Cardiology

- Cardiac care cycle
- Enhanced stent imaging
- Low-dose fluoroscopy
- MDCT in coronary imaging
- Advanced echocardiography
- Interventions and analysis
Dear Friends,

It gives me great pleasure to introduce this issue of Medicamundi, highlighting a selection of recent innovations in cardiology. The majority of these are the result of the care cycle approach: a paradigm shift in healthcare covering all aspects of patient care from disease prevention to screening and diagnosis, through to treatment, health management and surveillance.

The care cycle approach also provides the industry with a model for integrating products and services, creating a synergy that helps improve patient outcomes and reduce costs. At Philips, Simplifying Cardiac Care through the care cycle approach has led us to focus on four main cardiac themes:

- timely triage
- discovery to treatment
- minimally invasive interventions
- home health care.

Timely triage consists of examining, identifying and monitoring patients with high risk factors and managing them appropriately even before they become symptomatic. Early diagnosis thus allows for earlier interventions. Multidetector CT scanners and cardiac MRI yield valuable new information on heart function and viability, while investigations into simplification of procedures, and reductions in the amount of training required, are currently under way, focusing on dedicated task guidance and automation.

If a patient presents with acute myocardial infarction, the time from discovery to treatment (“Door-to-Balloon Time”) is critical. A major time saving can be effected by performing an ECG while the patient is still in the ambulance, and transmitting the results by wireless connection so that a path to treatment can be prepared before the patient arrives.

Minimally invasive procedures, such as balloon angioplasty, are increasingly the treatment of choice for cardiac patients. Here, StentBoost allows improved visualization of deployed stents, while new angiographic techniques reduce the radiation dose and quantity of contrast agent required.

Although the mainstay of every cath lab continues to be conventional X-ray, virtually every imaging modality has its role to play in the diagnosis and treatment of cardiac disease. Several novel applications of existing 3D imaging modalities are currently being explored for the treatment of structural heart disease, while new imaging parameters such as those generated with equilibrium radionuclide angiography can improve biventricular pacemaker placement.

Cardiology care cycles do not end when the patient is discharged from hospital. Managing chronic heart conditions at home helps to improve the quality of life and may reduce the need for frequent hospitalization.

I hope that you will enjoy reading this issue of Medicamundi and find it both interesting and informative.

Joris van den Hurk
Vice President Cardiology Care Cycles
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Clinical applications

The cardiology care cycle

J. van den Hurk
A. Mukherjee

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Cardiovascular disease (CVD) is the commonest cause of death worldwide [1]. It is estimated that 80% of premature deaths from CVD could be avoided by a healthy lifestyle [2]. The classic heart attack, or acute myocardial infarction (AMI), occurs when blood supply to part of the heart muscle is interrupted. This is usually due to occlusion of a coronary artery following the rupture of vulnerable atherosclerotic plaque in the arterial wall. If left untreated, the resulting ischemia can cause permanent damage to the heart muscle.

The classic symptoms of AMI in men include sudden chest pain (typically radiating to the left arm or left side of the neck), shortness of breath, nausea, palpitations, sweating, and anxiety. In women, the symptoms may be limited to a general feeling of fatigue and indigestion [3]. A heart attack is always a medical emergency, and immediate treatment is essential in order to limit the extent of the damage.

Effective cardiac care depends on a number of factors. These can be summed up in the Cardiology Care Cycle (Figure 1), covering all aspects of patient care from disease prevention to screening and diagnosis through treatment, health management and surveillance.

The different phases of the care cycle are closely linked to the development of the disease. Primary prevention aims at reducing the exposure to risk factors and usually targets the entire population or groups that are at risk of developing cardiac disease. Health promotion, health education and health protection are three main aspects of primary prevention.

Secondary prevention is targeted at (asymptomatic) individuals at risk in order to prevent or delay onset of the disease. Secondary prevention strategies include screening activities and prophylactic treatment. The onset of symptoms marks the transition to clinical disease. The next phases of the care cycle: diagnosis, treatment, management and surveillance, apply to individuals with the clinical disease.

The purpose of these phases is to prevent further impact from the disease by relieving the effects of the disease (e.g. by angioplasty or surgery), retarding further progress of the disease, and tertiary prevention (i.e. prevention of disease recurrence). Depending on the severity of the disease, care may include chronic treatment and surveillance.

The care cycle also offers a useful tool for assessing care delivery, and identifying those areas where cost-effectiveness and quality of care might improve. In addition, it enables industry to identify how products and services can best contribute to improving patient care and lowering cost.

At Philips, Simplifying Cardiac Care through the care cycle approach has led us to focus on four main cardiac themes:

- timely triage
- discovery to treatment
- minimally invasive interventions
- home health care.

1The US Department of Health and Human Services and the American Medical Association (AMA) define a care cycle as follows: “The array of health services and care-settings that address health promotion, disease prevention, and the diagnosis, treatment, management, and rehabilitation of a disease, injury, and disability. Included are primary care and specialized clinical services provided in community and primary care settings, hospitals, trauma centers, and rehabilitation and long-term care facilities”.
A host of diagnostic and imaging modalities are utilized to triage cardiac patients. Next to cardiography, echocardiography, and cardiac nuclear examinations, advanced imaging techniques such as multidetector CT [4] and cardiac MRI are gaining acceptance for complex cases, when impaired heart function is suspected.

Multi-detector computed tomography (MDCT) scanners have gained increasing clinical acceptance as a non-invasive modality of choice for cardiovascular imaging. The recently introduced Brilliance iCT scanner delivers improvements in speed, power and coverage, alongside enhanced dose reduction capabilities and workflow that provide improved imaging for cardiovascular diseases.

Cardiac magnetic resonance imaging (MRI) now offers methods to investigate the function of the heart in a clinical setting. Its use as a routine method in cardiology is, however, hampered by its relative complexity. Investigations into simplification of procedures, and reductions in the amount of training required, are currently underway, focusing on dedicated task guidance and automation.

The euHeart project
As from August 2008, Philips Healthcare is leading a new European Union funded research project called ‘euHeart’, which is aimed at improving the diagnosis, therapy planning and treatment of cardiovascular disease. The euHeart project complements the Philips Cardiology Care Cycle project by targeting the diagnosis and treatment phases of the care cycles for heart conditions such as heart failure, coronary artery disease, heart rhythm disorders, and congenital heart defects.

The project forms part of the Virtual Physiological Human (VPH) initiative – a collaborative effort that aims to produce a computer model of the entire human body so that it can be investigated as a single complex system (Figure 2). The euHeart consortium comprises public and private partners from 16 research, academic, industrial and medical organizations from six different European countries. The University of Oxford (Oxford, UK) is the scientific coordinator of the project, while King’s College London (London, UK) leads the clinical program.

Timely triage
Timely triage consists of examining, identifying and monitoring patients with high risk factors and managing them appropriately even before they become symptomatic. Early diagnosis thus allows for earlier interventions.

Discovery to treatment
Reducing time from discovery in the pre-hospital to treatment is critical. In the case of patients presenting with symptoms of an acute myocardial infarction (AMI), a 12-lead ECG is the standard
diagnostic tool that distinguishes between those cases where the ST segment of the ECG signal is elevated, referred to as ST elevation MI (STEMI) and those where it is not elevated (non-STEMI, or nSTEMI). STEMI is the most dangerous form of AMI and minutes count in determining survival. The care cycle approach for STEMI patients is shown in Figure 3.

If STEMI is detected, whether in the pre-hospital setting by the paramedic, or in the emergency department, it is critical that timely reperfusion treatment is provided. The standard of care for STEMI patients is percutaneous coronary intervention (PCI, angioplasty and stent insertion) in the cath lab, in less than 90 minutes from arrival at the hospital. Scientific evidence suggests that the risk of in-hospital death increases with each 15-minute interval beyond 90 minutes (Figure 4). More recent studies suggest the time be measured from “Discovery” in the pre-hospital setting [5]. In the case of long transport times or other situations where PCI is not available within the 90 minute guideline, thrombolysis is an alternate treatment [6].

There are several ways in which time to treatment can be reduced (Figures 5 and 6). Most of these are related to improving team work across the care cycle: between emergency medical services, the emergency department and the cardiac cath team [7, 8].

Example: A major time saving can be effected by enabling decision making in the ambulance and emergency department (Figure 7). For example, the ECG can be performed while the patient is en route to the hospital, and the results transmitted to the hospital by wireless connection so that they are available when the patient arrives.

The availability of a monitor/defibrillator with 12-lead ECG capability is critical. Specifically designed for use by paramedics, the Philips HeartStart MRx ALS Monitor (Figure 8) combines full 12-lead view with superior diagnostic measurements. If the patient arrests with ventricular fibrillation, the patented SMART Biphasic defibrillation waveform comes into action. The HeartStart MRx Monitor/Defibrillator also allows paramedics to transmit patient data from the ambulance to the hospital’s ER en route. Upon reception of the data at the hospital, clinicians can use the ECG data to begin assessing and preparing for the treatment the incoming patient will need. By allowing a hospital to begin organizing its resources before the patient arrives, the MRx can help reduce the time to treatment.
In addition to transmitting ECG data to the hospital prior to the patients’ arrival, the HeartStart MRx integrates seamlessly with the hospital’s ECG management system TraceMasterVue, enabling critical patient information to be seen where it’s needed – even in the cath lab.

**Minimally invasive interventions**

Coronary surgery is increasingly being replaced by minimally invasive interventions carried out in the intervention cath lab (Figure 9). Percutaneous transluminal angioplasty (PTCA) and stenting are already well-established techniques, but the scope and accuracy of the procedures is increasing with the availability of three-dimensional imaging and image enhancement techniques for better visualization of stent placement [9].

Novel acquisition techniques such as dual axis rotational angiography (XperSwing) provide adequate information for the diagnosis of coronary artery disease with reduced X-ray dose and contrast agent usage [10].

Structural heart disease (SHD) intervention is another area where several novel applications of existing 3D imaging modalities are currently being explored. New 3D ultrasound imaging techniques using live 3D TEE are increasing the understanding of how the heart fills, improving diagnosis and treatment of diastolic dysfunction, including mitral valve repair, avoiding the need for valve replacement.

The EP Navigator fuses 3D CT and fluoroscopy images for navigation. It allows the user to confirm the position of any catheter or lead position with respect to detailed images of the 3D cardiac anatomy, allowing complex EP procedures to be carried out with greater confidence [11].

Several novel applications of existing 3D imaging modalities are currently being explored. These include registration of pre-procedure CTA and MRA 3D data sets with live fluoroscopy, and the application of real-time 3D transesophageal echocardiography (TEE).

**Home health care**

The cardiology care cycle does not end when the patient is discharged from hospital. Managing chronic heart conditions at home is designed to improve the quality of life and may reduce the need for frequent hospitalization [12-14].

Telehealth solutions enable clinicians to remotely monitor patients’ vital signs and other relevant data and send them short surveys about their health status. This combination of objective data and subjective responses enables the clinician to make more timely care decisions and helps prevent unnecessary hospitalizations.

**Remote Patient Monitoring**

Philips Remote Patient Monitoring provides secure, two-way flow of information between remote caregivers and chronically ill patients. The TeleStation is the hub for the transmission and other vital signs data (automatically
collected from the wireless measurement devices or manually entered) and provides interactive communication between care providers and patients at home.

The TeleStation prompts patients to answer health assessment survey questions—which can be customized to their clinical problem. Every day, patients take their own vital signs measurements as prescribed by their doctor: weight, blood pressure, pulse, glucose level, blood oxygen level and/or ECG rhythm. They also answer survey questions sent by their clinician, which may include general health assessment questions and/or targeted follow-up questions, and enter self-reported data as directed. The information is then automatically transmitted through an ordinary phone line via modem to secure web-based Clinical Review Software. Clinicians can track daily patient measurements, store and retrieve historical data in both tabular and graphical format, and generate reports—promoting faster follow-up and intervention.

The TeleStation will automatically send an AutoCheck survey to follow up on out-of-limit readings. Clinicians can tailor patients’ daily interactions to help reinforce specific topics: signs and symptoms, medication and side effects, diet and lifestyle, and compliance with care protocols.

These automated interactions can streamline clinical workflow by minimizing unnecessary phone calls and by enabling clinicians to contact the highest priority patients—equipped with the data they need for more timely intervention.

**Philips Lifeline**

Philips Lifeline helps seniors and people with mobility problems to live in their own homes, with greater independence and dignity. Lifeline is the preferred provider of medical alert services to members of the Visiting Nurse Associations of America, and to thousands of leading hospitals across the United States.

Lifeline has a large and experienced group of response staff. A simple touch on the Personal Help Button connects the subscriber to a qualified Professional Response Associate at any time of the day or night. The Associate assesses the situation and then notifies the appropriate support and medical response team as required.

**Information technology (IT)**

Information technology has a key role in the Cardiology Care Cycle. In addition to Xcelera Cardiac PACS and departmental IT systems, Philips offers a Cardiovascular Information Management System (CVIS). The CVIS collects and aggregates patient data across all care...
settings involved in cardiac care. All information is integrated into a single, relational database and provides authorized healthcare professionals with quick and easy access to patient information via any standard PC/workstation across the enterprise.

In addition to patient data, the CVIS also provides scheduling, staff and resource management, cost capturing, and the generation of reports and statistical information, thereby supporting the management of a cardiovascular service line.

The CVIS connects with various clinical information systems such as Cath lab workflow management systems (Xper IM), Philips Xcelera PACS and TraceMasterVue ECG management systems, as well as systems from other manufacturers.

**Conclusion**

The care cycle approach represents a paradigm shift in the provision of healthcare for those patients at risk of cardiac disease. It covers all aspects of patient care from disease prevention to screening and diagnosis through treatment, health management and surveillance.

The care cycle also offers a useful tool for assessing care delivery, and identifying those areas where cost-effectiveness and quality of care might need improvement.

For industry, the care cycle helps to identify how the integration of products and services can create synergies that help improve patient care and reduce costs.

**References**


Clinical applications

Feasibility evaluation of dual axis rotational angiography (XperSwing) in the diagnosis of coronary artery disease

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During coronary angiography, the use of potentially harmful X-ray radiation and iodine contrast agent should be kept to a minimum, without compromising the diagnostic accuracy of the procedure. Coronary angiography is conventionally performed in multiple stationary views at different angles around the patient. A complete X-ray run with contrast injection is made in each view. An alternative to stationary views is rotational angiography, in which the X-ray system rotates around the patient during the acquisition of a single run. Rotational angiography can provide a significant reduction in both contrast agent usage and radiation dose of up to 30%, without compromising the clinical utility of the images [1-2]. The rotations are made around a single axis in a single plane and usually two rotations are needed to image the left coronary artery (LCA) and one rotation for the right coronary artery (RCA). In addition, some static views are made at the discretion of the physician to obtain additional views, since single axis rotations are limited in their ability to cover all desired anatomical views in a single rotation. Recently, a new technique of dual axis rotational coronary angiography has been developed called XperSwing (Philips Healthcare, Best, the Netherlands). During dual axis rotations the X-ray system rotates with curved trajectories around the patient, thereby allowing imaging in all desired anatomical views in a single run (Figure 1). The trajectories are pre-programmed and are optimized to maximize the clinical image content, while staying within safe boundaries in order to avoid any collisions. Dedicated trajectories are available for the left and the right coronary arteries (Figure 2).

In this article the intermediate results of an ongoing study investigating the effect of XperSwing on contrast and radiation dose utilization are reported. Contrast utilization and radiation dosage of XperSwing were...
compared to conventional biplane coronary angiography (standard angiography). In addition, the procedure times for XperSwing and standard angiography were evaluated.

Materials and methods

A total of twenty-six patients undergoing diagnostic coronary angiography were randomized to either standard angiography ($n = 13$) or XperSwing angiography ($n = 13$). All acquisitions were performed on a biplane flat-panel detector system (Allura Xper FD10/10, Philips Healthcare, Best, the Netherlands). For this evaluation the system was equipped with the prototype option of XperSwing.

For the standard angiography group, the pre-specified protocol used six projections for the LCA and three projections for the RCA. A monoplane acquisition was obtained for the second run of the RCA. The injector setting for maximum contrast flow was 3.5 mL/second (total 7 mL) for the LCA and 2.5 mL/second (total 5 mL) for the RCA.

For the XperSwing angiography group one dual axis rotational angiography was made for the LCA and one dual axis rotational angiography for the RCA. The XperSwing trajectories used can be found in Figure 1. The injector settings for maximum contrast flow were 2.5 mL/second (total 17.5 mL) for the LCA and 2.0 mL/second (total 7 mL) for the RCA.

If the diagnostic information from either the standard or XperSwing group was deemed insufficient, additional images could be taken. The necessity of this additional run was judged by the operating cardiologist. Any additional runs were acquired in monoplane. Both the protocol images, plus any additional images, were included in the final data analysis.

For both patient groups, total contrast agent utilization, patient radiation dose and angiographic procedure time were evaluated. The contrast agent utilization was recorded in mL, the patient radiation dose was recorded using the internal dose meter of the X-ray system (dose area product in Gycm$^2$) and the procedure time was measured between engaging the coronary ostium and the moment when the cardiologist determined that a diagnostic study had been completed. The time needed to review the acquired angiographic runs was included in the procedure time.

Patients who had prior angiography, acute coronary syndrome, serum creatinine $\geq 1.5$ mg/dL or suspicion of vasospastic angina were excluded. All catheterizations were performed using a 4-french catheter. After intra-coronary nitroglycerin injection, angiography of the LCA was first performed, followed by the RCA. All injections were performed with an auto-inject system (ACIST). All operators were experienced with rotational scanning.

Results

As is dictated by the site protocol for acquiring images (Figure 3), the number of angiographic runs (9 runs) in the standard group was substantially higher than in the XperSwing group (2 runs). For four out of 13 (31%) of the XperSwing patients, additional (steeper) views
were needed in order to better visualize the left main trunk bifurcation. The total number of runs required in order to achieve adequate diagnosis was on average 9.1 runs for the standard group and 2.5 runs for the XperSwing group. There was no significant difference in procedure time between the standard group (3 min. 24 seconds) and the XperSwing group (3 min. 28 seconds).

The average contrast utilization for a procedure (Figure 4) was also significantly (p < 0.05) higher for standard angiography (33.5 mL) compared to that necessary for XperSwing angiography (27.2 mL). Similarly, the X-ray dose required (Figure 5) for standard angiography (56 Gycm²) was significantly higher than that required for XperSwing angiography (27 Gycm²).

Conclusions

The preliminary results of this study, comparing standard angiography with XperSwing angiography, shows the potential of XperSwing to reduce both contrast agent usage and radiation dose. In 69% of patients XperSwing provided complete and sufficient information for the diagnosis as judged by the primary operator. In the remaining 31% of XperSwing patients one or more additional static views were performed to properly diagnose the LTM bifurcation. These additional views were taken into account with the X-ray dose and contrast load savings.

XperSwing rotational angiography is a promising technique for the reduction of contrast agent and X-ray dose in diagnostic coronary angiography. Contrast reduction is especially beneficial for patients with increased risk of renal insufficiency. Additional studies are needed to assess diagnostic accuracy and verify the contrast and dose reduction.

References


Clinical applications

StentBoost: a useful clinical tool

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Having the ability to accurately visualize stent deformation, deployment, expansion, apposition to the vessel wall and overlap with other stents is imperative in complicated percutaneous coronary intervention (PCI) cases. Traditional standard angiographic techniques may be insufficient to allow for the definition of these stent characteristics. Intravascular ultrasound (IVUS) has filled this need by allowing endovascular imaging of the vessel and stent interaction. IVUS is not only invasive and time consuming, but it also has an impact on the catheterization, laboratory efficiency and cost-effectiveness. In cases in which IVUS is not used, image enhancement, such as StentBoost (Philips Healthcare, Best, the Netherlands), allows for the interpretation of stent deformation, expansion, overlap with other stents and apposition to the vessel wall [1-5].

StentBoost enhances the image quality of stents by integrating a series of non-contrast images from a single run after motion compensation. This enhanced image is subtracted from a contrast-filled image from the same run. The enhanced subtracted image shows improved contrast of the stent and shows the relation between the location of the stent and the vessel wall. The visualization dynamically fades in and out, between the stent image and the vessel.

Figure 1. The small ramus showing severe ostial/proximal disease with moderate disease throughout the remainder of the vessel.

Figure 1a.
RAO caudal view of the LCA.

Figure 1b.
LAO caudal view of the LCA.

Figure 1c.
LAO cranial view of the LCA.

Figure 1d.
RAO cranial view of the LCA.
image, in order to show the relationship between the two. A StentBoost image is automatically generated from a single standard acquisition at 15 frames per second consisting of 2 seconds without contrast agent injection followed by 2 seconds with contrast injection at 3 mL/sec for a total of 6 mL of contrast agent. During acquisition the balloon is left in place because the algorithm uses the balloon markers for motion compensation of the acquired images, thereby allowing stent enhancement and display of the stent in relation to the surrounding vessel wall. In a recently published study by Mishell et al., StentBoost provided superior correlations for stent expansion measured by IVUS compared to quantitative coronary analysis [5]. There was a good correlation \( r = 0.75; p < 0.0001 \) between IVUS and StentBoost measurements on minimum stent diameter (MSD) [5], while Koolen et al. found an even better correlation \( r = 0.8061; p < 0.005 \) for MSD [4].

Case

A 64-year-old female, with a past medical history significant for hypertension, diabetes mellitus, hyperlipidemia, ongoing tobacco abuse and coronary artery disease status-post (s/p) 5 stents to the right coronary artery (RCA) in 2004 and a history of stent thrombosis, presented with acute onset of chest pain. Due to an inferior ST segment elevation myocardial infarction (STEMI) the patient was referred as an emergency case for cardiac catheterization. She received a heparin and abciximab bolus in the emergency department, along with aspirin, metoprolol, morphine and nitroglycerin.

Angiography

The images were obtained on the Allura Xper FD20 (Philips Healthcare, Best, the Netherlands). The unobstructed left main supplies the left anterior descending artery (LAD), left circumflex and a small ramus intermedius. The LAD supplies three small diagonals before terminating at the apex as a small tortuous vessel. There is mild to moderate diffuse disease throughout the LAD system. The left circumflex supplies one large obtuse marginal (OM) before terminating in the atrio-ventricular (AV) groove as a diminutive vessel. There was a 50% - 60% stenosis in the proximal portion of the OM. The small ramus had severe ostial/proximal disease with moderate disease throughout the remainder of the vessel (Figure 1a - d). There were no collaterals appreciated. The large dominant RCA supplies a large postero-descending artery (PDA) and the AV continuation of the RCA is large and extensive, supplying three moderate to large postero-lateral branches. There were stents in the proximal and mid RCA followed by two stents at the PDA bifurcation extending into the PDA and the AV continuation. There was a large filling defect in the AV continuation stent consistent with thrombus and the distal RCA continuation had thrombolysis in myocardial infarction (TIMI II) flow (Figure 2).

Procedure

The RCA was already engaged with a 7 French JR4 (Vistabrite, Cordis, Miami, Fl, USA) guide catheter and a 300 cm 0.014 inch Patriot wire (Boston Scientific, Nattick, Massachusetts, USA) was introduced into the distal RCA with support from a 2.0 x 12 mm Maverick balloon (Boston Scientific, Nattick, Massachusetts, USA). The decision was made to perform aspiration thrombectomy and an export catheter (Medtronic, Minneapolis, Minnesota, USA) was advanced, but would only enter into the very proximal portion of the stented region of the AV continuation, aspiration was performed and inspection of the removed material did reveal some thrombus. Next the 2.0 mm Maverick balloon was advanced, but would also not cross, suggesting that the wire was going through stent struts, therefore, the wire was withdrawn and re-advanced to the distal RCA, which then permitted advancement of the balloon. Two inflations within the stented region were performed with flow restoration.

StentBoost

The stenting technique used in the bifurcation has important clinical consequences. Based on the stented anatomy the operator may decide to do simultaneous or alternate balloon inflations if necessary. Standard angiographic images failed to clearly show the relationship between both stents. After inspection of the region using StentBoost (Figure 3a - e) to further elucidate...
the possible bifurcation stenting technique used, and therefore to maximize stent expansion, the decision was made to perform kissing balloon inflations at the PDA bifurcation. The bifurcation stenting technique used was corroborated with IVUS, clearly showing that the AV continuation stent was positioned inside the PDA stent (Figure 4). A second Patriot wire (Boston Scientific, Natick, Massachusetts, USA) was introduced into the PDA with a 2.75 x 12 mm Quantum Maverick Rx balloon (Boston Scientific, Natick, Massachusetts, USA). With the 2.75 x 12 mm Quantum Maverick RX balloon in the PDA and the 2.5 x 16 mm NC Stormer (Medtronic, Minneapolis, Minnesota, USA) in the AV continuation, simultaneous high pressure kissing balloon inflations were performed (Figure 5a). The balloons were withdrawn and repeat angiography, both with and without the guide wires in multiple projections, revealed TIMI III flow, 0% residual stenosis and no evidence of dissection or thrombus (Figure 5b).

