REVIEW ARTICLE

Future of IR: Emerging Techniques, Looking to the Future...and Learning from the Past

Marco Midulla*, Lorenzo Pescatori†‡, Olivier Chevallier*, M. Nakai*†, A. Ikoma‡, Sophie Gehin*, Pierre-Emmanuel Berthod*, Romaric Ne*, Romaric Loffroy* and Michael Dake§

Innovation has been the cornerstone of interventional radiology since the early years of the founders, with a multitude of new therapeutic approaches developed over the last 50 years. What is the future holding for us? This article presents an overview of the in-coming developments that are catching on at this moment, particularly focusing on three items: the new applications of existing techniques, particularly embolotherapy and interventional oncology; the cutting-edge devices; the imaging technologies at the forefront of the image-guidance. Besides this, clinical vision and patient relation remain crucial for the future of the discipline.

Keywords: Interventional Radiology; Innovation; Embolization; Interventional Oncology; Image Fusion

Introduction
With the title, Innovative solutions: an axiom of Interventional Radiology [1], Michael Dake, a pioneer of the endovascular treatment of thoracic aortic diseases in the 1990s, addressed a short commentary regarding a case reporting the management of an exceedingly rare congenital aneurysm of the thoracic descending aorta in a premature newborn using a novel and creative once-in-a-lifetime procedure mini-invasive interventional approach, in the Journal of Vascular and Interventional Radiology (JVIR) back in 2012 [2]. Michael Dake stated: “That represents evidence of the magic of Interventional Radiology – a compelling and spirit-lifting reaffirmation of the timeless and beautiful truth that less is more”.

Since the early years of the discipline in the mid to late 1960s, the history of therapeutic radiology, so-called “Interventional” in 1967 by Alexander Margulis, has been an exciting way of innovation focused on the development of mini-invasive solutions for patient care. A vortical succession of events, from the first rudimental angioplasty performed in 1964 by Charles Dotter at the Oregon University in the United States, to all new therapeutic concepts, treatment modalities, and devices progressively introduced in modern medical practice (Table 1). In the 1970s balloon angioplasty was introduced by a German cardiologist working in Zurich, Andreas Gruntzig; embolizations were welcomed by a sarcastic editorial with the title “Turned-off Bleeders” in Gastroenterology; complex liver interventions, such as transhepatic embolizations and the concept of Transhepatic Portosystemic Shunt (TIPS), appeared in 1969 and were implemented in the following years for the first in-human implantation in Germany in the early 1980s. The 1980s was the decade of the stents, as three famous worldwide devices were introduced in 1985: the Palmaz, the Gianturco and the Wallstent, each named for their respective physician-inventors [3]. At the end of the century a revolution of the management of aortic disease took place, first at the thoracic level with the introduction of the stent-grafts. First invented in the mid-1980s by the vascular surgeon Nicolai Volodos in Kharkov, an industrial city of the ancient Soviet Union, (now Ukraine). Volodos’ works gained attention in occident, and the first abdominal implantations were performed in Buenos Aires, Argentina by Juan Carlos Parodi in 1990 and Nancy, France in 1994. In the mid to late 1990s, with two publications in the New England Journal of Medicine (NEJM), Michael Dake, then Professor of interventional radiology at the Stanford University, introduced endovascular therapy of thoracic aortic disease for aneurysms in 1994 and dissections in 1999 which universally changed the way for physicians and, mainly, patients.

Beyond this glorious past, interventional radiologists keep staying involved in the progressive changes of modern medicine thanks to their natural propensity to imagine new solutions for managing pathologic contexts in a mini-invasive and targeted manner. The aim of this article is to provide an overview of current developments. We identify three main items: the new fields of applications for existing techniques; cutting-edge devices; and the imaging technologies at the forefront of the image-guidance.
New Fields of Application: Embolotherapy

The “Emborrhoid technique”

