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Issue Highlights

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Optimizing Advanced Imaging Technologies through Artificial Intelligence Innovations to Address the World-Wide Cardiovascular Disease Pandemic

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We all die of something! Indeed, cardiovascular disease (CVDs) deaths have almost become normalized as a likely cause of death globally. Nearly 18 million people, 32% of all deaths worldwide, were related to CVD in 2019. In broad strokes, cardiac mortality can be attributed to ischemic (i.e., 85%) or nonischemic and arrhythmogenic causes, the latter broadly occurring among all categories of CV disease. Importantly, three-quarters of the victims of CV disease occur in populations of low- and middle-income countries. Clearly, cardiovascular diseases can be ameliorated by addressing behavioral risk factors such as tobacco use, unhealthy diet and obesity, physical inactivity and harmful use of alcohol, but the answer is not so straightforward as myriad genetics and epigenetic factors account for a substantial portion of the outcome variability. Consequently, our overarching goal as physicians is to detect and characterize the onset of cardiovascular disease as early possible to allow an opportunity to intervene with counselling and medicines as well as surgeries and device-related therapies when necessary.

Cardiovascular imaging is a cornerstone of cardiac diagnosis and management, with echocardiography becoming a screening gateway modality to advanced imaging techniques that provide further characterization to diagnose disease and to quantify therapeutic responses serially. Artificial Intelligence (AI)- and Deep-learning (DL) enhanced point-of-care ultrasound technologies are rapidly emerging to allow global assessments of myocardial health in emergency departments and at the bedside in hospitals, in rural communities and increasingly in remote regions of the world. Democratization of advanced imaging techniques has been stifled by imaging related costs, technologist training and availability, and image data processing resources. Extending the benefits of advance imaging beyond tertiary healthcare institutions to smaller hospitals and outpatient centers nationally and to middle- and low-income countries internationally is the fundamental unmet need to reduce global CV deaths. United Imaging Healthcare and United Imaging Intelligence have accepted this world CVD challenge, which is increasingly reflected in AI and DL-enabled innovations for computed tomography (CT), nuclear medicine (NM, PET/CT, PET/MR) and cardiac magnetic resonance imaging (cMRI).

Cardiovascular related deaths are dominated by vascular diseases of the heart (coronary and microvasculature), and the large great vessels. Diagnostic cardiac catheterization was introduced by André Cournand and Dickinson Richards in the 1940s, followed by selective coronary angiography by Mason Sones in the 1960s. With the advent of catheter-based interventions, pioneered by Andreas Gruentzig in the 1970s. In the last 50 years, there has been tremendous progress in the refinement and expansion of these techniques. Today, percutaneous coronary intervention (PCI) access is through the femoral and the radial arteries. Coincidently, never ending development of interventional technologies have emerged from discrete single coronary artery (CA) lesions procedures to left main CA interventions, and more recently to multivessel coronary disease cases with risks too high for surgical solutions.

Cardiac catheterization is traditionally compartmentalized into two phases: diagnostic and interventional procedures. Initially, diagnostic cardiac catheterization delineated the coronary vascular bed anatomy to assess the extent of atherosclerotic disease and to identify significant intervenable flow-limiting lesions. Over time eyeball assessments of lesions gave way to direct measurements of stenosis relative to adjacent “normal” segments. The development of wire based Doppler flow assessments

(Fractional Flow Reserve (FFR), and later Instantaneous wave - Free Ratio (iFR)) led to an anatomical – physiology based assessment of lesion significance and the potential for improvement after revascularization. These data, obtained on the cath lab table, informed referrals to interventional specialists and surgeons for subsequent revascularization. Diagnostic catheterization procedures are still performed in most interventional cardiology programs, but developments in Cardiac CT coronary angiography are rapidly becoming a preferred way to risk-stratify patients for revascularization.

In this issue of United Imaging uINNOVATION-GLOBAL 2023, Dijia Wu and Jiayin Zhang (UII Shanghai, China) describe the role of Deep Learning-based Reconstruction of Coronary CT Angiography (CCTA) for Patients with Diverse Anatomical and Pathological Complexities. As is the case for most advanced imaging techniques, CCTA image post-processing reconstruction is time-consuming and interpretation is complicated by complex anatomy, such as chronic total occlusion (CTO), anomalous coronary anatomy, by-pass grafts, stents and calcifications. Advanced multi-row CT detector arrays are now offered by all vendors. The uCT 960+ with its 320 row detector and 250msec full heart acquisition represents the penultimate CT scanner in the UIH line. These authors delineate the DL-assisted image processing model, uAI® Discover Coronary CT solution and its two main components: a Spatial Anatomical Dependency (SAD) module and the Hierarchical Topology Learning (HTL) module.