Discussion

The StentBoost feature on the Allura Xper imaging system allows for the rapid evaluation of stent deployment post-PCI while the balloon markers are still in place. This approach allows the operators to recognize under expansion and more aggressively post-dilate stents when necessary [1, 2]. In this case the difficulty in clearly understanding the bifurcation stenting technique used was limited by the conventional angiography technique used. Once it was obvious that the AV continuation stent came as proximal to the edge of the PDA stent the decision was made to perform kissing balloon inflations and more aggressively post-dilate the AV continuation stent. This finding was corroborated by IVUS, which is a more time consuming technique.

Conclusion

StentBoost allows for the evaluation (deployment and apposition) of the stent post-PCI [1-5]. The technique has been rapidly incorporated due to its ease of application and the fact that it does not expose the patient to a significant
amount of extra contrast agent or radiation, since it is carried out with the post-deployment conventional angiogram. The only requirement is for the balloon markers to be kept in place in order to facilitate the software’s motion compensation. In this case its use was expanded and StentBoost was helpful in defining the bifurcation stenting technique used on the index procedure, therefore facilitating the intervention. It can also facilitate stent positioning and overlap in otherwise difficult to see stent edges. StentBoost adds a new, simple and cost-effective visualization technique to the imaging armamentarium that provides better stent definition than the traditional standard angiography.

References


Clinical applications

Optimization of pulsed fluoroscopy in pediatric radiology using voiding cystourethrography as an example

In the 11th “Report on Carcinogens” of the United States National Toxicology Program [1], X-irradiation and ionizing irradiation were placed on the list of known human carcinogens. This fact caused at least some confusion in the United States and led to a statement by the Radiologic Society of North America. This discussion was set in motion by a report by Pierce and Preston in 2000 on “Radiation-related Cancer Risks at Low Doses among Atomic Bomb Survivors” [2], as well as by this finding being featured in the national press [3].

Radiation hygiene has an especially large role in the case of pediatric patients. Small children are approximately ten times more sensitive to radiation than middle-aged adults. The higher radiation risk in children arises on the one hand from the longer life expectancy, and on the other it is clearly correlated with the high radiation dose to the organs in children compared with adults subjected to comparable X-ray examinations [4-6].

Nevertheless, the above-mentioned reports were not a motive, but a confirmation, of the need for the continued intensive effort to optimize X-ray examinations in children in accordance with the ALARA principle (As Low As Reasonably Achievable). The ALARA principle was first introduced by the United States Nuclear Regulatory Commission in order to limit the radiation burden on occupationally exposed individuals, rather than that on patients [7]. This principle was then carried over by radiologists to the exposure of patients.

The earlier studies [4-6] described the radiation dose reduction measures employed to limit the radiation burden in pediatric patients during fluoroscopic examinations, especially with respect to voiding cystourethograms (VCUs). It is easy to decrease the radiation burden by reducing the image intensifier entrance dose, by using shorter fluoroscopy times etc., but it is more difficult to do this while maintaining acceptable imaging and diagnostic quality.

When grid-controlled fluoroscopy became available for applications in pediatrics as a technology to reduce radiation dose, while simultaneously improving the diagnostic image quality [8, 9], the Department of Pediatric Radiology at the University of Mainz in Germany undertook to examine this new technology with regard to its medical relevance.

### Materials and methods

This study was carried out using a standard over-table fluoroscopy system (Philips Diagnost 96, Eindhoven, the Netherlands) with triplicate format moveable 38 cm image intensifier and digital fluoroscopy chain (digital spot imaging (DSI). The digital television chain has the last image hold option (LIH). The X-ray generator

<table>
<thead>
<tr>
<th>Pulse rate</th>
<th>Adult patient characteristic curve DAP for D</th>
<th>Adult patient characteristic curve DAP for D/2</th>
<th>Pediatric patient characteristic curve DAP for D</th>
<th>Pediatric patient characteristic curve DAP for D/2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hz</td>
<td>cGycm²</td>
<td>cGycm²</td>
<td>cGycm²</td>
<td>cGycm²</td>
</tr>
<tr>
<td>Cont.</td>
<td>98</td>
<td>54</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>6.25</td>
<td>53</td>
<td>28</td>
<td>23</td>
<td>14</td>
</tr>
<tr>
<td>3.13</td>
<td>29</td>
<td>17</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>1.56</td>
<td>17</td>
<td>8</td>
<td>7</td>
<td>5</td>
</tr>
</tbody>
</table>

D = normal image intensifier entrance dose rate (IIDR); D/2 reduction of IIDR by 50%.
has grid-controlled fluoroscopy with four frame rates: continuous, 6.25, 3.13 and 1.56 Hz. The corresponding image intensifier dose rates are: 0.24, 0.20, 0.14 and 0.10 µGy/s. Using an additional function, all image intensifier dose rates can be decreased to half the values specified. The cut-off dose for spot images via the image intensifier is 0.66 µGy. For fluoroscopy, the user can choose from two kV/ mA characteristic curves. One characteristic curve with a typical 20 ms pulse width can be used for standard examinations (adult characteristic curve). The second characteristic curve (pediatrics) with a typical pulse width of 10 ms is adapted to the specific pediatric requirements. This special characteristic curve ensures that, as a rule, the examination kV limit of 70 kV is maintained, even for the smallest subjects (infants). The focus-detector distance is 110 cm.

Even though the anti-scatter grid could be easily removed as required, all examinations, except for those in neonatal patients, were conducted with a stationary carbon fiber anti-scatter grid (N 60, r 13, f 120) [10].

Other dose-relevant technical factors in the imaging system include:

- digital spot imaging (DSI) via the image intensifier
- grid-controlled fluoroscopy (GCF) for regulation of the dose rates for pulsed fluoroscopy within the pulse duration
- image quality exposure (IQX) for radiation dose regulation in digital spot imaging
- additional 0.1 mm Cu and 1 mm Al pre-filtration
- adaptive correction of field measurement (ACFM) for all fluoroscopy modes and DSI [8].

The dose-area product (DAP) values of the various modes, as measured in our facility, are listed in Table 1. The 14 fluoroscopy modes shown in this Table are based on the rationale of giving the examiner the choice between a higher contrast fluoroscopic image quality at a lower tube voltage (adult patient characteristic curve) or a fluoroscopic examination focusing on a lower radiation dose level at higher tube voltage (pediatric patient characteristic curve) allowing for lower contrast in the object and image. The examinations of the GCF long-term study were conducted in the period from January 1, 2003 to December 31, 2004 by three experienced pediatric radiologists who had also conducted a previous study [11]. Since fluoroscopic examinations, and the assessment of the clinical image quality, are always examination-dependent, one of the prerequisites of a long-term observation is the consistency of the examiners and thus of the examination processes, as was the case here. The diagnostic image quality was assessed by the examiner. In this case, care was also taken to ensure the image quality was verifiably sufficient.

A regular consistency check ensures that the respective settings have not changed during the VCU study. For the long-term study, the DAP was measured at each patient examination with the M2 Diamentor (PTW, Freiburg, Germany) and added to the documentation.

All VCU's were evaluated from the period specified above with respect to the radiation dose requirement (DAP). For this purpose, the patients were divided into three age groups: less than 1 year, 1 - 5 years and over 5 years. The contrast agent for the VCU was delivered to the bladder by means of suprapubic bladder puncture. The filling phase of the bladder was observed using only a single radiation pulse, while voiding was observed under continuous pulsed fluoroscopy at 1.56 Hz. The studies were documented almost exclusively using fluorograb images from the fluoroscopy. Where spot images were acquired, this was done separately. Almost all the examinations were carried out with the anti-scatter grid in the X-ray beam. Documentation was done on laser film.

For almost all examinations, the operators chose the pediatric patient characteristic curve, with a pulse rate of 1.56 images/second and the image intensifier dose rate D/2. Despite this selection, the image quality of the individual fluoroscopic pulse images was still sufficient to produce diagnostic-quality documentation from the fluoroscopy (LIH or fluorograb) images. This was repeatedly documented by a comparison between LIH images and digital spot images.

<table>
<thead>
<tr>
<th>Mode</th>
<th>n</th>
<th>DAP &lt; 1 year</th>
<th>DAP 1 - 5 years</th>
<th>DAP &gt; 5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulsed fluoroscopy (1.56 Hz)</td>
<td>584</td>
<td>3.2 (2.3)</td>
<td>4.8 (3.1)</td>
<td>11.4 (11.9)</td>
</tr>
</tbody>
</table>

Table 2. Age-dependent dose-area products (DAPs) for voiding cystourethrograms (VCUs) from the GCF/IQX long-term study from January 1, 2003 to December 31, 2004. The figures show the means and standard deviation () of the DAP (specified in cGycm²) for pulsed fluoroscopy and last image hold option (LIH) documentation for VCU in pediatric patients. The DAPs for three age groups are compared with the respective current diagnostic reference values [12].
made at the same time. The high quality of the LIH and fluorograb images made it possible to dispense with the digital spot images almost completely (Figure 1a and 1b).

**Results**

During the specified period between January 1, 2003 and December 31, 2004, 584 VCs were carried out with the GCF/IQX technology and the data were evaluated with respect to the three age groups (n = 179 < 1 year, n = 254 1 - 5 years and n = 151 > 5 years) (Table 2).

Diagnostic reference values for specific examinations correspond to the 75th percentile from a large, multicentric survey of radiation dose values. Thus, they also correspond to the current German standard [12].

Over 95% of all the examinations could be carried out exclusively using the pediatric patient characteristic curve, a pulse rate of 1.56 Hz and an image intensifier dose rate of 0.10 µG/s. Here the anti-scatter grid was always in the X-ray beam. The image quality of the LIH images was good enough that they were used for documentation purposes. No digital images were required for this group.

For the examination of premature infants and neonates, the pediatric patient characteristic curve was also chosen with a pulse rate of 1.56 Hz. Here, the image intensifier dose rate was decreased from 0.10 µG/s to 0.05 µG/s (D/2). The anti-scatter grid was removed from the X-ray beam before the examination. In a few cases, digital images had to be made for documentation.

For pediatric patients over 5 years old, the examinations were first started using the pediatric patient characteristic curve, a pulse rate of 1.56 Hz, an image intensifier dose rate of 0.10 µG/s and the anti-scatter grid in the X-ray beam. In rare cases, a higher image quality (adult patient characteristic curve) was briefly selected during the examination. Table 3 illustrates the high radiation dose saving potential of the GCF/IQX technology. It shows the development of the DAP over a period of 15 years [11-13] and the radiation dose

<table>
<thead>
<tr>
<th>n</th>
<th>DAP/% &lt; 1 year</th>
<th>DAP/% 1 - 5 years</th>
<th>DAP/% &gt; 5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Diagnostic reference values as of 2005 [12].</td>
<td>90/100</td>
<td>120/100</td>
<td>240/100</td>
</tr>
<tr>
<td>b. 100 mm technique and continuous fluoroscopy to 1993 [11].</td>
<td>101</td>
<td>44/49</td>
<td>93/78</td>
</tr>
<tr>
<td>c. Digital imaging and continuous fluoroscopy to 1997 [13].</td>
<td>40</td>
<td>54</td>
<td>99</td>
</tr>
<tr>
<td>d. DSI and pulsed fluoroscopy (1.56 Hz) as of 2003.</td>
<td>584</td>
<td>3.2/4</td>
<td>4.8/4</td>
</tr>
</tbody>
</table>

Table 3. Compilation of method-dependent and age-dependent dose-area products (DAPs) (cGycm²) for voiding cystourethrogram (VCU) results of the long-term study as of 1990 and information from the relevant literature. The % values are related to the diagnostic reference values in (a) below.

a. Diagnostic reference values for specific examinations correspond to the 75th percentile from a large, multicentric survey of dose values [12].

b. 100 mm technique on an under-table system with continuous fluoroscopy and 0.2 mm Cu pre-filtration without anti-scatter grid in the X-ray beam (before 1993) [11].

c. Digital spot imaging (DSI) with an over-table system with continuous fluoroscopy and 1 mm Al + 0.1 mm Cu pre-filtration [13].

d. DSI on an over-table system with pulsed fluoroscopy and 1 mm Al + 0.1 mm Cu pre-filtration and high line grid (from 2003).
Discussion

The direct relationship between the image dose level and the image quality attained has been long known and is highlighted again and again when innovative imaging systems are used [14, 15]. Thus the question as to the image quality required has always been answered to the effect that we need exactly the image quality that enables the required diagnosis to be made. In order to make this possible, four different image qualities can be selected (two characteristic curves and two) in each pulsed fluoroscopic mode (Table 1).

Given the correct application parameters, DSI should meet the same criteria as other imaging techniques: the best image is the one that answers the medical question at hand with the lowest radiation dose.

The study by Kuon et al. [16] impressively demonstrates that not only the technique and the equipment design can contribute to radiation dose level reduction but also, and in particular, the operator. Kuon shows that consistent collimation alone can reduce the DAP by between 46% and 65%. Unfortunately, this conclusion is only valid for systems with adaptive correction of field measurement ACFM. In systems without an adaptive measuring field, collimation (decreasing the irradiated area) results in upward adjustment of the dose rate (recognizable because areas of low density are overexposed so that information is lost).

Without a technique like ACFM, infants especially are subjected to an increased radiation dose of up to a factor 5 for consistent collimation as compared with the situation without collimation. Using the ACFM available in this study enabled the radiation dose to be cut with each collimation, i.e. half the area: half the DAP.

The switch to pulsed fluoroscopy is not trivial. There is a learning curve required to understand the paradigm shift in imaging and to become accustomed to examinations where an image of the subject being examined is obtained only about every 0.6 seconds. The gaps between the images are bridged by freezing the last image (gap filling) without any flickering. Obviously, the swallowing process in patients cannot be studied at such slow frame rates. On the other hand, examinations of the urogenital and gastrointestinal tract, including the esophagus, are easily possible [9]. Examinations of the various organs, and the pylorus and duodenum in children, permit the frame rates to be reduced to the lowest value of 1.56 Hz without any loss of the detail important for diagnosis.

Consideration should be given to the fact that the visual pathway results in the eye-brain integration system only noticing an image about every 0.2 seconds, even with continuous fluoroscopy, so that the continuous visual impression is compounded to all intents and purposes from a sequence of stroboscopic “experiences” (images). Consequently, continuous fluoroscopy offers no advantage from the viewpoint of the physiology of vision [17, 18].

In order to ensure examiners have the same impression of the image with pulsed fluoroscopy as with continuous fluoroscopy, further factors of vision physiology [17-19] must be taken into consideration.

At high frame rates, the contrast resolution of the visual system drops. Since image noise represents low-contrast “information”, it is not detected at high frame rates. If the frame rate is decreased, the contrast sensitivity of the visual system [20] increases up to a frequency of 5 Hz.

Low contrasts, such as noise, are detected and are distracting. In order to compensate for this impression, an increase in the signal-to-noise ratio is required to improve the image quality. In diagnostic radiology, this requires an increase in the radiation dose used to form the image for a single frame. Thus, when the frame rate is halved from continuous (25 full fps) to 1.25 fps, the image intensifier dose rate must not be reduced to 50%, but to 80%, and at 6.25 Hz it must not be reduced to 25% but to 58%. This frequency-dependent image intensifier dose rate adjustment is described as the eye integration factor (EIF). Like any physiological factor, the EIF varies slightly for each operator [18, 19].

The eye integration factors selected for our system for 6.25, 3.12 and 1.56 Hz yield an image intensifier dose rate of 0.20, 0.14 and 0.10 µGy/s.

The necessity of increasing the radiation dose of the single pulse has two consequences:

- The theoretically possible radiation dose-saving effect of the image intensifier dose rate is partly used up again by the EIF (the theoretical radiation dose of a single pulse is 1/25 of the dose/second for continuous fluoroscopy; because of the EIF, the image intensifier dose rate is reduced to 40%, not just 5%, at 1.56 Hz).

- The single frame radiation dose increased by the EIF is another reason for the greater contrast and better detail of all pulse images.

The signal-to-noise ratio improves, making the
fluoroscopic image quality obtained sufficient for diagnostic purposes. Hence, the production of spot images (IQX) becomes unnecessary to a great extent.

A very favorable effect seen in examinations is the fact that, in 50% of examinations, a normal, acceptable image is already obtained with the first pulse, and at the latest it is present with the second pulse. This substantially shortens the time required for fluoroscopy. This is made possible by an in-pulse regulation of the dose rate, which still has an immediate effect on the same pulse. In some cases, the whole examination can therefore be completed within 16 - 32 pulses, which is equivalent to a total irradiation time of 160 - 320 ms.

The grid-based control of the tube is a major factor in reducing the radiation dose. Due to the short pulse width of typically 10 ms in pediatrics, this not only makes generating images possible without any blurring due to movement (Figure 2), but also, in contrast to generator-controlled pulse production, generates pulses with steep flanks, thus solving the “ramp and trail” problem [21]. In the case of small subjects (pediatric patients), the steepness of the flanks results in considerable savings in radiation dose.

A fluoroscopic technique that produces an optimum image contrast with a minimum radiation dose must have a different combination of kV and mAs in neonates and infants than in adults. For neonates and older pediatric patients, a special pediatric patient characteristic curve was created [8, 22, 23], which controls the kV for the same subject in contrast to a traditional kV/mA characteristic curve at a higher value.

The dose rate is controlled to correspond to a (pediatric) control curve especially adjusted to save radiation doses. When a higher radiation dose is required the tube voltage is first increased before starting from 70 kV, and then the tube current (mA) is also increased [8]. While the tube current has a linearly proportional effect on the dose rate, increasing the voltage results in an exponential increase in radiation dose and the radiation becomes harder, so that the required patient entrance dose can be decreased for a constant radiation dose requirement at the image receptor [8, 19, 21].

The German standard DIN 6809-7 states that for the same subject at 70 kV, the patient entrance dose is about 74% lower than at 50 kV [23]. This documents the disproportionate effect that a characteristic curve adapted for pediatrics has on radiation dose saving. The second effect of this control is evident in the lower image contrast, since the object contrast decreases as the voltage rises. Thus it is shown that the image contrast is again somewhat improved by leaving out the anti-scatter grid. However, the image contrast of small, calcium-containing structures is very low, even when using a grid. If questions need to be clarified, e.g. concerning concretions seen in fluoroscopy, the normal contrast control curve (adult patient characteristic curve) must be selected.

Although the image intensifier dose rate in this study was set deliberately higher than the technically possible minimum value, the measured average values of the DAP for our examinations were about 4% of the legal diagnostic reference value for the VCU (Table 3). The previous diagnostic image quality is not only maintained, but is improved, when the radiation dose of the individual pulses is increased.

This study shows that complying with the ALARA concept is a complex process, in which a number of factors play an equal role. These factors include the equipment design, operation...
of the equipment, duration of fluoroscopy, number of images, radiation dose level per image and dose rate. However, the human factor is the unifying one and can be controlled to a great extent with proper training [16, 17, 24].

In conclusion, it has been determined that in imaging with pulsed fluoroscopy, a large number of variables play a part. The consideration and use of these variables enable considerable reduction in radiation dose levels, compared to continuous fluoroscopy, with a simultaneous improvement in image quality. The operator must, in part, evaluate his or her existing knowledge in a new and critical manner. With pulsed fluoroscopy, a dramatic change occurs for perceptions based on experience with conventional imaging and continuous fluoroscopy, and the paradigms derived from these perceptions.

Until now the rule has been that for infants a consistent collimation must be carried out on the area being examined. The new paradigm is that a consistent collimation should only take place if the system has an ACFM for digital images and fluoroscopy. Until now, the anti-scatter grid had to be removed in pediatrics. The new paradigm is that the anti-scatter grid should not be removed for pulsed fluoroscopy with a pediatric patient characteristic curve and an additional pre-filtration with 1 mm Al and 0.1 or 0.2 mm Cu. Due to the increased kV and the additional pre-filtration, the radiation is made harder and the object contrast is lowered. Without the anti-scatter grid in the path of the X-rays, more digital spot images would again have to be made for documentation purposes and the DAP would increase as a result.

A radiation dose reduction/examination of approximately 80% with a simultaneous improvement in image quality is thus achievable using pulsed fluoroscopy in pediatric patients [25]. Dose-area products will thereby be obtained that are in the range of approximately 4% of the diagnostic reference value. This has been demonstrated in our example of voiding cystourethography.

The lack, or insufficient use, of most options for optimization available in the equipment has recently been pointed out, including the use of fluoroscopy for interventional procedures [16, 24-26]. This emphasizes the necessity for implementing the paradigm shifts identified above and imparting them through further training. Training programs should highlight these techniques that are so pertinent to reducing radiation dose level.

References


Clinical applications

Brilliance iCT: initial experiences with the new generation of cardiovascular computed tomography systems

MetroHealth Medical Center, located in Cleveland, is one of the largest healthcare providers in Northeast Ohio. MetroHealth is a leader in trauma, emergency and critical care, medical research and education, and is an affiliate of Case Western Reserve University School of Medicine. The Medical Center was the first hospital in the world to install the Philips Brilliance iCT scanner in October 2007. In this article, we present our early experiences in cardiovascular imaging with Brilliance iCT.

Background

Computed tomography angiography (CTA) has been widely adopted for most vascular applications. High-resolution, cross-sectional, isotropic images generated by multi-detector computed tomography (MDCT) scanners have been utilized successfully to image the vascular system. However, prior to recent enhancements in the speed, power and coverage of these MDCT scanners, challenges remained for the most demanding CTA application – imaging the coronary arteries.

The small caliber and rapid motion of the coronary arteries presents a significant technical challenge for CT scanners, which previously lacked the temporal resolution, spatial coverage and X-ray tube capacity to reproducibly image the coronaries at a broad range of heart rates and in a single breath hold.

The evolution of MDCT technology over the past decade from 2-slice to 64-slice configurations has addressed many of these challenges. Sub-second rotation times, isotropic sub-millimeter resolution and improved cardiac reconstruction algorithms have followed the trend of increasing slices. The combination of these enhancements has resulted in more consistent, higher-quality imaging of the coronary arteries. Clinical investigations using 16-, 40-, and 64-slice systems demonstrated the robustness and diagnostic accuracy of MDCT angiography (MDCTA) for the detection of coronary artery disease (CAD) [1-3], the increased mid-term prognostic value of MDCTA [4] and the positive impact of MDCTA on clinical decision making in the emergency room [5-8]. The combination of technological enhancements, and the body of scientific clinical proof, have thus established MDCTA as a viable non-invasive modality for coronary imaging.

Despite these advances – and the ability to image the majority of patients – there are still challenges in the performance of MDCT coronary imaging that need to be addressed. The temporal resolution and spatial coverage of 64-slice systems is still not sufficient to reliably image all of the fastest-moving coronary artery segments in all patients. As an example, obesity has been cited as an increasingly major health issue and is a significant independent risk factor for mortality from all causes, but especially from cardiovascular disease. However, imaging of the expanding bariatric and obese population with the limited X-ray output of 64-slice scanners...
• Industry’s fastest rotation time of 0.27 sec, resulting in a standard temporal resolution of 135 msec

• Longitudinal coverage of 8 cm

• 120 kW tube and generator system providing high power for short-duration cardiac scans and larger patients

• Scalable Nano-Panel detector system reduces electronic noise, thus enabling high-quality imaging at reduced radiation dose

• RapidView image reconstruction system with Quad Core processors provides true cone-beam reconstruction for artifact-free, thin-slice imaging, while also improving temporal resolution via sophisticated adaptive multi-cycle reconstruction for optimized cardiac imaging

• Two-dimensional (2D) anti-scatter grid improves Hounsfield Unit (HU) uniformity, thus enhancing image quality over a larger z-axis coverage

• Dynamic Eclipse DoseRight collimator to significantly reduce radiation dose

• Smart Focal Spot system, doubling the number of samples and projections resulting in 256 slices

• Isotropic, sub-millimeter (0.67 mm x 0.67 mm x 0.67 mm) reconstructed voxel size

• Workflow improvements via an integrated ECG system with advanced QRS detection algorithm and robust arrhythmia handling mechanism.

In the following sections we discuss and present examples of early experiences with cardiovascular CT imaging using the Brilliance iCT scanner. All images shown are generated using the Comprehensive Cardiac Analysis application (CCA) on the CT workstation (Extended Brilliance Workspace).

Cardiovascular clinical applications

Retrospectively ECG-gated spiral coronary computed tomography angiography (CTA)

Using the Brilliance iCT scanner, we have noticed significant improvements in coronary artery imaging. The increase in volume coverage, the isotropic sub-millimeter resolution and the substantial improvement in temporal resolution make consistent, high-quality imaging of all coronary artery segments achievable. Using a
pitch of 0.14, the entire cardiac anatomy (12 cm) can be now covered in as little as five seconds. This has the additional benefit of facilitating a reduction in contrast agent volume compared to previous generation scanners.

