Trends that Impact IR's Future

Zukunftstrends der Interventionellen Radiologie

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ZUSAMMENFASSUNG

Die Zukunft der interventionellen Radiologie (IR) wird sich entsprechend der aktuellen Trends in den Bereichen Medizin, der Biologie von Krankheiten, der Technologie und der IR-Geräte und Ausstattungen weiterentwickeln. Die größte Auswirkung werden Trendwenden haben, die eine Differenzierung der IR von anderen Behandlungsgebieten im Fokus haben. Die Differenzierung dreht sich um Bildführungswissen und verfahrenstechnische Behandlungskompetenzen und umfasst drei Schlüsselkomponenten: Zugang, Zuordnung und Maßnahme, die den gemeinsamen roten Faden im Fachwissen der Bildgebung darstellen. Die wichtigsten Trends, die diskutiert werden, sind: Bildgesteuerte Diagnostik (IgDx), bildgesteuerte Behandlung (IgRx), Subspezialisierung in der IgRx, Design großer Geräte für IgRx, multimodale IgRx, interdisziplinäre IgRx und dezentrale Entwicklung der IgRx. Der Erfolg hinsichtlich des Erreichens einer patientennahen „Front-Line"-Position wird nicht nur die Zukunft der IR, sondern auch der Radiologie als Fachgebiet bestimmen. Die IgRx ist eine Anti-Kommerzialisierungs-Immunisierung.

Kernaussagen:

- Es ist sinnvoll, diagnostische (IgDx) und therapeutische (IgRx) IR-Verfahren konzeptionell zu trennen.
- Die Subspezialisierung in der IgRx wird zu Neuerungen in der IR-Praxis für alle Behandler führen.
- Fortschritte der auf IR angepassten Bildgebungsgeräte und die Integration der multimodalen Bildgebung werden neue Behandlungsmethoden erschaffen, erweitern und erleichtern.
- Andere Behandlungsgebiete werden ergänzend in die IgRx integriert.
- Die Erweiterung der IR-Leistungen auf die ambulante Bildgebung und die Ambulanzen wird dazu beitragen, die wichtige direkte Patientenversorgung zu etablieren.
- Die Übernahme dieser Trends wird dem sigmoidalen Kurvenverlauf der „Diffusion von Innovationen" folgen, der sich über verschiedene Zeitintervalle erstreckt.

ABSTRACT

The future of IR will evolve as a result of current trends in advances in medicine, disease biology, technology, and IR devices and accoutrements. Changes in the trends that lie at the center of the differentiation of IR from other treatment specialties will have the greatest impact. Differentiation revolves around image guidance knowledge and procedural treatment skills and involves three key components: access, mapping, and action, all of which have the common thread of imaging knowledge. The main trends that are discussed are: image-guided diagnostics (IgDx), image-guided treatment (IgRx), sub-specialization in IgRx, large device design for IgRx, multimodality IgRx, interdisciplinary IgRx, and decentralized IgRx growth. Success in attaining a patient-facing "front-line" patient position will determine the future not only of IR but of radiology as a field. IgRx is anti-commoditization immunization.

Key Points:

- It is useful to conceptually separate diagnostic (IgDx) and treatment (IgRx) IR procedures.
- Subspecialization in IgRx will innovate IR practices for all practitioners.
- Advances in IR-tailored imaging equipment and integration of multimodality imaging will create, expand, and facilitate new treatments.
- Other treatment disciplines will be integrated into IgRx in a complementary fashion.

- Expansion of IR services into outpatient imaging sites and outpatient clinics will help establish important direct patient care.
- The adoption of these trends will follow a "diffusion of innovations" sigmoid curve pattern spanning different time intervals.

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IR Evolution

Writing about any future gives one pause, in particular with respect to interventional radiology (IR) services, which I believe are currently undergoing a period of rapid change, a "punctuation" in evolutionary terminology [1]. Evolution works on a substrate, the present. A statement such as "the future is not what it used to be" may not be as ludicrous as it seems, because when the present substrate changes noticeably so does the future. Evolution to the future state of IR services is driven by differential, selective forces such as advances in medicine, biology of disease, technology, procedural devices, imaging equipment, and the healthcare market acting upon the present.

Normally when assessing a future state, I would recommend scenario planning as a means to develop hedging strategies to adapt to inherent uncertainty. Such planning uses axes of uncertainty, with payment models in the healthcare market being a common one. For example, market forces measured in dollars spent in the United States ($68 billion) on IR services show substantial growth [2, 3]. This can change because in the US, IR reimbursement is facing the challenge of decreased Medicare payments [4]. Other typical axes of uncertainty include changes in technology and medical practice and the trends affecting these axes are the ones we will emphasize.

