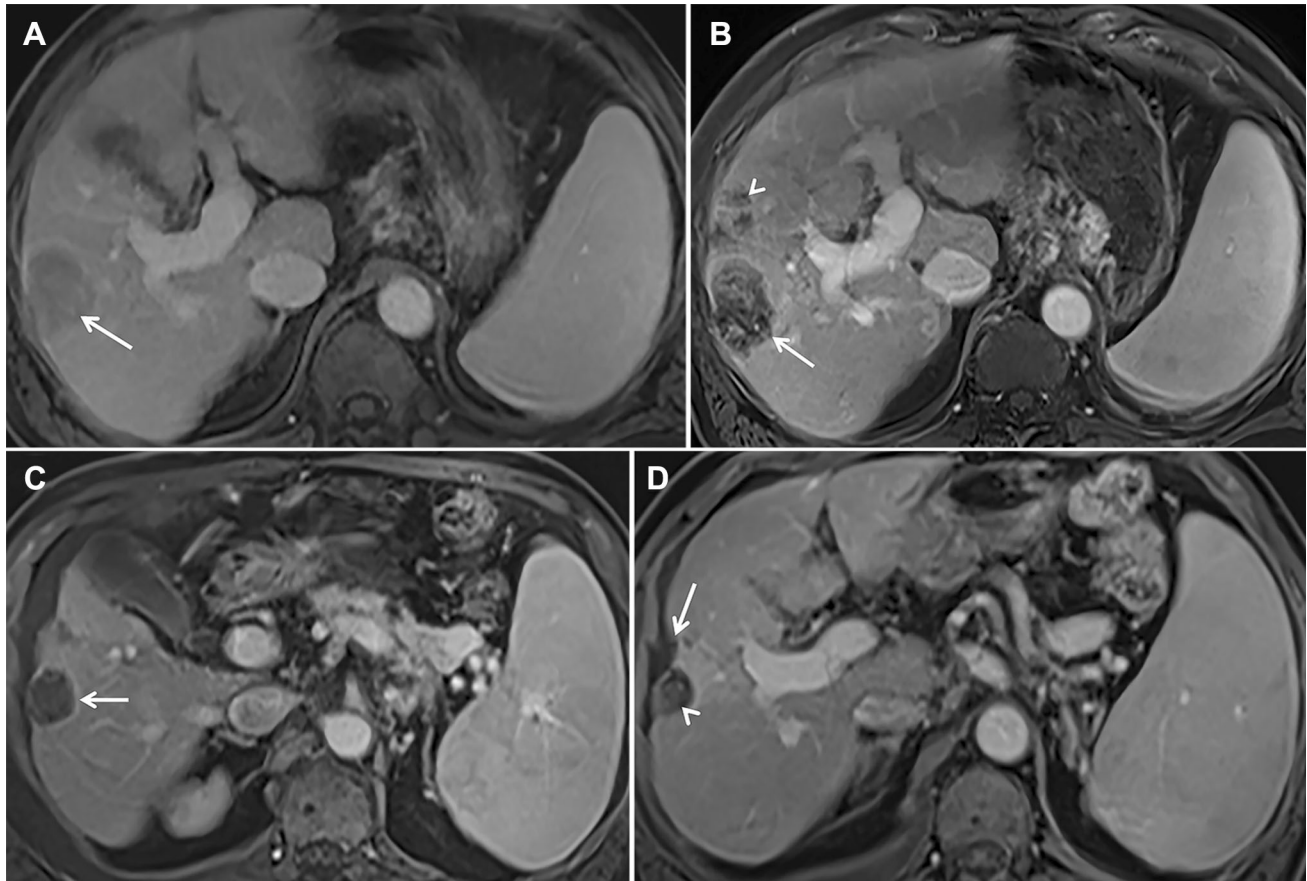
Imaging

Imaging was acquired by MRI (our institutional standard) or CT.

(a) Abdominal MRI protocol for liver imaging included transverse and coronal T2-weighted half-Fourier acquisition single-shot turbo spin echo, T2-weighted turbo spin echo with fat suppression. Unenhanced and dynamic gadolinium-enhanced T1-weighted images were acquired by fat-suppressed gradient echo using shared prepulses (arterial/venous phases). Gadopentetate dimeglumine (Magnevist; Bayer HealthCare Pharmaceuticals, Berlin, Germany) was administered at a dose of 0.1 mmol/kg, followed by 20 mL saline flush (2 mL/s) with a power injector (Spectris; Medrad, Inc, Warrendale, PA).

(b) CT imaging included unenhanced arterial and portal venous phases according to our standard HCC protocol for the liver. Contrast-enhanced images were obtained after 40 s in the arterial phase and 70 s in

Table 1. Baseline characteristics

Factor	Variable	N = 62 (%)
Gender	Male	41 (66)
	Female	21 (34)
Age (years)	Median (range)	71 (22–96)
ECOG	0	44 (71)
	1	18 (29)
Etiology of liver disease	Hepatitis C	26 (42)
	Alcohol	3 (5)
	Cryptogenic	15 (24)
	Hepatitis B	7 (11)
	Autoimmune	3 (5)
	Non-alcoholic steatohepatitis	7 (11)
	Hemochromatosis	1 (2)
Child–Pugh score	A5	25 (40)
	A6	37 (60)
Cirrhosis	Yes	56 (90)
	No	6 (10)
Portal hypertension	Yes	44 (710)
	No	18 (29)
AFP	> 200	9 (15)
	< 200	53 (85)
Method of diagnosis	Imaging	43 (69)
	Biopsy	19 (31)
Lesion size (cm)	Median (range)	2.5 (1.2–4.8)
UNOS TNM	T1 < 2 cm	15 (24)
	T2: 2–3 cm	27 (44)
	T2: 3–5 cm	20 (32)

Table 3. Follow-up for overall tumor response

Criteria	Tumor response	No. of patients (%)
mRECIST @ 1 month	Complete responders	21 (34)
EASL	Responders	60 (97)
	Non-responders	2 (3)
WHO	Responders	40 (65)
	Non-responders	22 (35)

Table 2. Tumor response criteria

	WHO	EASL	mRECIST
Responders			
CR	100% decrease of tumor size	100% decrease of enhancing tissue	No enhancing tissue within the target tumor
PR	50% reduction of cross-product size	≥ 50% reduction in enhancing tissue	≥ 30% reduction of the longest diameter in the enhancing tissue from baseline
Non-responders			
SD	Less than 50% decrease or less than 25% increase in size	No changes seen or less than any of the previous categories	No changes seen or less than any of the previous categories
PD	25% increase in the tumor cross-product size compared to baseline or appearance of a new lesion	> 25% increase in the size of the enhancing tissue compared to baseline	> 20% increase in the size of the enhancing tissue compared to any previous study

Fig. 2. **A** MRI showing baseline lesion (arrow). **B** MR image at 1-month follow-up after RS showing worrisome enhancement and "residual tumor artifact" in the treated lesion (arrow); also seen near the treated lesion are "parenchymal holes" in no-tumor-bearing areas corresponding to parenchymal changes secondary to treatment (arrowhead). **C** MR image at 3-month follow-up, the worrisome enhancement seen at 1 month has disappeared, and the lesion now shows complete necrosis (arrow); parenchymal changes have also improved. **D** MRI at 12 months, showing complete necrosis (arrowhead) and capsular retraction (arrow).

the venous phase after the injection of 125 mL of iohexol (Omnipaque 350; GE Healthcare, Waukesha, WI) at a rate of 5 mL/s.

(c) C-arm CT: imaging was performed using a Siemens Artis zeego Syngo DYNA CT software, non-ionic iodinated contrast agent (omnipaque® = iohexol, GE Healthcare Company, UK), and a high-pressure syringe (Mark V Provis, MERAD.INC, USA). The DYNA CT scan was conducted 6 s after the start of the injection of the contrast agent with the following parameters: acquisition frame rate, 60 frames/s; collection matrix, 1024 × 1024; rotation speed, 30°/s; and acquisition time, 7 s.

Tumor response

Radiological tumor responses were assessed using World Health Organization (WHO) criteria for size, the European Association for the Study of the Liver (EASL) criteria [24, 25], and the modified Response Evaluation

Criteria In Solid Tumors (mRECIST) [26] for necrosis (Table 2).

While tumor size remains the main parameter in oncologic treatment response, for Y90 the use of size to evaluate response is not the most accurate method, due to the inherent characteristics of the therapy; size may increase or remain stable after treatment, without any correlation to actual tumor viability. For this reason, the degree of necrosis and enhancing tissue has been accepted as criteria for response. EASL and mRECIST have proven to be better predictors of survival than WHO and RECIST for HCC surveillance after locoregional therapies [27–29].