Furthermore, the new integrated ECG acquisition system, advanced QRS detection algorithm and robust arrhythmia handling offer significant benefits. Optimum coronary imaging is enabled through the “Beat-to-Beat” variable delay algorithm that captures the same physiological quiescent phase [9-10]. R-tag editing is rarely necessary, given improved tracking of the R-tags along the QRS complex with ECG gating.

Temporal resolution is optimized, beyond what is enabled through the scanner hardware, by using an adaptive multi-cycle reconstruction algorithm that combines data from as many adjacent cardiac cycles as are present in the acquired data [11-12]; using this approach it is theoretically possible to achieve a temporal resolution between 36 and 135 msec. These technical improvements have substantially increased the chances of visualizing the entire coronary tree on a more consistent basis.

Figure 2 shows a clinical example of a coronary CTA scan acquired on the Brilliance iCT scanner. A 53-year-old male, with a history of chest pain, was referred for coronary CTA. The CT acquisition was performed using a volume of 80 cc of contrast (Optiray 350, Mallinckrodt) injected intravenously at a flow rate of 5 cc/sec. Automatic bolus tracking was used for optimal contrast enhancement. A region-of-interest was placed in the proximal descending aorta and scans were initiated six seconds after a pre-set threshold (150 HU) was reached. The average heart rate during the acquisition was 58 ± 5 BPM. An acquisition of 14 cm length was completed in six seconds. Though a small focal calcified plaque was observed in the proximal left anterior descending (LAD) artery, no significant CAD was found.

**Low-dose coronary computed tomography angiography (CTA): Step & Shoot Cardiac**

Various approaches exist to mitigate the risks of radiation exposure if the primary indication for a cardiac CTA exam is coronary artery assessment (e.g. if functional information is not needed). One such approach is Step & Shoot Cardiac, a prospectively ECG-gated sequential (axial) mode of scanning in which the X-rays are turned on only during a physiologically quiescent cardiac phase (e.g. ventricular diastasis), thus enabling a reduction in radiation dose of up to 80%.

Step & Shoot Cardiac uses a suite of proprietary algorithms to ensure consistent, high-quality coronary imaging. These algorithms include dedicated, true cone-beam reconstruction algorithms to reconstruct thin-slice 3D datasets for coronary evaluation. These advanced reconstruction algorithms prevent the artifacts that would appear if approximation algorithms were used to generate thin slice datasets. In addition, Step & Shoot Cardiac incorporates proprietary, advanced algorithms that accurately predict the arrival of the next cardiac cycle and
identify the quiescent cardiac phase. Robust, real-time arrhythmia handling available in the Brilliance iCT scanner serves to prevent unnecessary radiation dose to the patient by automatically turning off the X-rays upon the detection of a premature heartbeat, and until the heart rate stabilizes.

Figure 3 shows a clinical example of a coronary CTA performed using Step & Shoot Cardiac on the Brilliance iCT scanner. A 37-year-old female with shortness of breath and a family history of myocardial infarction was referred for a low dose Step & Shoot Cardiac coronary CTA scan. A total volume of 80 cc of contrast (Optiray 350, Mallinckrodt) was used with bolus timing as explained previously. The average heart rate during the scan was 55 ± 4 BPM and images were acquired over just two cardiac cycles. No significant CAD was found. The effective radiation dose was 4.3 mSv, well in line with average annual background radiation levels, and much lower than what would have been delivered using conventional spiral cardiac CTA.

**Tube power when needed: imaging obese patients**

Obese patients (e.g., patients with a body mass index [BMI] > 30 and/or weighing > 300 lbs) presenting with chest pain represent a challenge for assessment of underlying symptoms. Exercise stress testing is often not possible due to limited exercise capacity in these patients and standard imaging with echo or nuclear techniques is limited due to body habitus. In general, MDCT scanning in these patients is a challenge as the reduced SNR of the acquired images makes diagnosis difficult. With Brilliance iCT scanner’s significant increase in tube power (and thus superior SNR), compared to the existing generation of CT systems, we have been able to acquire high-quality scans in these patients. Shown in Figure 4 is a coronary CTA performed on the Brilliance iCT scanner of a morbidly obese female patient (BMI of 50) with a family history of CAD and a sub-optimal nuclear stress test. Using a total contrast volume of 90 cc (Optiray 350, Mallinckrodt) an acquisition length of 14 cm was covered in 5 seconds. The scan was of excellent quality, with no abnormal coronary findings. The average heart rate during the scan was 60 ± 7 BPM.

**Emerging applications**

The excellent speed, power and coverage available in the Brilliance iCT scanner, compared to the existing generation of CT systems, should enable users to see an expansion in their abilities to image cardiovascular diseases beginning today and extending well into the future.

At MetroHealth, we have observed an increase in incidental coronary findings in patients who have not yet been triaged. As an example, we performed a routine, non-gated chest CTA scan on a 76-year-old female patient suffering from melanoma. An acquisition length of 28 cm was covered in as little as 4 seconds with a reasonable radiation dose (8.6 mSv). Though this type of scan is not traditionally used to assess coronary arteries, and the contrast protocol was not optimized accordingly, the coverage and speed
of the scanner resulted in motion-free coronary artery images, thereby also enabling us to perform diagnostic coronary assessment with confidence. Figure 5 shows a coronal maximum intensity projection (MIP) of the right coronary artery (RCA) obtained from this non-gated chest CTA scan.

In addition to enhancing the use of MDCT in routine cardiac imaging, the synergistic combination of speed, power and coverage of the Brilliance iCT scanner should expand the use of MDCT into the frontiers of imaging and the forefront of cardiovascular care. This paradigm shift will encompass areas such as specific, focused assessments, expanded cardiovascular interventions and revolutionary analyses of global cardiovascular function.

Although MDCT has been used for valve and valve implant assessment, its role was limited by temporal resolution and coverage. The temporal resolution was insufficient to reproducibly image the valve leaflets and the smaller coverage required spiral acquisitions to cover the anatomy of interest, thereby preventing cine imaging. The wide coverage of the Brilliance iCT scanner makes it possible to perform focused valvular assessment and to study dynamic flow via cine imaging at a specific axial location. In addition, its fast speed allows the motion of the valve leaflets to be frozen. Similar techniques can be used to enable novel dynamic focused assessments requiring high temporal resolution and wider coverage, including dynamic stent assessment, dynamic coronary flow assessment, vascular compliance, aortic distensibility, compression of intra-myocardial coronary segments or anomalous congenital anatomy, and others.

Focused assessment can be extended beyond diagnosis, therapy planning and follow-up. The Brilliance iCT scanner may find expanded use in the cardiovascular interventional suite. For example, dynamic imaging and volume fluoroscopy [13] of the heart enables advanced treatment of electrophysiological diseases, such as atrial fibrillation and ventricular tachycardia, structural heart defects, such as patent foramen ovale (PFO), and atrial- and ventricular-septal defects, ischemic conditions and minimally invasive procedures.

In addition to the aforementioned focused assessments and interventions, the wider coverage and faster speed enable novel global assessments of cardiovascular function. While left ventricular function can be analyzed using the current generation of MDCT, the combination of coverage and speed of the Brilliance iCT scanner opens up new possibilities in anatomical and physiological assessment. Using a cine axial scan, capable of covering the entire left ventricle and myocardium, advanced analysis of functional parameters, mechanical stress and strain analyses — including true 4D inter- and intra-ventricular dyssynchrony and computational fluid dynamics (CFD) of the ventricle and vascular networks. Ultimately the advanced imaging capabilities of this machine will enable the transition from 4D morphological to 5D quantitative physiological imaging. More specifically, combining 4D anatomical information with myocardial contrast kinetics defines a path to true myocardial perfusion measurements. These true measurements will facilitate more accurate characterization of ischemic stunned, hibernating or infarcted myocardial tissue in the context of acute coronary syndromes (ACS), revascularization therapy and electrophysiological interventions.

**Conclusion**

With its increased speed, power and coverage the Brilliance iCT scanner provides improved imaging possibilities for use in cardiovascular diseases. It has paved the way to expand the application of cardiovascular MDCT to broader patient populations, providing consistent coronary image quality with reduced contrast and over a wider range of variable heart rates. Incorporating improved dose management, scanning and reconstruction methodologies, it has enabled the radiation dose of a coronary CTA exam to be brought down to average background radiation levels. While it is expected that the scope and applicability of cardiovascular MDCT will to continue to broaden to include areas such as whole-organ perfusion and other emerging applications, this scanner is also well positioned for use in existing, as well as emerging, neurovascular and body applications.

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**Figure 5.** A coronal MIP from a routine, non-gated chest CTA examination performed on the Brilliance iCT scanner. The speed and coverage of the scanner enabled visualization of the coronary arteries. This image shows the right coronary artery (RCA) with diffuse calcium through most of the course of the vessel.

The Brilliance iCT scanner provides improved imaging possibilities for cardiovascular diseases.
References


Imaging the motion of the heart with echocardiography: advanced technology provides deeper insights into physiology and diastolic function

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The pace of technological innovation in echocardiography remains impressive. For example, the Phillips iE33 provides novel live three-dimensional (Live 3D) imaging, and it also provides higher quality Doppler tissue and pulsed-wave Doppler imaging capabilities. With these new capabilities, clinicians can begin to image and quantitate, and thereby appreciate, subtle details related to diastolic physiology that with “old” technology may have been interpreted as “noise” and disregarded or averaged out. The application of these imaging capabilities in clinical practice presents both a challenge and an enormous opportunity in the field of cardiology.

The meaning of “diastolic function”

Because of the acknowledged epidemic of heart failure [1-3], in particular diastolic heart failure [4-6], it has become increasingly important to understand the meaning of “diastolic function”. In clinical cardiology the term “diastolic function” is interpreted as relating to how the heart fills. By analogy the term “systolic function” is usually interpreted in terms of left ventricular ejection fraction (LVEF) where normal LVEF = (stroke volume)/(end-diastolic volume) falls in the 50% or greater range. No analogous simple, dimensionless parameter of diastolic function has been proposed. To appreciate the meaning of “diastolic function” the elegant and curious physiology of filling needs to be considered in some detail.

Common misconceptions remain about how the heart works when it fills. Diastolic function can be better understood when one appreciates that the left ventricle is a mechanical suction pump at, and for a little while after, mitral valve opening. In other words, at mitral valve opening, blood does not get pushed into the ventricle by the atrium, but is instead mechanically sucked in by the ventricle [7-9]. One may wonder where the energy driving suction arises, and the surprising answer is: systole. As the ventricle contracts and overcomes the peripheral arterial load during ejection, it also compresses elastic elements both internal to and external to the myocardium. This stored elastic energy is released when enough of the cardiac muscle relaxes, and the elastic elements drive the recoil of the ventricle until a relaxed equilibrium configuration is achieved.

To fill effectively, a ventricle must remain compliant during filling (not be too stiff), quickly relax the “cramp” that was the previous systole (effective relaxation), and be able to physically accommodate the incoming blood volume. Thus stiffness and relaxation are intrinsic ventricular properties that are useful in determining and quantitating diastolic function, and volumetric load (also termed pre-load) represents the extrinsic parameter that modulates diastolic function.

How to measure diastolic function

Many ideas have been tried with the intention of extracting both intrinsic and extrinsic ventricular properties. Early work focused on pulsed-wave Doppler-echo measured trans-mitral flow velocity contours. In terms of filling, diastolic intervals consist of early rapid filling E-waves followed by diastasis and followed by atrial systole-generated A-waves. As a first approximation, E- and A-wave contours were simplified as having triangular shape. To this day triangle-based indexes, including the peak heights of the E- and A-waves and their ratio, (Epeak, Apeak, Epeak/Apeak), the deceleration time and width (duration) of the E-wave (DT, Edur), and the velocity time integral (VTI) of the E- and A- waves (Figure 1A), are routinely measured. The use of a triangular approximation to the E-wave shape is convenient, especially when one considers the quality of images available using “old” technology. However, as a result of the improved temporal resolution and image processing capabilities of current technology, the curvature of E-wave contours
can clearly be discerned and the information they convey can be determined (Figure 1B). Despite these advances, physiologically important curvature features of the E-wave are usually disregarded. However, there is benefit in understanding the physical and physiological principles that govern the curvature, and this is discussed in more detail below (parametrized diastolic filling [PDF] model).

Technological advances allow the measurement of even smaller (i.e. tissue) velocities. This allows measurement of the longitudinal displacements of the mitral annulus. Once again, the shapes of mitral annular velocity contours were initially considered as triangles, with determination only of the peak, labeled E’. E’ proved useful in selected patient populations for estimation of end-diastolic pressure (EDP) [8]. Improved technology has revealed further details regarding the curvature and oscillations of the E’-wave and these detailed insights are discussed at greater length below.

Additional novel imaging capabilities include techniques such as speckle tracking, which allows for strain and strain-rate measurements. Speckle tracking is a recent example of technological progress, because it relies on the information content inherent in the seemingly random arrangement of bright speckles present in all echocardiographic images [10].

While the various echo-based imaging modalities represent different levels of technological innovation, much remains to be learned in relation to how to interpret the recorded data. In the kinematics-based approach utilized here, the use of physical models and mathematical techniques is advocated in order to extract relevant information from all modes of imaging and thereby more fully understand the rules that govern how the heart works when it fills.

### Pulsed-wave Doppler imaging

#### The parametrized diastolic filling (PDF) formalism

In routine practice, the curvature of the E-wave is ignored when the E-wave is approximated as a triangle. By considering the kinematic analog of the role of the heart as a suction pump, a deeper understanding into the physiological determinants of E-wave curvature has been gained, thereby making the triangular approximation unnecessary.

The filling of the ventricle can be modeled by comparing it to a recoiling spring (a mechanical oscillator) that has an inertial load and is moving against a resistance [11]. The model is called the parametrized diastolic filling (PDF) formalism. To be specific, this formalism (kinematic model) stems from Newton’s Laws of Motion and characterizes the E-wave in terms of a driving force (the atrio-ventricular pressure gradient), a damping/viscous force that resists trans-mitral flow, and an inertial load due to tissue and blood.

Using this model, by solving the associated differential equation, mitral flow velocity can be mathematically predicted as the solution to the equation of motion. In other words: all ventricles are mechanical suction pumps, and fill by obeying the same law of motion. The parameters that specify the motion, however, vary from heart to heart. As a simple analogy consider the trajectory of a stone thrown in the air. The arc the stone makes varies from throw to throw, and depends on the initial velocity and angle of launch, while the laws of inertia and gravity that determine the stone’s trajectory remain the same for each throw.

Each mitral flow E-wave can be uniquely determined by three parameters: the initial displacement of the spring $x_i$, which is linearly related to the E-wave VTI (i.e. volumetric preload) [8], a stiffness parameter $k$, which is linearly related to chamber stiffness ($dP/dV$) [12] and a resistance/damping parameter or chamber viscoelasticity/relaxation index $c$ (g/s).
which accounts for filling-related energy losses [8]. The spring constant, $k$, primarily determines the width of the E-wave. A high spring constant (i.e. a stiff spring) will generate a tall narrow E-wave as seen in the “constrictive-restrictive” pattern. The resistance/damping parameter is mainly responsible for the tail of the E-wave and is directly responsible for the inflection point (change in curvature from "cup-down" to "cup-up") seen in the deceleration portion. A high value for the resistance/damping parameter in general gives rise to the "delayed relaxation" pattern on the E-wave. Accordingly, the resistance/damping parameter, $c$, can be used as a relaxation parameter.

The PDF model parameters ($x_0$, $c$, $k$) for each E-wave can be obtained through model-based image processing (MBIP), detailed in Figure 2. Shortly after the E-wave is selected, the maximum velocity envelope is identified and is fitted numerically by the solution to the PDF model, yielding the three best-fit PDF parameters ($x_0$, $c$, $k$) and a measure of goodness-of-fit.

With a mathematically accurate model of the E-wave, subtle details of curvature that are absent in the triangular shape approach, prove to be useful. The analysis of E-waves via this model has shown that diabetes increases the resistance/relaxation parameter, $c$, of early rapid filling in both rats [13] and humans [14]. Importantly, these two studies showed that for hearts with normal LVEF, in contrast to the relaxation/viscosity parameter, $c$, conventional E-wave indexes, such as $E_{peak}$ or DT, were unable to differentiate between normal and diabetic subjects. A further manifestation of the resistance/relaxation property of the ventricle is that all ventricles fill to a volume that is less than the maximum (lossless) ideal filling volume. An index which characterizes this efficiency of filling, the kinematic filling efficiency index (KFEI) has been shown to be lower in normal LVEF diabetics compared to normal controls [15]. Furthermore, the resistance/relaxation parameter, $c$, has been shown to be linearly related to relaxation characterized by $\tau$, the (invasively-determined) time constant of isovolumic relaxation [16].

**Doppler tissue imaging (DTI)**

Doppler tissue imaging (DTI) has become routine in diastolic function assessment.
The information obtained from DTI holds great potential for diagnosis of diastolic relaxation abnormalities. The absence of mitral annulus oscillation (MAO) is a good predictor of relaxation-related diastolic dysfunction. In a recent study, it was found that patient groups without MAO tended to have prolonged τ and isovolumic relaxation time (IVRT), lower E peak/A peak and E-waves, and increased E peak/E' [23]. With advancing technology, cardiologists can easily and reliably utilize MAO to gain additional information about diastolic function.

However, with past technology it was difficult to appreciate the shape of the DTI generated E-wave and subsequent multiple annular oscillations, which has been previously noted [17-19]. Such oscillations may have been considered to be noise. Importantly, these annular oscillations obey the laws of oscillatory motion and thereby are amenable to MBIP-based quantitation [20-22]. With current technology, the presence or absence of oscillations is clearly evident, as shown in Figure 3.

The ability to image longitudinal and radial motion to high precision has permitted characterization of spatially distinct compensatory mechanisms in diastole. In other words, because maintenance of cardiac output and stroke volume constitute the prime directives in survival, it follows that impairment of longitudinal motion should be accompanied by compensation in radial motion in order to preserve stroke volume.

The situation is analogous to determining the quality of brakes by measuring the braking distance of a car. One car may take 50 feet to stop on a dry road, while another requires 80 feet to stop on a wet road. In this situation the road-independent, intrinsic braking function cannot be determined. In the clinical realm, quantitation of diastolic function is indeed blind to the “road”. In fact, in the clinical setting, load-dependence of echo-indexes can lead to the “road.” In the clinical setting, load-dependence of echo-indexes can lead to the “road.” The presence of MAO is a good predictor of relaxation-related diastolic dysfunction. In a recent study, it was found that patient groups without MAO tended to have prolonged τ and isovolumic relaxation time (IVRT), lower E peak/A peak and E-waves, and increased E peak/E' [23]. With advancing technology, cardiologists can easily and reliably utilize MAO to gain additional information about diastolic function.

With no reliable LIIDF available, clinical practice has focused instead on averaging measurements from multiple beats. For example, in analyzing the E peak one would measure several consecutive E-waves, and then report the average E peak. Thus, if any information regarding diastolic function is present in the actual beat-to-beat variation, then this information is lost due to averaging.
In a recent study, a solution to the LIIDF problem was found. Mathematical analysis of E-wave shapes reveals a novel index that is extremely well conserved in the face of load variation [26]. The key insight into extracting this load-independent index lies in analyzing not just one, but several E-waves, all preferably acquired at varying load states (Figure 4). To determine the LIIDF, first stiffness ($k$), damping ($c$) and initial stretch parameters ($x_o$) for each E-wave, as described above, were extracted. In addition, the peak height of the E-wave ($E_{peak}$) was measured. For each E-wave, the product of $k$ and $x_o$ gives us the model-predicted maximum driving force promoting forward flow, which is the analog of the peak instantaneous atrio-ventricular pressure gradient. The product of each E-wave’s $c$ and $E_{peak}$ defines the maximum resistive force opposing atrio-ventricular flow. Thus, for each E-wave a $kx_o$ value and the associated $cE_{peak}$ value was computed, and as a result each E-wave represents a point in the $kx_o$ vs. $cE_{peak}$ plot. The LIIDF is the slope, $M$, of the linear regression between all ($cE_{peak}$, $kx_o$) points, where each point is extracted from a separate E-wave.

The initial work studied healthy volunteers subjected to tilt-table maneuvers to change load, and cardiac catheterization patients with load variation due to respiration. Healthy subjects showed significant E-wave shape changes as the tilt angle was varied from upright to supine to head-down. Despite the dramatic visual E-wave shape variation, all associated ($cE_{peak}$, $kx_o$) points remained co-linear ($R^2 = 0.98$), demonstrating that the slope of the $kx_o$ vs. $cE_{peak}$ regression is a constraint on E-wave shape that is independent of load. Furthermore, it was found that in subjects undergoing cardiac catheterization the LIIDF slope ($M$) was significantly lower in subjects having diastolic dysfunction (elevated filling pressures > 18 mmHg), compared to subjects with normal diastolic function (Figure 5). Thus, the LIIDF is easily determined by analysis of a series of load-varying E-waves, is constant in the face of load variation and differentiates between normal diastolic function subjects and subjects with diastolic dysfunction.

The method of LIIDF determination relies critically on the differences between E-wave shapes. The practical utility and clinical power of the LIIDF resides in its application in sequential studies, where each subject serves as their own control. Using this approach, whether therapy has resulted in “beneficial” or “adverse remodeling”, LIIDF can be assessed in load-independent terms. Furthermore the LIIDF in and of itself can serve as a therapeutic target for diastolic function improvement.

**Figure 5. Contrasting normal vs. abnormal diastolic function in terms of the load-independent index of diastolic function (LIIDF).**

Left panel: Nine trans-mitral flow images from a subject with an end-diastolic pressure (EDP) of 35 mmHg (abnormal diastolic function).

Right panel: Seven trans-mitral flow images from a subject with an EDP of 12 mmHg (normal diastolic function).

For each E-wave a corresponding $cE_{peak}$ and $kx_o$ value was determined and plotted on the $kx_o$ vs. $cE_{peak}$ plot. Thus nine E-waves with dotted frame borders define nine points, shown as dotted circles. Similarly seven E-waves with solid frame borders define seven points, shown as solid circles. The $kx_o$ vs. $cE_{peak}$ regression for nine dotted points is $M = 0.95$, $B = 19.0$, $r^2 = 0.98$. The regression for the seven solid points is $M = 1.15$, $B = 5.10$, $r^2 = 0.99$. Notice both regressions are highly linear, but the subject with abnormal diastolic function has a lower slope ($M$) and higher intercept ($B$) compared to the normal subject.

**Future applications**

The future is bright because improvements in imaging speed, fidelity and processing will continue to emerge. In principle this will allow a more complete “model-based image analysis” approach to quantitatively characterize fluid and heart tissue motion. The PDF approach, and the LIIDF developed from it, are early harbingers of things to come, ultimately leading to automated, observer-independent, quantitative assessment of four-chamber heart function at the push of a button. Of course the important role of the sonographer will remain, but technology will do more than its share to advance the science and art of diagnosis and assessment of therapy.
References


Clinical applications

The road to mitral valve repair with live 3D transesophageal echocardiography (TEE)

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Chronic severe mitral regurgitation due to mitral valve prolapse is well established as a significant cause of cardiovascular morbidity and mortality [1-3]. Surgical intervention is often necessary in these patients to preserve life expectancy. Mitral valve repair is now well established as surgical techniques have advanced and repair is applicable in practically all patients with mitral valve prolapse due to degenerative mitral valve disease [2]. Valve repair offers a distinct event-free survival advantage compared with replacement using a bioprosthetic or mechanical valve [3, 4].

Despite consensus regarding the outcome and benefits of mitral valve repair, and support from practice guidelines [5], it is interesting to note that a significant number of patients with degenerative mitral-valve disease continue to undergo planned mitral valve replacement all over the world. The reasons for this are multifactorial, but one principal issue is a poor match between the complexity of the degenerative mitral process and the expertise and experience of the operating surgeon [6]. Moreover, assessment by echocardiographers of the etiology of prolapse disease as well as the location of the lesion depends on the skill and experience of the readers.

Transesophageal echocardiography is the imaging modality of choice for the mitral valve, and recent advances in live 3D imaging technology are facilitating definitive assessment of patients with chronic mitral regurgitation. This article describes the clinical utility of 3D cardiac imaging using the Philips X7-2T TEE transducer and the iE33 3D echocardiographic imaging system.

Assessment of mitral regurgitation by 2D echocardiography

2D transthoracic echocardiography is the most common imaging modality used to assess patients with suspected mitral regurgitation. Frequently these patients present to the clinic with symptoms of dyspnea, fatigue or other symptoms of left heart failure. The classic finding on physical examination is a systolic murmur radiating to the left axilla. 2D echo color Doppler techniques show the presence of a regurgitant jet within the left atrium. Figure 1 shows a 2D echocardiogram of the mitral valve.