We will review some trends in the current substrate that can act as selective forces to influence but not predict the future of IR services. The selected trends are those that help differentiate IR services because changes in them will have a greater impact on their future state. There are, of course, always unanticipated developments such as the Covid-19 crisis, but crises have a way of accelerating trends already underway. The intent of this manuscript is not to predict the future but to highlight salient trends that will influence it.

While shying away from prediction, it is conceptually useful to view these trends as innovations. Consequently, their influence on the future of IR services will follow the dynamics of the "diffusion of innovations". One well-known model of "diffusion of innovations" describes a general adoption sequence by groups of practitioners categorized as innovators, early adopters, early majority, late majority, and laggards [5]. These groups exhibit different times and rates of adoption with the cumulative numbers forming a classic sigmoid curve usually spanning years. Not until adoption reaches the 15–25 % threshold, the estimated "tipping point", does the innovation take on a life of its own to spread further [5]. All of the described trends will follow a sigmoid adoption curve but on different timescales. The time frames mentioned in this piece are meant to estimate the time to get to the mid-early adopter time frame in large healthcare systems situated in major urban settings. This is close to the "tipping point".

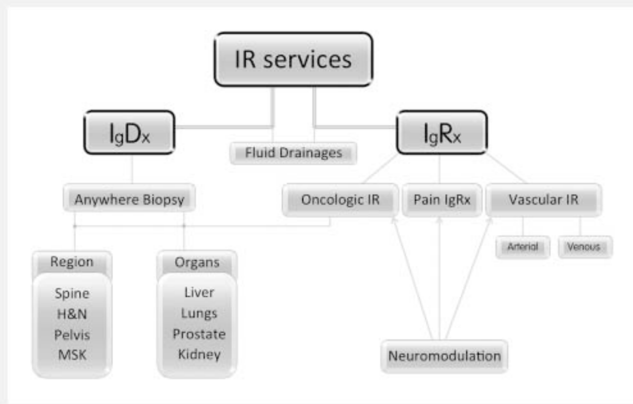
Patient Centrality

IR had humble beginnings when many patients who could not or would not be treated by other physician specialties for various medical reasons were referred. Now the trend is for patients to see interventional radiologists directly because of their track record of effectiveness, efficacy, low cost and safety [6]. These were clear selection forces. IR practice increasingly takes greater responsibility for direct pre- and post-procedure patient care rather than outsourcing this to other subspecialists. This has been vital in earning the much-needed trust of patients and their physicians to gain legitimacy in the treatment domain. Expansion of direct patient care, however, is not differentiating for IR, rather it is a catch-up step to other treatment specialties. Progress here will be heterogeneous as it takes time, space, money, new staff, and experience to build successful outpatient clinic practices. The general adoption time frame will be 2–4 years, while for any individual organization it may take 1–2 years to actually build.

Distillation of IR Differentiation

In a simplified, capsule summary, I shall repurpose the acronym AMA: for "Access, Map, and Action" because continual progress in those three essential steps differentiates IR services. "Access" relies heavily on technical skill, imaging skills, and judgment. "Map" means understanding the territory and the targets which requires anatomic, physiologic, and functional imaging skills. "Action", whether diagnostic or therapeutic, requires technical skills, medical knowledge, and clinical judgment. In short, IR service differentiation relies on the coherent combination of image-guided technical skills, deep imaging knowledge, and informed clinical judgment. The leveraging of imaging knowledge is essential for each differentiation feature.

To better understand differentiating components, it may be useful to reflect on IR terminology, which tends to emphasize the technical aspects of interventional practices. IR is a short, memorable, and even a catchy acronym, but it seems incomplete in capturing the depth, breadth, and differentiators of the field. One could consider dividing current IR practice into two types of image-guided procedures: diagnostic (IgDx) and treatment (IgRx) (► **Fig. 1**).



▶ **Fig. 1** This diagram depicts the conceptual organization of IR services into the major IgDx and IgRx subcategories each with further subdivision: IgRx into oncologic, vascular, and pain services; and IgDx into regional and organ subdivisions.