Over the last 2–3 years one of the main topics that has gained the attention of the interventional community concerns embolization therapy. The treatment of hemorrhoidal disease by transarterial embolization of the superior rectal arteries (SRA) (Figure 1), and nicely presented by Vincent Vidal and his team in Marseille under the name of “emborrhoid technique” [4], was inspired by previous experiences reporting embolization as an alternative to surgery in urgent cases of massive bleeding [5]. Ligation of the terminal branches of the superior rectal artery, to reduce the arterial supply to the hemorrhoids, is already performed in routine surgical techniques, with more or less tissue resection: the Milligan and Morgan’s hemorrhoidectomy (resection of the three hemorrhoidal cushions); the Longo procedure (resection of a ring of a ring of rectal mucosa); the more recent Elective Doppler-guided hemorrhoidal artery ligation (DG-HAL) [6–8]. Hemorrhoidal disease is primarily managed by conservative treatment combining hygiene and dietary measures with phlebotonics, while surgical intervention is reserved to 10% of the patients [9]. The main issue remains a prompt recovery but the complication rate ranges from 2% to 20%, with various post-operative disadvantages such as hemorrhage, stenosis, anal incontinence, and abscess. Peritonitis due to rectal perforation has been also described [10–13]. Transarterial embolization proposes a mini-invasive selective approach to achieve targeted occlusion of the arterial inflow without recurring to an invasive surgery that requires specific equipment such as an anoscope. The first publication of the early experience in three patients has been followed by a more recent report in 2016 reporting safety and efficacy of the technique in 40 subjects [14]. Particles and coils were used as embolization agents. Early results at one month demonstrated a significant regression of the hemorrhoidal bundles, absence of ischemic risk, and normal sphincteric function recovered after one month. Hospitalization and recovery time were respectively 2.5 ± 0.5 days (with 75% of the patients discharged on the first day) and 6.2 ± 0.9 days. Further prospective trials are required to better define the role of the technique beside the surgical gold standards; concurrently, applications of the emborrhoid technique in particular urgent contexts of variceal bleeding and high-risk patients are showing up in the literature and deserve attention [15–16].

Bariatric Embolization

Another cutting-edge application of the embolization therapy in the gastrointestinal tract is the treatment of obesity. The rationale of the so-called “bariatric embolization”, introduced through an in-animal study in 2007 by a group from the John Hopkins Institute in Baltimore, is founded on the suppression of the ghrelin-producing cells, in the fundus of the stomach, by selective embolization of the left gastric artery (LGA) [17] (Figure 2). Obesity, defined as a body mass index (BMI) ≥30 kg/m², is nowadays a high-impact health issue worldwide with related morbidity and mortality; it is a recognized risk factor for type 2 diabetes and several different diseases of the liver, heart, joints, lungs and even malignancies [16–18]. Lifestyle modifications are adopted as a first-line therapeutic approach, nonetheless the weight-loss can be obtained for 5–10% in overweight (BMI between 25 and 29.9 kg/m²) and obese (BMI between 30 and 34.9 kg/m²) patients in about three years [19–22]. Severe obesity or patients with high comorbidity can require more aggressive management by bariatric surgery, endoscopic interventions or pharmacotherapy. Embolization completes this therapeutic pattern and the clinical outcomes are under investigations. To date, there are three ongoing clinical trials focused on BAE: in the USA, the Gastric artery Embolization Trial for Lessening of Appetite Nonsurgically (GET LEAN) from Dayton Interventional Radiology at Ohio State University; the Bariatric Embolization of Arteries for the Treatment of Obesity (BEAT) carried out at Johns Hopkins Hospital; the Chinese
trial NCT02786108 from Zhong-Da Hospital in Nanjing [23–25]. In all these studies authors are using 300–500 m or 500–710 m particles to embolize all the LGA branches and, in some case, the gastroepiploic artery (GEA). No major complications were registered while minor events, such as superficial ulcer of the mucosa at the targeted zone, was encountered. Excess body weight loss varied from 9% at three months to 17.2% at six months (with mean body weight loss among 9.2 kg). Although the actual evidence in favor of BAE is still low, more and more data support the safety and early effectiveness of this minimally invasive procedure, that in the future could be even combined with other therapeutic resources to improve the results, for instance, in severely or morbidly obese patients.