Patients with mild or moderate mitral regurgitation that does not affect left ventricular...
function, or physical symptoms such as decreased exercise tolerance, are simply followed over time to determine whether valvular or ventricular function is worsening. When deterioration ensues, the indicated therapy remains cardiac surgery. Importantly, standard 2D echocardiograms sometimes do not provide images with sufficient detail to delineate the exact mechanism of regurgitation, and specifically the type of disease creating the prolapse, such as fibroelastic deficiency or Barlow’s disease.

The test of choice for assessment, especially intraoperatively, to plan and assess mitral valve repair is transesophageal echocardiography (TEE). However, until recently, standard TEE provided only live 2D images.

2D versus 3D echocardiographic transducers

Ultrasound has been in use for cardiac imaging for over fifty years. Echocardiography combines portability, safety, low cost and widespread availability. The most significant advances that have occurred over the years include:

• development of two-dimensional real-time imaging to replace (spatial) one-dimensional M-mode imaging
• development of spectral Doppler techniques to evaluate valve flow and chamber filling
• development of color Doppler for spatial mapping of blood flow movement
• the placement of an ultrasound imaging sensor on a transesophageal gastroscope.

The ultrasound transducer gives echocardiography a unique position among cardiac imaging techniques. The transducer converts electrical energy into mechanical oscillations and vice versa.

In order to understand what sets 3D systems apart from conventional scanning systems, it is necessary to consider some acoustic principles. Current 2D systems transmit and receive acoustic beams in a flat 2D scanning plane. This is accomplished by sweeping an acoustic scan line within this 2D plane (Figure 2).

True three-dimensional ultrasound steering has been the subject of much academic and industrial research that began in the 1980s. The key difference between 2D and 3D imaging is that the latter involves beam sweeping in three dimensions (Figure 3). This poses several technical challenges:

• creating a transducer array with up to 3000 electrically active elements
• processing 3D data at rates exceeding 50 - 100 Mbytes/s
• presenting 3D data on a 2D screen
• quantifying data for physiologic measurements and for 3D intervention [7, 8].

The X7-2t transducer has been developed to overcome the problems of three-dimensional acquisition and processing. In this transducer the conventional PZT transduction material has been replaced by PureWave crystals. These crystals are far more homogeneous than the conventional material, down to the atomic level, enabling them to transfer energy with greater efficiency and precision, and with a greatly enhanced bandwidth. The result is better acoustic penetration and higher spatial resolution.

Transmission of a 3D image generated using thousands of elements via a conventional cable would require a cable containing thousands of wires, making it prohibitively thick. The first transducers for three-dimensional echocardiography were used with chest wall imaging. The problem of transmitting the acquired data was solved by integrating the beamforming circuitry in the handle of the transducer, rather than in the system itself. This allowed a relatively thin ergonomic cable to be used for this clinical application, as much of the processing already took place in the handle. However, while the handle of a chest wall transducer could hold these electronics, they would not fit into the tip of a TEE probe. Another revolutionary leap was needed to miniaturize the circuitry even more.
In 2007, innovations in miniaturizing beamforming electronics made it possible to create a 3D TEE imaging transducer [7]. Figure 4 shows the tip of a TEE transducer containing several thousand elements and electronics with a processing capacity that, ten years ago, would have been equivalent to 50 laptops. Moreover, reduced power consumption keeps the heat dissipation low enough to make 3D TEE imaging safe for esophageal use.

Mitral valve anatomy

In addition to defining a segmental approach to mitral valve anatomy, Carpentier and coworkers also proposed a pathophysiologic triad that is a useful adjunct to clearly differentiating the particulars of mitral regurgitation [9]. The triad consists of the etiology (such as Barlow’s disease or fibroelastic deficiency), the lesions (in the case of degenerative diseases primarily chordal rupture, chordal elongation, leaflet distension, annular and/or leaflet and/or papillary muscle calcification, and annular dilatation), and the dysfunction (which is defined based on the systolic position of the margin of the leaflets in relation to the annular plane).

The main two etiologies of degenerative mitral valve disease are Barlow’s disease and fibroelastic deficiency [10, 11]. Barlow’s disease results in myxoid degeneration of the mitral valve, creating excess tissue in multiple valve segments, chordal thickening and elongation and, less commonly, rupture usually associated with significant annular dilatation and sometimes calcification. Fibroelastic deficiency, on the other hand, results from a presumed deficiency of connective tissue [12], and leads to thinning of chordae and single, or sometimes multiple, chordal rupture. The prolapsing segment may be distended, but the remaining segments of the valve are classically entirely normal (Figure 5).

Distinguishing Barlow’s disease (Figure 6) from fibroelastic deficiency, as well as clearly defining the lesions and type of leaflet dysfunction, is of the utmost importance for the imager, as it will guide appropriate informed...
consent regarding timing of an intervention [13]. Additionally, such distinction may help in the choice of where the surgery should be performed, as complex lesions and Barlow’s disease should ideally trigger referral to a reference mitral center in order to maximize the likelihood of a successful repair [6].

Pre-operative assessment of mitral regurgitation
An accurate segmental analysis is the optimal approach to performing a thorough echocardiographic assessment of the mitral valve affected by a disease process. It enables the various anatomical components of the mitral valve to be assessed individually in a systematic manner, which will allow identification of all lesions and resulting dysfunctions, as well as help determine the etiology in most circumstances. Transesophageal echocardiography (TEE) is, however, currently the most valuable modality for imaging of the mitral valve, and is generally regarded as a standard of care for the surgical assessment of mitral valve disease [14].

When using two-dimensional (2D) TEE to diagnose mitral valve pathology, or judge the success of mitral valve repair, the operator needs to obtain multiple two-dimensional multi-planar tomographic views with and without color Doppler to fully characterize the mitral valve. The systematic examination consists of four standard mid-esophageal views (four chamber, bi-commisural, two-chamber and long axis views) and the transgastric basal short axis view.

Examination of the mitral valve using real time 3D TEE
The recent development of a three-dimensional fully-sampled matrix-array TEE (Live 3D MTEE) transducer now allows real-time acquisition and on-line display of 3D images of the mitral valve and ventricle [15]. To obtain the surgical view of the mitral valve (i.e., the view the surgeon has when positioned on the patient’s right side when examining the mitral valve through the opened left atrium), the valve is best imaged in the 3D zoom mode. This mode displays a small magnified pyramidal volume of the mitral valve which may vary from a 20° × 20° up to 90° × 90° depending on the density setting, resulting in high-quality volume rendered images of mitral valve MV apparatus including the anterior and posterior leaflets, as well as anulus, commissures and subvalvular structures. Prior gated 3D TEE acquisition methods display the mitral valve from both atrial and ventricular perspectives that are unique to 3D imaging. What distinguishes 3D MTEE from rotational 3D acquisition is the consistency of superb quality of the mitral valve, devoid of rotational artifacts. It is anticipated that with the ability of real-time acquisition, on-line adjustments of rendering and cropping capabilities, this modality will be used routinely in the peri-operative planning of MV surgery.

Quantification of mitral valve anatomy
While visualization of anatomy in its true three-dimensional state is important, many physicians believe that the most significant value 3D echocardiography has for adult echocardiography is the ability to perform accurate and reproducible quantification. True myocardial motion occurs in three dimensions, and traditional 2D scanning planes do not capture the entire motion, or else move or “slip” while scanning.

Quantifying implies segmenting structures of interest from the 3D voxel set. This interface is typically constructed as a mesh of points and lines and displayed in a process known as surface rendering. This also allows the mitral apparatus to be segmented at end-systole with great accuracy. The true three-dimensional nature of the mitral annulus, leaflets and chordal apparatus can be measured. This further allows sophisticated analyses of the nonplanar shape of the mitral annulus. These 3D measurements include: annular diameters, annular nonplanarity, commissural lengths, leaflet surface areas, aortic to mitral annular orientation.

Post-repair assessment
Immediately following mitral valve repair, there are several important aspects of the final valve anatomy which must be addressed by the imager. Of course, the most critical aspect of post-operative valve analysis is to confirm the absence of significant residual mitral regurgitation. The depth of coaptation should be documented and be at least 5 mm in a 2D long axis view to ensure adequacy of coaptation.

It is important to perform a segmental assessment to rule out residual regurgitation along any aspect of the coaptation surface, including the commissures. If a residual leak is identified, the lesions responsible (such as a leaflet clef or perforation) and the residual dysfunction (such as leaflet restriction or prolapse) should be sought and reported in a segmental fashion. Common causes of a residual leak include uncorrected segmental prolapse or restriction, a residual restricted leaflet indentation, an incorrectly sized or positioned ring that distorts the zone of coaptation, leaflet perforation of the leaflet from an annuloplasty suture or a defect...
in a leaflet closure line. Any significant degree of mitral valve regurgitation (other than trivial to mild regurgitation) should usually prompt a return to cardiopulmonary bypass and subsequent valve re-exploration to correct residual or new defects. This strategy is imperative to avoid a heightened risk of re-operation in the patient early during follow-up, as there is a correlation between residual mitral regurgitation and early re-operation.

Systolic anterior motion (SAM) of the anterior mitral leaflet is a phenomenon almost unique to mitral valve repair, resulting from a mismatch of annular septo-lateral dimension and the residual combined leaflet height. Typically, the margin of the anterior leaflet is displaced into the outflow tract, causing both a significant outflow tract gradient as well as varying degrees of mitral insufficiency. The best echocardiographic view to interrogate this is the mid-esophageal long axis view. In some circumstances volume loading and increasing the ventricular after-load repositions the anterior leaflet minimizing the outflow tract gradient and valve regurgitation. If such maneuvers are not successful, valve re-exploration with placement of a larger ring, leaflet height shortening, or even valve replacement, is required.

**Live 3D TEE from the cardiac surgeon’s perspective**

Surgical techniques have progressed significantly, so that even some of the most complex cases of mitral prolapse are now treated with repair rather than replacement. It has now become imperative that cardiologists additionally become familiar with the classification of the etiology and lesions that underlie the degenerative disease process that results in the mitral valve prolapse. As these techniques have evolved, however, cardiac imaging of the mitral valve has remained unchanged in mainstream practice since the advent of multiplane TEE. Now, live 3D TEE represents a significant step forward in the management of patients with mitral valve disease.

The lesions and etiology of degenerative mitral valve disease have specific implications in terms of the “complexity” of techniques required to achieve a successful valve repair. A better understanding of the etiology and lesions will guide optimal referral and management of patients with severe mitral regurgitation.

While the overall mitral valve repair rate continues to increase in the United States, the rate of progress is too slow for many patients, as current estimates suggest that replacement rates still approach 50% in patients with degenerative disease. Most simple prolapses due to fibroelastic deficiency can be repaired by experienced cardiac surgeons, while most complex valves can be repaired in the hands of mitral valve subspecialists, so by matching the valve to the surgeon, most valves should be successfully repaired [6, 13].

Echocardiographers should become more familiar with the causes of degenerative mitral regurgitation, and specifically the lesions that lead to the valve dysfunction. New 3D echocardiographic techniques are making this easier. The lesions identified on echocardiography guide the surgical approaches and techniques needed to effect a repair. For example, if the echocardiographer notes a tall posterior leaflet (> 2 cm) then such a patient should only be referred to a surgeon comfortable with the techniques used to address excessive leaflet height (such as the sliding leaflet plasty [16, 17]).

The use of real-time 3D echocardiography is facilitating both lesion identification and localization, as it becomes integrated into everyday practice, and this is providing better information for the cardiologist, anesthesiologist and surgeon to guide optimal referral and surgical practice. This provides significant information both for referral and for surgical planning. These 3D echocardiographic visualization and quantification techniques provide more information about valve morphology than was ever available before, while making it easier for the cardiologist, anesthesiologist and surgeon to provide optimal care for their patients.

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**Live 3D TEE represents a significant step in the management of patients with mitral valve disease.**

**Mitral valve repair, rather than replacement, can improve patient outcome.**
Structural heart disease interventions: rapid clinical growth and challenges in image guidance

Investigations and research

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Structural heart disease (SHD) interventions represent a broad category of percutaneous treatments for patients with both congenital heart disease (CHD) and acquired heart disease involving structural and functional abnormalities of heart valves, cardiac chambers and the proximal great vessels [1, 2]. In the last five years, there has been an explosion in the number of innovative approaches to these catheter-based treatments, ranging from the modification of anatomical structure and function, using balloon dilatation and tissue ablation, to the deployment of various plugs, valves, clips and cinching devices (Table 1).

The current status of SHD interventions ranges from well-established procedures, such as percutaneous balloon valvuloplasty for stenotic valve conditions, which has been incorporated into clinical practice guidelines as the preferred

<table>
<thead>
<tr>
<th>Time period of emerging into practice</th>
<th>Percutaneous SHD interventions</th>
<th>Image guidance modality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-2000</td>
<td>Balloon valvuloplasty</td>
<td>Fluoroscopy</td>
</tr>
<tr>
<td></td>
<td>Balloon septostomy</td>
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<td>Catheter ablation of SVT</td>
<td></td>
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<tr>
<td>Last 5 years</td>
<td>Device closure of PFO, ASD, VSD, PDA</td>
<td>Fluoroscopy plus ICE and TEE Early mapping systems</td>
</tr>
<tr>
<td></td>
<td>Repair of paravalvular leaks</td>
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<tr>
<td></td>
<td>Catheter ablation of atrial fibrillation, VT</td>
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<tr>
<td></td>
<td>Alcohol septal ablation for hypertrophic cardiomyopathy</td>
<td></td>
</tr>
<tr>
<td>Next 5 years</td>
<td>Mitral valve repair</td>
<td>Fluoroscopy plus 2D and 3D TEE and ICE Advanced mapping systems Fluoroscopy overlay on 3D CTA, MRA, and angio reconstructions</td>
</tr>
<tr>
<td></td>
<td>Aortic and pulmonic valve implantation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Next generation devices for PFO and ASD</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Left atrial appendage occlusion devices</td>
<td></td>
</tr>
<tr>
<td>Future</td>
<td>Valve replacement with a variety of mechanical and biologic types</td>
<td>3D imaging wedded to robotic navigation Advanced ICE imaging</td>
</tr>
<tr>
<td></td>
<td>Repair of all valves</td>
<td></td>
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<tr>
<td></td>
<td>Biodegradable closure devices</td>
<td></td>
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<tr>
<td></td>
<td>Myocardial regenerative therapies via intramyocardial delivery</td>
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<tr>
<td></td>
<td>Device closure of all LV aneurysms and pseudoaneuysms</td>
<td></td>
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<tr>
<td></td>
<td>Shunts for Complex CHD</td>
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</table>

Table 1. The development of structural heart disease (SHD) interventions.

SVT: supra-ventricular tachycardia; PFO: patent foramen ovale; ASD: atrial septal defect; VSD: ventricular septal defect; PDA: patent ductus arteriosus; VT: ventricular tachycardia; ICE: intracardiac echocardiography; TEE: transesophageal echocardiography; CTA: computer tomographic angiography; MRA: magnetic resonance angiography; CHD: congenital heart disease.
therapeutic approach in specific clinical situations, to investigative technologies still in development, such as percutaneous valve implantation [3]. While many pivotal, industry-sponsored trials are currently enrolling patients, and will have results available in the next 2 - 5 years, other technologies remain in the very early phases of concept and design development (see the “Future” category in Table 1). As Tables 1 and 2 illustrate, the potential for growth in this unique clinical area is staggering.

The volume of patients undergoing SHD interventions is rapidly increasing, and may even surpass the number of many vascular interventions performed within the next decade. The rate of growth, however, depends heavily on the outcome of several ongoing clinical trials investigating pathological conditions that are very common in adult cardiology practices (Table 2). For example, device closure of patent foramen ovale (PFO) in adults to prevent embolic stroke and reduce migraine frequency are the subject of several trials that, if positive (i.e. demonstrate that device closure is superior to medical therapy), will make tens of thousands of patients immediately eligible for treatment [4, 5]. In addition, the incidence of atrial fibrillation continues to increase and requires lifelong anti-coagulation to prevent embolic stroke. Clinical trials investigating the ability of left atrial appendage (LAA) occlusion devices to prevent thrombus formation in the left atrium leading to embolism are ongoing. Should these clinical trials demonstrate either superiority or equivalence of device therapy versus chronic anti-coagulation in preventing embolic stroke in patients with atrial fibrillation, another major expansion of patients eligible for SHD interventions will occur. Finally, catheter based treatments for valvular aortic stenosis and mitral regurgitation have already shown preliminary results that will likely lead to the treatment of patients who had previously been ineligible for traditional surgical valve repair or replacement. In addition, many patients will potentially be switched from open surgical to catheter-based treatments if comparative studies show benefit with less risk.

SHD interventions show a significant departure from the inherent nature of the two prior waves of new interventional treatments: percutaneous coronary intervention and non-coronary vascular disease interventions, such as carotid stenting. Unlike these vascular therapies, where over-the-wire technologies in the well-defined space of small branching vascular trees are used, SHD interventions frequently involve navigation in open 3D space, defined by relatively large cardiac chambers, interaction with moving targets, such as heart valves, and deployment of devices, such as occluders and heart valves, that function quite differently from traditional vascular scaffolds. These differences subsequently impact procedural performance by relying heavily on

<table>
<thead>
<tr>
<th>Lesion</th>
<th>General</th>
<th>Specific patient groups or defining statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFO</td>
<td>1:4 to 1:5 of population.</td>
<td>• 36% - 59% of young adults presenting with cryptogenic stroke have a PFO.</td>
</tr>
<tr>
<td>Aortic stenosis</td>
<td>Most common etiology is related to aging.</td>
<td>• 6% of all people over age 90 have hemodynamically significant aortic stenosis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• In patients over age 80, operative mortality of surgical aortic valve replacement approaches 30%.</td>
</tr>
<tr>
<td>Mitral regurgitation</td>
<td>Frequently accompanies heart failure from all causes and surgical therapy not feasible.</td>
<td>• Affects as many as 9.3% of people age 75 and older.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Of the 5 million people suffering from heart failure in the USA, 15% - 20% have moderate to severe mitral regurgitation.</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>The vast majority of patients with AF currently require long-term full anti-coagulation. The left atrial appendage is the site of thrombus formation in 90% of patients with non-valvular AF.</td>
<td>• The prevalence of stroke associated with AF increases with age.</td>
</tr>
<tr>
<td>(AF)</td>
<td></td>
<td>• AF is thought to be responsible for one-sixth of all ischemic strokes in people over age 60.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The risk of stroke among all patients with AF is about 5% per year, which is about five to six times the risk of age-matched patients in sinus rhythm.</td>
</tr>
</tbody>
</table>

AF: atrial fibrillation; PFO: patent foramen ovale; USA: United States of America.
the operator’s knowledge (both structural and spatial) of cardiovascular anatomy and physiology, training with unique navigational devices, incorporation of new procedural skills and familiarity with novel image guidance technologies.

Interventional cardiologists performing SHD interventions must understand anatomy to a degree similar to that of cardiac surgeons. Unlike surgeons, however, interventional cardiologists do not have the advantage of learning cardiovascular anatomy in the setting of direct anatomic exposure during open-heart surgery. Interventionalists instead rely heavily on medical images produced by ultrasound, computed tomography angiography (CTA), and magnetic resonance angiography (MRA), which can be processed into 3D formats and are somewhat useful in providing an understanding of patient-specific anatomy. Although 3D reconstructions and graphical display of modalities, such as cardiac CTA, are infrequently used for traditional diagnostic purposes, these applications are becoming much more important to the interventionalist when planning both structural and vascular procedures.

Beyond their required understanding of structural and spatial cardiovascular anatomy, interventional cardiologists performing SHD interventions must also learn new procedural skills and gain familiarity with novel navigational and therapeutic devices. Within the last five years, simulators designed to train operators in the intricacies of catheter-based interventions (i.e. increased hand-to-eye coordination, translating the manipulation of objects in 3D space with movements on a 2D screen, etc.) have been developed. In interventional cardiology, simulation-based training has been used in both the investigative phase as well as the post-approval roll-out of a variety of SHD interventions [6]. These simulators are designed to familiarize operators with various aspects of catheter-based closure (i.e. anatomy, imaging modalities, etc.). This approach also allows for the added advantage of enabling the early learning curve of physicians to occur during simulation and not on real patients, who could potentially be exposed to increased risk due to the inherent novelty of the procedures.

Recently, there have been several technological advances in imaging modalities used in both the evaluation and treatment of SHD [7]. Ultrasound guidance has increasingly been used in SHD interventions. The emergence of percutaneous closure of atrial septal defect (ASD), PFO and ventricular septal defect (VSD) marked the routine incorporation of ultrasound imaging. Transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE) are routinely used in children and adults to assess defect and device sizes, guide device deployment and assess the procedural result. Furthermore, the development and incorporation of intracardiac echocardiography (ICE) has provided image clarity equivalent to that achieved with TEE, without the burdens associated with prolonged esophageal probe placement (i.e. increasing the depth of anesthesia, need for an expanded team to perform the procedure, etc.).

The research group at the University of Colorado has taken the emergence of SHD interventions, requirements for training in an entirely new procedural skill-set, and the need for more in-depth anatomical understanding as the impetus to develop the technical capability to transform medical images to physical models of patients’ hearts (see Figure 1) [8]. An accurately sized physical model of the patient’s heart is a powerful and efficient tool for visualizing and simulating the sequential steps of a SHD intervention. While computer graphics

Recent technological advances in imaging SHD include ICE, TTE and TEE.
allow 3D visualization, they are limited by an inherent lack of realism and cannot be held in the physician’s hands, turned and studied using direct visualization. In addition, the planned pathway of catheters to the SHD target is better understood in a 3D spatial representation, which is more realistic than the 2D projection images obtained by fluoroscopy. Likewise the deployment of a device can be simulated with an immediate and clear understanding of its potential impact on surrounding structures (Figure 2).

Alignment of delivery catheters and devices to the 3D target, a technical aspect that is common to many SHD interventions, is likely facilitated by 3D imaging. Two examples are instructive: Firstly, large ASD devices are deployed in a sequential fashion with the left atrial disc deployed first. Before the center and the right atrial disc can be deployed, however, the left disc must be aligned parallel to the 3D curved plane of the defect. Device misalignment may not be recognized due to the limitations of 2D imaging and subsequent complete device deployment may result in failure of the right and left atrial discs to be properly positioned, leading to the need to recapture the device and

Figure 2. A challenging structural heart disease (SHD) intervention is closure of a ventricular septal defect (VSD). There is complex anatomy of both the defect and surrounding tissues that must be understood and visualized during the procedure. The delivery system can come from several routes, including the superior vena cava, the inferior vena cava, and transseptally through the mitral valve. The upper two panels show a model made from the CTA of a patient with a VSD and helped plan the procedure. Note the blue catheters in the model. This simulation of possible catheter pathways to the VSD proved that the best approach to close this VSD was from the superior vena cava. The bottom left panel shows the device (AGA Medical Corporation) and the bottom right panel shows the implanted device, visualized by 3D TEE, after successful placement guided by 3D TEE.

The need for 3D imaging to guide structural heart disease (SHD) interventions

Because traditional 2D imaging modalities remain limited in their ability to represent the complex 3D relationships present in SHD, the growing number of SHD interventions performed worldwide has heightened the need for advanced 3D imaging modalities. Although complex moving 3D structures, such as heart valves and chamber defects, can be imaged with 2D cross-sectional ultrasound images, they require the physician to mentally integrate the slice images into the context of a 3D object. These challenges in imaging, both acquisition and interpretation, are compounded when performing a SHD intervention. The delivery catheter, device and target are often very difficult to visualize simultaneously in single a cross-sectional image. As a result, a significant amount of time is spent searching for the optimal view to evaluate and guide the procedure, integrating multiple images to make clinical and technical decisions, and assessing the procedural results after device deployment. These challenging visual-spatial and technical tasks are the primary reasons underscoring the steep learning curves associated with many SHD interventions. Such complexities are also the reason why SHD interventions often require a team of physicians, including experts in echocardiography and advanced imaging.
redeploy following appropriate device repositioning. In situations such as this, the superior anatomic representation of the interatrial septum offered by 3D imaging may further enhance optimal device positioning, thereby avoiding the repeated need to recapture and redeploy. The second example involves the investigatory Evalve clip used to repair regurgitant mitral valves by clipping together the center portions of the two valve leaflets [13]. The deployment of a mitral valve clip can only be attempted after the delivery catheter is coaxially aligned with the center of the mitral valve orifice so that the clip system can be advanced in a pathway that permits proper alignment of the clip with the two leaflets. Given the non-planar orientation of the mitral valve annulus, achieving coaxial alignment of the delivery catheter with the center of the mitral valve orifice is challenging when limited to 2D fluoroscopic or echocardiographic views. By simultaneously providing both anatomic and spatial representations of the mitral valve, 3D imaging should facilitate the manipulation and alignment of the delivery catheter to the mitral valve orifice, thereby increasing the odds of achieving procedural success.