▶ **Abb. 1** Dieses Diagramm zeigt die konzeptionelle Gliederung der IR-Leistungen in die Hauptunterkategorien IgDx und IgRx mit jeweils weiterer Unterteilung: IgRx in onkologische, vaskuläre und Schmerzleistungen und IgDx unterteilt in regional und organbezogen.

Trends Creating Selection Forces

While there are multiple parallel, compounding, and intersecting trends, this paper will concentrate on five that seem to have selection potential: the increasing role of tissue acquisition (IgDx), subspecialization within IgRx, new large devices designed for IgRx, multimodality imaging in IgRx, and the growth of interdisciplinary IgRx.

Image-guided Diagnostics (IgDx)

While "precision medicine" is unfolding slowly, pari passu is a need for in-depth tissue analysis. IR services are developing the complete set of skills to safely position needles into tissue, anywhere in the body under multimodality image guidance, creating an image-guided diagnostic service (IgDx). While IgDx in the form of image-guided biopsies is less glamorous, it plays an essential role in "precision medicine" both in diagnosis and in response assessment [7]. IR services are uniquely capable of offering accurate, high quality, and reliable tissue acquisition services on a large scale. Biopsy (bx) procedures require technical skill, imaging skills, and judgment, i. e., all three AMA steps to ensure adequacy for the increased diagnostic molecular and genetic information needed for precision medicine [7]. Bx technical skills must assure safe and accurate placement under image guidance ("Access+Map") using cost-effective resources and timely clinical judgment ("Action") [7]. In the future, "smart needles" will be equipped with multiplexed sensors to provide real-time, in-vivo information not available through ex-vivo pathology. Noninvasive radiomics, radiogenomics, liquid biopsies, circulating tumor cells, cell-free DNA, circulating tumor DNA, etc., will furnish useful information, but it will be complementary to actual tissue analysis especially in multifocal disease. The demand for tissue continues to grow for establishing the primary diagnosis, for monitoring disease progression, and for assessing treatment response in clinical trials. An organized IgDx service can also serve as an on-ramp for follow-up treatment, especially tumor ablations using various energy forms personalized to tissue and location. It can identify eligible patients as it builds trusted clinical relationships [8]. This trend is accelerating and more organized IgDx service will be offered in greater numbers over the next 1–3 years, particularly in practices running clinical trials.

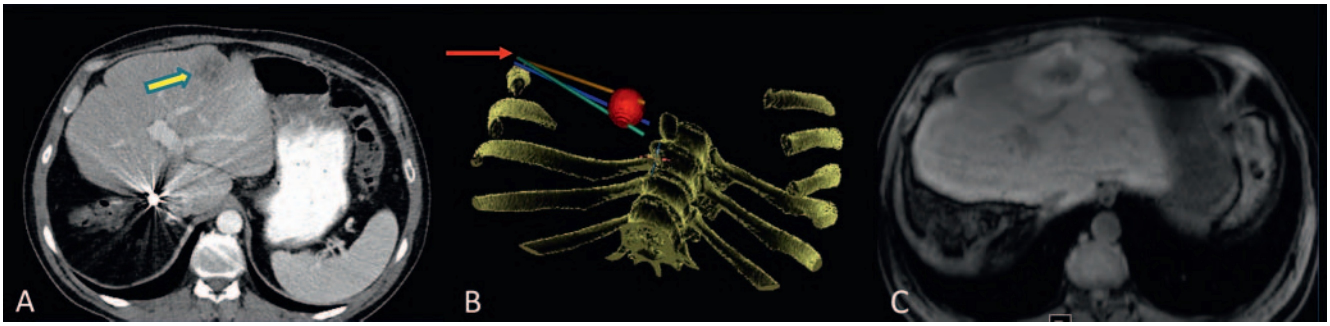
Image-guided Treatment (IgRx)

While several different terms could be used, my preference is image-guided treatment (IgRx) to highlight the treatment and outcomes of an IR service. This IgRx acronym better links technical skills (Access) with image knowledge in guidance (Map) to patient treatment (Action) than the term "IR" does alone. The differentiating imaging skills become increasingly relevant as other subspecialties adopt minimally invasive interventional treatments, another major trend. IR's adoption of direct patient care responsibility including outpatient clinic practice is clearly important but represents a matching rather than differentiation of skills.