Tumor size was assessed using the WHO criteria [25]. The sum of baseline cross-product (pre-treatment) is compared with the follow-up to determine the percentage change in size by WHO. Tumor necrosis was assessed using both EASL and mRECIST guidelines [24, 26]. EASL recommends measuring the cross-product of the enhancing tissue inside the target tumor and comparing
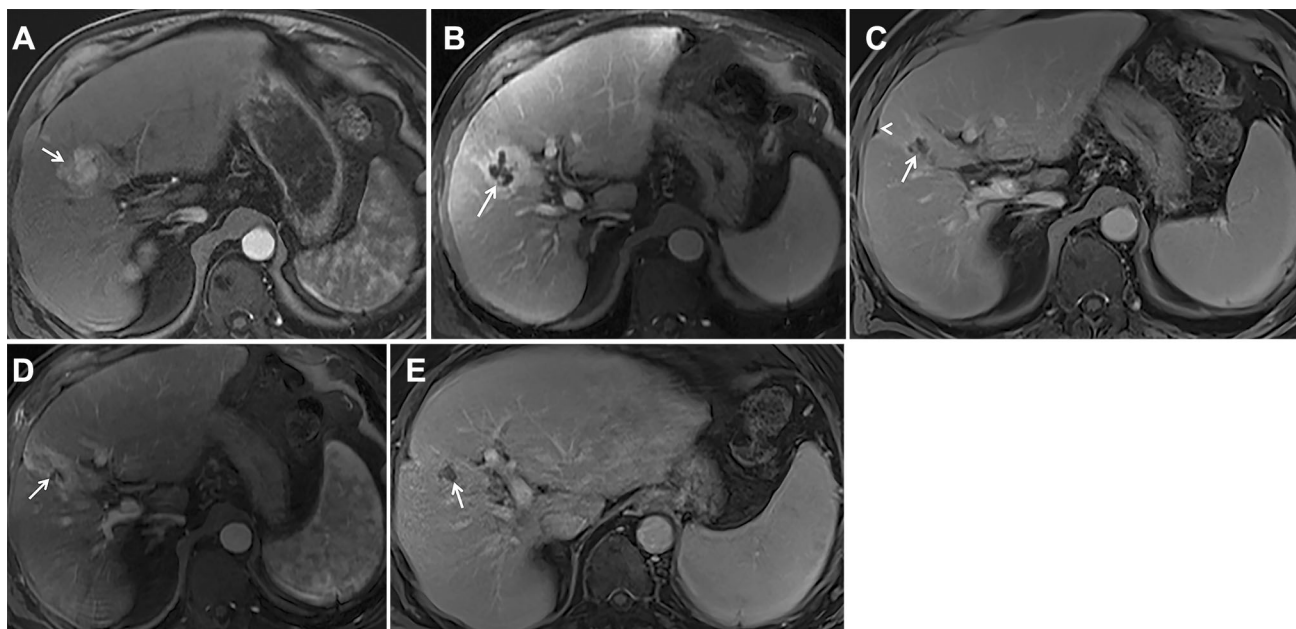
Fig. 3. **A** Pre-treatment contrast-enhanced MR image showing hyperenhancing lesion in segments V-VIII (arrow). **B** Post-treatment MR image at 1-month follow-up showing worrisome enhancement, with nodular artifact (arrow). **C** MR image at 6-month follow-up, showing that the initial worrisome enhancement has resolved on delayed imaging without additional treatment (arrow). Capsular scar is noted (arrow-head). **D** MR image at 10-month follow-up showing less worrisome enhancement on arterial phase and progressive improvement (arrow). **E** MR image follow-up at 17-month follow-up showing complete disappearance of worrisome enhancement and complete necrosis, with progressive segment collapse. No local disease progression was seen at any moment of the follow-up (arrow).

it to the baseline; mRECIST measures the longest diameter of arterially enhancing tissue in the target tumor (Table 2).

In our cohort, mRECIST CR at one-month follow-up was observed in 21 (34%) patients. Response by WHO (CR and PR) was achieved in 65% (40/62) of the patients, which is higher than the average reported response rate with Y90 (20%–40%) [30, 31]; EASL response was achieved in 97% (60/62) of the patients which is in accordance with the reported response rate for overall Y90 [32, 33] (Table 3).

Persistent enhancement and residual tumor artifact

Two common and alarming findings in our analysis were the presence of what we called "persistent enhancement" and "residual tumor artifact."

"Persistent enhancement" refers to a pattern of enhancement that resembles infiltrative disease, an opaque marbled enhancement; "residual tumor artifact" is the presence of enhancement inside the treated lesion, which presents with suspicious characteristics such as nodular enhancement and thick/uneven enhancing capsule [34, 35] (Fig. 2).

In our review, of the 32 patients that presented with persistent enhancement at 1-month, 20 (63%) patients showed complete resolution at 3-month follow-up,

without any local disease progression at subsequent follow-up scans. These persistent findings may be explained by delayed necrosis [35]. (Figs. 3, 4, 5). Additional details on the phenomenon of "persistent enhancement" are provided in Fig. 6.

Local tumor progression

Treatment failure should be differentiated by the cause: (a) lack of technique effectiveness (i.e., incomplete tumor irradiation) and (b) new lesion in the liver. This difference leads to a wide range in the time to progression depending on the cause.

The goal of radiation segmentectomy is to selectively treat the index tumor and at the same time provide a safe margin of radiated area for any small satellite lesions in the treated segment. In this review, local tumor progression was established as any progression or new lesion in the targeted segment determined by imaging follow-up using WHO, RECIST, and mRECIST criteria for all the patients in the cohort. All images were reviewed by 2 board-certified radiologists.

Of the 62 patients in our review, 18% (11/62) of the patients had local tumor progression at some point in their follow-up. The median time to progression (TTP) was 2.4 years (95% CI 2.1–5.7). Only 6% of these 11 patients had imaging findings corresponding to "persistent enhancement" at 1-month follow-up.
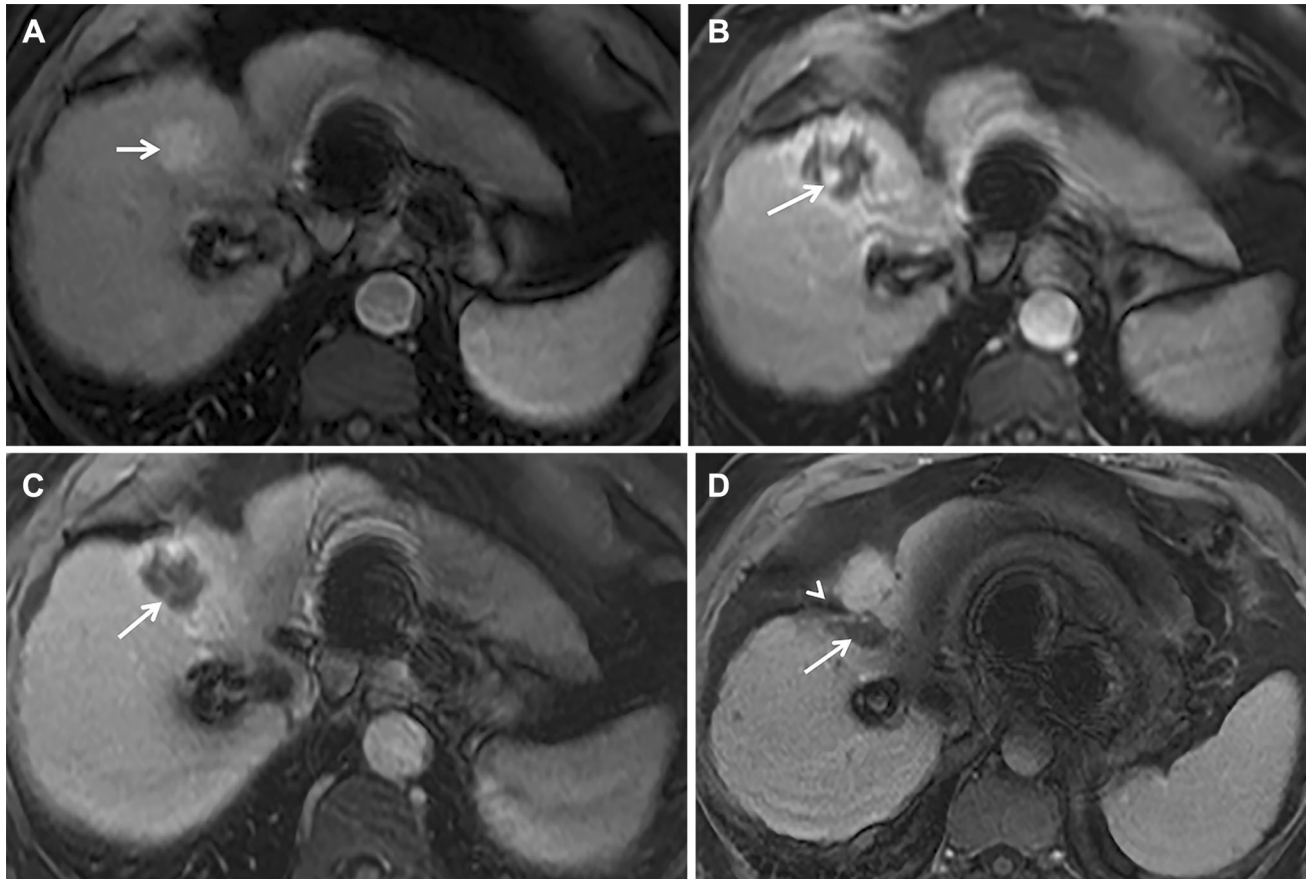
Fig. 4. **A** Pre-treatment contrast-enhanced MR image showing hyperenhancing tumor (arrow). **B** Post-treatment MRI with worrisome enhancement and suspicious nodular residual tissue inside the treated lesion (arrow). **C** MRI at 3-month follow-up, showing that the initial worrisome enhancement is no longer seen and complete necrosis of the lesion is now evident (arrow). **D** MRI follow-up 7 years after the initial RS treatment, showing excellent local tumor control and no evidence of local disease (arrow). Atrophy of the treated segment is seen (arrowhead).
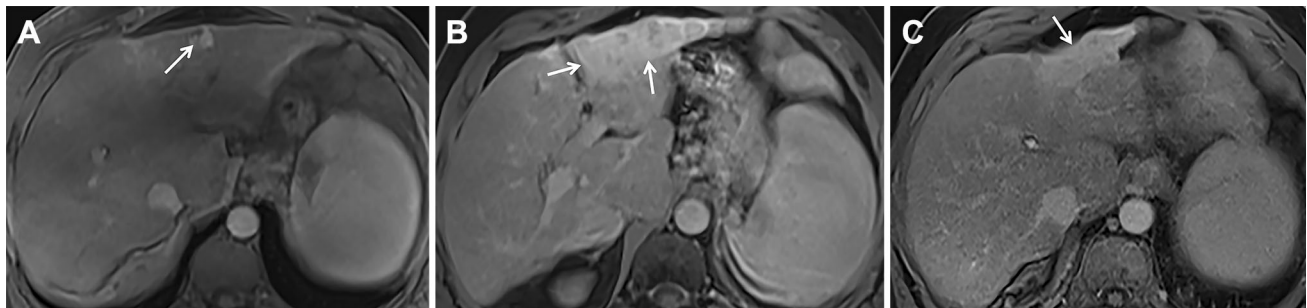
Fig. 5. **A** Pre-treatment contrast-enhanced MR image showing arterially hyperenhancing tumor in segment II (arrow). **B** Contrast-enhanced MRI at 1-month follow-up, showing diffused enhancement in the treated segment that is concerning for infiltrative disease but in reality is related to treatment radiation effect (arrows). **C** MRI at 1-year follow-up showing continued radiation-enhancing effect in the treated segment, with signs of local disease control. Segment retraction is also seen (arrow).