Coronary artery calcium scoring (CACS) is assessed noninvasively with cardiac CT to provide estimates of calcified plaque as a biomarker of atherosclerotic plaque build-up and cardiovascular risk. Endorsed by the American College of Cardiology, CACS can help guide the use cholesterol reducing medications as well as suggest the benefit for additional stress-testing. Drs. Anand, Ramachandra, Pooja, Raju, Gandhamal, and Kumar share results of a CTA study involving 153 patients to assess the Clinical Significance of CAC score in Predicting Coronary Artery Disease. They describe the clinical relevance of combination of CT-coronary angiogram and CACS calculations as an initial screening method for patients with mild to moderate symptoms and as a gateway to timely intervention.

While CCTA is a welcome front-end addition to coronary artery screening and disease management, patients who are obese or present with high heart rates are challenging. The diagnostic efficacy of CCTA in high base mass index (BMI) patients can be compromised by image noise, reduced spatial resolution, and diminished contrast-to-noise ratio. Also, high heart rates can lead to motion artifacts, blurring, and incomplete vessel opacification, which further compromise image data accuracy and precision. In this issue of uINNOVATION-GLOBAL 2023, Drs. Osborne, Surapeneni, Murdock, and Gao address these issues in their report entitled Clinical Evaluation of Advanced Algorithms for CCTA: A Focus on High BMI and Elevated Heart Rate Populations. This report describes three new and interrelated processes, Auto ALARA. CardioXphase and CardioCapture. Human exposure is constrained to as low as reasonably achievable (ALARA), which is the radiation safety standard for all X-ray and nuclear techniques. AutoALARA is an automatic exposure control algorithm to automatically adjust X-ray tube voltage and current to optimize image quality while minimizing radiation dose. CardioXphase algorithm adopts the best phase selection method for a multi-phase reconstruction step with a focus on coronary arteries using a small Field of View (FOV) and reduced matrix size. CardioCapture involves an innovative AI-driven motion correction module that is focused in the vicinity of the coronary arteries. An advanced imaging pilot study is reported that endorses the significance and potential of individually tailoring advanced algorithms to address specific challenges among high-risk atherosclerotic patients with coronary disease.

Advanced coronary interventions have evolved from an initial ocular reflexive phase, i.e., “see a lesion – stent a lesion”, to Doppler-enabled physiologic culprit lesion assessments, and to remodeling of complex coronary arterial plaque segments employing intravascular ultrasound, intravascular optical coherence tomography, intravascular lithotripsy, plaque atherectomy, balloon angioplasty, and stenting. CT angiography delineates the vascular lumen and provides an assessment of intramural calcifications, but it does not provide significant noninvasive insight into the intricacies of plaque disease.

uINNOVATION-GLOBAL 2023 highlights two discussions

regarding PET/CT. The first by Amanda Roby entitled Myocardial Perfusion Imaging by PET with Myocardial Blood Flow is Proving to be the Gatekeeper for Identifying Physiologic Severity of CAD by Guiding Treatment with Invasive Procedure and Revascularization – so Why is Adoption Limited? The author acknowledges the resource and skill barriers entailed in initiating an MPI patient care center and contends that the efficiency cost savings are possible with improved physician and technologist collaboration to achieve optimal benefit. The second article is an Expert Interview with Jens Huettges (CTO, Cardiac Imaging, Inc). In this discussion, Jens Huettges describes the mobile cardiac imaging business, the ability of mobility to reach communities with poor access to advanced PET/CT cardiovascular imaging, the attributes of PET perfusion needed for high quality images, and the future of the modality.