Subspecialization in IgRx

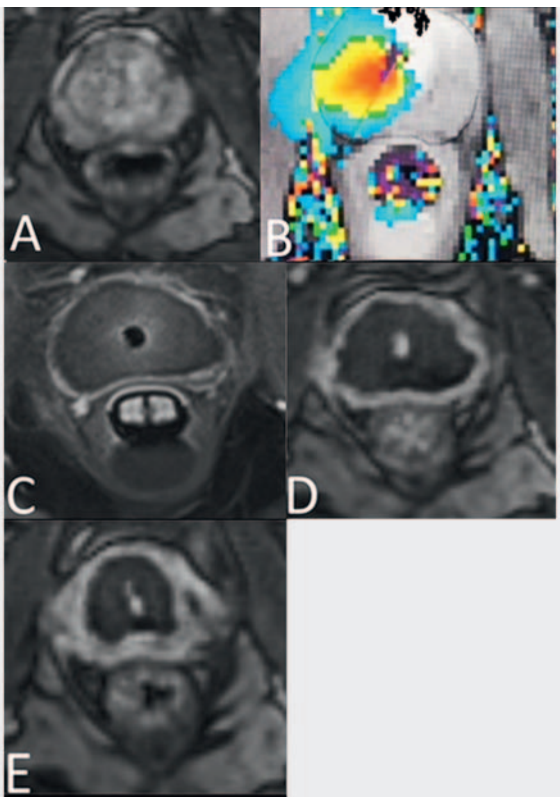
In addition to greater IgRx volume, there is a trend toward subspecialization primarily as "oncologic IgRx" and "vascular IgRx" (▶ **Fig. 1**). This reflects the continued advancement in medical knowledge, biologic knowledge, technical knowledge, treatment progress, imaging technology, and the development of large and small devices in the oncologic and vascular domains. For IgRx to grow robustly, it must delve into subspecialty care to match the expanding funds of knowledge possessed by referring physicians and patients. Interventional neuroradiology was an early example because of the specialized domain knowledge and training necessary to work with neurosurgeons and neurologists. Significant imaging skills became part of the training. While unusual, UCLA Radiology has favored IR faculty having two fellowships: a diagnostic one to gain superior imaging skills, and an IR one to acquire patient care and procedural skills.

IR services have been moving toward subspecializing in vascular IgRx and oncologic IgRx. Where the scale of program permits, vascular IgRx has even begun to subspecialize into arterial and venous systems. In a similar fashion, oncologic IgRx has begun organ-based subspecialization into the liver, kidney, lung, and prostate, and also into region-based specialization such as the spine, musculoskeletal, pelvis, and head and neck (cancer) which differs from classic, interventional neuroradiology (▶ **Fig. 1**). This subspecialization trend is not dissimilar to that seen in surgery with vascular surgery, oncologic surgery, endocrine surgery, head and neck surgery, etc. For IgRx the key differentiating feature of multimodality advanced imaging skills is their application prior to treatment, in real-time during treatment, and in post-treatment assessment (▶ **Fig. 2–4**).



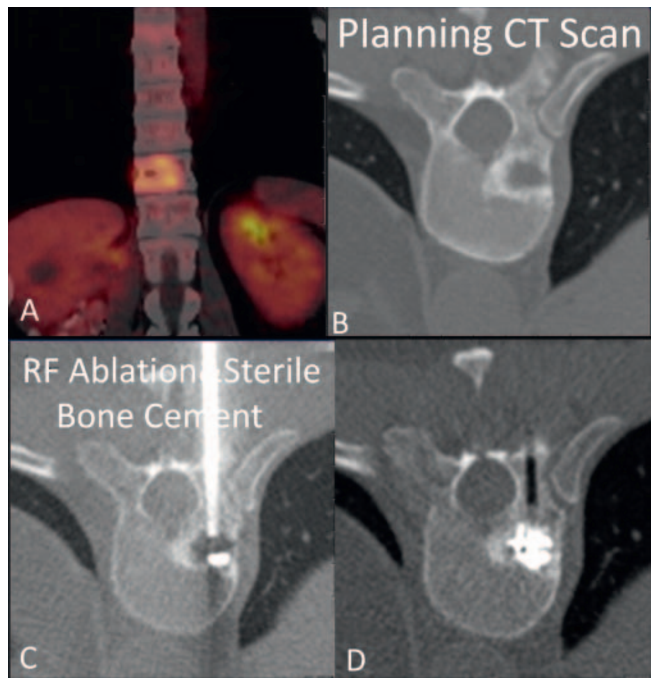
▶ **Fig. 2** **A** CT showing the colorectal metastasis to be treated. **B** 3 D CT confirmation of placement of triple antenna microwave. **C** Post-ablation MR showing an excellent ablation margin.