Incomplete tumor treatment

Incomplete tumor coverage can lead to a perception of "residual tumor" and subsequent disease progression. Most cases can potentially be avoided if recognized during pre-treatment imaging planning. Performing meticulous angiography and using cone-beam CT can indicate when catheter reposition or vessel embolization is necessary [36].
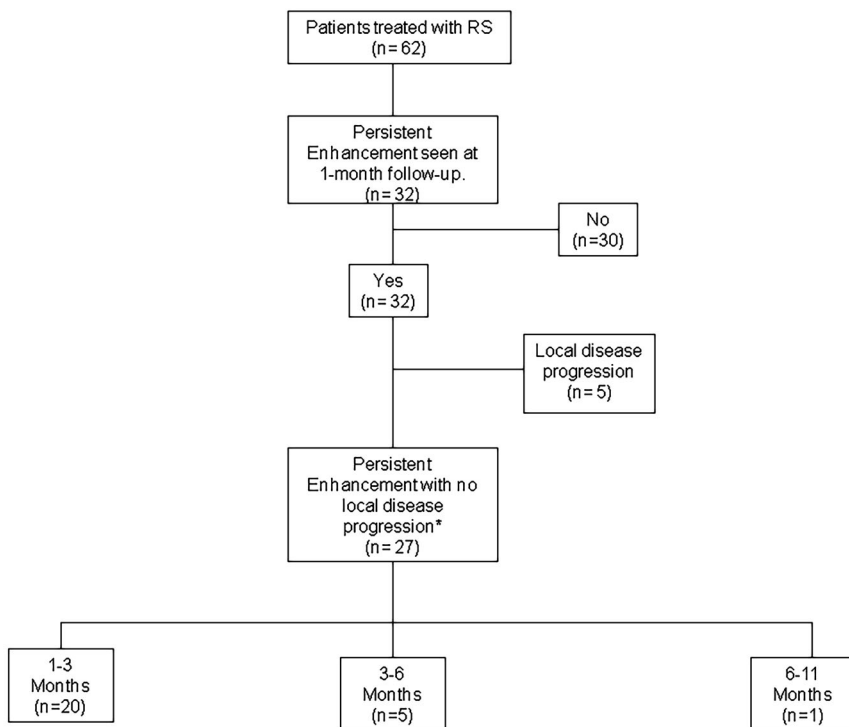
Fig. 6. Imaging Evolution of "Worrisome" Tumor Imaging Findings flow chart.
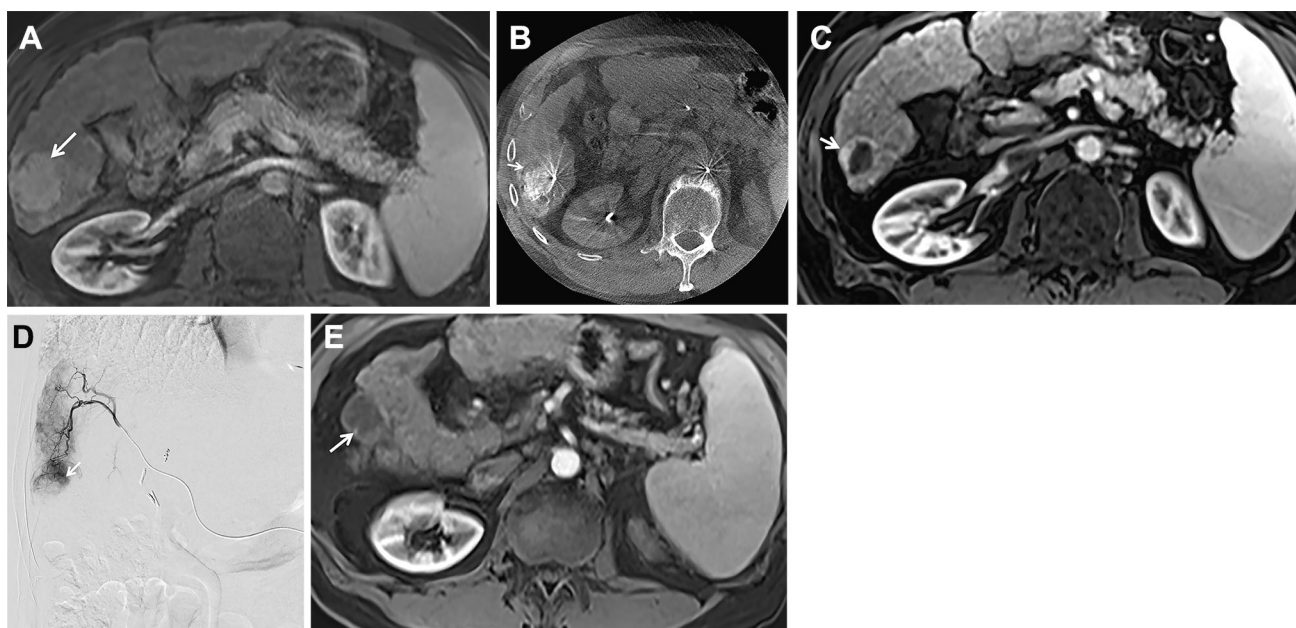

Fig. 7. **A** Pre-treatment contrast-enhanced MRI, showing arterial hyperenhancing lesion in segment VI (arrow). **B** Cone-beam CT, showing crescentic unenhanced tissue (arrow) predicting viable disease after treatment due to incomplete targeting. **C** Contrast-enhanced MRI at 1-month follow-up showing thick crescent-shaped residual tissue concerning for residual tumor (arrow). This is directly correlated to the pre-treatment cone-beam CT in Fig. 6B. This is an untreated disease and is not a post-Y90 effect. **D** Second Y90 angio-gram, showing enhancing tissue corresponding to the residual tumor (arrow). **E** 1-year follow-up after the second Y90, showing complete necrosis (arrow).

Persistent enhancement, when seen in controls, cannot be assessed independently, and they should always be reviewed retrospectively with all the patients' studies ruling out an incomplete tumor irradiation. Our data show that most persistent enhancement will disappear or show evidence of improvement by the third month after treatment; because of this, continued imaging follow-up is advised, unless there is evidence suggesting incomplete treatment (Fig. 7).