**Embolization of inflammatory joint disease**

A completely new field of application for embolization therapy is in the musculoskeletal system and in particular, the treatment of resistant painful conditions such as osteoarthritis, frozen shoulder (adhesive capsulitis) and overuse injuries (tendinopathy and enthesopathy) (Figure 3). The recent works of Dr. Okuno from the Musculoskeletal Intervention Center at Edogawa Hospital in Tokyo have stressed the use of the technique in these emerging indications [26–30]: the rationale is focused on reducing the inflammatory angiogenesis that can contribute to the chronic pain by enabling growth of new unmyelinated sensory nerves along their path. Authors report the use of the modern mini-invasive approach with three or four French radial or femoral access and assess the neovascularization of the targeted zone by digital subtraction angiography (DSA). Embolization is performed with both pharmacological agents and calibrated microspheres (imipenem/cilastatin sodium, IPM/CS; 10–70 m particles). Results in terms of pain relief seem promising, thus endovascular therapy could gain a new role in the manage-
ment of those conditions where no consensus exists, for instance the frozen shoulder.

The Next Step of Interventional Oncology: Interventional Immuno-oncology

In 2006 the World Conference of Interventional Oncology took place in Cernobbio in front of the picturesque view of the Lake Como in northern Italy, and a new field of medicine was born. At that time, the term “Interventional Oncology” assembled the different techniques and new therapeutic concepts for cancer that had been developing with Interventional Radiology under a discipline that was subsequently integrated into the modern approach for oncologic patient care. We are aware nowadays of the role of the percutaneous ablation therapies and chemotherapeutic regimens and radio-embolizations in the therapeutic algorithms for cancer care. In the last few years a more innovative concept is appearing, well explained in some recent cutting-edge reviews published in radiologic and clinical journals [31–33]: the interventional immuno-oncology (IO). Curiously, the acronym IO is already used by both radiologists and oncologists to refer respectively to interventional radiology and immuno-oncology. The meeting between these two disciplines is becoming a promising field of innovation for the mini-invasive, patient-specific approach to neoplastic pathology therapy, able to maximize the efficacy of percutaneous tumor ablation therapies and improve the systemic immunologic response to the residual neoplastic cells. The phenomenon, whereby a locally applied therapy triggers a distal antitumor response, is termed the abscopal effect [31, 33]. The different techniques, radiofrequency (RF), microwave (MWA), cryoablation, focused ultrasound (FUS), and embolization, variably induce tissue necrosis, thus exposing the tumoral antigens to the immune system and stimulating the physiologic immune response. Specific in-animal trials have assessed the potential of each ablative therapy for interacting with the immunologic processes [34–38]; for instance, among the different ablative percutaneous solutions, cryoablation seems to have the best potential, so much so that some authors have referred to it in terms of “in-vivo dendritic cell vaccine” to highlight the effective impact on the immunologic mechanisms.
Several different elements (intracellular organs, antigens, damage-associated molecular patterns DAMPs) are released after the tumoral necrosis and phagocytized by the dendritic cells (DC) activating the complex pathways of the immune response (nuclear factor kappa-light-chain-enhancer of activated B cells, NF-κB; Heat Shock Protein 70; chemokines, like the Monocyte Chemoattractant Protein-1, CXCL16; cytokines like the TNF-α, IL-1, & IL-16; danger signals such as ATP, cal-reticulin, HMGB1). Oncologists have already adopted immunotherapy to activate and enhance the physiologic response; immuno-modulating drugs are largely divided in two classes, respectively targeting the innate immune system and the adaptive response. New pharmaceuticals are, for instance, the inhibitors of the "check-points" that prevent the inappropriate activation of a cell-mediated immune response (adaptive), such as the Ipilimumab used in metastatic melanoma, the PD-1 inhibitors (Pembrolizumab, Nivolumab, Durvalumab, Avelumab) approved for the treatment of melanoma, renal cell carcinoma, bladder cancer, non-small cell lung cancer, Hodgkin lymphoma, Merkel cell carcinoma and solid tumors. Combination of these new drugs targeting both the adaptive and innate immune system with ablative treatments has been tested in animal models, showing improvement of mean survival, cytolytic activity, tumor-specific T cell activation and dendritic cell maturation. The progressive advances in the understanding of the interactions between interventional therapies and the immune response will advance future clinical applications of interventional immunoncology and offer an exciting field of innovation for interventional radiologists (Figure 4).