▶ **Abb. 2** **A** Die CT zeigt die zu behandelnde kolorektale Metastase. **B** 3D-CT zur Bestätigung der Platzierung der Triple-Antenna Mikrowelle. C MRT nach Ablation zeigt einen ausgezeichneten Ablationsrand.



▶ **Fig. 3** **A** Pre-treatment prostate MR scan (PSA = 7.8 ng/mL). **B** Real-time, MR-based temperature monitoring during treatment with high-frequency US hyperthermia. **C** Immediate post-ablation MR scan. **D** MR scan 1 month post-ablation (PSA = 1.1 ng/mL). **E** MR scan 3 months post-ablation (PSA = 0.1 ng/mL).

▶ **Abb. 3** **A** MRT-Aufnahme der Prostata vor der Behandlung (PSA = 7,8 ng/mL). **B** MRT-basierte Temperaturüberwachung in Echtzeit während der Behandlung mit Hochfrequenz-US-Hyperthermie. **C** MRT-Aufnahme unmittelbar nach Ablation. **D** MRT-Aufnahme 1 Monat nach Ablation (PSA = 1,1 ng/mL). **E** MRT-Aufnahme 3 Monate nach Ablation (PSA = 0,1 ng/mL).



▶ **Fig. 4** **A** Coronal view of PET/CT showing increased uptake in L3 colorectal metastasis. **B** Pre-treatment, planning CT shows lytic metastatic site in L3 vertebral body. **C** CT during treatment, RF ablation of metastatic soft tissue, and early injection of cement. **D** Post-treatment CT showing completion of cement injection into lytic vertebral body lesion.

▶ **Abb. 4** **A** Koronale Ansicht in der PET/CT mit erhöhtem Uptake in der kolorektalen Metastase L3. **B** Vor Behandlung zeigt die Planungs-CT eine lytische Metastasierungsstelle im L3-Wirbel. **C** CT während der Behandlung, RF-Ablation von metastasiertem Weichgewebe und frühzeitige Injektion von Zement. **D** CT nach der Behandlung zeigt den Abschluss der Zementinjektion in die lytische Wirbelkörperläsion.

There are two additional areas of subspecialization to consider, one near-term and another longer-term. Pain is a pervasive clinical symptom appearing in many disease entities in which image guidance can make local treatment more effective. This is particularly true for higher risk regions such as the spine and some visceral organs. There is, of course, overlap in the oncologic and pain patient populations (▶ **Fig. 4**). Treatment of pain may have unexpected added value for patient outcomes by improving mortality such as noted with vertebral augmentation [9, 10]. IgRx for pain has significant potential for mitigating the current opioid crisis [10]. Seeking IgRx alternatives to systemic narcotic drug therapy has uncovered some surprising applications such as geniculate artery embolization for severe osteoarthritis of the knee (and other joints) (▶ **Fig. 5**).

A longer-term opportunity is the relatively new field of neural control of disease (NCD) using image-guided, localized neuromodulation of the sympathetic and parasympathetic nervous systems. This inchoate treatment field, which is potentially very broad, will be pursued by multiple specialties. Radiologists practicing IgRx should take note, as this appears to be a sustainable long-term trend using the AMA steps to treat non-traditional targets by blocking or modulating neural signals in the ganglia and peripheral nerves. IR already practices a form of NCD in treating pain by using epidural nerve blocks, celiac plexus neurolysis, and superior hypogastric and Ganglion of Impar neurolysis [10]. Renal sympathetic denervation is a good current example [11]. The newer directions use neuromodulation of additional targets such as the stellate ganglion (▶ **Fig. 5**). While neuromodulation of the sympathetic and parasympathetic nervous system is in its nascent stage, the potential for achieving unique NCD outcomes with precise image guidance make this new technological and biological area attractive for IgRx.

This same trend will appear as subspecialization initially centered in a few medical centers, but the treatments they develop, perform, and perfect over time will spread to benefit all practitioners including "generalists" around the world [12, 13]. The speed of subspecialization and dissemination of its advances will depend on the local availability of resources, time, and equipment to allow them to be implemented on a clinically practical level. This will follow the classic "sigmoid curve" of diffusion of innovations. This subspecialization trend is, in fact, never-ending as innovation enters the field and medical knowledge expands. This trend is a continuous work-in-progress which is gaining momentum as the following trends progress. It will pick up pace over the next 2–4 years.

