



syngo DynaCT now takes it to the Heart

by Andrew Hall, PhD

syngo DynaCT Cardiac marks the next step in the evolution of syngo DynaCT. It now enables intra-procedure 3D imaging in the EP lab.

According to the American Heart Association® (AHA), about 2.2 million Americans suffer from atrial fibrillation (AFib). The number has been increasing since the 1960s and researchers predict that more than 15 million people in the US will develop this arrhythmia by 2050. With these numbers in mind, it is obvious that strategies will be needed for effective therapy. Specialized centers worldwide nowadays treat atrial fibrillation with radio-frequency (RF) ablation. In contrast to first-line drug therapy, which has significant side effects and is not effective in the long term, RF ablation is a viable option for many patients to treat heart rhythm disorders. As these procedures evolve and the success rate increases, more accurate images of the heart anatomy will be required. Furthermore, as more patients undergo this procedure, the health care system will need to find more efficient ways to perform this kind of therapy.

3D images of the heart are needed

One of the challenges is to navigate in three-dimensional (3D) space using a 2D projection image of the heart. While it is possible to capture 2D images of the heart from various projection angles, creation of a true 3D image of the heart during

the procedure is currently not possible with C-arm systems. AFib ablation procedures require a detailed knowledge of the left atrial anatomy. Electroanatomical mapping systems and pre-operative CT scans do provide a representation of 3D anatomy, but both have inherent inaccuracies. Electroanatomical mapping systems create only an approximation of the 3D structure, and pre-operative CT images, often taken days or weeks before the procedure, can be an inaccurate representation of the morphology of the heart on the day of the procedure.

Angiography led the way

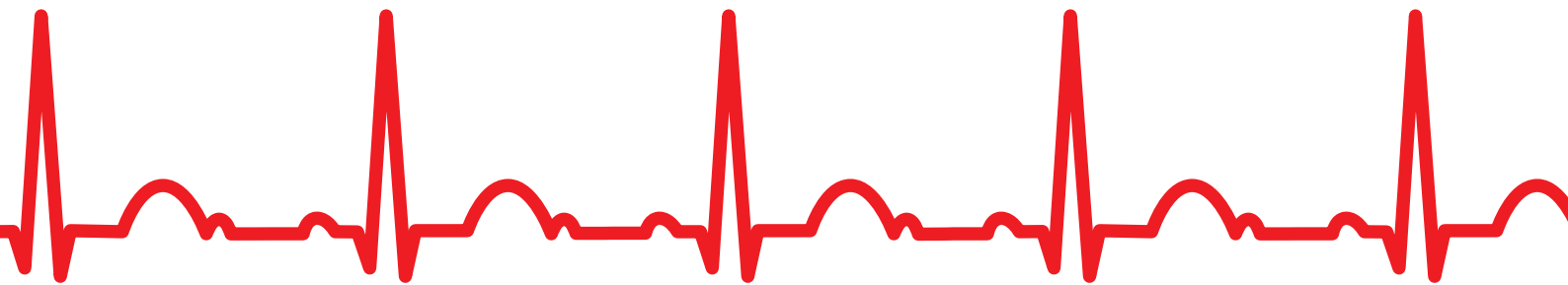
In 2004, syngo DynaCT was cleared for use and soon set a trend in interventional angiographic imaging. It is on its way to becoming an indispensable tool for angiographic interventions, e.g. neurovascular stent imaging, liver tumor embolization, brain bleed detection or transjugular intrahepatic portosystemic shunt (TIPS) placement. Based on this success, the technology has recently been developed further for imaging dynamic structures such as the beating heart. Similar to cross-sectional imaging in the angio suite with rotational angiography, syngo DynaCT Cardiac also uses the C-arm of the x-ray system in the EP lab to create a 3D image of a body region, in this case the heart. This is accomplished by rotating the C-arm laterally around the patient while collecting an array of equally spaced 2D x-ray projection images, and then using algorithms to reconstruct a three-dimensional image.