Rim enhancement

Rim enhancement constitutes a benign finding related to capsular fibrosis suggesting a favorable response to

Table 4. Follow-up imaging findings

Imaging finding	No. of patients (%)
Ascites	1 (2)
Perihepatic fluid	4 (6)
Contraction of treated segment	56 (90)
Capsular retraction	55 (89)
Persistent enhancement	32 (52)
Geographical enhancement correlating with cone-beam CT	58 (94)
Rim enhancement	21 (34)

Median time to follow-up was 17 months (range: 2–120 months)

treatment [37] and not viable tumor as demonstrated in previous studies [30, 38]. It may persist for months, with no time-dependent pathologic correlation.

In our review, 34% (21/62) of the patients had rim enhancement in their imaging follow-ups (Table 4).

Non-tumor imaging findings

Benign findings like ascites and perihepatic edema can also be seen after RS. They are related to local inflammatory response following treatment and radiation exposure to the liver capsule. In the case of RS, because of the smaller area of radiation treatment, perihepatic fluid, and ascites are not as frequent as compared to instances of Y90 to broader territories. They have no clinical significance and are transient (Table 4).
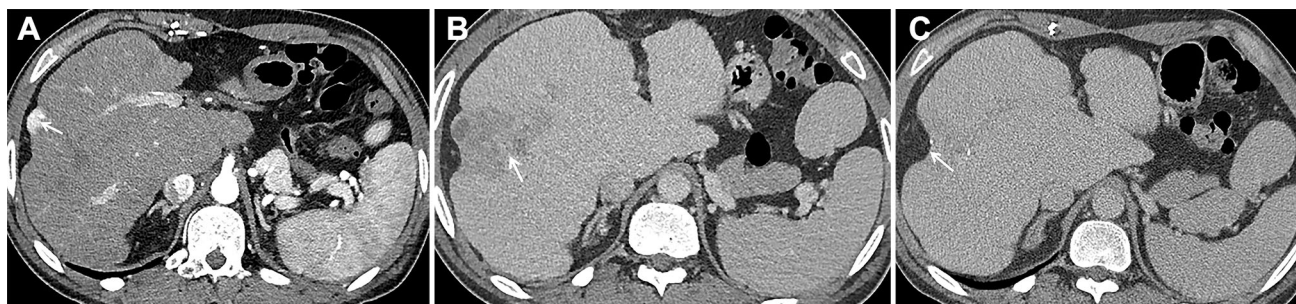
Capsular retraction and segment atrophy

Radiation segmentectomy commonly leads to retraction of the capsule and atrophy of the treated segment; this capsular retraction has been previously hypothesized as having to do with the tumor necrosis and treated tissue fibrosis and scarring [39]. It is also important to understand that the lack of capsular retraction and segment atrophy, although rare, does not imply a failure of treatment (Figs. 8, 9).
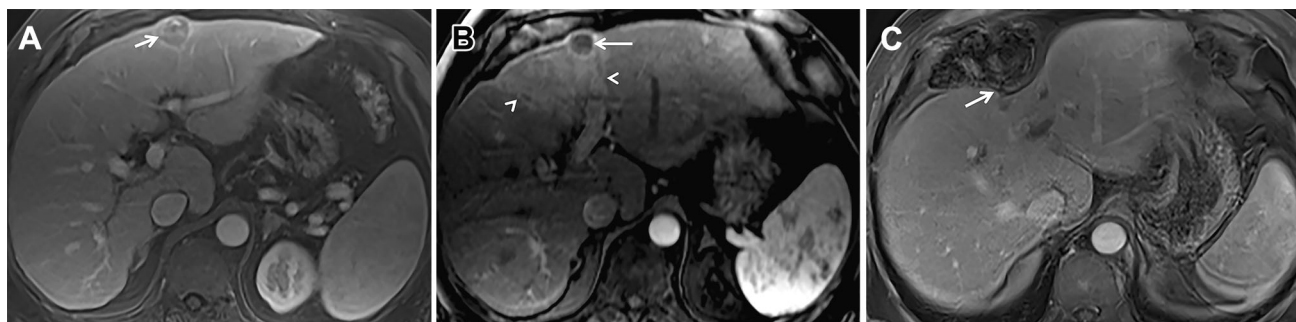

Fig. 8. **A** Pre-treatment CT right lobe hepatoma (arrow). **B** CT at 1-month follow-up showing fatty infiltration in the treated segment (arrow). **C** CT image at 9-month follow-up demonstrating capsular retraction and complete response (arrow).
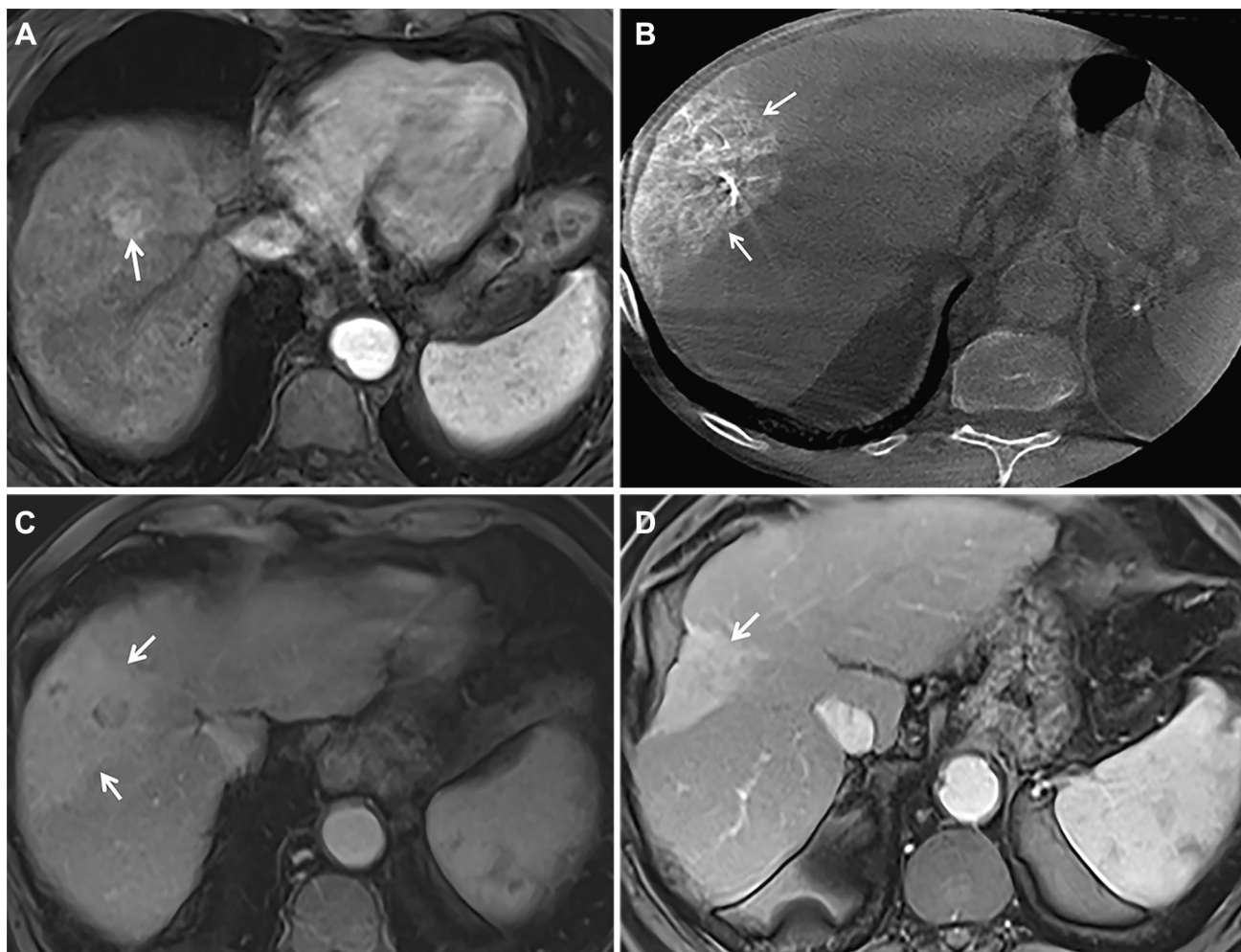