**Innovative Devices: Vascular Dialysis Access**

During the last three years, two percutaneous devices have been developed, thereby introducing a new concept of the percutaneous arteriovenous fistula (AVF) creation. As is well known, AVF provide the best vascular access for hemodialysis in patients with end-stage renal disease, with low risk of infections and a better cost-benefit ratio compared to catheters and grafts. Surgical technique is standardized since long time and the innovation would substantially provide the advantage to avoid incision. The systems commercially available use a single or double catheter approach respectively, while also using a RF tool to create the fusion channel between the arterial and venous wall. The thermal resistance anastomosis device (TRAD) is a single-catheter system creating the AVF by direct puncture of the deep communicating vein (DCV) and the proximal radial artery (PRA) under ultrasound (US) guidance. Angioplasty of the new shunt is performed with a 4–5 mm balloon. Results published in 2018 for 34 patients showed a primary and primary assisted patency rate as expected, of 82% and 94% respectively with successful maturation of the AVF (diameter > 6 mm for 10 cm, flow > 600 mL/min) [39–41]. These positive outcomes have been also confirmed by the US multicenter pivotal trial [41]. The second device consists of a pair of over-the-wire 6-F catheters using magnetic force aligned in the ulnar vein and artery. Connection is accomplished by a RF cutting current that vaporizes the tissue. The results of the prospective, multicenter Novel Endovascular Access Trial (NEAT) have been presented this year (2018)

**Figure 4:** Interventional management of a renal mass in an inoperable patient, combined approach: transarterial pre-operative embolization is performed through femoral access (b) using selective catheterization (c) and injection of glue (d), thus obtaining devascularization before percutaneous ablation. (e) CT-guided cryotherapy; combination of the percutaneous ablative therapies and the immune-modulating drugs in the so-called “Interventional Immunoncology” becomes an unexplored field of application with a tremendous potential to investigate in the next future.
for 80 patients showing a success rate of 98%, a primary
efficacy endpoint of 87% (% of endoAVFs physiologically
suitable for hemodialysis within three months of creation;
freedom from fistula stenosis and thrombosis and brachial
artery flow ≥500 mL/min and vein diameter ≥4 mm) and
a patency rate at 12 months of 69% [42]. These outcomes
are in favor of a valuable new mini-invasive modality for
the creation of functional AVF with low complication rate.

**Image-guidance Technologies**

**Virtual Reality**

Since the time of fluoroscopy, the panel of techniques and
methods used to guide percutaneous interventions has
evolved tremendously. A real revolution has been intro-
duced over the last decade by the multimodality image
fusion concept that has definitely gained major atten-
tion in the modern scenario of the interventional radi-
ology. The use of the cone-beam CT (CBCT) in combina-
tion with preoperative imaging has become an invaluable tool
to accomplish complex endovascular repair and improve
embolization and interventional oncology practice. More
recently, cutting-edge technology available in commercial
products such as the information-communications field
and video games, is advancing extended reality in medi-
cal use. Elchanan Bruckheimer, a pediatric cardiologist
from Israel introduced first the application of this new
technology in clinical medical imaging [43], as shown
in an episode of the famous American TV series *Grey’s
Anatomy*. Extended reality generally defines the spectrum
or “virtuality continuum” of the interaction between the
observer and a surrounding environment artificially modi-

dified through a wide range of digital creations. As shown
in **Table 2**, augmented reality (AR) and virtual reality (VR)
stay at the two ends of the spectrum respectively, with
insertion of 2D or 3D digital images in an “untouched”
native environment (AR) and creation of a completely new
synthetic scenario (VR) [44].