Currently, there are two methods of using 3D image data to guide percutaneous interventions. The first uses a 3D CTA- or MRA-derived image set obtained pre-procedurally [14]. The image is segmented to illustrate important anatomical features (i.e. location of pulmonary veins and valve annuli, relationships of major vascular structures to surrounding cardiac chambers, etc.). The segmented image is then transferred to a workstation in the procedure area, which allows the image to be displayed during the intervention. The image is then registered, scaled and localized in 3D space with the X-ray system, using objects that are present in both images (e.g. vertebral column, cardiac borders and other internal landmarks). Subsequently, when the X-ray system is rotated, the registered CTA or MRA image rotates to maintain the alignment of the two images. Thus, using this system, the operator has the unique opportunity to use live-fluoroscopy with a background 3D image containing the soft tissue cardiac structures. This type of 3D image-guided approach has been utilized in procedures such as aortic coarctation stenting, VSD closure and ASD closure (Figure 3) [7, 14].

The second major approach to 3D image guidance is the recently available real-time (RT) 3D ultrasound imaging. In 2007 Philips Healthcare released the Live 3D TEE iE33 Echo System, which enables viewing of 3D image data in a variety of graphical display modalities. The Division of Cardiology at the University of Colorado has used RT 3D TEE in over fifty of the more difficult SHD interventions including complex ASD and PFO closure, mitral balloon valvotomy, mitral repair using the Evalve clip and alcohol septal ablation of obstructive hypertrophic cardiomyopathy (Figures 4 and 5) [1, 14, 15]. The learning curve of applying this novel technology has been steep and has involved not only gaining familiarity with the equipment, but also standardizing views, achieving effective communication between the echocardiographer and interventionalist and dissecting every intervention into a series of tasks, each requiring a unique visual guidance solution. The technical benefits offered by RT 3D TEE guidance in SHD interventions, however, far outweigh the present logistical challenges faced in incorporating its use. The surface renderings generated from RT 3D TEE image data truly represent a landmark in interventional cardiology as they offer the ability to navigate in the heart using live 3D imaging. For example, when used to navigate a catheter across the mitral valve for either delivery of an Evalve clip or during percutaneous balloon valvuloplasty, the catheter,
Figure 4. This four-panel figure shows images from the three-dimensional transesophageal echocardiography (3D TEE)-guided placement of a closure device in a patient’s patent foramen ovale (PFO). Panel A shows the deployed left atrial disc and the delivery catheter. Panel B shows the position of the left atrial disc after the interventionalist has pulled back the delivery catheter and partially deployed the device to engage the left atrial side of the PFO. The bottom panels show the successfully deployed device by 3D TEE (Panel C) and X-ray (Panel D). Thin moving structures, such as the interatrial septum, are sometimes difficult to visualize completely with 3D TEE, so that it is common to switch from live 3D imaging to the simultaneous display of two planes of 2D ultrasound imaging, which is also provided for in the iE33 Echo System. Images courtesy of Ernesto Salcedo, MD.

Figure 5. One of the more challenging investigative SHD interventions is the placement of a clip that fastens the mid-portion of the anterior and posterior leaflets of the mitral valve together, in order to reduce the severity of mitral regurgitation. The clinical trial is comparing this form of repair of the valve to traditional open surgical repair. 3D TEE, as shown here, is making a major difference in facilitating the procedure by simultaneously showing the entire guiding catheter, clip delivery system, along with the mitral valve and surrounding structures in 3D during manipulation of the equipment. This allows easier alignment with the mitral valve orifice, which is challenging in 2D slice images [13]. The insert image is the X-ray image showing a deployed clip and a second clip attached to the delivery system. The white arrows point to the delivery catheter in each image. Image courtesy of Robert Quaife, MD.
cardiac tissue and mitral valve are displayed as solid structures with no transparency thereby mimicking the process actually taking place inside the patient’s heart (Figure 5).

With these novel 3D imaging techniques comes the need to address several outstanding issues. First, the presentation and orientation of 3D image data that are most appropriate and useful to the interventionalist need to be determined. Second, there is the need to develop a means to interactively correlate the delivery catheter and device deployment controls to the 3D image being presented to the interventionalist. Many SHD delivery systems have controls that allow the system to change shape, turn and advance, but it is up to the interventionalist to register the results of these manipulations in the 3D space of the patients' hearts. While RT 3D imaging offers the interventionalist realistic visual images, improving the process of orienting and registering the interventional equipment to the presented image data remains unchartered terrain. Forging a marriage of imaging equipment and interventional devices, where precision and predictability are possible, and thereby moving beyond the practice of “turning the catheter and seeing where it goes” could further revolutionize 3D image guidance in SHD interventions.

Finally, the advances in 3D imaging and SHD interventions allow a more in-depth approach to anatomical characterization (Figure 6). New devices are also being designed in response to advances in the anatomical understanding of SHD targets [16].

Conclusions

SHD interventions are growing in number and form the third major arena of interventional cardiology after coronary and non-coronary vascular interventions. Imaging modalities, both primary and assisted, are evolving as rapidly as the interventions being performed. Whereas ICE has already significantly influenced the performance of simple SHD interventions, integration of novel 3D imaging modalities, such as CTA, MRA and RT 3D TEE is drastically impacting the efficient performance of complex SHD interventions. Several logistical challenges, including the need to optimize and standardize 3D views and registering device manipulation with presented image data, still require investigation. Solutions to these issues in the form of advanced image processing, anatomy-based comprehensive analysis, multidimensional fusion and integrated navigation systems could further revolutionize SHD interventions.
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Investigations and research

Cardiac resynchronization therapy: the role of equilibrium radionuclide angiography

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The clinical problem and CRT

Heart failure (HF) is the largest growing field in cardiology and the most frequent reason for hospitalization in the USA. Severe HF effects 5,000,000 patients, with 1,000,000 hospitalizations and 250,000 deaths yearly. In spite of advances in its pharmacotherapy, many patients have severe, refractory HF symptoms, and a poor prognosis [1].

Cardiac resynchronization therapy (CRT) is a relatively new, invasive, expensive but effective non-pharmacologic method which helps many with severe, medically refractory HF. CRT implants pacemaker leads in the right atrium, right ventricle (RV), and coronary sinus to innervate the left ventricle (LV), in order to minimize electrical disturbances that exacerbate HF, and achieve synchronous biventricular pacing.

Abnormal conduction, left ventricular dyssynchrony and heart failure

Abnormal electrical conduction, common in advanced HF, worsens cardiac function. One-third of patients with systolic heart failure have a QRS duration > 120 ms [2]. Intraventricular conduction abnormalities such as left bundle branch block (LBBB) delay regional wall motion, leading to dyssynchrony. Dyssynchrony is inefficient contraction, where contraction of the septum and lateral walls to circulate the blood are not synchronized. LV dyssynchrony is associated with increased HF mortality [3].

Cardiac resynchronization therapy (CRT) seeks to restore synchrony, coordinating contraction. It improves HF symptoms and overall clinical status, and reduces hospitalizations and mortality [4, 5]. CRT is the standard care for selected patients with moderate to severe HF. Yet, owing to broad CRT inclusion criteria and limited knowledge regarding its mechanism, 30% - 40% of CRT patients do not improve clinically, or worsen. Those improving do so unpredictably and variably. Also, CRT candidates represent only 30% of patients with refractory HF, excluding those with narrow QRS complexes [6] where 30% - 50% have dyssynchrony and could benefit from CRT [7, 8].

The Guidelines for the Diagnosis and Management of Chronic Heart Failure [9] present the inclusion criteria for CRT:

- severe HF symptoms
- sinus rhythm
- New York Heart Association (NYHA) Class III-IV symptoms despite optimal medical therapy
- LV ejection fraction (EF) ≤ 35%, with cardiac dyssynchrony defined as an electrocardiographic QRS duration > 120 ms.

The Guidelines exclude those with QRS ≤ 120 ms. Even among such selected patients, only 60% - 70% improve with CRT.

The needs

Measuring dyssynchrony

A wide QRS complex is a surrogate for mechanical dyssynchrony used to select CRT patients. Baseline QRS duration is a good marker of interventricular dyssynchrony, but left intraventricular dyssynchrony, which is a more accurate predictor of CRT response, does not correlate with baseline QRS duration [10]. Some patients with intractable HF and wide QRS have no left intraventricular dyssynchrony and may not respond to CRT, while others with a narrow QRS have left intraventricular dyssynchrony and would benefit from CRT but are excluded from the Guidelines [11]. There is a need for a reproducible measure of ventricular synchrony to guide patient selection and optimize CRT.

Pacemaker location

Pacing the LV from the “latest contracting segment” could improve the response to CRT.
There is no currently accepted method which directs the location of the lead, which is placed by rote in the lateral wall.

**The right ventricle**

Here, there are some unanswered questions. How does RV synchrony relate to the RV pacemaker site and to success in CRT? Do patients with RV failure have right ventricular dyssynchrony? Would they benefit from CRT? We are currently unable to evaluate RV synchrony.

**Imaging solutions**

**The current state**

There is no established method to measure regional or global synchrony. This relates in part to the challenging problem and, also, to the fact that until recently only echocardiographic applications have been explored.

**Echocardiography**

Echocardiography assesses LVEF in patients with advanced HF, assesses mechanical dyssynchrony, is applied to program optimal post-CRT atrioventricular and interventricular pacemaker timing, and is used to assess the long-term CRT effects on the LVEF and ventricular volumes [12].

Echocardiography is the most widely applied imaging modality for synchrony evaluation, using a variety of functional indices generated on M-mode, 2D and 3D [8] including strain rate imaging, tissue synchronization imaging and tissue Doppler, which is the most documented of methods. A variety of echocardiographic indices have demonstrated a relationship to CRT outcome [13], an ability to select patients benefiting from CRT, and aids to optimally localizing the pacemaker.

Yet, echocardiography is imperfect. Measurement of echocardiographic parameters are operator-dependent, sometimes have limited viewing and sampling windows, as well as sampling errors, and others are complex with prolonged acquisition and limited availability. In this application, some studies reveal a reduced reproducibility [14] of echocardiographic measures and an inconsistency between measurements and predicted CRT outcome [15, 16].

**Magnetic resonance imaging (MRI)**

Cine MRI is an excellent imaging modality for dyssynchrony. MRI tagging measures myocardial deformation during contraction and quantitates regional LV function. Comprehensive color-coded 3D strain maps can be constructed and displayed, and LV dyssynchrony can be calculated [17]. However, MRI is more expensive than echocardiography, with lower temporal resolution. Parameters related to wall motion and thickening are not well developed. Furthermore, MRI is contraindicated in patients with pacemakers and is not an option after CRT.

**Scintigraphic methods**

Scintigraphic methods present the optimal environment for digitization of physiologic data, with high reproducibility, and tomography. Recent work presents evidence of potential benefit when widely available scintigraphic methods, such as equilibrium radionuclide angiography (ERNA) and myocardial perfusion scintigraphy (MPS), are applied in unique ways to CRT evaluation.

**Myocardial perfusion scintigraphy (MPS)**

Gated SPECT myocardial perfusion scintigraphy (MPS) accurately measures LV wall thickening. It has been applied to measure ventricular synchrony with a correlation to CRT outcome [18]. This scintigraphic method compares well with echocardiographic synchrony indices [19] and can also evaluate viability. However, such scintigraphic data is generally undersampled and burdened with (unrecognized) noise related to underperfused segments [18, 19].

There is a need for a widely available, inexpensive, accurate, objective, reproducible way to measure the pattern and extent of ventricular synchrony and apply it in order to select CRT patients, and predict and optimize their outcome [20]. Such a method applied to the RV could be of great value in patients with conditions affecting the RV.

**Equilibrium radionuclide angiography (ERNA)**

**Overview**

Equilibrium radionuclide angiography (ERNA) provides widely available, objective, accurate, inexpensive, and reproducible biventricular function analysis, not contraindicated in pacemaker patients. The method is being developed in collaboration with Philips Healthcare as a tool for synchrony evaluation. The ERNA method presents a new basis for ventricular synchrony analysis and could help optimize CRT treatment.

ERNA relates intensity, or counts, to (ventricular) chamber volume, independent from volume measurements. Digitization can express
Phase image analysis

Phase image analysis is an ERNA-derived parametric imaging method, generated by the first Fourier harmonic, cosine curve, and fit of the blood pool time versus radioactivity curve. It presents a graphic representation of regional ventricular contraction which parallels regional excitation. This fitted curve is characterized by its amplitude, the curve magnitude, similar to the stroke volume of the raw curve, and phase angle, Ø, the timing of the curve within the cardiac cycle (Figure 1).

Ø relates to the sequence of regional contraction which is closely related to conduction [22, 23]. Earliest Ø relates to ventricular activation, mean Ø relates to the mean time of ventricular contraction, and the standard deviation (SD) of ventricular phase relates to the synchrony of contraction onset. Phase analysis, accurately and reproducibly evaluating the sequence and magnitude of regional wall motion, seems naturally adaptable to synchrony measurement.

ERNAs phase image analysis identifies and characterizes the pattern of regional and global ventricular contraction and synchrony [24]. We established a powerful phase image display and analysis method, supportive of objective quantitation, and have applied it to characterize contraction abnormalities [24-26] and a wide variety of conduction abnormalities including right and left bundle branch block (RBBB and LBBB) [27], left anterior hemiblock [28], pre-excitation with Wolff-Parkinson White Syndrome [29], augmented pre-excitation with pacing [30] and adenosine [31], the contraction/conduction pattern related to Mahaim fibers [32] and artificial pacemakers [24, 25].

We have displayed and characterized the effects of various pacing modes and the advantages of A-V synchrony [33] and we have developed a 3D SPECT reconstruction and display method to evaluate ventricular phase [34]. Fauchier [35] used the SD of RV and LVØ as the measure of synchrony to characterize the contraction patterns of myopathic ventricles, while Kerwin [36] applied it to assess the benefits of biventricular pacing.

New synchrony parameters

We developed two reproducible ERNA parameters to assess left intraventricular dyssynchrony: “synchrony”, S and “entropy”, E.

In preliminary studies S and E were compared with other methods, and showed the best correlation with clinical response in HF patients requiring CRT.

Definitions

“S” expresses the degree of synchrony when the region of interest, the ventricle, contains more than one Ø. A pixel’s amplitude and Ø define its vector, where a vector’s length is the amplitude written as |vi|, and:

$$S = \frac{\sum_{i=1}^{N} |v_i|}{\sum_{i=1}^{N} |v_i|}$$

S is the vector sum of all amplitudes based on the angular distribution of Ø, divided by the scalar sum of all vector lengths. S ranges from 0 (no synchronous contraction) to 1 (complete synchrony). Because S uses both phase and amplitude, it can be applied to the estimate of contraction potential if the region of interest were synchronized. If S is not 0, the potential functional gain is 1 - S.

Entropy, “E” – S may approach 0:

- if contraction is random
- if the region of interest consists of two sub-regions which are 180° out of synchrony.

Although ventricles present with a blend of these possibilities, their response to pacing may be very different. So we developed E:
where $M = \text{the number of phase angles}(\phi)$ in a region of interest and $p_i$ is the frequency of occurrence of $\phi_i$. $E$ measures the degree of randomness within the of region, ranging from 0 (complete order), to 1 (fully random, dyssynchronous contraction).

**Early work**

We performed a simulation study [37] measuring left ventricular $S$ and $E$ in normal planar ERNAs acquired clinically in the left anterior oblique projection. To analyze the response of $S$ and $E$ in ventricles with variable dyssynchrony, we applied these parameters to model regions of interest (ROI). An ROI over the LV evaluated parameters in the normal group (N). An ROI spanning the left atrioventricular boundary served as a model for an LV aneurysm (An), while a random background region served as a model for severe diffuse global dysfunction (Diff). An area of background, with approximately two-thirds over the LV, was a model of severe regional dysfunction (Reg). ROIs are shown in Figure 2, with related phase histograms in Figure 3. Figure 4 shows planar and SPECT amplitude and phase images in a normal patient.

The results are shown in Table 1. The mean phase angle, $\phi$, in the N group was similar to that previously reported, but was different from that in the other groups. The SD LV$\phi$ in the An, Diff and Reg groups were not different from each other. However, the $S$ and $E$ parameters were significantly different in all groups.

$S$ and $E$ calculated in ten varying ROIs of the same LV showed a variation of $\leq 0.02$. The new parameters were highly reproducible, well differentiated between patterns of systolic

$$E = \frac{M}{- \sum_{i=1}^{M} p_i \log_2(p_i)} - \log_2(M),$$

### Table 1. Comparison of left ventricular $S$ and $E$ in normal planar ERNAs and in ventricles with variable dyssynchrony.

<table>
<thead>
<tr>
<th></th>
<th>Mean LV$\phi$</th>
<th>SD LV$\phi$</th>
<th>LV $S$</th>
<th>LV $E$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normals $(n = 22)$</td>
<td>328.2° ± 19.3° *</td>
<td>12.2° ± 5.4° **</td>
<td>0.99 ± 0.01**</td>
<td>0.37 ± 0.08***</td>
</tr>
<tr>
<td>An $(n = 22)$</td>
<td>228.7° ± 21.1° *</td>
<td>92.1° ± 9.1°</td>
<td>0.41 ± .011 #</td>
<td>0.67 ± 0.07 ***</td>
</tr>
<tr>
<td>Diff Dysfunction $(n = 22)$</td>
<td>157.6° ± 28.0° *</td>
<td>95.1° ± 28.5°</td>
<td>0.24 ± 0.14 #</td>
<td>0.97 ± 0.02 ##</td>
</tr>
<tr>
<td>Reg Dysfunction $(n = 22)$</td>
<td>74.0° ± 19.3° *</td>
<td>97.6° ± 12.3°</td>
<td>0.70 ± 0.15</td>
<td>0.91 ± 0.03</td>
</tr>
</tbody>
</table>

* = all $p < 0.01$ vs each other; ** = $p < 0.01$ vs An, D and Diff; *** = $p < 0.01$ vs Diff and Diff; # = $p < 0.05$ vs each other and $p < 0.01$ vs Diff; ## = $p < 0.05$ vs Diff.

### Table 2. Post-CRT $S$ and $E$ compared with change in NYHA class

<table>
<thead>
<tr>
<th></th>
<th>Clinical Improvement in NYHA Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 $(n = 13)$</td>
</tr>
<tr>
<td>Change ± SD</td>
<td></td>
</tr>
<tr>
<td>Mean LV-RV$\phi$</td>
<td>18.2</td>
</tr>
<tr>
<td>LVEF</td>
<td>2.7 ± 4.5</td>
</tr>
<tr>
<td>SD$\phi$</td>
<td>7.7 ± 33.2</td>
</tr>
<tr>
<td>$S$</td>
<td>-0.06 ± 0.11</td>
</tr>
<tr>
<td>$E$</td>
<td>-0.05 ± 0.16</td>
</tr>
</tbody>
</table>

### Table 3. Pre-CRT $S$ and $E$ compared with change in NYHA class.

<table>
<thead>
<tr>
<th></th>
<th>Clinical Improvement in NYHA Class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 $(n = 13)$</td>
</tr>
<tr>
<td>Preoperative</td>
<td></td>
</tr>
<tr>
<td>LVEF</td>
<td>24.2 ± 8.1</td>
</tr>
<tr>
<td>SD$\phi$</td>
<td>51.4 ± 29.2</td>
</tr>
<tr>
<td>$S$</td>
<td>0.88 ± 0.10</td>
</tr>
<tr>
<td>$E$</td>
<td>0.62 ± 0.15</td>
</tr>
</tbody>
</table>
dysfunction. We have measured normal values for both RV and LV S and E.

S and E compared with clinical outcome
We studied 46 patients selected for CRT [38]. Seventy-two percent of the patients improved, but variably, after CRT. Patients were followed for more than six months and graded 2, 1 or 0 based on improvement in NYHA Class 2, 1 or 0 levels, respectively. Clinical change was correlated with LVEF changes, with the established measure of intraventricular synchrony, SD of LV Ø, the established measure of interventricular synchrony, mean LVØ - mean RVØ, S, and E after CRT. Table 2 shows the results.

Patients graded 2 showed large improvements in S and E, less in LVEF, and still less in SD LVØ. SD LVØ-SD RVØ correlated not at all. While change in LVEF and SD LVØ could separate patients who improved by two NYHA classes from those not improving, 0, these were not sensitive enough to differentiate moderate clinical improvement (1) from no improvement (0). A change in S was the only statistically significant parameter (p < 0.02) that differentiated patients in grade 1 from grade 0, while the intergroup differences in E approached significance. The study also suggested the lack of importance of measures of interventricular synchrony. Figure 5 shows serial images in a patient who improved by two NYHA classes.

S and E Pre-CRT
We sought to establish baseline cutoff values of S and E that predict a good CRT outcome [38]. LVEF, SD LVØ, and S and E calculated from pre-CRT ERNA, were compared with change in NYHA class, graded 2, 1, 0, as evaluated before and 6 months after CRT in the same group of 46 patients as described above. Table 3 shows the results. Baseline values of LVEF and SD LVØ could not differentiate clinical responders from non-responders.

When applied for patient selection, preoperative LVEF did not predict outcome. While overall 72% improved, a combined preoperative value of $S \leq 0.87$ and $E \geq 0.69$ predicted clinical improvement after CRT in 86% of patients. Patients with $S \leq 0.87$ and $E \geq 0.69$ showed a mean improvement of 1.48 NYHA Classes after CRT.

Figure 2. Regions of Interest (ROI) superimposed on the same phase image in a patient with normal systolic ventricular function. The examples show ROI applied for the calculation of mean Ø and SD Ø as well as S and E parameters in normal (N), LV aneurysm (An), diffuse global dysfunction (Diff), and severe regional dysfunction (Reg) groups.

Figure 3. Phase histograms extracted from the regions of interests shown in Figure 2 for the N, An, Diff, and Reg groups. The normal, bell-shaped distribution of Ø values near 0° is seen in relation to the N region of interest, with the typical biphasic distribution of Ø values in the An region of interest, a random Ø distribution in the Diff region of interest, and a combination of N and Diff patterns in the Reg histogram.

Figure 4. Pre- and post CRT images. Above: pre-CRT images; phase (left) and amplitude (right). Gross dyskinesis in the apical and septal regions of the phase image before CRT is evident in the yellow coloration in these ventricular regions (arrow), matching that of atrial phase. The amplitude image on the right is the first harmonic counterpart of regional stroke volume, showing large black regions of reduced emptying (arrow). Below: Phase (left) and amplitude (right) images in the same patient post-CRT. Dyskinesis in the apical and septal regions of the phase image before CRT is now replaced with synchronous inward systolic wall motion evident in the orange coloration in these ventricular regions (arrow). The amplitude image on the right now shows large regions of restored amplitude and emptying (arrow).

Figure 5. Planar (left) and SPECT (right) ERNA Phase Synchrony Display. The images on the left are planar ERNA phase images in a pre-CRT heart failure patient with severe dyssynchrony. At the top are the unthresholded phase image (left), and intensity thresholded for amplitude image (right). The image below is the phase histogram, plotting phase angle on the abscissa against the number of pixels with each phase angle on the ordinate. The earliest ventricular phase is shown in red, followed by orange, yellow green and finally blue, the atrial phase. The images on the right are SPECT images of the isolated left ventricle, acquired in the same patient with polar map (top left), SPECT phase image in the anterior view (top right) and the histogram (below).
CRT while patients with $S \geq$ and $E \leq 0.69$ did not improve, changing only 0.98 NYHA Classes.

Parameters of $S$ and $E$ can be used to determine patients with the best likelihood of significant improvement after CRT. An earlier study demonstrated the value of phase imaging for location of the latest contracting segment.

**ERNA phase imaging for guiding CRT pacemaker placement**

In HF patients requiring CRT, there is no reliable method for determining the optimal site to place the LV pacemaker, i.e. the coronary sinus lead. However, ERNA provides an assessment of LV function and the location of dyssynchrony.

To determine the value of ERNA phase imaging for identifying the latest contracting LV segment as a guide to placement of the LV pacemaker lead, we compared the clinical outcome after CRT in 28 patients with NYHA Class III and IV HF who had been referred for CRT device implantation. All patients had given informed consent. The patients were divided into two groups. In one group of 16 patients, coronary sinus lead placement was based on the ERNA determination of the latest contracting segment. In the other group of 12 patients, the pacemaker was placed in the conventional lateral wall location [39].

We found that 6/12, i.e. 50%, of patients who underwent traditional coronary sinus lead placement showed improvement in NYHA class, while 14/16, i.e. 88%, of patients who had ERNA-guided lead placement had an improvement in NYHA class. More patients in the ERNA-guided group, whether the latest contracting segment was found to be in the lateral wall or elsewhere, showed clinical improvement, compared with the traditional placement group ($p = 0.02$ by Chi square analysis). In one patient in the ERNA-guided group who showed no clinical benefit from CRT, a PET scan demonstrated scar at the pacemaker lead site. This probably explains why this patient did not benefit. In this group too, the change in $S$ also significantly predicted the clinical response to CRT.

However, although promising, this was not a randomized study and used planar data to localize the latest contracting segment.