Fig. 9. **A** Pre-treatment MRI showing segment IV lesion (arrow). **B** Post-treatment MRI at 3-month follow-up showing complete necrosis (arrow) and peri-tumor radiation effect (arrowheads). **C** 4-year post-treatment follow-up image showing complete capsular retraction and atrophy of treated segment (arrow).
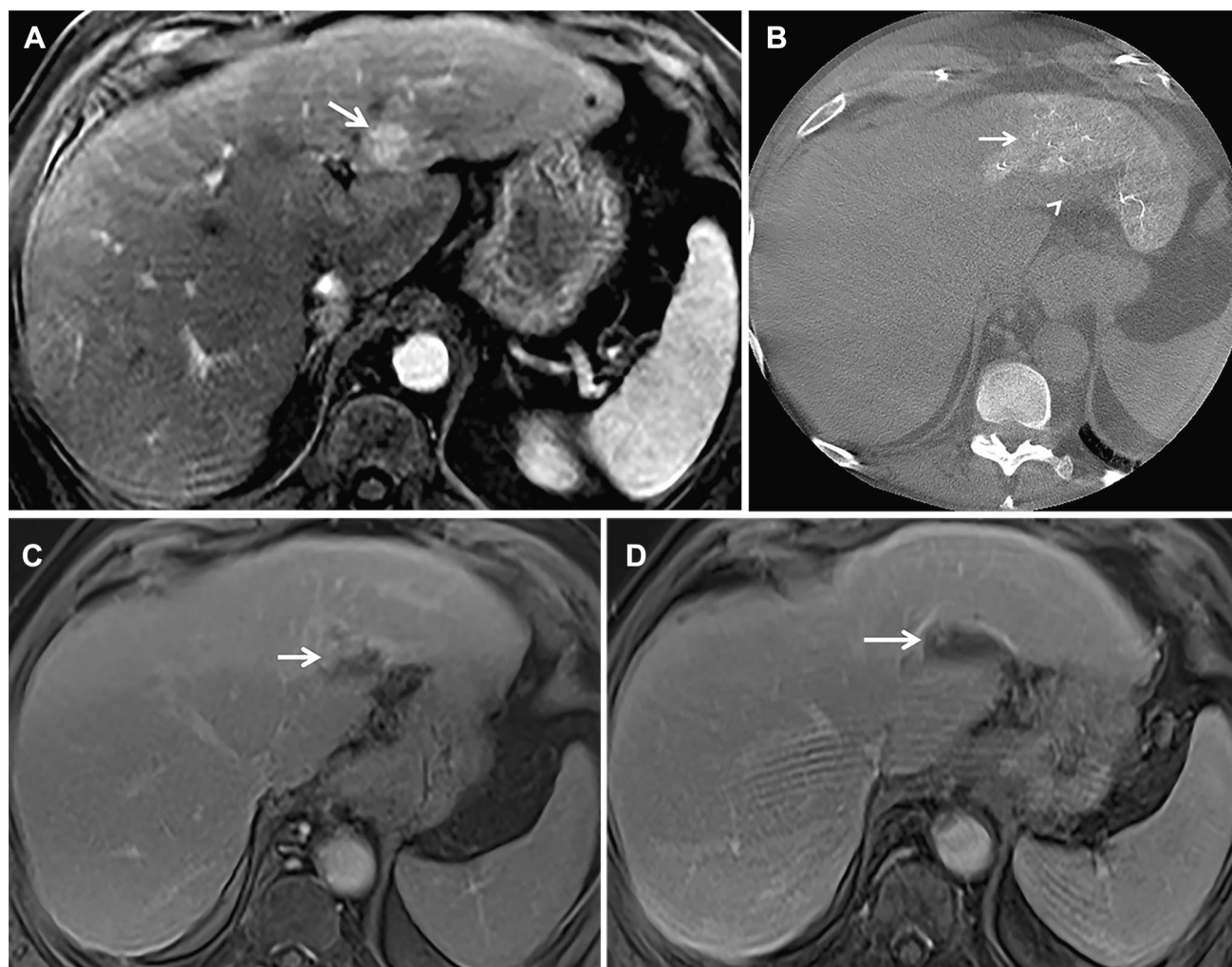
Fig. 10. **A** Pre-treatment contrast-enhanced MR image showing arterial hyperenhancing lesion (arrow). **B** Pre-treatment cone-beam CT that shows good targeting of the segment (arrows). **C** MR image at 1-month follow-up showing wedge-shaped geographical enhancement that correlates 1:1 with pre-treatment cone-beam CT (arrows). **D** 7-month image follow-up showing persistent geographical enhancement, scar formation, and segmental retraction corresponding to the treated area. (arrow).
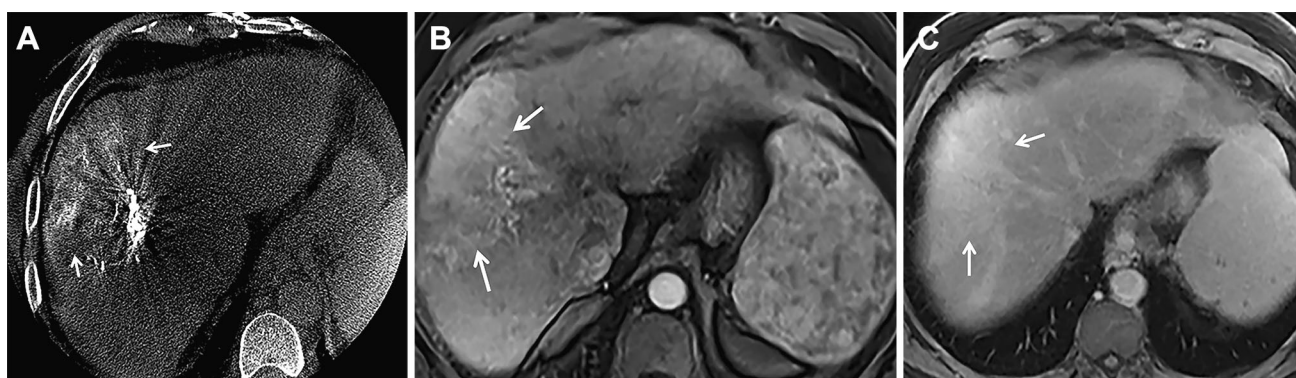
Fig. 11. **A** Pre-treatment cone-beam CT (arrow). **B** Contrast-enhanced MRI at 6-month follow-up showing geographical enhancement that correlates with pre-treatment cone-beam CT (arrows). **C** 1-year follow-up image showing persistent radiation effect and no evidence of local tumor progression (arrows).

Fig. 12. **A** Pre-treatment contrast-enhanced MR image, showing arterial hyperenhancing lesion in segment II/III (arrow). **B** Cone-beam CT (arrow) of branch perfusing around the planned treated territory (arrowheads), confirming that the lesion was perfused by a different branch. **C** Contrast-enhanced MRI at 1-month follow-up with worrisome enhancement and thick and irregular borders around target lesion (arrow). **D** 6-month follow-up image demonstrates the resolution of worrisome enhancement seen, showing no evidence of local tumor progression and complete segment retraction (arrow).

In our review, segment atrophy and capsular retraction were seen in 90% (56/62) and 89% (55/62) of patients, respectively (Table 4).

Geographical enhancement: correlating with cone-beam CT

Cone-beam CT has taken a major role in guaranteeing a successful treatment, by providing additional information during response assessments [16, 36].

A common finding, characteristic for Y90, is the presence of geographical enhancement with an extension greater than the treated tumor; this could be confused with active infiltrative tumor disease [40]. In RS, geographical enhancement usually presents with a characteristic wedge pattern. This wedge can be correlated perfectly to the pre-treatment cone-beam CT, reaffirming the relation of the enhancement with the treated segment.

This enhancement may persist for months and, in some cases, will not completely disappear, but the overall segment will progressively scar and contract. It is a benign finding specific to Y90 and does not correspond to an adverse treatment reaction or tumor progression (Figs. 10, 11). "Geographical enhancement" was seen in 94% (58/62) of the patients in our review (Table 4).

Adverse events

Radiation segmentectomy is regarded as a generally well-tolerated procedure that is associated with few adverse events, possibly due to the selective nature of the treatment. Previous studies have reported fatigue as the most common presenting symptom (52%) [4].