▶ **Fig. 5** **A** Plain film of lateral condyle knee osteoarthritis. **B** Pretreatment selective angiogram of geniculate artery. **C** Post-embolization angiogram showing pruning of multiple branches. **D** Angiogram 11 months after embolization showing stability of the treatment.

▶ **Abb. 5** **A** Übersichtsaufnahme des Condylus lateralis bei Kniegelenksarthrose. **B** Selektives Angiogramm der A. geniculata vor Behandlung. **C** Das Angiogramm nach Embolisation zeigt die Reduktion mehrerer Äste. **D** Das Angiogramm 11 Monate nach Embolisation zeigt die Stabilität der Behandlung zeigt.

Large Device Design for IgRx

Another major trend influencing the future is the design and manufacture of major imaging equipment specifically for IgRx. This is an important development because oncologic IgRx has relied on intercalating its image-guided procedures into high volume, diagnostic imaging schedules for CT, US, and even MR. That equipment is designed for efficient diagnostic imaging tasks, not for longer, interactive, treatment procedures. The overall growth of all IR in conjunction with its increasing clinical importance makes it commercially viable to build large imaging equipment and its accouterments, specifically for IgDx and IgRx. This ultimately improves IR service efficiency and efficacy, which further stimulates the market to build equipment for increasingly sophisticated IgRx including the much-awaited robotics. Commercial robotic equipment in direct contact with patients is already available allowing for performance of vascular procedures using both catheters and guidewires at distances varying from the control room outside the angiography suite to another hospital, city, or even country. The development of multiplexed, coaxial systems with integrated video/audio monitoring communications will allow "tele-IR services" analogous to diagnostic teleradiology or the development of "tele-surgery".

This newly designed equipment will reduce the competition for a limited time available on high-volume, high-margin diagnostic imaging equipment. This opens time for simulation of procedures and even full-dress rehearsals that will stimulate complementary technologies like 3 D printing for anatomic models (vascular, skeletal, etc.) and even virtual reality to enhance case-based simulations, as simulation in general has been an underutilized methodology. These combinations offer pretreatment practice and even trial and error should that be necessary for implanting devices or modifying anatomy. Dedicated IgRx imaging equipment will be designed with integrated robotics spurring its adoption into actual clinical practice to speed up procedures, refine their accuracy, and make a higher level of IgRx expertise available to a larger group of practitioners. While machine learning (ML) does not pose a significant replacement threat in IgDx or IgRx, continuous-learning, adaptive algorithms can use training databases of real-time imaging (fluoroscopy or cine) and provide operator feedback during all three steps of "AMA" for safer, more accurate access, improved target localization, and better assessment of endpoints and outcomes. Such ML can be used to optimize some procedures step by step, even adding contingency paths to sophisticated simulation in planning IgRx and during IgRx in real-time. This can reorganize training by combining cloud-based simulations with hands-on procedures. Eventually this type of ML will constructively mesh with robotics for advancing both IgDx and IgRx. Teleradiology will then include IgDx and IgRx to broaden their medical and social impact.

These developments will generate different business plans given the current reimbursement economics of IgRx compared to high-volume diagnostic imaging. Measuring the return on investment (ROI) in these business plans will have to use different, broader criteria to accommodate dedicated rooms for IgRx. Those criteria will reach beyond radiology department boundaries to include the hospital or health system as a whole. This hardware and software trend requires high capital investment. Hence it will develop more slowly as manufacturers build the equipment, get regulatory approval, and actually sell and install it. Widespread, more general adoption within this trend will extend to 3–10 years, reflecting design and manufacture time, capital equipment budgets reflecting financial depreciation schedules, and long site construction times. Despite the long timelines, a major non-financial benefit of IgRx to radiology is a frontline, patient-facing position in a healthcare system. This is immunization against commoditization.

Multimodality IgRx

The trend of dedicated equipment/devices is paralleled by a trend of using multiple imaging modalities for guidance, which enhances all of AMA by more accurately identifying, guiding, performing, monitoring, and assessing the outcome of IgRx. That image guidance will need to provide not only anatomic information, but also physiologic, functional, biologic, and molecular information increasingly captured in images. This multimodality approach will incorporate variegated streams of information in machines endowed with real-time machine and deep learning (ML/DL) capabilities. A harbinger of this is Google's ML/DL program to augment "AMA" in radiation oncology for head and neck tumors, a form of non-IR IgRx [14].