How to capture a beating heart?

Whereas angiography deals with static anatomical structures, the heart, which beats about 60 times per minute, causes some difficulties. Thorough thought was needed on how to adapt the existing angiography technology to image dynamic structures. This adaptation consists of making multiple sweeps (as opposed to the single sweep used for imaging static structures), while recording the ECG, such that a single arc of image data can be collected for one phase of the cardiac cycle, via retrospective gating, and a 3D image for that phase then reconstructed. Studies have been performed to investigate the ability of this technology to image the various structures of the heart. These studies have been successful in imaging structures including the four heart chambers, pulmonary outflow track, pulmonary veins and the proximal coronary arteries. Furthermore, since image data is collected over the entire cardiac cycle, it is possible to reconstruct 4D (3D plus time) images of the heart and its vessels.

Advantages of syngo DynaCT Cardiac

Up until the introduction of syngo DynaCT Cardiac, planning procedures like atrial fibrillation ablation was based on CT or MR images acquired before the examination. Morphologic information of these pre-



procedural images is limited by the time lag to the actual procedure. The pre-procedural approach does not account for temporal changes in the anatomical structures. With the introduction of *syngo* DynaCT Cardiac, cross-sectional images can now be acquired in the EP lab to guide your intervention.

There are several potential advantages to this imaging technique. By creating the 3D image immediately before the procedure, as opposed to days or weeks before, the resulting image is a better representation of the patient's anatomy at that time. Heart chamber volume is a function of overall blood volume, which can change over time. Also, the location of the esophagus can shift relative to the left atrium. It is also possible to create more than one 3D image during the procedure, should the physician suspect a change in the patient's anatomy. There is also a workflow advantage in that a pre-operative CT may not be required.

The principle of *syngo* DynaCT Cardiac

syngo DynaCT Cardiac is available in two different versions: with or without ECG triggering. *syngo* DynaCT Cardiac with ECG triggering utilizes images acquired from multiple ECG-triggered rotational angiography runs to display the 3D morphology of the heart. Image acquisition is performed during application of contrast agent in approximately 20 seconds. The 3D image is obtained by 3D reconstruction including retrospective ECG gating

on the *syngo* Workplace and is available for assessment in the EP lab within about two minutes after image acquisition.

The alternative application, *syngo* DynaCT Cardiac without ECG triggering, utilizes images acquired from one rotational angiography run to display the 3D morphology of the left atrium. Image acquisition is achieved in approximately five seconds after direct injection of contrast agent into the pulmonary artery. The 3D image is obtained by 3D reconstruction on the *syngo* Workplace and is available for assessment in the EP lab within less than 20 seconds after image acquisition. Regardless, whether the *syngo* DynaCT Cardiac with or without ECG triggering is used, the three-dimensional cardiac morphology can be displayed as

- volume rendering technique visualization
- surface model (by using advanced segmentation algorithms of *syngo* InSpace EP)
- endoscopic view ("Fly") visualization

Additionally it is possible to visualize the detailed cardiac anatomy within cross-sectional images (MPRs).

The AXIOM Artis product family with *syngo* DynaCT Cardiac greatly expands the therapeutic capabilities in electrophysiology. Whether floor or ceiling-mounted, biplane and/or with magnetic navigation, *syngo* DynaCT Cardiac can revolutionize the workflow in the EP lab. The ability to now create 3D images of the left atrium online during procedures provides the electrophysiologist with more detailed morphologic information and visual guidance to perform ablations with more confidence.