| Augmented Reality | True background | See-through display |
|-------------------|----------------|-------------------|
| Merged Reality    | True background| Immersive display |
| Mixed Reality     | True background| Immersive display |

The potential introduction of the extended reality (from augmented reality to virtual reality) is a new horizon that
can integrate the multimodality guidance and is gaining
attention of new start-ups and commercial companies.
Merged (MeR) and Mixed Reality (MxR) are the most

**Table 2:** The large spectrum of the Extended Reality, involving different type of virtual experiences where the observer
interacts with the surrounding environment. Merged (MeR) and Mixed Reality (MxR) are the most adapted concepts
for medical applications as they allow interaction with digital objects while preserving contact with the real surround-
ing environment (patient and operatory theatre).
adapted concepts for medical applications as they allow interaction with digital objects while preserving contact with the real surrounding environment. Clinical applications include intraprocedural visualization of patient’s data, 3D holographic reconstruction of organs anatomy for virtual interactive assessments and training purposes, patient and family preoperative information.

**Final Considerations: Looking to the Future... and Learning from the Past**

Imagination-innovation, lower impact on the patient and mini-invasive approach have been, and still remain, the cornerstones of our discipline. Interventional radiologists have the merit of being at the forefront of the modern medicine thus, as treated above, a wide panel of therapeutic options is nowadays part of standard algorithms of care. Technical advances are exciting and intrigue every physician particularly if he/she is an interventional radiologist. Nevertheless, the primum movens must be centered on a main issue: the patient. Interaction with people, that is seeing patients before and after the worst or best procedure, is mandatory; building outpatient clinic for direct referral to interventional radiology should be part of our practice; clinical vision and multidisciplinary discussion remain crucial for recognition of the specialty.

This, in our opinion, is the third cornerstone of interventional radiology and maybe the more innovative approach of our decade.

**Competing Interests**

The authors have no competing interests to declare.