Finally but not least, three papers address cardiac MRI, which is among the most promising tools for cardiac imaging, not only for questions unresolved by technically challenged echocardiography studies and quantitative structure-function-strain data but also for myocardial texture analysis. Myocardial texture analysis is the key approach for assessing tissue infiltrating diseases, including myocarditis, amyloidosis, and now cardiac fibrosis. Drs. Qi and Lyu provide a paper entitled Free-breathing Simultaneous Cardiac Multi-parameter Mapping: Technical Developments and Initial Clinical Experience. In typical practice, T1 and T2 relaxation mapping require a breath hold for each slice. While a single slice does not overwhelm a patient, it introduces significant sampling error and relatively poor estimates. Pathology development is nonhomogeneous at first among and within slices. Nine slices are often needed to cover the entire heart, which requires 18 breath holds for full T1 and T2 mapping characterization. This is increased to 27 breath holds if extracellular volume is calculated (post-gadolinium contrast). Cardiology patients with heart failure, elderly patients with arthritic spines and joints, and individuals prone to claustrophobia are challenged by the breathing requirements, even if the breath holds are short. The important data buried in myocardial relaxation maps might best be brought forward with a free-breathing simultaneous method for multi-parameter mapping. As anticipated, correction for respiratory motion and mitigating mapping errors is the crux of the challenge discussed. Additionally, in the context of myocardial fibrosis, a T1 ρ sequence, typically used in musculoskeletal imaging, is studied to increase sensitivity to low-frequency interactions between macromolecules, such as collagen, and bulk water. It is an innovative application attacking a clearly unmet need in heart failure.

In concert with the myocardial texture analysis theme, Drs. Aggrwal, Singh, Anand, and Kumar discuss the Role of Cardiac T1, T2 Mapping and Extracellular Volume Measurements for the Assessment of Clinical Cardiomyopathies. The investigators present preliminary pilot data affirming the power of these metrics as a prognostic tool with diagnostic advantage. Although the techniques and images required are available on many scanners, the resources to process the data are a challenge. The path of these investigators is further embraced and extended in the report by Watkins, Atteberry, Innanje, Sun, X. Chen, T. Chen, Syed, Mitchell, Wang, and Lanza entitled A Vision for Magnetic Resonance Imaging to Assess Cardiotoxicity. This collaboration between WUMS and UIH has an overarching mission to address the barriers to cMRI use and democratization worldwide. The short article describes the anticipated workflow of concurrent image acquisition and data post processing that will allow readers to simultaneously receive the images and the post-processing reports. Intended to help address MR technologist dependency and enhance serial study consistency, a brief synopsis of EasyScan® and AIshim® is provided. Beyond this start, on-going development with feature-tracking strain analysis is in progress. MyoScan® (Myocardial Solutions, Inc). is used as the strain reference. The expectation is that both tagging and feature tracking techniques will be clinically equivalent. The segmentation masks derived from the FT strain procedures are passed to segment the colorized T1 and T2 relaxation maps, which are envisioned as intuitive colorized maps of abnormal myocardium voxels (i.e., 2 std deviations above or below the nominal values of T1 and T2) overlaid onto corresponding short-axis grayscale slices. The percent volumes of abnormal myocardium for each slice and the entire heart are calculated. For cardiac amyloid, the highly sensitive extracellular volume metric is calculated and used at a high threshold to differentiate amyloid from cardiac fibrosis.

Collectively, this issue of uINNOVATION-GLOBAL 2023 offers a vision into the diversified directions that CT, PET/CT, and MRI are taking to enhance the utility of advanced imaging in the US and worldwide. All of the development strategies heavily utilize optimized imaging hardware, innovative software and AI/DL neural network processes. In virtually all cases, imaging workflows are accelerated, simplified and enhanced with advanced image post-processing results achieved on the scanner computer complex. Eventually, physician readers, whether onsite or accessed by telemedicine, will be presented a greater depth of information from which to produce a report. The anticipated ultimate goal is that patient care, regardless of residence, is not compromised by a lack of access to informative imaging results that might improve their medical outcomes and longevity.

Editor's Biography

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Dr. Gregory Lanza is a Cardiologist and Professor of Medicine, Biomedical Engineering, Radiology, Biology and Biomedical Sciences at the Washington University School of Medicine in St Louis. His clinical areas of interest include echocardiography and cardiac magnetic resonance imaging, with specific research interests in the development of novel nanotechnologies for biomedical molecular imaging and targeted drug delivery in cardiovascular, neurological, inflammatory, and oncological disease.

He obtained his Doctor of Philosophy from University of Georgia, Athens and his Doctor of Medicine from Northwestern University Medical School, Chicago; he did his residency and cardiology fellowship at Washington University School of Medicine in St Louis. He is also a recipient of numerous grants and prestigious awards.

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