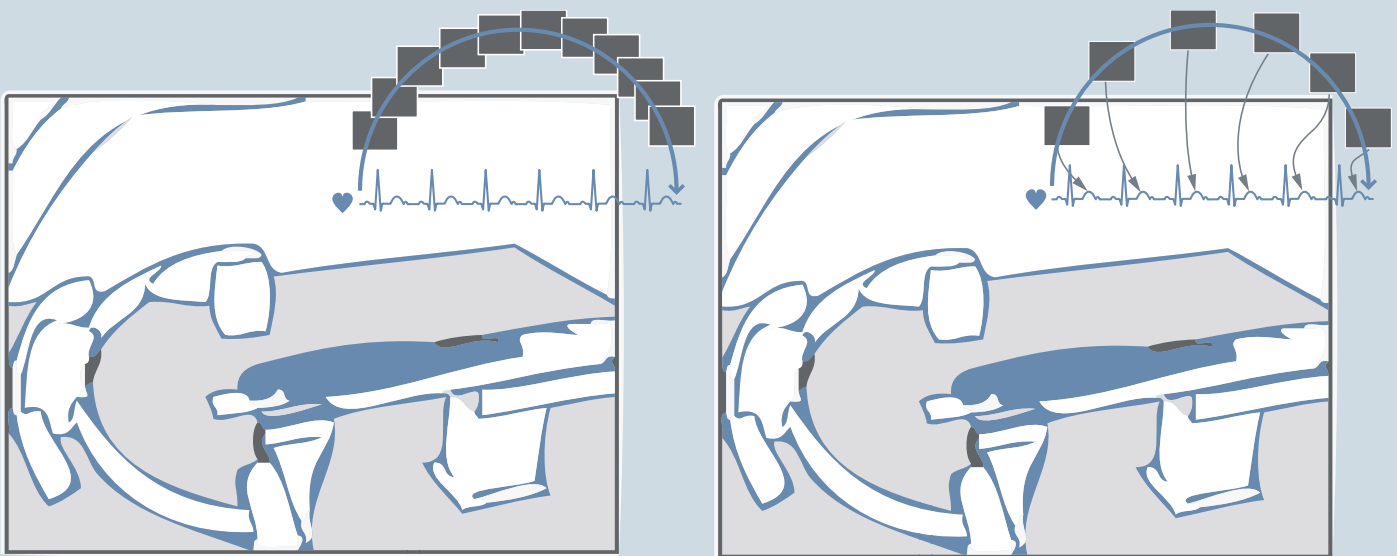
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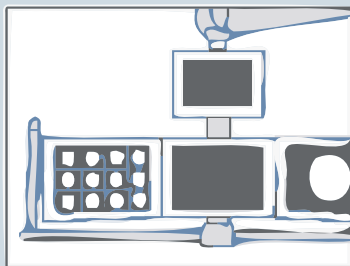
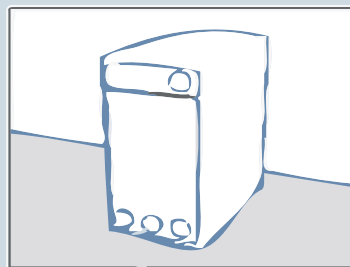
syngo DynaCT Cardiac at a glance

- supports confident planning of complex ablation procedures by enabling visualization of the actual state of the heart's anatomy in the EP lab
- improves orientation and catheter guidance through intra-procedural 3D imaging of the heart
- has the potential to save time and cost if used instead of pre-procedural CT scans



syngo DynaCT Cardiac without ECG triggering

syngo DynaCT Cardiac utilizes images acquired from one rotational angiography run to display the 3D morphology of the left atrium. Image acquisition is achieved in approximately five seconds after direct injection of contrast agent into the pulmonary artery. The 3D image is obtained by 3D reconstruction on the syngo Workplace and is available for assessment in the EP lab within less than 20 seconds after image acquisition.



syngo DynaCT Cardiac with ECG triggering*

syngo DynaCT Cardiac utilizes images acquired from one or multiple ECG-triggered rotational angiography runs to display the 3D morphology of the heart. Image acquisition is performed during application of contrast agent in approx. 20 seconds. The 3D image is obtained by 3D reconstruction including retrospective ECG gating on the syngo Workplace. The 3D image is available for assessment in the EP lab within about two minutes after image acquisition.