In our 62-patient cohort, no major adverse event was seen. Only one patient presented with a post-treatment biliary injury that resolved itself without any interven-
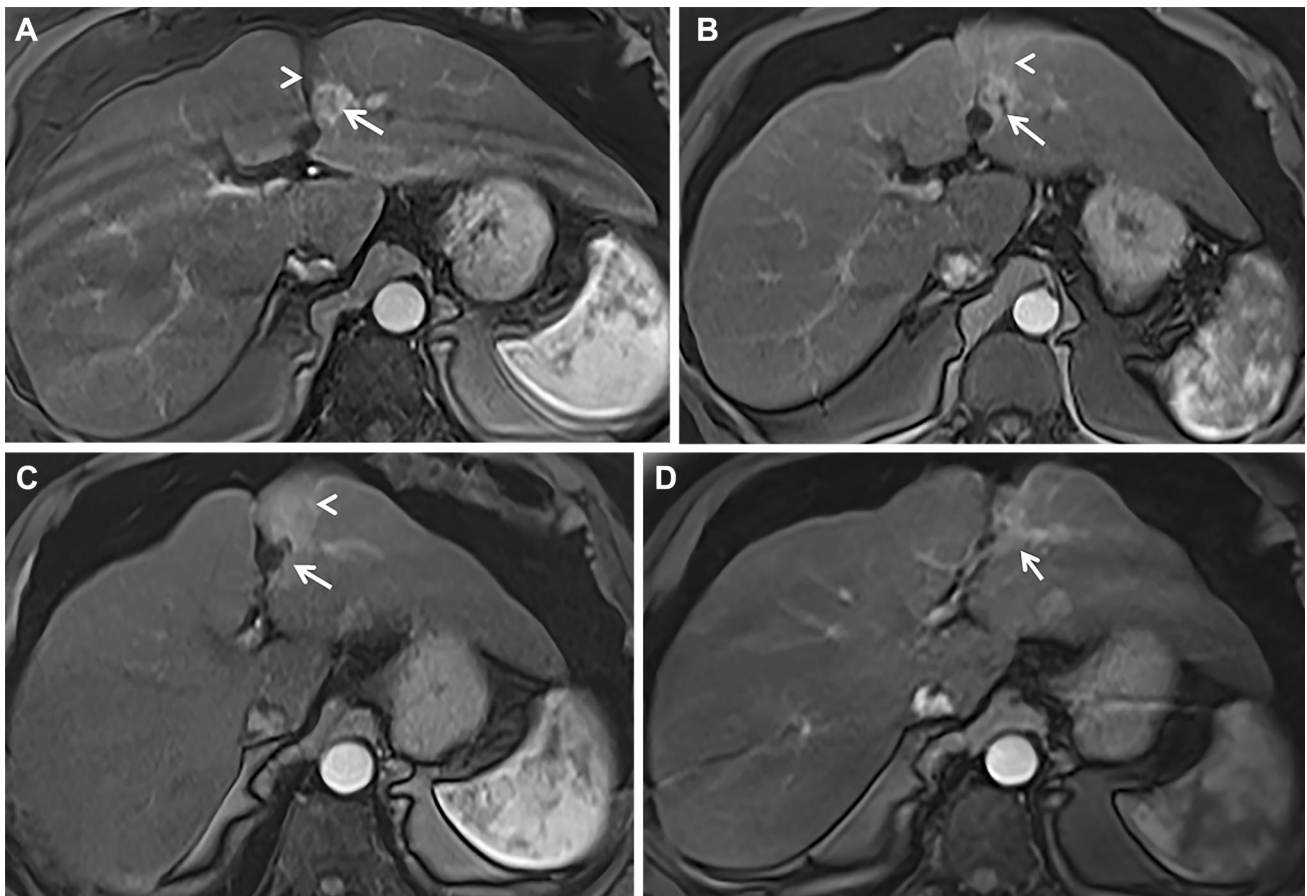
Fig. 13. **A** Pre-treatment contrast-enhanced MRI showing hyperenhancing lesion (arrow) abutting the falciform ligament (arrowhead), a difficult area to ablate. **B** Contrast-enhanced MRI at 1-month follow-up showing worrisome enhancement (arrow) and peritumoral radiation effect (arrowhead). **C** 6- month follow-up MRI showing persistent radiation effect (arrowhead) and improving worrisome enhancement (arrow). **D** 17-month follow-up image showing persistent radiation effect, complete necrosis of lesion, and no evidence of local disease progression (arrow).
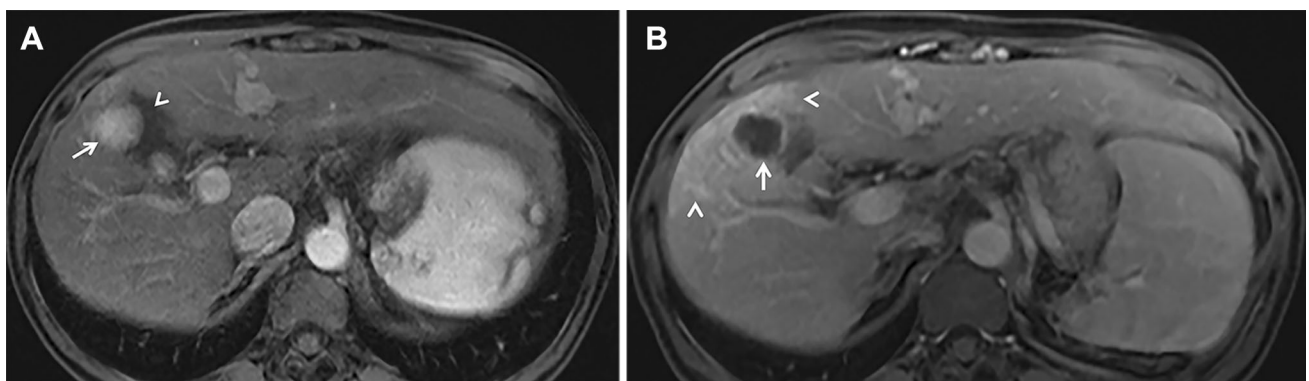
Fig. 14. **A** Contrast-enhanced MRI showing arterial hyperenhancing lesion (arrow) indenting the gallbladder wall (arrowhead). **B** 1-month follow-up image showing complete necrosis (arrow) and no injury to the gallbladder. Geographic enhancement is also seen (arrowheads). Patient did not experience adverse events.
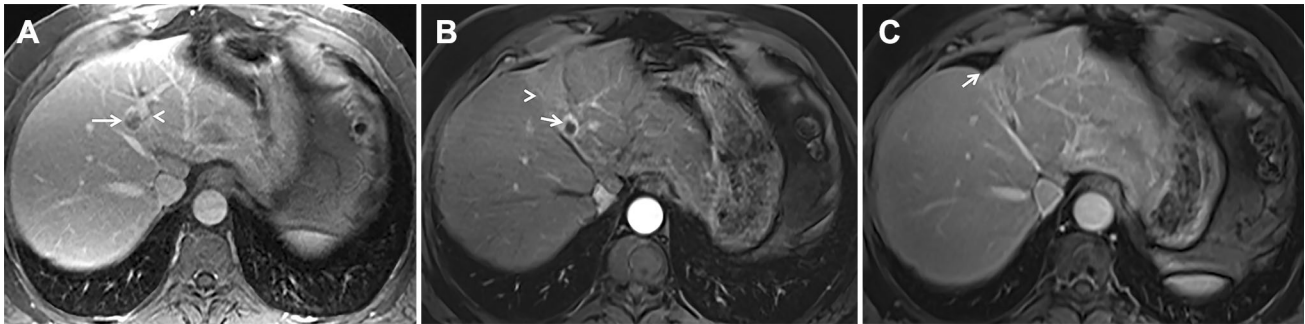
Fig. 15. **A** Pre-treatment MRI showing lesion in segment IV (arrow) touching the left portal vein (arrowhead); this will require a "central segmentectomy." **B** MRI at 1-month follow-up showing complete necrosis (arrow) and geographical enhancement (arrowhead). **C** 6-month follow-up image showing capsular retraction and segment IV atrophy (arrow). This is termed "central segmentectomy".
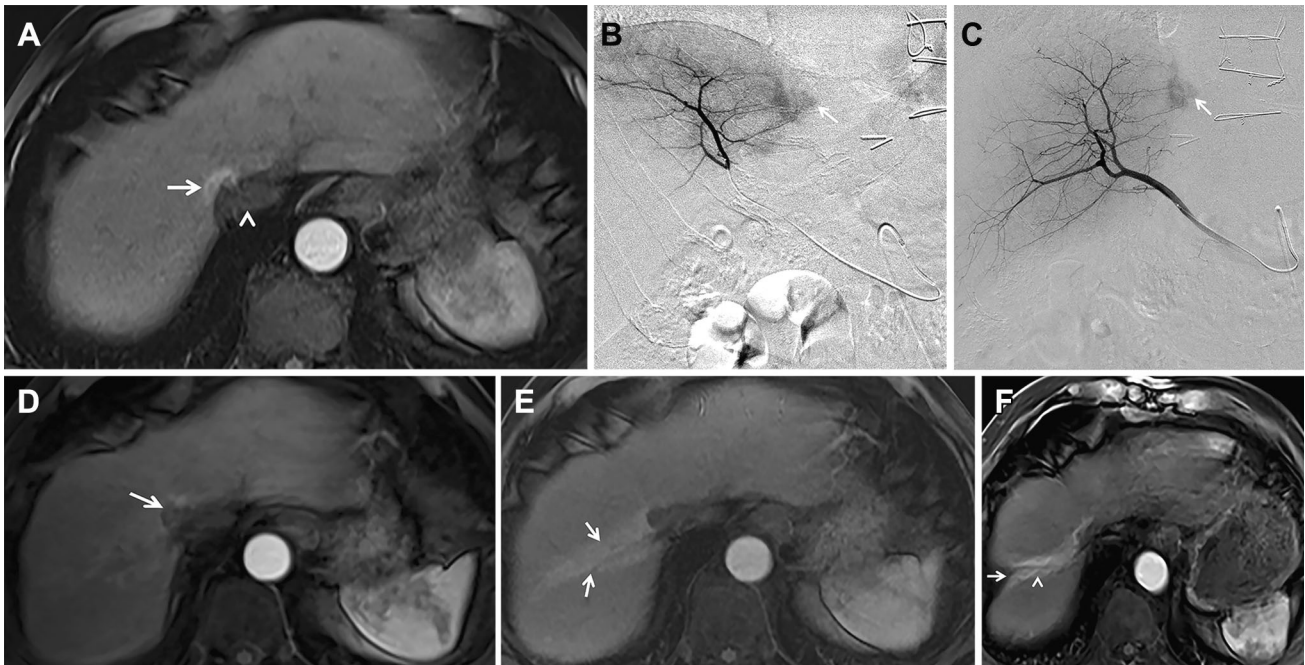
Fig. 16. **A** Pre-treatment MRI showing arterial hyperenhancing lesion (arrow) abutting the inferior vena cava (arrowhead). **B** Pre-treatment angiogram showing hypervascular lesion (arrow). **C** Pre-treatment in a different projection showing hypervascular lesion (arrow). **D** 1-month follow-up image demonstrating necrosis (arrow). **E** 6-month follow-up image showing wedge-shaped and perivascular radiation effect (arrows). **F** 6-month follow-up image confirming radiation effect in wedge shape (arrowhead) with capsular retraction (arrow).

tion. Low incidence of complications and adverse reactions can be correlated with the high tolerance of radiation segmentectomy when compared to other transarterial therapies.