**References**

1. Dake, MD. Innovative solutions: An axiom of interventional radiology. *J Vasc Interv Radiol*. 2012 Oct; 23(10): 1335–6. DOI: https://doi.org/10.1016/j.jvir.2012.07.001
2. Ferrara, SL, Kinney, TB and Hall, LD. Endovascular treatment of a congenital thoracic aortic aneurysm in a premature newborn. *J Vasc Interv Radiol*. 2012 Oct; 23(10): 1330–4. DOI: https://doi.org/10.1016/j.jvir.2012.07.001
3. Rösch, J, Keller, FS and Kaufman, JA. The birth, early years, and future of interventional radiology. *J Vasc Interv Radiol*. 2003 Jul; 14(7): 841–53. DOI: https://doi.org/10.1097/01.RVI.0000083840.97061.5b
4. Vidal, V, Louis, G, Bartoli, JM and Sielezneff, I. Embolization of the hemorrhoidal arteries (the emborrhoid technique): A new concept and challenge for interventional radiology. *Diagn Interv Imaging*. 2014 Mar; 95(3): 307–15. DOI: https://doi.org/10.1016/j.dii.2014.01.016
5. Berczi, V, Gopalan, D and Cleveland, TJ. Embolization of a hemorrhoid following 18 hours of life-threatening bleeding. *Cardiovasc Interent Radiol*. 2008; 31: 183–5. DOI: https://doi.org/10.1007/s00270-006-0179-4
6. Milligan, ET, Morgan, CN, Jones, LE and Officer, R. Surgical anatomy of the anal canal and operative treatment of haemorrhoids. *Lancet*. 1937; 119–24. DOI: https://doi.org/10.1016/S0140-6736(00)88465-2
7. Longo, A. Treatment of hemorrhoidal disease by reduction of mucosa and hemorrhoidal prolapse with circular stapling device: A new procedure. *6th world congress of endoscopic surgery*. Bologna: Monduzzi Editore. 1998; 777–84.
8. Scheyer, M, Antonietti, E, Rollinger, G, Mall, H and Arnold, S. Doppler-guided hemorrhoidal artery ligation. *Am J Surg*. 2006; 191(1): 89–93. DOI:https://doi.org/10.1016/j.amjsurg.2005.10.007
9. Madoff, RD and Fleshman, JW. American Gastroenterological Association technical review on the diagnosis and treatment of hemorrhoids. *Gastroenterology*. 2004; 126(5): 1463–73. DOI: https://doi.org/10.1053/j.gastro.2004.03.008
10. Sielezneff, I, Salle, E, Lécury, J, Brunet, CH, Sarles, JCI and Sastre, B. Morbidité post opératoire précoce après hémorroïdectomie selon la technique de Milligan et Morgan. Une étude rétrospective de 1134 cas. *J Chir*. 1997; 134(5–6): 243–7.
11. Senagore, AJ, Singer, M, Abcarian, H, et al. A prospective, randomized, controlled multicenter trial comparing stapled hemorhoidopexy and Ferguson hemorrhoidectomy: Perioperative and one-year results. *Dis Colon Rectum*. 2004; 47(11): 1824–36. DOI: https://doi.org/10.1007/s10350-004-0694-9
12. Racalbuto, A, Aliotta, I, Corsaro, G, Lanteri, R, Di Cataldo, A and Licata, A. Hemorrhoidal stapler prolapsectomy vs Milligan-Morgan hemorrhoidectomy: A long-term randomized trial. *Int J Colorectal Dis*. 2004; 19(3): 239–44. DOI: https://doi.org/10.1007/s00384-003-0547-3
13. Faucheron, JL and Gangner, Y. Doppler-guided hemorrhoidal artery ligation for the treatment of symptomatic hemorrhoids: Early and three-year follow-up results in 100 consecutive patients. *Dis Colon Rectum*. 2008; 51(6): 945–9. DOI: https://doi.org/10.1007/s10350-008-9201-z
14. Zakharchenko, A, Kaitoukov, Y, Vinnik, Y, et al. Safety and efficacy of superior rectal artery embolization with particles and metallic coils for the treatment of hemorrhoids (Emborrhoid technique). *Diagn Interv Imaging*. 2016 Nov; 97(11): 1079–1084. DOI: https://doi.org/10.1016/j.dii.2016.08.002
15. Maietti, D, Grazioso, L, Mosca, S, Fischer, M, Morelli, O and Rebonato, A. Rectal bleeding due to ectopic variceal bleeding: The “emborrhoid” technique as a bridge to TIPS placement. *Diagn Interv Imaging*. 2018 Jul 19. DOI: https://doi.org/10.1016/j.dii.2018.06.001
16. Venturini, M, De Nardi, P, Marra, P, et al. Embolization of superior recta arteries for transfusion dependent haemorrhoidal bleeding in severely cardiopathic patients: A new field of application of the “emborrhoid” technique. *Tech Coloproctol*. 2018 Jun; 22(6): 453–455. DOI: https://doi.org/10.1007/s10151-018-1802-5
17. Arepally, A, Barnett, BP, Montgomery, E and Patel, TH. Catheter-directed gastric artery chemical...
embolization for modulation of systemic ghrelin levels in a porcine model: Initial experience. Radiology. 2007; 244(1): 138–43. DOI: https://doi.org/10.1148/radiol.2441060790

18. Zhong, BY, Abiola, G and Weiss, CR. Bariatric arterial embolization for obesity: A review of early clinical evidence. Cardiovasc Interent Radiol; 2018 Jun 5. DOI: https://doi.org/10.1007/s00270-018-1996-y

19. Jones, LR, Wilson, CI and Wadden, TA. Lifestyle modification in the treatment of obesity: An educational challenge and opportunity. Clin Pharmacol Ther. 2007; 81(5): 776–9. DOI: https://doi.org/10.1038/sj.cpt.6100155

20. National Heart, Lung, and Blood Institute in cooperation with The National Institute of Diabetes and Digestive and Kidney Diseases. NIH publication. Clinical Guidelines on the Identification, Evaluation, and treatment of overweight and obesity in adults-the evidence report. 1998; 6(Suppl 2): 515–2095. National Institute of Health.