* currently only available on systems with 30x40 flat detector



Clinical Case Examples

Studies with *syngo* DynaCT Cardiac

Case 1

Atrial Fibrillation with ECG-gated *syngo* DynaCT Cardiac

Courtesy of Rebecca Fahrig, MD, Amin Al-Ahmad, MD, Stanford University Stanford, CA, USA

Patient History

58-year-old male, 178 cm, 86 kg

Diagnosis

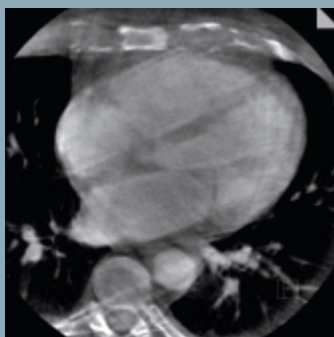
Atrial Fibrillation

Comments

The 3D image visualizing the left atrial morphology was generated by four subsequent ECG-triggered synchronized rotational C-arm angiography runs during peripheral venous injection (right arm) of diluted contrast agent with 15 sec scan delay. Cardiac gating (~60 to 70% of R-R interval) was applied during 3D reconstruction in order to achieve optimal time resolution.

Visualization

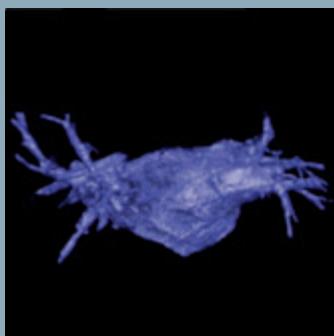
Volume rendered technique.



MPR axial



VRT image of heart



syngo InSpace EP – segmentation of LA

Case 2

Atrial Fibrillation with non-gated *syngo* DynaCT Cardiac

Courtesy of Andrea Natale, MD, Cleveland Clinic Foundation Cleveland, OH, USA

Patient History

57-year old male, 107 kg Sinus rhythm during image acquisition.

Diagnosis

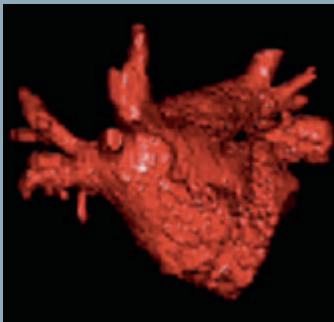
Atrial Fibrillation

Comments

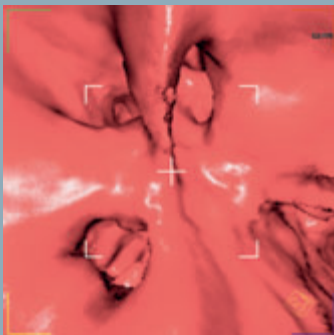
The 3D image was generated by a single 5 sec rotational C-arm angiography during selective contrast injection (15.5 ml/sec) into the pulmonary artery (5 sec x-ray delay). *syngo* InSpace EP was used to extract the surface of the left atrial morphology.



LA VRT image



syngo InSpace EP – segmentation of LA



syngo InSpace EP – Fly through LA

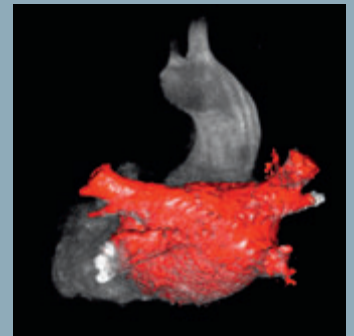
Case 3

Atrial Flutter
 with non-gated *syngo DynaCT Cardiac*
 Courtesy of Gery Tomassoni, MD
 Peter Gallagher, MD
 Aaron Hesselson, MD
 Central Baptist Hospital
 Lexington, KY, USA