**RV synchrony**

Normal values were established for SD RVØ, $S$ and $E$. Over one-third of patients demonstrated abnormal RV $S$ and $E$ prior to CRT [40]. However, unlike LV parameters of synchrony, the pre-CRT RV parameters of synchrony could not predict outcome post-CRT, nor did the serial change in RV synchrony correlate with clinical improvement [41].

**Short QRS**

SD LV Ø, LV $S$ and $E$ were significantly worse in 12 patients with advanced HF and LVEF < 35% than in 11 patients without HF, all with a narrow QRS [42]. Further, 25% of these HF patients with a narrow QRS had synchrony parameters in the range previously shown to provide a high likelihood of significant clinical improvement post-CRT [38]. ERNA with synchrony analysis can potentially identify those HF patients with a narrow QRS complex who might benefit from CRT.

**SPECT**

We have adapted synchrony analysis to SPECT ERNA images. The method separates ventricles from atria and from each other, purely assessing biventricular synchrony in a polar display. In 16 of 17 cases imaged by both planar and SPECT ERNA, SPECT $S$ was lower and SPECT $E$ higher than planar values, $p < 0.05$ [43]. In 11 of 17 cases the contraction sequence appeared similar in SPECT and planar synchrony analysis. Six cases had an apical aneurysm which obscured planar basal segments where $S$ was 10% greater than SPECT $S$. SPECT ERNA promises to provide a global synchrony assessment.

**Conclusion**

The ERNA method described above presents a new basis for ventricular synchrony analysis and could help optimize CRT and its cost-effectiveness. The phase synchrony parameters described already show promise for optimizing CRT patient selection, helping to determine the benefit of the CRT intervention, guiding pacemaker placement among those with standard selection criteria, and identifying new categories of patients who may benefit from CRT. Further adaptation of the method to SPECT technology and its integration with the findings of other imaging studies, as well as those for assessing regional viability, will refine these methods, expand their capabilities, and could well establish them clinically.
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Clinical applications

Integration of CT and fluoroscopy images in the ablative treatment of atrial fibrillation

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Radiofrequency pulmonary vein (PV) ablation has proved to be an effective treatment of paroxysmal and persistent atrial fibrillation [1-4]. Because of the complexity of the atrial-PV anatomy, imaging of the left atrium and pulmonary veins plays an important role in ensuring the successful outcome of the procedure. Additionally, the need to create ablation lines in three dimensions around the ostia of the pulmonary veins makes it important for imaging of this area to be integrated in the ablation procedure itself, rather than being a peripheral aid. Fluoroscopy alone shows no contrast differentiation between the pulmonary veins and the surrounding structures.

In this article we report on our experience over slightly more than a year with a CT/fluoroscopy integration system (Philips EP Navigator).

EP Navigator

EP Navigator provides an automatically segmented 3D CT image of the heart for navigation in electrophysiology procedures. The 3D CT images can be combined with live fluoro data from a Philips Allura Xper cath lab system. The user selects the 3D anatomy (e.g., left atrium and pulmonary veins) to be combined with the live fluoroscopic images.

Heart segmentation

Usually, the day before the procedure, all patients undergo a contrast-enhanced 64-slice CT scan of the chest. Automatic segmentation of the heart is done by matching a generic heart model to the CT images. This model has been described in detail by Ecabert et al. [5]. In brief, it is a surface model comprising the endocardial surfaces of the four chambers, the left ventricular epicardium, the pulmonary artery trunk, the aorta, the inferior and superior vena cava, the coronary sinus and four pulmonary veins (Figure 1).

The geometry of the model is described by 8,506 surface points defining 17,324 triangles. Information on the appearance of the cardiac structures in CT images is attached to each triangle in order to support the matching process. The model is matched to the CT images in five steps. First, the heart chambers (including the left ventricular epicardium) are detected in the image with a generalized Hough transformation and placed accordingly. Secondly, the location, orientation and scaling of the heart chambers are adjusted and, thirdly, the individual sizes of the chambers are optimized. The four chambers are then deformed to accurately represent the patient’s anatomy in the CT image.

In addition to this matching process, segments of the vascular structures are subsequently added and adopted, until each structure in the heart

Important note:
This article describes a study conducted outside the United States of America. At the time of publication, the U.S. Food and Drug Administration has not cleared RF ablation for the treatment of atrial fibrillation.
model is matched to the corresponding structure in the CT image.

**CT/fluoroscopy alignment**

During the procedure, a 6 F 10-pole catheter (Supra-CS, Bard Electrophysiology, Lowell, USA) is placed in the coronary sinus and a 4-pole catheter is positioned at the apex of the right ventricle. After two transseptal punctures, a circular 10-pole catheter (Lasso, Biosense Webster) is placed in the left superior pulmonary vein, close to the ostium. A pigtail catheter is introduced into the left atrium, and a contrast-enhanced rotational angiography run is performed (RAO 50° to LAO 50°).

In order to achieve good filling of the left atrium and pulmonary veins with contrast agent, a short asystole (about 6 seconds) is induced by administering a bolus of 30 mg adenosine intravenously shortly before the rotational angiography (Figure 2). Alternatively, rapid ventricular pacing (200 bpm) may be used to decrease output from the left atrium to the left ventricle.

The left atrium and pulmonary veins are reconstructed from the axial slices and segmented using the image processing workstation of EP Navigator (see above: Heart segmentation).

In the next step the CT scans of the left atrium are imported into the Allura Xper system and manually aligned with the X-ray imaging projections. In order to achieve reliable alignment, three fluoroscopy projections are used: right anterior oblique 40°, anterior-posterior, and left anterior oblique 40°. In each projection, the EP Navigator enables visual adjustment of the CT image of left atrium to match the fluoroscopic image. In the CT image, the markers used for alignment are the coronary sinus and right superior pulmonary vein. In fluoroscopy, the markers are the coronary sinus catheter and a circular diagnostic catheter (Lasso) placed in the right superior pulmonary vein (Figure 3).

The present version of EP Navigator does not allow for automatic fusion of the CT image and the contour of the left atrium/PVs in rotational angiography. Nevertheless, the anatomical information gained from the angiography is of

**Figure 2.** Left anterior oblique 30° projection of a rotational angiogram of the left atrium during adenosine-induced asystole. Complete filling with contrast agent provides excellent visualization of the left atrium and pulmonary veins. The image also shows a 10-pole coronary sinus electrode and a 4-pole right ventricular electrode.

**Figure 3.** During alignment of the CT image of the left atrium with fluoroscopy the coronary sinus catheter and a circular mapping catheter (Lasso) placed in the right superior pulmonary vein are used as landmarks. The tip of the ablation catheter is placed at the superior segment of the ostium of the left superior pulmonary vein.
Electrical isolation of the pulmonary veins

During the last year, 70 patients have been treated in our center by pulmonary vein isolation using the EP Navigator. In the first 50 patients we used the “double-Lasso” approach during which two Lasso catheters are placed in the right superior and inferior pulmonary veins. With the Lasso catheters in place, radiofrequency ablation is started at the superior segment of the right superior PV (about 5 - 10 mm outside the ostium) and is advanced inferiorly in order to create a ring-like ablation line that includes both PV ostia.

After electrical isolation of the right PVs (Figure 4) there is a waiting time of 30 minutes. During this time, reconduction of the PV occurs in about 30% of the patients. If this is the case the “gap” in the ablation line is again targeted with RF energy to achieve re-isolation.

The same procedure is then followed for the left PVs, with special attention being paid to the anterior ridge of the left superior PV immediately adjacent to the left atrial appendage. The end point of the procedure is the complete electrical isolation of all pulmonary veins.

In the second group of 20 patients, in order to reduce the length of the procedure, we used a single Lasso catheter placed sequentially in all four pulmonary veins. If the patient was in atrial fibrillation at the end of the procedure, electrical cardioversion to sinus rhythm was performed.

For ablation of the right superior PV (RSPV) we usually use a projection in fluoroscopy and the EP Navigator that clearly shows the transition of the PV ostium to the PV antrum. In the majority of the patients this is RAO between 30° and 10° (Figure 5). In this projection, the EP Navigator enables accurate positioning of the ablation catheter at the antral site of the PV ostium, thus avoiding RF application within the PV.

Turning the ablation catheter clockwise or counter-clockwise allows the anterior and posterior segments of the PV ostium to be reached, respectively. The anterior or posterior position is verified in the EP Navigator in the left anterior oblique (LAO) projection (usually about 40° - 50°). For ablation at the ostium of the right inferior PV (RIPV), the EP Navigator is rotated to the LAO 40° - 50° projection.
If necessary, the distance of the tip of the ablation catheter from the RIPV ostium is reassessed in an RAO projection (usually RAO 50° - 30°). During ablation, special attention is paid to the inspiration-dependent inferior displacement of the RIPV. This can be up to 18 mm [6]. The present version of EP Navigator does not align the CT image of the left atrium/PV to the respiration-dependent movements of these structures.

RF ablation of the left superior PV (LSPV) is performed in the LAO 40° - 50° projection in the posterior ostial segments and in the RAO 40° - 30° in the anterior segments. In the EP Navigator this projection enables a clear identification of the ridge between the RSPV and the left atrial appendage (Figure 6).

Application of RF energy proximal to the ostium of the left inferior PV (LIPV) is performed in the LAO 40° - 50° projection. Turning the ablation catheter clockwise or counter-clockwise moves its tip to the posterior or anterior segments of the ostium.

In the majority of the patients we do not perform additional ablation lines after isolation of the pulmonary veins. If this is considered to be necessary we perform two additional lines: a roof line (Figure 7) and an ablation line at the mitral isthmus (between the left inferior PV and mitral annulus) under guidance of the EP Navigator.

Limitations

Because of the lack of clear anatomic points for the fusion of fluoroscopy and computer tomographic images of the left atrium, the fusion process is performed using the fluoroscopic position of catheters placed in anatomic structures such as the coronary sinus and left superior PV, while the same structures are seen in CT. This imposes a significant limitation on the alignment process, as it does not rely on real anatomical reference marks.
Fine adjustment of alignment is done by using the anatomical information derived from rotational angiography. In the EP Navigator rotational angiography cannot be directly used as a template for adjusting the CT image of the left atrium.

Another limitation is that the present version of EP Navigator does not allow marking of the ablation points. For that reason the use of other mapping and annotation systems (like CARTO in our EP laboratory) is still mandatory.

**Future developments**

In order to enhance accuracy, future versions of EP Navigator should be able to trigger CT/fluoroscopy alignment from the respiratory movements of the patient. Additionally, the software should allow positional corrections in the event of involuntary patient movements. Automatic fusion based on the anatomical information from rotational angiography of the left atrium would markedly increase accuracy and probably decrease the time needed to perform the alignment. Finally, marking of the ablation points would enable the operator to track the ablation lines as they are created.

**Conclusion**

EP Navigator is very helpful in demonstrating all relevant structures during interventional treatment of atrial fibrillation. The ability to match the 3D CT image to the different fluoroscopic projections enables accurate positioning of the ablation catheter and helps to ensure safe ablation around the ostia of the pulmonary veins.

**References**


Cardiac Magnetic Resonance Imaging (MRI) has undergone a tremendous development over the last decade. It now offers a complete set of methods to investigate function and viability of the heart in a clinical setting. A number of Class I indications have already been established, including the detection of acute and chronic infarction and myocardial scar [1]. Recent multi-center data [2] and continuing advances in technology promise indication of MRI perfusion imaging as a first line tool for diagnosing myocardial ischemia in the near future.

Technological advances in MRI include methods to relax the interdependence between spatiotemporal resolution and imaging time. This aspect is of particular relevance to cardiac applications since both cardiac motion and clinically acceptable breathhold durations conventionally limit the achievable spatial resolution.

From a technical point of view, two different approaches for accelerating cardiac MRI sequences can be discerned. Parallel imaging, available as SENSE [3, 4] on Philips platforms, permits significant increases in spatiotemporal resolution at a given scan time by exploiting the spatial encoding capabilities of multi-element coil arrays. These Synergy coil arrays are standard add-ons for the Philips Achieva line of MR systems, featuring up to 32 independent elements with the latest equipment.

In 2D cardiac imaging protocols, SENSE reduction factors of up to three are routinely used. Beyond reduction factors of three to four, however, noise amplification in the images becomes noticeable. To overcome the limited gains in scan efficiency, in particular with 2D cardiac imaging, prior-knowledge driven methods have been developed. These techniques make use of information redundancy present in dynamic image series. Conceptually this can be understood by considering that different parts of the image exhibit different dynamics. For example, the chest wall signal remains constant over time while the portion of the image capturing the heart changes rapidly. By exploiting the differences in dynamics, specifically the fact that large fractions of the field-of-view remain static or change only very slowly over time, scan efficiencies can be significantly increased.

Among the prior-knowledge driven methods, \textit{k-t} BLAST and \textit{k-t} SENSE [5] have received considerable attention as they have enabled imaging of cardiac function [6] and perfusion [7] with spatiotemporal resolutions which have hitherto been impossible.

In first-pass myocardial perfusion imaging, high spatiotemporal resolution is of great importance. Sufficient temporal sampling is required to resolve the passage of the contrast agent. At the same time cardiac motion limits the available window for acquiring data to around 100 msec, particularly during pharmacologically induced stress. Given the time for magnetization preparation, a maximum of three slices at moderate spatial resolution of 2.5 - 3 mm can therefore be acquired with conventional techniques. At this spatial resolution, however, the transmural extent of ischemia can be difficult to resolve fully. In addition image artifacts due to cancellation of signal in voxels partially occupied by the paramagnetic contrast agent can compromise the visualization of non-ischemic areas, leading to so-called endocardial dark rim artifacts.

In order to relax the competing constraints in perfusion imaging, \textit{k-t} BLAST and \textit{k-t} SENSE have been successfully adapted to provide images at spatial resolutions approaching 1 mm in a clinical setting.

**Principle of \textit{k-t} BLAST and \textit{k-t} SENSE imaging**

In \textit{k-t} BLAST and \textit{k-t} SENSE, scans are accelerated by skipping data points along the spatial encoding and time axes in a regular fashion, thereby forming a sampling lattice as
shown in Figure 1. Straightforward image reconstructions from these undersampled data results in multiple aliases of the original object, rendering the images unusable.

In order to resolve the aliased signals resulting from undersampling, a statistical model is formed based on “training data”. Under the assumption that neighboring image points and time frames are correlated to a certain degree, the training data allow the object to be recovered at high resolution without any aliasing artifacts (Figure 2). While data acquisition in k-t BLAST and k-t SENSE is identical, there are differences between the two implementations in the image reconstruction of the multi-coil data. While in k-t BLAST data from each element of a coil array are reconstructed separately, with subsequent combination, k-t SENSE allows additional advantage to be taken of the spatial encoding capabilities of coil arrays, similar to that in conventional SENSE imaging. The advantage of k-t SENSE over k-t BLAST, however, only becomes significant when using large coil arrays such as the 32-element Cardiac Synergy coil.

Typical reduction factors achievable with k-t BLAST and k-t SENSE range from five- up to eight-fold accelerations in cardiac applications. However, acceleration factors up to 12-fold have been achieved using the 32-element cardiac Synergy array. Comparison of the image quality of standard SENSE and k-t SENSE using 12-fold undersampled data shows clear improvements over SENSE (Figure 3).

Continuous efforts in research aim at exploring the limits of prior-knowledge driven methods such as k-t BLAST and k-t SENSE. A particular focus is to investigate the accuracy of temporal depiction of small image details which tend to get compromised at very high acceleration factors.
It is the aim of ongoing studies to define maximum acceleration factors for different cardiac applications.

**Perfusion imaging with k-t BLAST and k-t SENSE**

In perfusion imaging, the original implementation of k-t BLAST and k-t SENSE with separate scan stages for the undersampled and training data is modified to enable interleaved acquisition of the training data. This is necessary for contrast-enhanced applications, given the non-periodicity of the signal dynamics. Accordingly, the sampling pattern is designed such that both the undersampled and the training data can be derived from a single scan (Figure 4).

Perfusion imaging protocols were implemented for both 1.5 T and 3.0 T Philips Achieva systems using the following settings:

- Saturation-recovery TFE with shortest repetition and echo times, flip angle 15°.
- Water-fat shift: 0.3 pixel (1.5 T), 0.6 pixel (3.0 T).
- 5x k-t BLAST or 5x k-t SENSE with 11 interleaved training profiles and training data plug-in.
- Spatial resolution: 1.1 - 1.3 mm, slice thickness: 10 mm.
- Injection of 0.1 mmol/kg Gadobutrolum (Gadovist, Schering, Berlin, Germany).
- Data acquisition during an inspiration breathhold.
- 5-element cardiac Synergy coil (1.5T); 6-element cardiac Synergy coil (3.0 T).

An exemplary data set from a study involving more than 50 patients is shown in Figure 5. The high spatial resolution permits excellent visualization of the ischemic territories both transmurally and circumferentially.

Relative to previous protocols using two-fold SENSE with a spatial resolution of 2.5 mm, image quality with five-fold k-t SENSE at a spatial resolution of 1.3 mm was consistently better, despite the higher resolution (Figure 6). The transmural extent of ischemia was clearly delineated. Endocardial dark rim artifacts were considerably reduced in size, in parallel with the voxel size.

**Outlook and conclusion**

With current implementations of k-t BLAST and k-t SENSE, scan accelerations of up to five-fold are achievable. Work-in-progress addresses image artifacts seen with scan accelerations beyond five-fold. Several directions are being explored in order to enable up to ten-fold k-t SENSE perfusion imaging. At
ten-fold acceleration, full coverage of the heart using 3D imaging at high spatial resolution becomes feasible.

Preliminary data from 3D perfusion imaging indicate the potential of volumetric perfusion approaches. Current implementations of k-t BLAST and k-t SENSE are sensitive to respiratory motion during data acquisition. Ongoing efforts are directed at reducing these breathing artifacts, in particular in stress perfusion acquisitions.

With the availability of k-t BLAST as a product option on Philips Achieva systems, MR perfusion imaging has become highly attractive, providing high-resolution information on the presence and extent of myocardial ischemia. Together with cine and late-gadolinium enhancement, MRI today provides the most sensitive imaging tool for a comprehensive non-invasive work-up of patients with ischemic heart disease.

References

Clinical research has clearly indicated the power of cardiac magnetic resonance (CMR) imaging for the diagnosis, treatment and monitoring of cardiac disease [1]. It has been shown that CMR imaging allows the inspection of a plurality of aspects, amongst which the anatomy of the heart and surrounding blood vessels, myocardial (heart muscle) contraction and resulting ventricular pump function, myocardial perfusion and viability, and ventricular and vascular blood flow. A brief description of CMR imaging is given below in the section on the State of the Art.

CMR imaging research has focused on applications for patients with coronary-artery-stenosis induced ischemia and infarction [2, 3]. However, research on imaging of other cardiac diseases is also ongoing. Thanks to its lack of ionizing radiation, CMR imaging is a preferred modality for congenital heart disease patients, who are often imaged many times during their life [4]. CMR imaging is also under investigation for electrophysiological disorders such as atrial fibrillation and ventricular tachycardia [5].

All major medical imaging equipment manufacturers and several software companies offer software for the quantitative analysis of CMR images. The quantitative information that can be derived ranges from global parameters such as ejection fraction to detailed local myocardial wall thickening. Philips offers the ViewForum MR Cardiac package, with which myocardial function, perfusion and viability, as well as ventricular and vascular blood flow, can be visualized, quantified and reported [6].

After years of intensive research, CMR imaging is now on the eve of being accepted and used more frequently in daily clinical routine. The Current Procedural Terminology (CPT®) Editorial Panel of the American Medical Association has recently issued eight new codes for the reimbursement of CMR imaging [7]. Although this may stimulate a broader application, the use of CMR in daily clinical routine is still hampered by the lack of well-trained personnel and the limited efficiency and ease-of-use of the imaging equipment and image analysis software [8]. Basically, one could say that CMR-based cardiac care is already effective, but its ease-of-use still needs to be improved significantly.

This article focuses on quantitative analysis, especially for the diagnosis of coronary artery disease. The section on Task Guidance below explains how the ease-of-use could be enhanced, and consequently the amount of training reduced, by introducing dedicated task guidance.

The section on Automation argues that the efficiency and reproducibility could be significantly improved by performing as much of the analysis as possible automatically, using dedicated image-processing techniques. The section on Comprehensive Visualization explains that the comprehensive representation of the many quantitative results in a single 3D visualization will significantly simplify the interpretation of the results. We also offer a section on Reporting which focuses on the reporting of analysis results, and a section on Future R&D that presents our vision of the future research that is considered to be essential for achieving broader acceptance of CMR in routine clinical practice.

State of the art

For patients with suspected coronary artery disease, a CMR examination typically consists of multiple image acquisitions (series or scans) serving different purposes [9]: functional CMR scans to assess the myocardial pump function, perfusion CMR scans to localize reduced blood supply to the myocardium, and viability CMR scans to localize infarcted myocardial tissue.
A growing number of whole-heart scans are also being made, in order to inspect the anatomy and function of the ventricles and especially of the coronary arteries (Figure 1).

**Functional CMR scans**

For functional CMR scans, “cine protocols” are used to acquire movies of the beating heart. These movies consist of 25 - 50 phases and can be obtained in different slice orientations. Typical slice orientations are short-axis (SA, 3-15 slices), 2-chamber long-axis (LA 2CH, 1 slice), 3-chamber long-axis (LA 3CH, 1 slice) and 4-chamber long-axis (LA 4CH, 1 slice).

Functional CMR images are used for the quantification of global volumetric properties (stroke volume, ejection fraction, cardiac output, etc.) and local myocardial wall properties (wall thickness, wall thickening, wall motion, etc.).

In Dobutamine Stress Magnetic Resonance (DSMR) examinations, functional CMR scans are made at increasing levels of pharmacologically induced stress. These examinations are used to detect stress-induced wall motion abnormalities, which are an indication of ischemia and may predict the presence of coronary artery stenoses [10].

**Perfusion CMR scans**

Perfusion CMR scans are usually obtained in only three short-axis view slices. The myocardium of the left ventricle is imaged during the first passage of a Gadolinium-based contrast agent. The use of ECG triggering “freezes” the motion of the beating heart, making it possible to recognize and quantify regional differences in contrast agent uptake, which are shown as changes in the image intensity [2].

**Viability CMR scans**

Viability CMR scans are made 15-20 minutes after the Gadolinium contrast injection. It has been found that the percentage of remaining contrast agent is higher in infarcted regions [11]. Quantitative assessment of myocardial viability involves measurements of infarct size/volume, infarct transmurality and of the remaining healthy tissue.

**Whole-heart CMR scans**

Whole-heart CMR scans typically contain 150 - 200 transverse slices covering the complete heart and the coronary arteries [12]. They are primarily used to relate the coronary-artery anatomy to diseased myocardial regions.

**Task guidance**

Current users of the CMR analysis applications are cardiologists, radiologists and technicians working mainly in academic hospitals. In this environment, the application is often being used to support research into new procedures and techniques. Consequently, until recently, the principal challenge has been to provide leading edge algorithms and functionality.

However, there is now a clearly discernible trend towards more routine use of CMR imaging and analysis. This means that CMR will become more common in community hospitals where throughput has high priority. The time needed from request to report has to be as short as possible without compromising the quality of the analysis results. In this environment, there will be many more users. Also, technicians may rotate jobs more, and the time available to be trained or read user documentation might be less. New and returning users need to be able to get “up and running” as soon as possible.

To allow application in clinical routine, CMR analysis has to become much simpler. To address this problem, we set up a team comprising representatives from industry and healthcare professionals. Our team adopted two main lines of approach. Firstly, we minimized the amount of interaction needed, through judicious use of automation. This is described below in the section on Automation. Secondly, we designed a user interface that better reflects the users’ way of working. This involved restructuring the global user interface and introducing task guidance. Globally, the user interface is now more accessible to technicians and cardiologists. To allow application in clinical routine, CMR analysis has to become much simpler.
structured around distinct activities which the users will recognize in their routine working procedure:
• CMR examination selection (from a work list)
• preparation
• viewing
• analysis
• reporting.

Preparation
During preparation the user selects the image series to be viewed and/or analyzed and, if the series could not be automatically characterized, adds labels to the series that describe the type of acquisition (function, perfusion, viability, etc.), the scan orientation (short-axis, long-axis, etc.) and the stress level. By spending a small amount of time preparing the examination in this way, much more time is saved later on during the core activities of viewing, analysis and reporting.

Viewing
During viewing the user inspects the images using powerful preset viewing protocols and an appropriate set of image viewing tools. Smart linking of e.g. image contrast/brightness, image locations and cine movie speed is part of the viewing protocols. During viewing, the user already has the possibility to type in observations which will later on appear in the report.

Analysis
After viewing, different types of analysis can be performed. For example, a user may choose to do a functional analysis followed by a viability analysis. In our approach both these analyses can be open at the same time, enabling the user to navigate between them with a single click. This will simplify the interpretation of the analysis results.

Reporting
Finally, during reporting the user can manage the observations and/or quantitative results that were generated during viewing and analysis and can summarize them into a report.