A multimodality approach will offer mixing and matching of complementary imaging technologies to provide different types of information in real-time to increase the efficiency and efficacy of IgRx. This will be accomplished by actual, physical placement of interacting machines in a single room or by asynchronous linking of 3 D imaging data using fusion software during image guidance. Sophisticated real-time fusion software will allow useful integration of information streams to augment each major AMA step in IgRx procedures. Cross-fertilization of technologies will facilitate the selection of the low-cost structures for IgRx, especially in outpatient venues. All of the major imaging modalities, fluoroscopy, angiography, ultrasound (US), CT, and increasingly MR will be mixed and matched for the subspecialty IgRx. In the new field of NCD, MR is likely to play a large role (▶ **Fig. 1, 6**). Multimodality IgRx is here and will be adopted more widely in the next 2–3 years as manufacturers make compatible equipment for all three AMA steps. However, full integration into specially designed treatment suites will be more along the time scale described above for large device IgRx. This customized treatment room design will be an opportunity for innovators and early adopters to establish clear, differentiated leadership positions in IgRx.

Interdisciplinary IgRx

As multimodality imaging trends pull in more imaging expertise, the trend of interdisciplinary treatment attracts additional funds of subspecialty knowledge, further expanding IgRx's applications and the need for additional imaging expertise. While there are competitive situations in IgRx, interdisciplinary cooperation with other specialists, such as oncologic surgeons, radiation oncologists, GYN surgeons, urologists, vascular surgeons, neurosurgeons, etc., will increasingly form teams to achieve desired outcomes in more complex IgRx. Radiology's contributions to interdisciplinary teams must leverage its imaging knowledge and skills to add differentiated value. IgRx has already for some time exhibited interdisciplinary cooperation between hepatologists, liver transplant surgeons, and oncologic IgRx in UCLA Health. Similar cooperation is expanding with radiation oncology (brachytherapy), GYN (uterine fibroids), and ENT (cancer). The interdisciplinary medical practices pattern will lead to "interventional" management team structures that guide the use of resources and treatment paths. Radiology will be a network hub rather than an isolated node.

While radiology has been "hired" to perform procedures, increasingly IgRx will be hired to achieve desired treatment outcomes. A side effect of an interdisciplinary trend will be the need for interventionalists of all stripes to create and live by similar metric dashboards. They will build a combined database for ML/DL. There will be a convergence of imaging technologies and treatment skills for all types of IgRx, which will be practiced inside and outside the sterile perimeter of operating rooms. Surgical IgRx will take place in hybrid OR rooms that will also accommodate the practice of radiologic IgRx. IgRx is simply too important and valuable to be relegated to one subspecialty or to be confined to a small geographic area of a department's real estate. This interdisciplinary trend will take longer to unfold as it entails cultural and human behavior changes beyond the technical ones, even financial ones. Again, this trend will be heterogeneous and will probably extend closer to 4–8 years before becoming widespread.

Outpatient Decentralized IgRx Growth

The convergence with other surgical subspecialties has spurred the growth of outpatient clinic practices in radiology as well as in cross-departmental, integrated clinics. Movement to lower cost structure outpatient venues is a growing trend, one being has-

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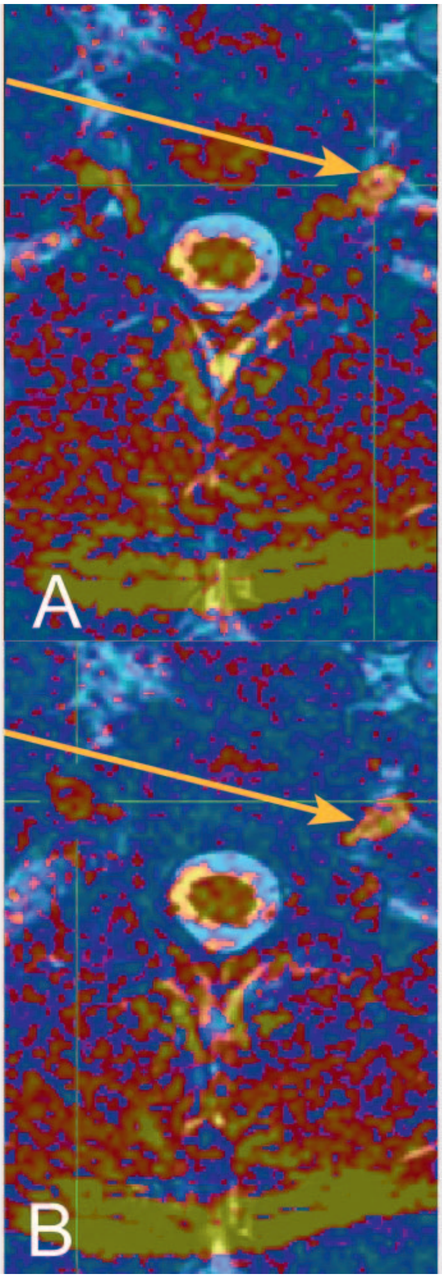