Additional assessment tools

Post-Y90 imaging changes may take time to appear; response by size or necrosis may not be evident in every patient. For these unclear cases, alternative diagnostic tools like diffusion-weighted MRI to measure diffusion coefficient, FDG PET to measure metabolic activity, volume changes, and angiographic response should be used [39]. Having all proven to be of great utility [41], these should be considered for unclear cases. They were not included in this review.

Clinical and laboratory correlations with imaging follow-up are always necessary. Overall patient condition, liver function panel, and tumor marker changes
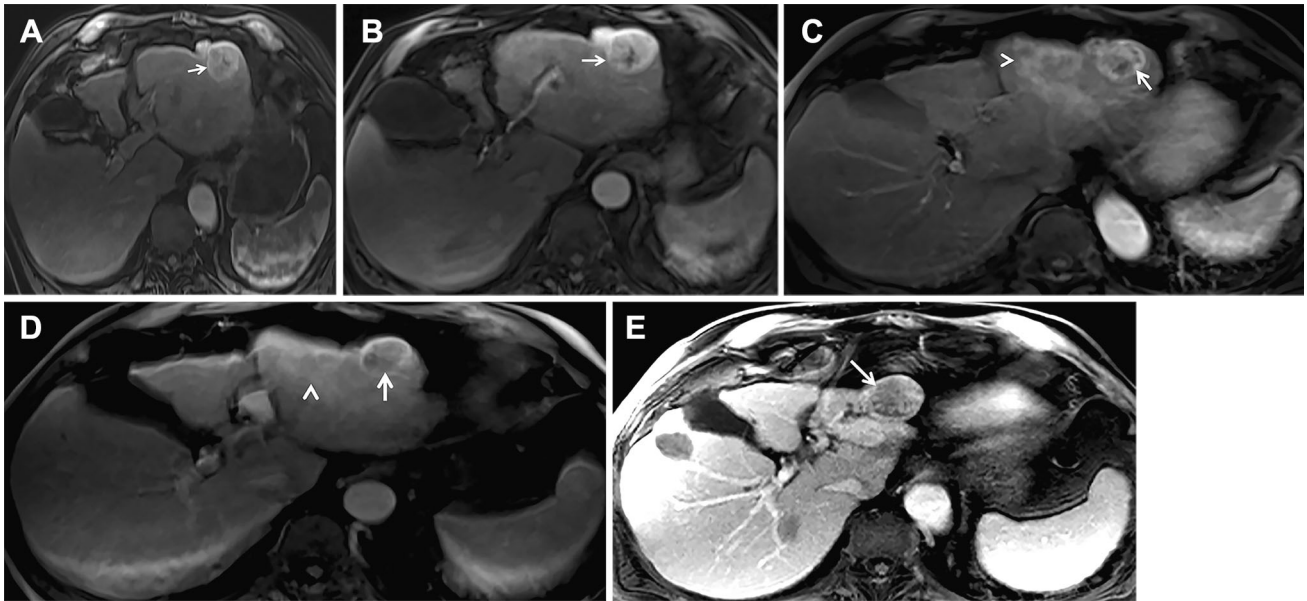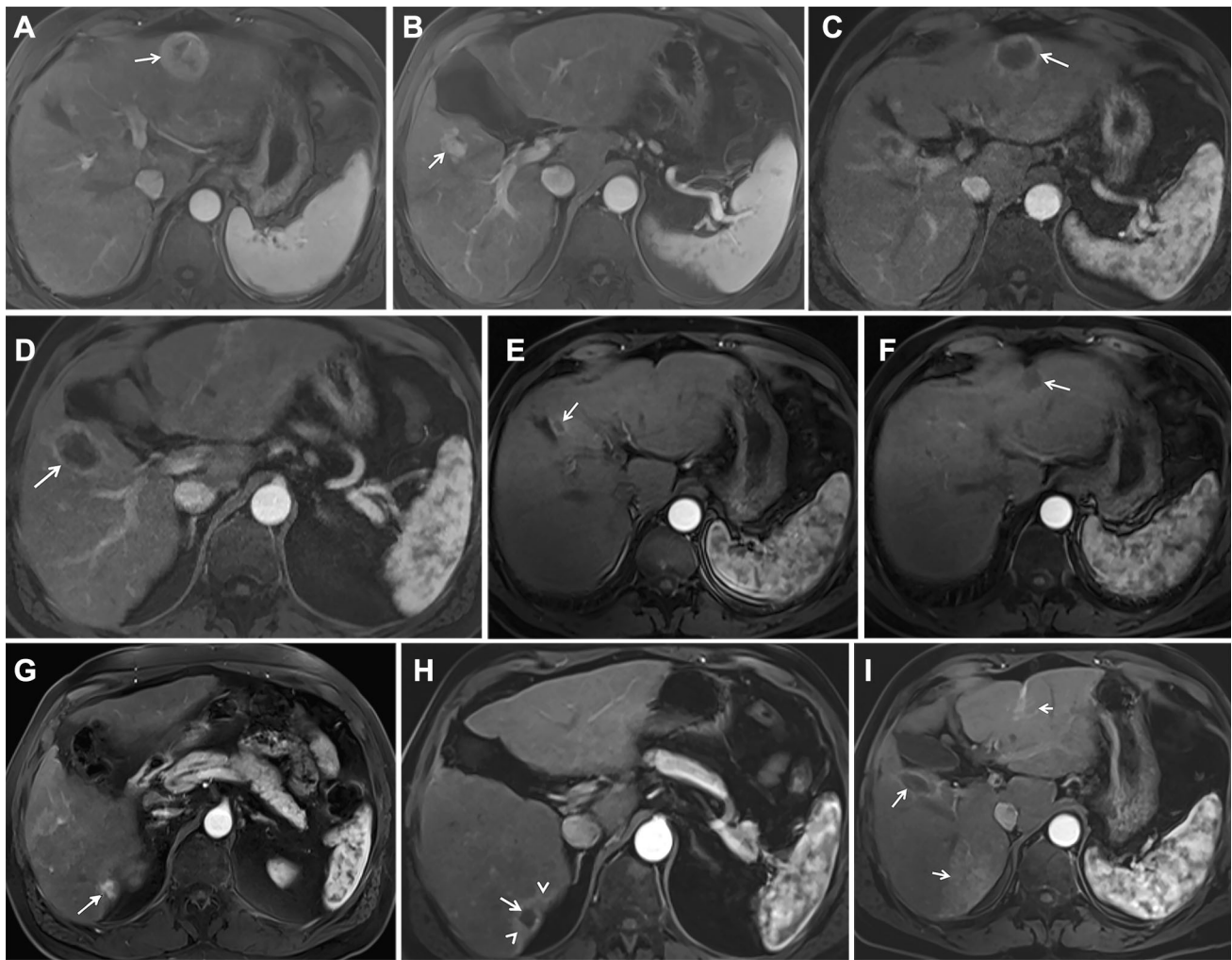
Fig. 17. **A** Pre-treatment MRI showing surface lesion in segment II (arrow). **B** MRI 1 month after RS showing enhancing lesion with worrisome enhancement (arrow). **C** MRI at 6 months showing persistent geographical radiation effect (arrowhead) and worrisome enhancement within the target lesion and adjacent parenchyma (arrow). **D** 10-month follow-up image showing improving necrosis (arrow) and persistent parenchymal enhancement (arrowhead). **E** MRI 40 months after RS, showing good local tumor control, with no disease progression (arrow). Patient underwent only one treatment.
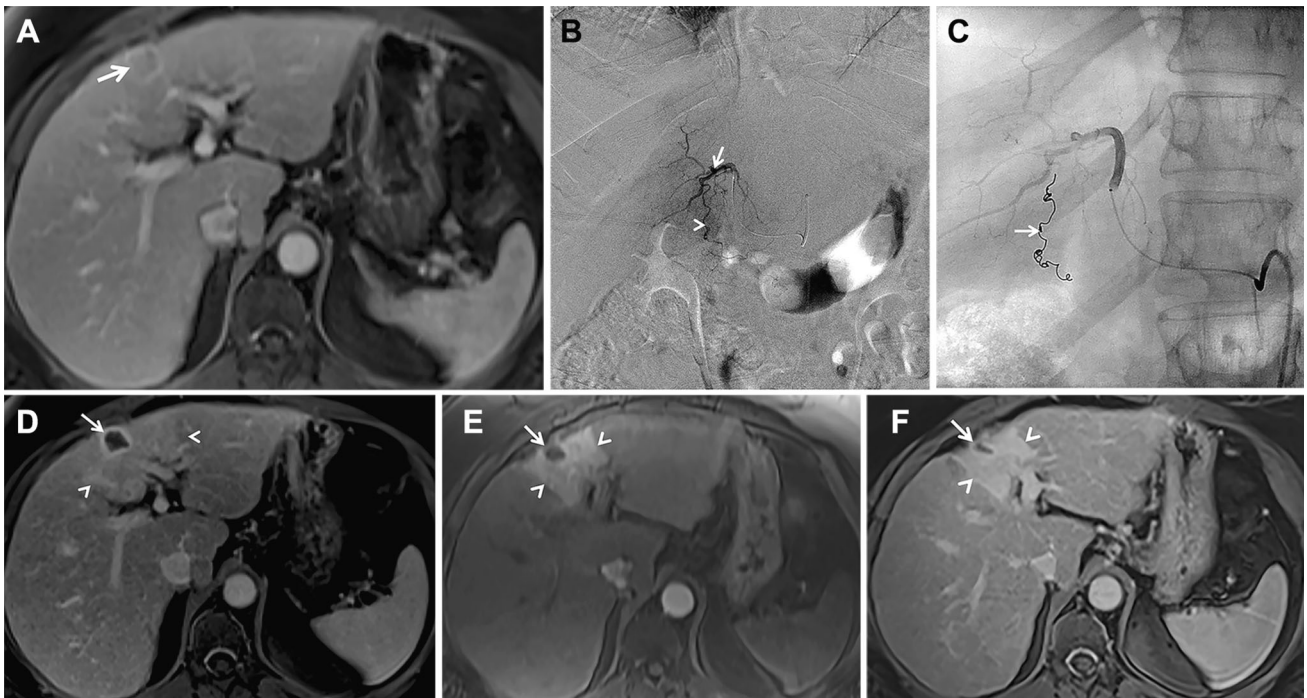
Fig. 18. Surface lesion and pre-treatment coil. **A** MRI showing lesion in segment IVa (arrow). **B** Pre-treatment angiogram showing middle hepatic artery (arrow) and falciform artery (arrowhead). **C** Pre-treatment angiogram showing middle hepatic artery after embolization of the falciform artery (arrow). **D** MRI 1 month after treatment showing complete necrosis, rim enhancement (arrow), and geographical enhancement (arrowheads). **E** 3-month follow-up image showing a decrease in lesion dimension, no tumor progression (arrow), and persistent radiation effect (arrowheads). **F** 6-month follow-up image showing a progressive decrease in lesion dimension (arrow), no tumor progression, and persistent radiation effect (arrowheads).