21. Montesi, L, El Ghoch, M, Brodosi, L, Calugi, S, Marchesini, G and Dalle Grave, R. Long-term weight loss maintenance for obesity: A multidisciplinary approach. Diabetes, Metab Syndr Obes. 2016; 9: 37–46.

22. Wadden, TA, Butryn, ML and Byrne, KJ. Efficacy of lifestyle modification for long-term weight control. Obes Res. 2004; 12(Suppl): 151S–62S. DOI: https://doi.org/10.1038/oby.2004.282

23. Syed, MI, Morar, K, Shaikh, A, et al. Gastric artery embolization trial for the lessening of appetite nonsurgically (GET LEAN): Six-month preliminary data. Journal of vascular interventional radiology: JVIR. 2016; 27(10): 1502–8. DOI: https://doi.org/10.1016/j.jvir.2016.07.010

24. Weiss, CR, Akinwande, O, Paudel, K, et al. Clinical safety of bariatric arterial embolization: Preliminary results of the BEAT obesity trial. Radiology. 2017; 283(2): 598–608. DOI: https://doi.org/10.1148/radiol.2016160914

25. Bai, ZB, Qin, YL, Deng, G, Zhao, GF, Zhong, BY and Teng, GJ. Bariatric embolization of the left gastric arteries for the treatment of obesity: 9-month data in 5 patients. Obes Surg. 2018; 28(4): 907–15. DOI: https://doi.org/10.1007/s11695-017-2979-9

26. Okuno, Y, Matsumura, N and Oguro, S. Transcatheter arterial embolization using imipenem/cilastatin sodium for tendinopathy and enthesopathy refractory to nonsurgical management. J Vasc Interv Radiol. 2013 Jun; 24(6): 787–92. DOI: https://doi.org/10.1016/j.jvir.2013.02.033

27. Okuno, Y, Oguro, S, Iwamoto, W, Miyamoto, T, Ikekami, H and Matsumura, N. Short-term results of transcatheter arterial embolization for abnormal neovessels in patients with adhesive capsulitis: A pilot study. J Shoulder Elbow Surg. 2014 Sep; 23(9): e199–206. DOI: https://doi.org/10.1016/j.jse.2013.12.014

28. Okuno, Y, Korchi, AM, Shinjo, T and Kato, S. Transcatheter arterial embolization as a treatment for medial knee pain in patients with mild to moderate osteoarthritis. Cardiovasc Intervent Radiol. 2015 Apr; 38(2): 336–43. DOI: https://doi.org/10.1007/s00270-014-0944-8

29. Okuno, Y, Iwamoto, W, Matsumura, N, et al. Clinical Outcomes of Transcatheter Arterial Embolization for Adhesive Capsulitis Resistant to Conservative Treatment. J Vasc Interv Radiol. 2017 Feb; 28(2): 161–167. DOI: https://doi.org/10.1016/j.jvir.2016.09.028

30. Iwamoto, W, Okuno, Y, Matsumura, N, Kaneko, T and Ikegami, H. Transcatheter arterial embolization of abnormal vessels as a treatment for lateral epicondyritis refractory to conservative treatment: A pilot study with a 2-year follow-up. J Shoulder Elbow Surg. 2017 Aug; 26(8): 1335–1341. DOI: https://doi.org/10.1016/j.jse.2017.03.026

31. Slovak, R, Ludwig, JM, Gettinger, SN, Herbst, RS and Kim, HS. Immuno-thermal ablating-shaping the anticancer immune response. J Immunother Cancer. 2017 Oct 17; 5(1): 78. DOI: https://doi.org/10.1186/s40425-017-0284-8

32. Hickey, RM, Kulik, LM, Nimeiri, H, et al. Immunologic and its opportunities for interventional radiologists: Immune checkpoint inhibition and potential synergies with interventional oncology procedures. J Vasc Interv Radiol. 2017 Nov; 28(11): 1487–1494. DOI: https://doi.org/10.1016/j.jvir.2017.07.018