The user interface
In the user interface, the activities are represented by a horizontal line of buttons across the top of the application (Figure 2a) similar to the main navigation bar on many web pages. Within each of the activities a list of tasks can be executed. In software engineering terms, these can be seen as use-cases [13]. For each task, the user is guided by a vertical task panel on the left-hand side of the user interface. Each task is related to a specific goal, for example “segment the left ventricle”.

Figure 2. The user interface.

Figure 2a. Overall structure of the user interface. This example shows left ventricle segmentation in short-axis functional analysis.

Figure 2b. Task guidance for LV segmentation in short-axis functional analysis.
A task consists of one or more task steps and the buttons within each of the task steps are the individual functions that need to be used. The task panel only shows the functions directly related to the selected task.

Figure 2b shows a zoomed version of the task guidance for short-axis analysis functional analysis. The Figure shows the task steps and functions that have to be performed for segmenting the left ventricle. The list of tasks comprises:

• segmentation of the left ventricle
• segmentation of the right ventricle
• display of the quantitative analysis results.

Automation

The need for automatic segmentation

Diagnosis based on quantitative analysis results may involve the delineation of up to 3,500 myocardial contours. Manual delineation is too cumbersome and time consuming for daily clinical routine. Moreover, the myocardial contours in one image type, e.g. functional CMR, indicate the same anatomical structures, e.g. the left ventricle, as in the other image types (perfusion, viability). Repeated delineation of the contours in the different image types therefore seems to be a waste of effort.

In daily clinical practice, fast automatic contour delineation is therefore a prerequisite. In this section we briefly introduce four new algorithms for automatic segmentation of the myocardium:

• functional CMR segmentation
• DSMR segmentation
• viability CMR segmentation
• whole-heart and coronary-artery segmentation.

Functional CMR segmentation

Due to its multi-slice and multi-phase nature, an SA functional analysis can easily require the delineation of up to 1,500 contours. Consequently, the most significant efficiency improvement can be obtained by automating this delineation task.

Our new SA functional segmentation method consists of two steps. First, the myocardial end- and epicontour are automatically detected for the end-diastolic (ED) phase, using the new algorithm described below. Then, these contours are automatically propagated to the other phases in the cardiac cycle, using the propagation method described by Hautvast et al. [14].

The new automatic ED contour detection algorithm first roughly localizes the LV in a two-step approach. First, a region of interest is determined based on the local image intensity variation over time. Then, a ring detection algorithm capable of detecting the dark myocardium localizes the LV within that region. The detected ring is used to initialize a geometric template that models the myocardium as a closed ribbon structure, composed of an imaginary centerline and a variable width. This model is adapted to the image in a coarse-to-fine approach, until the final delineation is obtained (Figure 3).

In a validation study on 119 clinical SA cine CMR data sets, the LV endo- and epicardial contours were positioned with Root Mean Square (RMS) errors of 1.51 ± 0.77 mm, and 1.79 ± 0.88 mm, respectively [15].

In the same study it was found that propagation of the automatically detected ED contours results in end-systolic (ES) contours that are as accurate as the ES contours that resulted from the propagation of manually delineated ED contours. More importantly, on a subset of 10 data sets, it was found that users need significantly less time to verify and correct fully automatically detected end-diastolic contours (28.7 ± 23.8s slice) than they need for drawing these contours (44.5 ± 31.7s per slice).

DSMR Segmentation

It might be assumed that the contours on all images of all stress levels in a DSMR examination could be easily obtained by re-using the SA functional CMR contour detection algorithm described earlier. This algorithm has, however, been optimized for functional images at rest. It does not perform well enough at the higher stress levels due to the large variations in LV shape and contraction present at these levels. As a result, the time required to manually correct propagated contours and the size of corrections increase with increasing stress level (Figure 4a). Furthermore, the accuracy of the automatic ED contour
detection algorithm decreases with increasing stress level.

For the segmentation of DSMR images, we have developed a dedicated algorithm that is capable of propagating automatically generated contours from one stress level to another. The algorithm consists of a combination of image registration, contour propagation and contour averaging techniques [16]. As a result, the user no longer needs to correct the same delineation error at each stress level. Moreover, the size of corrections no longer increases with the stress level. This saves a substantial amount of time (Figure 4b).

Viability CMR segmentation
The viability imaging protocol is optimized to maximize contrast between healthy and infarcted myocardial tissue. The contrast between infarcted tissue and the left-ventricular blood pool is however often very limited or even totally absent. This makes automatic segmentation of LV myocardial contours in viability images a particularly difficult task.

We have developed a method that uses the LV contours detected in the functional CMR images as a shape prior to viability segmentation. These contours are used to construct a 3D mesh representing the LV. The segmentation algorithm starts by roughly localizing the LV in all viability images using a ring detector. The detected rings are then aligned with the 3D LV mesh and the SA viability contours are obtained by an affine transformation of this 3D mesh (Figure 5). The resulting contours are positioned with RMS positioning errors of $2.0 \pm 0.4$ mm and $1.9 \pm 0.7$ mm, for the LV endocardium and epicardium, respectively [17].

Whole-heart and coronary-artery CMR segmentation
Very recently, a model-based method has been developed for the fully automatic segmentation of all heart chambers and part of the great vessels around the heart [18]. Techniques are also available for the semi-automatic tracking of the coronary arteries in these image data [19]. Figure 6 shows an example of a resulting segmentation.
Overall segmentation performance
Table 1 shows a comparison between the time needed for fully manual segmentation and the time that can currently be obtained with dedicated segmentation algorithms (not including whole-heart and coronary-artery segmentation).

Comprehensive visualization
A widely accepted method of visualizing left-ventricular quantitative analysis results is the “bull’s eye” plot. In this plot, the myocardium is mapped onto a set of concentric rings, where each ring corresponds to one slice of the original image data (Figure 7a). A collection of these bull’s eye plots is used to represent different analysis results, e.g. for myocardial wall thickening, perfusion and viability (Figure 7b). The combined visual interpretation of these plots is left to the clinical user.

A bull’s eye plot does not contain any information about the patient-specific ventricular anatomy. Consequently, it does not show the relation between the left ventricle and other important anatomical structures such as the coronary arteries, the right ventricle and the aorta.

<table>
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<th>Images</th>
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<th>Automated (min)</th>
</tr>
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<tr>
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<td>1540</td>
<td>3346</td>
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</table>

Table 1. Time required to delineate a CMR exam manually and with automation.

Figure 5. The viability CMR segmentation scheme.

Figure 6. Whole-heart and coronary artery segmentation.
However, particularly in the case of myocardial ischemia and infarction, it is of the utmost clinical importance to visualize the anatomical relationship between the myocardium and the coronary arteries.

The American Heart Association (AHA) has proposed a standard left-ventricular bull’s eye representation containing 17 segments and has indicated the “standard” relation between these segments and their supplying coronary arteries (Figure 8) [20]. The AHA diagram is a useful guide, but there is a large variation in coronary anatomy. Consequently, the relationships proposed by the AHA are only valid for “standard” patients, so that it is not always possible to uniquely assign a segment to a specific vessel [21].

In order to accurately assess which coronary artery is responsible for the ischemia or infarction, the anatomy of the left-ventricular myocardium and that of the coronary arteries have to be jointly visualized. Moreover, this visualization should also clearly show the regions with reduced myocardial contraction, perfusion and/or viability. In other words, the visualization should be comprehensive, containing all patient-specific anatomical and quantitative information that is relevant for the clinical task at hand.

Figure 9a shows an example of a comprehensive 3D visualization of an automatically segmented whole-heart and coronary anatomy, together with the infarcted regions [22]. The left-ventricular outer surface has been transparently visualized using the surface rendering technique. The inner surface and the surfaces of all other heart components have been visualized in different colors with non-transparent surface rendering.

The infarcted tissue that was semi-automatically segmented from CMR viability images and was registered with the whole-heart CMR image data is represented in yellow using the volume rendering technique. A projection is also made of the 3D ventricle and the coronary arteries on a plane below the ventricle. This projection is in fact a “continuous” bull’s eye plot (i.e. without rings) containing a projected overlay of the coronary arteries.

The visualization in Figure 9a comprehensively shows the relationships between the infarcted myocardial regions and the supplying coronary arteries (arrows). The computer display gives the user the possibility to flexibly rotate, zoom and/or pan the whole-heart visualization and merge it with the original anatomical image data (Figure 9b). Any other quantitative analysis result can be visualized as well, e.g. as a color overlay of the left ventricular outer surface.

Furthermore, positional linking is possible between locations on the left-ventricular surface and their corresponding locations in the original anatomical image data.

The whole-heart visualization serves, in fact, as the visual summary of all analysis results and

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**Figure 7a.** The myocardium is mapped onto a set of concentric rings, where each ring corresponds to one slice of the original image data.

**Figure 7b.** Bull’s eye plots for myocardial thickening (function), perfusion and viability, made with ViewForum MRcardio Rel. 6.1. The middle ring represents the apex and the outer ring the valve plane of the ventricle.

**Figure 8.** The 17 segment AHA diagram and corresponding coronary territories.
as the “navigator” for linking to the original image data and associated quantitative analysis results.

**Reporting**

The final step in the analysis chain is the storage and reporting of the results. There is currently no worldwide-accepted storage and reporting format for this data. Generated reports can usually be stored in one or more of the widely accepted formats such as PDF, RFT, MS-Word, HTML, XML, etc.

The DICOM standards committee has recently standardized a template for the structured reporting of 3D CT/MR cardiovascular analysis results: DICOM Structured Reporting (DICOM SR Suppl. 97) [23]. However, this template is only appropriate for a small part of the quantitative analysis results. Segmental analysis results can be included according to the 17-segment AHA diagram, but the template does not contain a standardized representation for the very rich 3D visualizations and associated detailed analysis results that were discussed in the section on Comprehensive Visualization above. DICOM SR does, however, allow the inclusion of information in a proprietary format. Accepting this DICOM SR format would enable at least partially standardized storage of results and operability between analysis and reporting solutions.

**Future research and development**

This article has focused on improving the simplicity of the quantitative analysis of cardiac MR image data. The analysis itself is, however, only one of the links in the chain from imaging to clinical report. There is also a need for Research and Development (R&D) directed towards optimizing the MR imaging itself and optimally coupling imaging and analysis. An example of optimized imaging is auto-viability, a relatively new imaging protocol that automatically provides the optimal contrast between healthy and infarcted myocardial tissue [24].

We have also been mainly concerned with assisting the diagnosis of coronary artery disease. More R&D is needed to extend CMR analysis to treatment planning, follow-up and monitoring, and towards application to other cardiac diseases. For example, CMR analysis may also play an important role in planning the placement of biventricular pacemaker leads for the treatment of atrial fibrillation, and in the diagnosis, treatment and monitoring of congenital heart disease.

Finally, it should be realized that cardiac disease is imaged and analyzed with a plurality of imaging modalities, each having its own characteristics, advantages and disadvantages. Although CMR has the potential to become a “one-stop-shop” diagnostic imaging modality, a combination of imaging modalities will most certainly be applied in clinical practice for the near future. Multi-modality reporting tools will then be needed to optimally combine the complementary information supplied by each of these modalities.

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The cardiology care cycle
J. van den Hurk and A. Mukherjee

The cardiology care cycle approach represents a paradigm shift in the provision of healthcare for those patients at risk of cardiac disease. It covers all aspects of patient care from disease prevention to screening and diagnosis through treatment, health management and surveillance. The cardiology care cycle also offers a useful tool for assessing care delivery, and identifying those areas where cost-effectiveness and quality of care might improve. For the industry, the cardiology care cycle helps to identify how the integration of products and services can create synergies that helps improve patient care and reduce costs.

Feasibility evaluation of dual axis rotational angiography (XperSwing) in the diagnosis of coronary artery disease

This paper reports the initial results of an evaluation of dual axis rotational angiography (XperSwing) to assist in coronary artery disease diagnosis. Twenty-six patients were randomly assigned to standard or XperSwing angiography. XperSwing provided adequate information for diagnosis in 69% of cases. In 31%, additional views were needed for good visualization of the left main trunk bifurcation. Contrast agent utilization and X-ray dose were significantly lower for XperSwing than for standard angiography in this group of patients. However more research is needed to prove such benefits.

StentBoost: a useful clinical tool
J.A. Garcia, N.H. Bakker, R. de Paus and J.D. Carroll

StentBoost is an angiographic technique that allows better visualization of deployed stents in coronary arteries by enhancing the image quality of the stent using motion compensating and integration of non-contrast projection images from a fixed gantry position. This enhanced image is overlaid on a contrast image, assisting with the interpretation of stent deformation, expansion, overlap with other stents and apposition to the vessel wall. A case is presented in which the use of StentBoost allowed improved visualization of the bifurcation stenting technique used in a patient presenting with acute stent thrombosis almost two years after the index procedure.

Optimization of pulsed fluoroscopy in pediatric radiology using voiding cystourethrography as an example
R. Schumacher and H. Allmendinger

In order to optimize fluoroscopy in children, the authors studied the effects of digital grid-controlled pulsed fluoroscopy on radiation dose and image quality in 584 pediatric voiding cystourethrograms. Erasing the charge on the TV pick-up tube between pulses, and optimizing each individual pulse with a special pediatric kV/ma control curve, improve contrast, noise and radiation dose. Consequently fluorograb images, instead of spot images, can be relied on nearly exclusively. Radiation dose is reduced by 80% when compared with continuous fluoroscopy, even though the higher kV values of the pediatric control curve suggest the use of an antiscatter grid.

Brilliance iCT: initial experiences with the new generation of cardiovascular computed tomography systems
D. Rosenblum, K. Katoloski, P.J. Diaz, S. Tamarkin, D. Friedman and B. Milner

Multi-detector computed tomography (MDCT) scanners have gained increasing clinical acceptance as a non-invasive modality of choice for cardiovascular imaging. The recently introduced Brilliance iCT scanner delivers improvements in speed, power and coverage, alongside enhanced dose reduction capabilities and workflow that provide improved imaging possibilities for use in cardiovascular diseases. In this article, the authors present their preliminary experiences in cardiovascular CT (CVCT) imaging with Brilliance iCT.

Imaging the motion of the heart and blood with echocardiography: advanced technology provides deeper insights into physiology and diastolic function
S.J. Kovács, L. Shmuylovich and W. Zhang

Innovation in echocardiographic imaging, such as pulsed-wave, Doppler tissue, color m-mode, speckle tracking, strain, strain-rate and live three dimensional (Live 3D), has increased the understanding of how the heart fills, and has improved diagnosis and treatment of diastolic dysfunction. However, cardiologists do not yet fully utilize the richness of information that current technology provides. Cardiologists utilize the physical laws that govern the motion of tissue and blood to elucidate novel physiology and determine its clinical relevance. Seeking physical and physiological causal explanations for echocardiographic observations has generated new insights, and has advanced the frontiers of cardiovascular physiology and clinical cardiology.
The road to mitral valve repair with live 3D transesophageal echocardiography (TEE)
R.M. Lang, I.S. Salgo, A.C. Anyanwu and D.H. Adams

This article describes the benefit of performing mitral valve repair, rather than replacement, to improve patient outcome, and how 3D ultrasound imaging is helping to make the management of repair more definitive. Philips’ new Live 3D X7-2t transesophageal ultrasound transducer provides detailed views of mitral valve anatomy in patients that were not available before. The article also describes the importance of quantification and parametric imaging of mitral valve pathology, making it easier for cardiologists, anesthesiologists and surgeons to delineate valve defects more clearly, so that surgical planning can take place with greater confidence.

Structural heart disease interventions: rapid clinical growth and challenges in image guidance
J.D. Carroll, S.J. Chen, M.S. Kim, A.R. Hansgen, A. Neubauer and O. Wink

Structural heart disease (SHD) interventions represent the most rapidly growing area of interventional cardiology, requiring new operator skills, and new imaging techniques for guiding the procedures. Several novel applications of existing three-dimensional (3D) imaging modalities are currently being explored. These include registration of pre-procedure CTA and MRA 3D data sets with live fluoroscopy, and the application of real-time 3D transesophageal echocardiography (TEE). This article describes the cooperation between the University of Colorado clinical, imaging research teams and Philips imaging scientists in investigating the unique imaging requirements of SHD interventions, as well as designing, testing and seamlessly integrating possible solutions.

Cardiac resynchronization therapy: the role of equilibrium radionuclide angiography
E.H. Botvinick, N. Badhwar and J.W. O’Connell

Heart failure is the commonest cardiac diagnosis in the United States, with one million hospitalizations yearly. Even with advanced drug therapy, many patients develop intractable heart failure and die. Ventricular contraction magnitude and synchrony have significant prognostic impact. Dyssynchrony can be improved by cardiac resynchronization therapy (CRT), with biventricular pacemaker placement, which improves symptoms and survival in some medically refractory heart failure patients. However, benefit may not be optimal and not all patients benefit. This article presents the current and potential impact of new synchrony imaging parameters, particularly those generated with equilibrium radionuclide angiography, on CRT patient selection and treatment.

Integration of CT and fluoroscopy images in the ablative treatment of atrial fibrillation
C. Kriatselis, M. Tang, M. Roer, J-H. Gerds-Li and E. Fleck

Electrical isolation of the pulmonary veins by radiofrequency ablation has proved effective in treating both paroxysmal and persistent atrial fibrillation. However, the complex anatomy of the left atrium and the pulmonary vein ostia makes this procedure very challenging, requiring anatomical information on all relevant structures. Integration of this information in the ablation procedure could increase accuracy and safety. The EP Navigator fuses a 3D CT image of the left atrium/pulmonary veins with the live fluoroscopic image, allowing the ablation to be guided by direct visualization of the relevant structures. The authors report on one year’s experience with the EP Navigator.

High-resolution MR perfusion imaging with k-t BLAST and k-t SENSE
S. Kozerke and S. Plein

Cardiac Magnetic Resonance Imaging is continuing to gain impact in a clinical setting. The latest advances in MRI technology permit dynamic contrast-enhanced imaging of ischemia at unparalleled spatiotemporal resolutions. By exploiting information redundancy present in dynamic image series of the heart, methods such as k-t BLAST and k-t SENSE enable the encoding of voxel sizes down to 1 mm, thereby significantly excelling conventional methods with respect to spatial resolution.

Simplifying cardiac MR analysis
M. Breeuwer, G. Hautvast, S. Higgins and E. Nagel

After years of research and development, cardiac MR (CMR) analysis is now on the eve of routine application. However, its widespread use is hampered by its relative complexity and the need for specialized training. The authors describe how the procedure can be simplified, and the amount of training reduced, by introducing dedicated task guidance and far-reaching automation. Interpretation of the several different quantitative results can also be simplified by presenting them as a single, easily interpreted 3D display. In conclusion, the authors present their vision of the future research needed to achieve broader acceptance of CMR analysis in routine practice.
Le cycle de soins en cardiologie

J. van den Hurk et A. Mukherjee

Le cycle de soins en cardiologie repose sur une approche fondamentalement différente de la prise en charge des patients présentant un risque de maladie cardiovasculaire. Il recouvre tous les aspects de la prise en charge du patient, de la prévention au dépistage et au diagnostic, en passant par le traitement, le suivi médical et la surveillance.

Le cycle de soins en cardiologie constitue également un outil précieux d’évaluation thérapeutique et d’identification des domaines dans lesquels la qualité et le rapport coût-performance peuvent être améliorées.

Pour les industriels du domaine de la santé, le cycle de soins en cardiologie permet de déterminer comment l’intégration des produits et des services peut créer des synergies facilitant l’amélioration de la prise en charge des patients et la réduction des coûts.

Test de faisabilité de l’angiographie rotationnelle à deux axes (XperSwing) dans le diagnostic des affections coronariennes


Cet article présente les premiers résultats d’une évaluation de l’angiographie rotationnelle à deux axes (XperSwing) pour l’aide au diagnostic des maladies coronariennes. Vingt-six patients ont été randomisés entre angiographie standard et XperSwing. XperSwing a fourni des informations pertinentes pour le diagnostic dans 69 % des cas. Dans les 31 % restants, des images supplémentaires ont été nécessaires pour bien visualiser la bifurcation de l’artère coronaire principale gauche. Les doses d’agent de contraste et de rayonnement étaient considérablement plus faibles avec XperSwing qu’avec l’angiographie standard dans ce groupe de patients. Les recherches devront toutefois être approfondies pour démontrer les avantages de cette technique.

StentBoost: un outil clinique utile

J.A. Garcia, N.H. Bakker, R. de Paus et J.D. Carroll

StentBoost est une technique d’exploration angiographique qui permet de mieux visualiser les endoprothèses vasculaires déployées dans les artères coronaires en améliorant la qualité de l’image de l’endoprothèse grâce à la compensation du mouvement et à l’intégration d’images de projection sans contraste à partir d’une position fixe du portique. Cette image optimisée est superposée sur une image de contraste afin d’aider à interpréter la déformation et l’expansion de l’endoprothèse vasculaire, son chevauchement avec d’autres endoprothèses et son apposition contre la paroi vasculaire. Dans le cas présenté ici, l’utilisation de StentBoost a permis de mieux visualiser l’endoprothèse vasculaire pour bifurcation posée chez un patient présentant une thrombose aiguë presque deux ans après la procédure.

Optimisation de la radioscopie pulsée en radiologie pédiatrique dans l’exemple de l’urétérographie permictionnelle

R. Schumacher et H. Allmendinger

Afin d’optimiser la radioscopie chez les enfants, les auteurs ont étudié les effets de la radioscopie pulsée numérique commandée par grille sur la dose de rayonnement et la qualité de l’image lors de 584 urétéographies pédiatriques permictionnelles. L’élimination de la charge de la lampe de captage entre chaque impulsion et l’optimisation de chaque impulsion avec une courbe de contrôle pédiatrique spéciale en kV/mA améliorent le contraste, le bruit et la dose de rayonnement. En conséquence, les images obtenues avec la fonction Fluorograd, au lieu des images Spot, sont presque toujours suffisantes. La dose de rayonnement est réduite de 80 % en comparaison avec la radioscopie continue, même si les valeurs en kV plus élevées de la courbe de contrôle pédiatrique nécessitent l’utilisation d’une grille antidiffusion.

Brilliance iCT : premières expériences avec la nouvelle génération de systèmes de tomodensitométrie cardiovasculaire

D. Rosenblum, K. Kutoloski, P.J. Diaz, S. Tamarkin, D. Friedman et B. Milner

L’utilisation des scanners de tomodensitométrie multidéTECTeurs (TDM-MD) en tant que méthode non invasive d’imagerie cardiovasculaire est de plus en plus utilisée. Le nouveau scanner Brilliance iCT offre des améliorations en termes de vitesse, de puissance et de couverture d’acquisition, ainsi qu’une réduction de dose et un processus de travail optimisés qui améliorent les fonctionnalités d’imagerie pour les maladies cardiovasculaires. Dans cet article, les auteurs présentent les résultats préliminaires qu’ils ont obtenus en TDM cardiovasculaire (TDM-CV) avec Brilliance iCT.

Capture du cœur et du flux sanguin en mouvement par échocardiographie : cette technologie avancée permet une meilleure compréhension de la physiologie cardiaque et de la fonction diastolique

S.J. Kovács, L. Shmaylovich et W. Zhang

Les innovations dans le domaine de l’imagerie échocardiographique, telles que le doppler pulsé, le doppler tissulaire, le mode TM couleur, la technologie 2D Speckle de suivi des bruits de rétrodiffusion, la mesure de déformation, la vitesse de déformation cardiaque et l’imagerie 3D temps réel, ont permis de mieux comprendre la fonction de remplissage du cœur, ainsi que d’améliorer le diagnostic et le traitement des dysfonctionnements diastoliques. Cependant, les cardiologues n’exploitent pas encore toute la richesse des informations fournies par la technologie actuelle. Ils se réfèrent aux lois physiques qui régissent le mouvement des tissus et du sang pour comprendre les nouveaux phénomènes physiologiques et déterminer leur pertinence clinique. La recherche d’explications causales physiques et physiologiques des observations échocardiographiques a généré de nouvelles perspectives et repoussé les frontières de la physiologie cardiovasculaire et de la cardiologie clinique.
**Perspectives de réparation de la valve mitrale grâce à l’échocardiographie transœsophagienne (ETO) 3D temps réel**
R.M. Lang, I.S. Salgo, A.C. Anyanwu et D.H. Adams

Cet article décrit les avantages d’une réparation de la valve mitrale par rapport à un remplacement pour l’amélioration de l’état du patient et explique comment l’échocardiographie 3D aide à pérenniser la gestion de la réparation.

La nouvelle sonde transœsophagienne 3D temps réel X7-2t de Philips fournit des vues détaillées de l’anatomie de la valve mitrale qu’il était impossible d’obtenir auparavant.

L’article décrit également l’importance de la quantification et de l’imagerie paramétrique des pathologies de la valve mitrale afin que les cardiologues, les anesthésistes et les chirurgiens puissent mieux délimiter les malformations de la valve pour une planification chirurgicale plus efficace.