Fig. 19. Multisegmental segmentectomy: **A** Pre-treatment MRI showing lesion in segments II-III (arrow). **B** Pre-treatment MRI showing the second lesion in segment IV (arrow). **C** MRI at 1-month follow-up showing good treatment response in segment II-III lesion and rim enhancement (arrow). **D** MRI at 1-month follow-up showing good treatment response in segment IV lesion and rim enhancement (arrow). **E** Image at 8 months demonstrating a continued decrease in lesion size and persistent necrosis (arrow). **F** Image at 8 months demonstrating a continued decrease in lesion size and persistent necrosis (arrow). **G** A new lesion seen in segment VI 12 months after first treatment (arrow). **H** 1-month follow-up image after Y90 to new segment VI lesion, showing complete necrosis (arrow) and geographic enhancement (arrowheads). **I** 1-month follow-up image after Y90 to new segment VI lesion, persistent complete necrosis previously treated segment II-III and IV lesions (arrows).

need to be assessed in every follow-up as they provide important additional information, although it is important to remember that tumor marker changes do not always correlate with imaging response [42, 43].

Some important limitations in our review are the retrospective nature of the study and the cohort from only a single center. Important strengths include the homogeneity of this cohort and the single treatment modality. Long follow-up time also strengthens our findings; imaging modality was heterogeneous using both CT and MRI contrast-enhanced studies.

Miscellaneous cases

For completeness sake, we have included some additional cases that highlight the other manifestations of RS that can also be encountered (Figs. 12, 13, 14, 15, 16, 17, 18, 19, 20) These additional examples illustrate cases of lesions abutting the falciform ligament, gallbladder, inferior vena cava, liver surface, as well as central segmentectomy, multisegmental injections, and radiation segmentectomy in portal vein thrombosis.
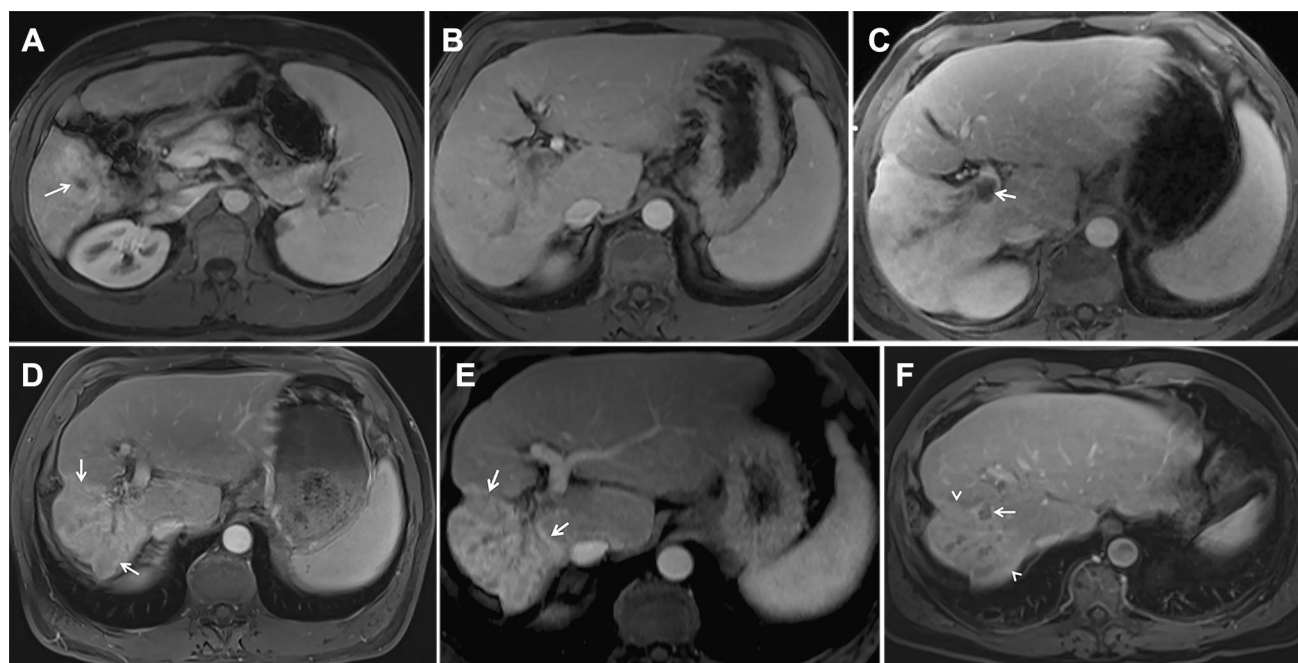
Fig. 20. **A** Pre-treatment MRI showing lesion in segments VI-VII and right portal vein invasion (arrow). **B** 1-month follow-up image after radiation segmentectomy to the posterior sector of the right lobe. **C** 3-month follow-up image showing retraction of the portal vein tumor and lack of enhancement (arrow). **D** 5-month follow-up image showing significant atrophy (arrow). **E** 9-month follow-up image demonstrating parenchymal enhancement secondary to radiation (arrows). **F** 12-month follow-up image showing continued atrophy of the treated segment (arrowheads) and continued response of the treated lesion (arrow).

Conclusion

Oncologic imaging response assessment is a complex task, which continues to evolve as new treatments are being developed. It plays a major role, as it is the method by which treatment success, recurrent disease, and complications are assessed. This evaluation would affect subsequent patient management. Response assessment after RS requires a learning curve with common pitfalls that can lead to false-positive interpretations and secondary unnecessary treatments. It is important to recognize that treatment responses and pathological changes both are time dependent. Findings such as benign geographical enhancement and initial benign pathological enhancement can easily be misinterpreted. Capsular retraction and segmental atrophy are some other examples of unique post-RS response that are not seen in any other treatment.

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