► **Fig. 6** Two adjacent slices of the stellate ganglion using a diffusion-weighted modified dual echo steady-state (DW-mDESS) pulse sequence. It is a 3 D, fast steady-state, free precession imaging technique that provides controllable levels of both diffusion and T2-weighted image contrast. Restricted diffusion from peripheral nerves and/or ganglia retain MR signal on these DW-mDess images, allowing for greater conspicuity in comparison to the surrounding tissues.

► **Abb. 6** Zwei benachbarte Schichten des Ganglion stellatum unter Verwendung einer diffusionsgewichteten modifizierten Dual-Echo-Steady-State (DW-mDESS)-Pulssequenz. Dabei handelt es sich um eine schnelle 3D-Steady-State Free Precession Bildgebung, die einen kontrollierbaren Grad an Diffusions- und T2-gewichteten Bildkontrast bietet. Durch die eingeschränkte Diffusion von peripheren Nerven und/oder Ganglien bleibt das MRT-Signal auf diesen DW-mDESS-Bildern erhalten, was eine größere Auffälligkeit im Vergleich zu den umgebenden Geweben ermöglicht.

tened by the Covid crisis. This is a good example of a crisis accelerating a trend already underway. Outpatient practices bring business model challenges given the significant differences from both surgical practices and large-scale diagnostic radiology. IgRx teams need to run these clinics efficiently with mid-level professionals and become more adept with telehealth, home-based care, and fast-moving developments in outpatient monitoring. This trend is being hastened by the Covid-19 crisis and thus will be more prevalent in the next 1–2 years.

This increased exposure to not only outpatient care and even home care will require additional skills in team building and skills in managing communication media that link to referring subspecialty physicians, primary care providers, mid-level professionals and, of course, patients. Mastering communication media including "chat" will introduce radiologists to non-traditional players like Apple, Amazon, and Google, as well as a gaggle of new telehealth intermediaries such as MDLive, Teladoc Health, and Livongo [15, 16]. IR services will include new home monitoring technology with these intermediaries playing complementary and supportive roles by building and maintaining patient relationships.

A real-world phenomenon is that once a trend appears and grows, its complementary trend oftentimes also appears and grows. IgRx started outside ORs in radiology but is now finding its way back into the OR. Much of current IgRx is situated in complex, hospital-type environments, but a complementary trend will transport IgRx into community-situated outpatient centers to deliver simpler, lower cost versions. To grow, IgRx will be practiced in more decentralized venues, which necessitates balancing subspecialization with practical access. Such practices require new skills in a more networked approach to IgRx beyond the tasks of simply scheduling "rooms" in a hospital. This brings to mind the famous F. Scott Fitzgerald quote, "The test of a first-rate intelligence is the ability to hold two mutually contradictory ideas in the mind simultaneously without losing the ability to function". The evolution of IgRx will create this test with increasing subspecialty, multimodality, and interdisciplinary IgRx complexity while at the same time building a technical, geographic workflow for much wider dispersion of less complex practices.

While we have covered salient trends, their influence on the future of IR services will be governed by two factors. One factor already discussed is the diffusion of innovations pattern. The other is the ability of these trends to attract diverse, talented individuals capable of acquiring the rich constellation of skill sets enumerated in this piece. A new generation of radiologists will build a diverse radiology culture strongly inclusive of IgRx. IgRx has a very bright future if its radiology practitioners influence the design and manufacturing of advanced IgRx technology and build on the technical talents, the imaging knowledge, the clinical judgment, and the interpersonal skills needed to inhabit a prominent "front-line" position with patients. The future of radiology as a subspecialty field, depends on expanding its patient services and, for IgRx, creating and maintaining distinct differentiation in all three key "AMA" steps. While ML will broadly alter the practice of radiology, it will not replace IgRx radiologists. Radiology's use of IgDx and IgRx technologically, medically, geographically, and even conceptually will shine brighter Klieg lights on the overall value radiology brings to patients.

Conflict of Interest

The authors declare that they have no conflict of interest.

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