**Interventions en cas de maladie cardiaque structurelle : progrès et défis du guidage par image**
J.D. Carroll, S.J. Chen, M.S. Kim, A.R. Hasugen, A. Neubauer et O. Wink

Les interventions en cas de maladie cardiaque structurelle (MCS) représentent le domaine le plus porteur de la cardiologie interventionnelle ; elles requièrent de nouvelles compétences et de nouvelles techniques d’imagerie pour guider les procédures.

Plusieurs nouvelles applications de techniques d’imagerie 3D existantes sont actuellement à l’étude. Elles incluent l’enseignement de groupes de données 3D pré-IRM et pré-TDM avec radioscopie en temps réel et l’application de l’échocardiographie transœsophagienne 3D temps réel (ETO).

Cet article décrit la coopération entre les équipes de recherche clinique en imagerie de l’Université du Colorado et les spécialistes en imagerie Philips pour l’étude des exigences d’imagerie uniques des interventions MCS et pour la conception, la mise à l’essai et l’intégration transparente des solutions possibles.

**Thérapie de resynchronisation cardiaque : le rôle de l’angiographie radioisotopique d’équilibre**
E.H. Botvinick, N. Badhwar et J.W. O’Connell

L’insuffisance cardiaque est le diagnostic cardiaque le plus courant aux États-Unis, avec un million d’hospitalisations chaque année. Même avec une pharmacothérapie avancée, de nombreux patients développent une insuffisance incurable et décèdent.

Le synchronisme et l’ampleur des contractions ventriculaires ont un impact pronostic significatif. L’asynchronisme peut être amélioré grâce à la thérapie de resynchronisation cardiaque (TRC), avec pose d’un stimulateur cardiaque biventriculaire qui améliore les symptômes et la survie chez certains patients dont l’insuffisance cardiaque est rebelle aux traitements médicamenteux. Cependant, les avantages ne sont pas toujours optimaux et tous les patients n’en bénéficient pas. Cet article présente l’impact actuel et potentiel des nouveaux paramètres d’imagerie de synchronisme, notamment ceux générés avec l’angiographie radioisotopique d’équilibre, sur le choix des patients à traiter par TRC et le déroulement du traitement.

**Intégration d’images de radioscopie et de TDM dans le traitement ablatif de la fibrillation auriculaire**
C. Kriatselis, M. Tang, M. Roser, J-H. Gerds-Li et E. Fleck

L’isolation électrique des veines pulmonaires par le biais d’une ablation par radiofréquence s’est avérée efficace dans le traitement de la fibrillation auriculaire paroxysmale et persistante. Cependant, l’anatomie complexe de l’oreillette gauche et de l’ostium des veines pulmonaires rend cette procédure très complexe et nécessite des informations anatomo-radiologiques sur toutes les structures concernées.

L’intégration de ces informations dans la procédure d’ablation pourrait améliorer la précision et la sécurité du traitement.


**Imagerie de perfusion RM haute résolution avec k-t BLAST et k-t SENSE**
S. Kozerke et S. Plein

L’imagerie cardiaque par résonance magnétique est de plus en plus répandue en milieu clinique. Les dernières avancées dans le domaine de la technologie IRM permettent une imagerie dynamique de contraste de l’ischémie à des résolutions spatio-temporelles inégalées. En exploitant la redondance des informations fournies par les séries d’images dynamiques du cœur, les méthodes telles que k-t BLAST et k-t SENSE permettent de coder des voxels de 1 mm seulement, surpassant de loin les méthodes conventionnelles en matière de résolution spatiale.

**Simplification des analyses IRM cardiaques**
M. Breuer, G. Hautvast, S. Higgins et E. Nagel

Après des années de recherche et de développement, l’analyse RM cardiaque (RMC) est en passe de devenir une procédure de routine. Cependant, son utilisation reste entravée par sa relative complexité et le besoin d’une formation spécifique.

Les auteurs expliquent comment simplifier la procédure et réduire la durée de formation requise en proposant un guide des tâches spécifique et une automatisation approfondie. L’interprétation des différents résultats quantitatifs peut également être simplifiée à l’aide d’un écran 3D unique et convivial.

En conclusion, les auteurs présentent leur vision des recherches nécessaires pour que l’analyse RMC soit plus largement utilisée dans la pratique de routine.
Der kardiologische Versorgungszyklus

J. van den Hurk und A. Mukherjee

Der Ansatz des kardiologischen Versorgungszyklus bedeutet einen Paradigmenwechsel bei der Betreuung von Patienten mit Risiko für eine kardiologische Erkrankung. Er deckt alle Aspekte der Patientenversorgung ab; von der Prävention über das Screening und die Diagnose bis hin zur Behandlung, Gesundheitsvorsorge und Überwachung.

Der kardiologische Versorgungszyklus dient auch als leistungsfähiges Instrument zur Beurteilung der erbrachten Versorgungsleistungen und zur Identifizierung von Bereichen, in denen noch Verbesserungspotenziale hinsichtlich der Kosten- und Versorgungsqualität bestehen. Für die Gesundheitsbranche ist mit dem kardiologischen Versorgungszyklus besser nachvollziehbar, wie die Integration von Produkten und Dienstleistungen Synergien schaffen kann, mit denen die Patientenversorgung verbessert und die Kosten gesenkt werden können.

Untersuchung zur Durchführbarkeit der zweidimensionalen Rotationsangiographie (XperSwing) in der Diagnose koronarer Herzkrankheiten


In dieser Veröffentlichung werden die ersten Ergebnisse einer Studie zum Stellenwert der Rotationsangiographie (XperSwing) als diagnostisches Hilfsmittel bei koronaren Herzkrankheiten vorgestellt. 26 Patienten wurden nach dem Zufallsprinzip auf die Standard- und die XperSwing-Angiographie aufgeteilt. XperSwing lieferte in 69% der Fälle hinreichende Informationen zur Diagnosestellung. Bei 31% war für eine bessere Visualisierung der Bifurkation des linken Hauptstammes zusätzliche Bildgebung erforderlich. Die verwendeten Kontrastmittelmenge und die eingesetzte Röntgenstrahlendosis waren bei der untersuchten Patientengruppe mit XperSwing signifikant geringer als mit der Standard-Angiographie. Zum endgültigen Nachweis dieser Vorteile sind jedoch weiterführende Studien erforderlich.

StentBoost: Ein nützliches klinisches Hilfsmittel

J.A. Garcia, N.H. Bakker, R. de Paus und J.D. Carroll


Optimierung der gepulsten Durchleuchtung in der pädiatrischen Radiologie am Beispiel von Miktionszystourethrogrammen

R. Schumacher und H. Allmendinger

Zur Optimierung der Durchleuchtung bei Kindern haben die Autoren die Wirkung der digitalen gepulsten Gittergesteuerten Durchleuchtung (Grid Controlled Fluoroscopy) auf die Strahlendosis und Bildqualität bei 584 Miktionszystourethrogrammen pädiatrischer Patienten untersucht. Durch Neutralisierung der Ladung auf der TV-Aufnahme und durch Optimierung der einzelnen Impulse mit einer speziell für die pädiatrische Anwendung entwickelten kV/mA-Kontrollkurve konnte eine Verbesserung in Bezug auf Kontrast, Rauschen und Strahlendosis erreicht werden. Das Verfahren ist sehr zuverlässig und kann daher in fast allen Fällen anstelle von Einzelbildern eingesetzt werden. Im Vergleich zur kontinuierlichen Durchleuchtung sinkt die Strahlendosis um 80%, obgleich die höheren kV-Werte in den pädiatrischen Kontrollkurven die Verwendung eines Antistreurasters nahelegen.

Brilliance iCT: Erste Erfahrungen mit der neuen Generation kardiovaskulärer Computertomographiesysteme

D. Rosenblum, K. Kutoloski, P.J. Diaz, S. Tamarkin, D. Friedman und B. Milner

Die Multidetektor-Computertomographie (MDCT) findet in der klinischen Praxis zunehmende Verbreitung als nicht-invasives Verfahren der Wahl zur kardiovaskulären Bildgebung. Der kürzlich eingeführte Scanner Brilliance iCT bietet neben Verbesserungen in Bezug auf Dosisreduktion und Arbeitsablauf auch mehr Schnelligkeit, Leistung und einen größeren Erfassungsbereich. Somit erweitern sich die Möglichkeiten der Bildgebung bei kardiovaskulären Erkrankungen. In diesem Artikel berichten die Autoren über ihre vorläufigen Erfahrungen mit dem Brilliance iCT bei kardiovaskulären CTs.

Visualisierung der Bewegungen von Herz und Blut mittels Echokardiographie: Technologische Fortschritte ermöglichen tiefe Einblicke in die Physiologie und diastolische Funktion

S.J. Kovacs, L. Shmuelovich und W. Zhang

Der Weg zur Mitralklappenreparatur: Transösophageale Echokardiographie (TEE) mit Live-3D-Bildgebung
R.M. Lang, I.S. Salgo, A.C. Ayeyanwu und D.H. Adams

Dieser Artikel beschreibt die Vorteile einer Mitralklappenreparatur gegenüber einem Mitralklappen austausch zur Verbesserung des Outcomes und erläutert, wie die 3D- Ultraschallbilddgebung die Planung und Durchführung eines solchen Eingriffs maßgeblich unterstützt.

Der neue Live 3D X7-2t von Philips, ein transösophagealer Ultraschallkopf, liefert detaillierte Ansichten der Mitralklappenanatomie, die bislang in dieser Form nicht verfügbar waren.


Integration von CT- und Durchleuchtungsbildern in die ablative Behandlung des Vorhofflimmerns
C. Kriattieli, M. Tang, M. Rosier, J-H. Gerds-Li und E. Fleck


Hochauflösende MR-Perfusionsbilddgebung mit k-t BLAST und k-t SENSE
S. Kazerbe und S. Plein

Die kardiale Magnetresonanztomographie gewinnt in der klinischen Praxis immer mehr an Bedeutung. Die jüngsten Fortschritte in der MRT-Technologie erlauben dynamische kontrastverstärkte Bilddgebung von Ischämien in beispiellosen raumzeitlichen Auflösungen. Durch die Ausnutzung der Informationsredundanz, die bei dynamischen Aufnahmeserien des Herzens gegeben ist, können durch Methoden wie k-t BLAST und k-t SENSE Voxelgrößen bis zu 1 mm kodiert werden. Im Hinblick auf die Raumauflösung werden konventionelle Methoden damit deutlich übertroffen.

Vereinfachung der kardialen MR-Analyse
M. Brenner, G. Hautvast, S. Higgins und E. Nagel


Abschließend erörtern die Autoren, welche Forschungsmaßnahmen in Zukunft ihrer Ansicht nach erforderlich wären, damit die kardiale MR eine breitere Akzeptanz als Routineanwendung in der Praxis findet.
El ciclo de cuidados cardíacos

J. van den Hurk y A. Mukherjee

El ciclo de cuidados cardíacos constituye un nuevo modelo de asistencia sanitaria para aquellos pacientes con riesgo de sufrir enfermedades cardiacas. Abarca todos los aspectos del cuidado del paciente, desde la prevención, la exploración y el diagnóstico, pasando por el tratamiento y control del paciente. El ciclo de cuidados cardíacos ofrece además una útil herramienta para evaluar la asistencia que reciben los pacientes, así como para identificar aquellos aspectos en los que podrían ahorrarse recursos o en los que podría mejorar la calidad de la asistencia.

Para el sector, el ciclo de cuidados cardíacos sirve de gran ayuda para identificar la forma en que la integración de productos y servicios pueden dar lugar a la mejora de la calidad de la asistencia al paciente, así como para una reducción de costes.

Evaluación de viabilidad de la angiografía rotatoria de doble eje (XperSwing) en el diagnóstico de la coronariopatía


Este artículo expone los resultados iniciales de una evaluación de la angiografía rotatoria de doble eje (XperSwing) para coadyuvar en el diagnóstico de la coronariopatía. Se designaron aleatoriamente 26 pacientes para someterlos a angiografía estándar o mediante XperSwing. La XperSwing facilitó una información adecuada para el diagnóstico en un 69% de los casos. En el 31%, se necesitaron proyecciones restantes para visualizar correctamente la bifurcación del tronco principal izquierdo. El agente de contraste y la dosis de radiación utilizados en este grupo de pacientes fueron significativamente más bajos con la XperSwing que con la angiografía convencional. Sin embargo, es necesario seguir investigando para demostrar dichas ventajas.

StentBoost: una herramienta clínica útil

J. A. García, N. H. Bakker, R. de Paus y J. D. Carroll

StentBoost es una técnica angiográfica que permite una mejor visualización de los stents implantados en las arterias coronarias, debido a una mayor calidad de imagen de los mismos utilizando la compensación de movimiento y la integración de imágenes de proyección sin contraste obtenidas desde un soporte fijo. Esta imagen mejorada se superpone a una imagen de contraste, que ayuda a la interpretación de la deformación, expansión y superposición de los stents con otros stents y de su aposición a la pared vascular. Se presenta un caso en el que el uso del StentBoost permitió una mejor visualización de la técnica de la colocación de stents en bifurcación utilizada en un paciente que presentaba una trombosis de stent aguda, casi dos años después del procedimiento inicial.

Optimización de fluoroscopia de pulso en radiología pediátrica mediante una cistouretragrafía miccional como ejemplo

R. Schumacher y H. Almenendinger

Para optimizar la fluoroscopia en niños, los autores estudiaron los efectos de una fluoroscopia de pulso controlada por rejilla digital sobre la dosis de radiación y la calidad de imagen en 584 cistouretragramas miccionales pediátricos. Eliminando la carga del tubo de recogida de televisión (TV pick-up tube) entre pulsos y optimizando cada uno de los pulsos con una curva especial de control pediátrico kW/mA, se mejoró el contraste, el ruido y la dosis de radiación. Por consiguiente, se puede confiar casi exclusivamente en las imágenes fluorográficas, en lugar de usar imágenes inmediatas. La dosis de radiación se reduce en un 80% en comparación con la fluoroscopia continua, aunque el aumento de los valores de kV, que indica la curva de control pediátrico, sugiere el uso de una rejilla antidispersante.

Brilliance iCT: experiencias iniciales con la nueva generación de sistemas de tomografía computarizada en exploración cardiovascular

D. Rosenblum, K. Kutoloski, P. J. Diaz, S. Tamarkin, D. Friedman y B. Milner

Los escáneres de tomografía computarizada multidetector (TCMD) han adquirido una creciente aceptación clínica como modalidad no invasiva para la exploración cardiovascular por imagen. El escáner Brilliance iCT, introducido recientemente, presenta mejoras en velocidad, potencia y cobertura, además de una mayor posibilidad de reducción de las dosis y un flujo de trabajo que mejoren las posibilidades del diagnóstico por imagen para enfermedades cardiovasculares. En este artículo, los autores presentan sus experiencias preliminares en imágenes de TCCV cardiovascular con el Brilliance iCT.

Imágenes del movimiento cardíaco y sanguíneo con ecocardiografía: avances tecnológicos que mejoran la comprensión de la fisiología y la función diastólica

S. J. Kovács, L. Shmuylovich y W. Zhang

Las innovaciones en la imagen ecocardiográfica, como la onda pulsada, Doppler de tejidos, el modo M a color, el seguimiento del ruido de moteado (speckle), la deformación del miocardio, la tasa de deformación miocárdica y la imagen tridimensional en tiempo real (Live 3D), han ampliado el conocimiento sobre cómo se llena el corazón y ha mejorado el diagnóstico y el tratamiento de la disfunción diastólica. Sin embargo, los cardiólogos no sacan el máximo partido a la abundancia de información que ofrece la tecnología actual. Los cardiólogos utilizan las leyes físicas que rigen el movimiento de los tejidos y la sangre para desentrañar los nuevos conceptos fisiológicos y determinar su relevancia clínica. La búsqueda de explicaciones causales físicas y fisiológicas a las observaciones ecocardiográficas ha generado nuevas perspectivas y ha ampliado las fronteras de la fisiología cardiovascular y la cardiología clínica.

Resúmenes Español
El camino hacia la reparación de la válvula mitral mediante ecocardiografía transesofágica 3D en tiempo real
R. M. Lang, I. S. Salgo, A. C. Anyanwu y D. H. Adams
Este artículo describe las ventajas de reparar la válvula mitral, en lugar de sustituirla, para mejorar la respuesta de los pacientes, y explica cómo la imagen con ultrasonidos en 3 dimensiones está contribuyendo a asentar la técnica de la reparación. El nuevo Live 3D X7-2t, de Philips, transductor de ultrasonidos transesofágico en 3D y tiempo real, ofrece imágenes detalladas de la anatomía de la válvula mitral que antes no podían obtenerse. El artículo también explica la importancia de la imagen cuantitativa y paramétrica en la patología de la válvula mitral, ya que permite a los cardiólogos, anestesiastas y cirujanos determinar valvulopatías más claramente, con el fin de que la planificación quirúrgica pueda llevarse a cabo con más seguridad.

Intervenciones en cardiopatías estructurales: rápido crecimiento clínico y retos en la tecnología de imágenes
J. D. Carroll, S. J. Chen, M. S. Kim, A. R. Haugen, A. Neubauer y O. Wink
Las intervenciones en cardiopatías estructurales representan el área de mayor crecimiento en el ámbito de las intervenciones de cardiología intervencionista, por lo que son necesarias nuevas aptitudes en los cirujanos y nuevas técnicas de imagen para guiar los procedimientos. Actualmente, se están investigando varias aplicaciones novedosas de modalidades de imagen tridimensional ya existentes. Éstas incluyen el registro de ATC anterior al procedimiento y los conjuntos de datos de ARM en 3D, con fluoroscopia en tiempo real, y la aplicación de la ecocardiografía transesofágica en 3D en tiempo real. Este artículo describe la cooperación entre los equipos de investigación clínica por imagen de la Universidad de Colorado, y los científicos de diagnóstico por imagen de Philips destinados a investigar los requisitos de imagen específicos de las intervenciones en cardiopatías estructurales, así como para diseñar, probar e integrar rigurosas posibles soluciones.

Terapia de resincronización cardiaca: el papel de la angiografía de equilibrio con radionúclidos
E. H. Botvinick, N. Baddour y J. W. O’Connell
La insuficiencia cardiaca es el diagnóstico cardiaco más frecuente en los Estados Unidos, con un millón de hospitalizaciones anuales. Incluso con un tratamiento farmacológico especializado, muchos pacientes desarrollan una insuficiencia cardiaca resistente a cualquier tratamiento y mueren. La magnitud y la sincronía de la contracción ventricular tienen un impacto significativo sobre el pronóstico. La asincronía puede reducirse mediante la terapia de resincronización cardiaca (TRC), con la colocación de un marcapasos biventricular, que mejora los síntomas y la supervivencia de algunos pacientes con insuficiencia cardiaca resistente al tratamiento. Sin embargo, puede que el beneficio no sea óptimo y que no todos los pacientes lo obtengan. Este artículo presenta el impacto actual y potencial de los nuevos parámetros de imagen de sincronía, en particular, los generados con el equilibrio de radionúclidos en la angiografía, en la selección y el tratamiento de pacientes con terapia de resincronización cardiaca.

Integración de imágenes TC y fluoroscópicas en el tratamiento ablativo de la fibrilación auricular
C. Kriatselis, M. Tang, M. Roiser, J-H. Gerdes-Li y E. Fleck
Se ha demostrado la efectividad del aislamiento eléctrico de las venas pulmonares mediante la ablation por radiofrecuencia tanto en el tratamiento de la fibrilación auricular paroxística, como en la persistente. Sin embargo, la compleja anatomía de la aurícula izquierda y los oríferos de las venas pulmonares hace que este procedimiento resulte muy complicado, y que requiera información anatómica acerca de todas las estructuras relevantes implicadas. La integración de esta información en el procedimiento de ablación podría aumentar la precisión y la seguridad. El EP Navigator fusiona una imagen TC en 3D del ventrículo izquierdo/venas pulmonares con la imagen fluoroscópica en tiempo real, lo que permite dirigir la ablación visualizando directamente las estructuras relevantes implicadas. Los autores describen su experiencia con el EP Navigator durante un año.

Imagen de perfusión por RM de alta resolución con k-t BLAST y k-t SENSE
S. Kazerke y S. Plein
La imagen por resonancia magnética cardiaca sigue adquiriendo importancia en contextos clínicos. Los últimos avances en tecnología de RM permiten la exploración por imagen dinámica contrastada de la isquemia en resoluciones espaciotemporales sin parangón. Utilizando la abundante información presente en la serie de imágenes dinámicas del corazón, métodos como el k-t BLAST y el k-t SENSE permiten codificar medidas en vóxeles de hasta 1 mm, por lo que superan de forma significativa los métodos convencionales en relación con la resolución espacial.

Simplificación de los análisis cardiacos por RM
M. Breuwer, G. Hautvast, S. Higgins y E. Nagel
Después de años de investigación y desarrollo, el análisis cardiaco por RM (RMC) está a punto de alcanzar una aplicación habitual. Sin embargo, la extensión de su uso se ve obstaculizada por su relativa complejidad y por la necesidad de formación especializada que implica. Los autores describen cómo puede simplificarse el procedimiento y cómo reducir la formación introduciendo una dirección de tareas específica y un alto nivel de automatización. La interpretación de los distintos resultados cuantitativos también puede simplificarse presentándolos como una única pantalla en 3D de fácil interpretación. En conclusión, los autores presentan su visión de la investigación futura necesaria para alcanzar una aceptación más generalizada de los análisis con RMC en la práctica habitual.
Technology news:

New products

Introducing BrightView XCT Nuclear Medicine system

BrightView XCT integrates BrightView SPECT with Philips’ advanced flat-panel X-ray CT. Until now, attenuation correction in cardiac studies has been a challenge due to the complexities inherent in table indexing and sag, CT slice artifacts and patient breath-hold requirements. BrightView XCT offers several clinical advantages with improved registration confidence between emission and transmission maps because the table doesn’t move between studies, in most cases. The flat panel CT allows the entire heart volume to be acquired in just one rotation. And patients can breath normally throughout both the SPECT and CT acquisition steps for greater patient comfort and better diaphragm alignment. And all of this is possible with low CT dose levels and without changing the way you like to work. What’s more, Philips provides comprehensive support and training throughout system life. Helping you to make the most of BrightView XCT from day one.

Philips CT Step & Shoot Cardiac

Philips Healthcare’s new Step & Shoot Cardiac is a unique scanning mode for its Brilliance iCT and 64-channel CT scanners. CT angiography exams are ideal for helping to diagnose coronary artery disease (CAD) in asymptomatic patients, providing structural roadmaps for interventional cardiology procedures and in follow-up of treatment (e.g. CABG, stenting, etc.). Step & Shoot Cardiac reduces radiation dose while maintaining or exceeding the image quality of the retrospective technique. It is a prospective, ECG-gated axial scanning mode in which X-rays are turned on only during the physiological phase of interest. Accurate synchronization of the X-rays with ECG ensures continuity in tracking the same physiological phase of the heart from one step to the next.

Clinical studies at Wisconsin Heart Hospital have found that the Step & Shoot Cardiac feature delivers an 80 percent dose reduction compared with retrospective helical CT angiography techniques.

This diagram represents four steps for the 64-channel scanner, which is reduced to two steps on the new iCT scanner.

Crisp, clear volume rendered image of the heart is possible using low amounts of radiation dose.
Customers immerse themselves in interventional insight

At the American College of Cardiology (ACC) 2008 annual scientific session and exhibition, the Philips cath lab experience was launched. Featuring connectivity between the Allura Xper FD family, Xper Information Management and Xcelera multimodality information management solution, the Philips cath lab experience is based on a simple yet powerful concept – since the procedures that physicians and clinicians perform are becoming increasingly complex, the advanced technologies to assist them in diagnosing and treating their patients should be as simple to use as possible. Philips’ offerings for cardiovascular interventions are designed to simplify cath lab workflow, which can empower physicians and clinicians to focus on their patients and may help them to deliver faster, more accurate diagnosis and treatment.

With advanced image acquisition and visualization tools, multimodality access, hemodynamic monitoring and integrated reporting, the Philips cath lab experience enhances interventional insight and creates a fluid workflow that works for caregivers and their patients. To learn more about the clinical and workflow benefits of the comprehensive offerings of the Philips cath lab experience, visit www.philips.com/cathlab

Philips Healthcare introduces the Ambient Experience Interventional Suite

Philips’ new Ambient Experience Interventional Suite provides a unique opportunity for patients to gain a sense of control over their environment. Selectable themes transform the suite with projected images and dynamic colored lighting – all designed to relax, soothe and maximize interaction between patient and staff.

In addition, architectural enhancements help to optimize room design. In true collaborative fashion, Philips Healthcare works with the hospital to effectively reduce clutter, recess cabinetry, and improve lighting to produce open, less stressful surroundings that provide clinical staff with a comfortable interventional environment. Creating a human technology interface that will revolutionize the way medical procedures are performed