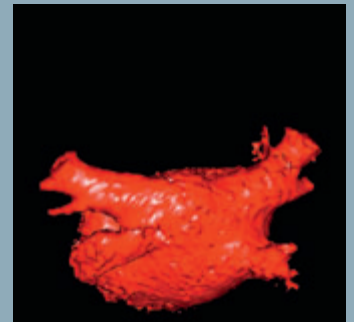
Patient History
 55-year-old male, 102 Kg
 Sinus rhythm during image acquisition

Diagnosis
 Atrial flutter

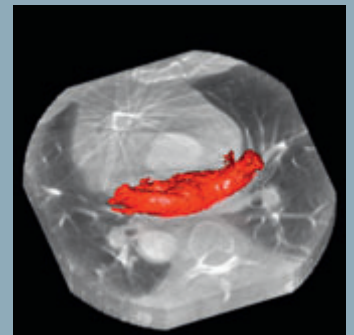
Comments
 The 3D image was generated by a single 5 sec scan, during selective contrast injection into PA, using 15 cc/sec, and 95 cc total. *syngo InSpace EP* was used to extract LA surface. MPR image overlay shows location of esophagus just posterior to LSPV ostium.



Surface rendering superimposed on VRT



Segmented left atrium



Overlay of segmented left atrium on an MPR image

Technical Details

ECG-Gated Image Reconstruction and Data Acquisition

A periodic motion of the heart is assumed. The challenge is to exclude movement in the reconstruction process as much as possible; only those projections for which motion of the heart is expected to be minimal are used for the reconstruction. Minimal movement occurs in the end diastolic phase, which can be detected in the ECG in a relative time window of usually 60-100% between subsequent R-peaks. For CT-like imaging with an angiography C-arm system, multi segment reconstruction has to be used since a single scan lasts several heart cycles. Current C-arm devices cover an angular range of $\pi+2\cdot$ fan-angle for circular short-scan reconstruction, rotating at a constant angular speed ω (constant with the exception of acceleration and deceleration at the start and end of a run) in 4-10 seconds depending on the total number of projection images desired. The angular position φ of the x-ray source can be expressed as $\varphi=\omega\cdot t$ with time t . The cardiac phase τ ranges from 0-100% and indicates the phase within a current R-R-peak interval. Figure 1a shows, for an ideal acquisition, the correspondence of the angular position of the x-ray source φ to the cardiac phase τ . Projection data are selected in a time window centered at the reconstruction phase τ_{recon} with width τ . The width τ determines the temporal resolution. At a heart rate of 60 bpm, data are selected in typically 4-10 distinct angular intervals of the x-ray source positions. In Figure 1 the number of angular intervals is reduced for clarity. After one short scan, there remain gaps in the selected data. The angular range of each missing gap depends on the temporal resolution, i.e. the width τ of the time window. Missing data should be avoided since they cause image degradations comparable to or even more severe than those caused by movement. The problem can be overcome by acquiring a series of

almost identical short-scans. The phase or the start time of the scan is selected carefully such that each scan covers a complementary angular range in the desired time window. The total number N of scans required for data completeness depends on the temporal resolution to be achieved and is provided by $N\geq 1/\Delta\tau$

Complementary data can be obtained by a series of N acquisitions with the same angular speed. To make sure that subsequent runs cover maximally disjointed intervals of the angular position φ of the x-ray source in the required time window, the starting phase of the j -th run is triggered with a time delay $\tau_{0,j}^f$ relative to the R-peak of the ECG:

$$^{(1)} \tau_{0,j}^f = (j-1)/N \text{ with } j=1, \dots, N$$

As illustrated in Figure 1b the time delay of the j -th run results in the coverage of an angular interval adjacent to the angular interval covered by the previous run ($j-1$). The covered angular intervals of all runs are equally distributed over the whole scan range. For a minimum number of runs $N_{\text{min}}=1/\Delta\tau$ the angular intervals are disjointed but seamlessly appended to each other. Data gaps would occur if the number of runs fell below the minimum number N_{min} . It is important to note that the time delay is independent of the required time window. Thus, with a series of forward runs, projection data can be selected corresponding to any reconstruction phase. In particular, a dynamic sequence of image frames can be reconstructed from a single series of forward runs.