33. Ng, J and Dai, T. Radiation therapy and the abscopal effect: A concept comes of age. Annals of Translational Medicine. 2016; 4(6): 118. DOI: https://doi.org/10.21037/atm.2016.01.32

34. Behm, B, De Fazio, P, Michl, P, et al. Additive antitumour response to the rabbit VX2 hepatoma by combined radio frequency ablation and toll like receptor 9 stimulation. Gut. 2016; 65(1): 134–43. DOI: https://doi.org/10.1136/gutjnl-2014-308286

35. den Brok, MH, Sutmulder, RP, Nierkens, S, et al. Synergy between in situ cryoablative and TL9 stimulation results in a highly effective in vivo dendritic cell vaccine. Cancer Res. 2006; 66(14): 7285–92. DOI: https://doi.org/10.1158/0008-5472.CAN-06-0206

36. Redondo, P, del Olmo, J, López-Díaz de Cerio, A, et al. Imiquimod enhances the systemic immunity attained by local cryosurgery destruction of melanoma lesions. J Invest Dermatol. 2007; 127(7): 1673–80. DOI: https://doi.org/10.1038/sj.jid.5700777

37. den Brok, MH, Sutmulder, RP, Nierkens, S, et al. Efficient loading of dendritic cells following cryo and radiofrequency ablation in combination with immune modulation induces anti-tumour immunity. Br J Cancer. 2006; 95(7): 896–905. DOI: https://doi.org/10.1038/sj.bjc.6603341

38. den Brok, MH, Sutmulder, RP, van der Voort, R, et al. In situ tumor ablation creates an antigen source for the generation of antitumor immunity. Cancer Res. 2004; 64(11): 4024–9. DOI: https://doi.org/10.1158/0008-5472.CAN-03-3949
39. Mallios, A, Jennings, WC, Boura, B, Costanzo, A, Bourquelot, P and Combes, M. Early results of percutaneous arteriovenous fistula creation with the Ellipsys Vascular Access System. *J Vasc Surg*. 2018 Apr 18. DOI: https://doi.org/10.1016/j.jvs.2018.01.036

40. Hull, JE, Elizondo-Riojas, G, Bishop, W and Voneida-Reyna, YL. Thermal Resistance Anastomosis Device for the Percutaneous Creation of Arteriovenous Fistulae for Hemodialysis. *J Vasc Interv Radiol*. 2017 Mar; 28(3): 380–387. DOI: https://doi.org/10.1016/j.jvir.2016.10.033

41. Hull, JE, Jennings, WC, Cooper, RI, Waheed, U, Schaefer, ME and Narayan, R. The pivotal multicenter trial of ultrasound-guided percutaneous arteriovenous fistula creation for hemodialysis access. *J Vasc Interv Radiol*. 2018 Feb; 29(2): 149–158. DOI: https://doi.org/10.1016/j.jvir.2017.10.015

42. Lok, CE, Rajan, DK, Clement, J, et al. Endovascular proximal forearm arteriovenous fistula for hemodialysis access: Results of the prospective, multicenter novel endovascular access trial (NEAT). *Am J Kidney Dis*. 2017 Oct; 70(4): 486–497. DOI: https://doi.org/10.1053/j.ajkd.2017.03.026

43. Bruckheimer, E, Rotschild, C, Dagan, T, et al. Computer-generated real-time digital holography: First-time use in clinical medical imaging. *Eur Heart J Cardiovasc Imaging*. 2016 Aug; 17(8): 845–9. DOI: https://doi.org/10.1093/ehjci/jew087

44. Silva, JNA, Southworth, M, Raptis, C and Silva, J. Emerging applications of virtual reality in cardiovascular medicine. *JACC Basic Transl Sci*. 2018 Jun 25; 3(3): 420–430. DOI: https://doi.org/10.1016/j.jacbts.2017.11.009