From a clinical point of view, acquiring a series of forward runs has a severe drawback. A significant amount of time is lost by moving the C-arm back to its start position without acquiring any projection data. We assume that the whole acquisi-

tion will be accomplished during a single breathhold and during an injection of contrast agent. It is therefore imperative to keep the overall acquisition time to a minimum so that most patients can easily comply with the breathhold requirement, and so that uniform vessel opacification is maintained while minimizing the total amount of contrast agent administered. A more clinically viable solution consists of a series of alternating forward and backward runs.

The total time of data acquisition can be shortened significantly by acquiring projection images while the C-arm is returning to the start position of the next forward run. These runs in reverse direction will be called backward runs. Arbitrarily, the timing of the runs will be designed such that the same pattern of angular coverage will be obtained as could be achieved using only forward runs (see Fig. 1c). For those runs acquired in the forward direction, Eqn. (1) still holds with a set of j indices restricted to odd numbers when beginning with a forward run. A proper time delay for the backward runs can be found by considering the fact that the angular positions φ of the x-ray source at the time instants associated with the reconstruction phase τ_{recon} should be the same as they would have been in a series of pure forward runs. Therefore the triggered time delay $\tau_{0,j}^b$ relative to the R-peak of the ECG for the backward runs can be expressed by

$$^{(2)} \tau_{0,j}^b = 1 - \tau_{\text{end}} + 2 \cdot \tau_{\text{recon}} - (j-1)/N$$

with j indices restricted to even numbers, and τ_{end} as the heart phase at the end of the first forward run ($j=1$). Note that for brevity the modulo 1 operation keeping the quantities in the range of 0 and 100% is omitted in Equation (2) and in the following. Equation (2) reveals that opti-

imum triggering depends on the chosen reconstruction phase, and conversely, that a choice of triggering determines the optimum reconstruction phase. Thus, when trying to reconstruct images at cardiac phases other than the optimal reconstruction phase τ_{recon} the temporal resolution will be decreased. However, given a fixed delay time τ_{obj}^b there is more than one optimal reconstruction phase τ_{recon} . Resolve Eqn. (2) to the form $2 \cdot \tau_{recon} = \dots$, where \dots is expressed in units of the cardiac phase and therefore is in the range from 0-1. There are two solutions for the optimal reconstruction phase, namely $\tau_{recon}^{(1)} = \dots / 2$, and $\tau_{recon}^{(2)} = (\dots + 1) / 2$ due to the periodicity of the cardiac phase. In addition, for an even number N of acquisition runs, the temporal distribution of the angular position φ of the x-ray source shows a beneficial symmetry. Angular positions inside the time window of minimum extent are indicated by a black line which zigzags around τ_{recon} . Outside of that time window, other zigzag curves can be found above and below that also cover the full temporal range of the heart phase. Thus, in addition to the selected reconstruction phase τ_{recon} , best temporal resolution is also achieved at $\tau = \tau_{recon} \pm i/N$ where i is any integer value such that $0 \leq \tau < 1$. Unfortunately, in the case of an odd number N of acquisition runs, such simple symmetry does not exist. In conclusion, for reconstruction of a fully resolved 4D image stack, a series of pure forward runs are preferable. However, the clinical benefit of reducing the total acquisition time clearly outweighs the reduced flexibility in choosing the reconstruction phase retrospectively.

Excerpt from: G. Lauritsch, J. Boese et al. "Towards Cardiac C-Arm Computed Tomography" in IEEE Transactions on Medical Imaging, Vol 25, No 7, July 2006, p. 922 - 934.

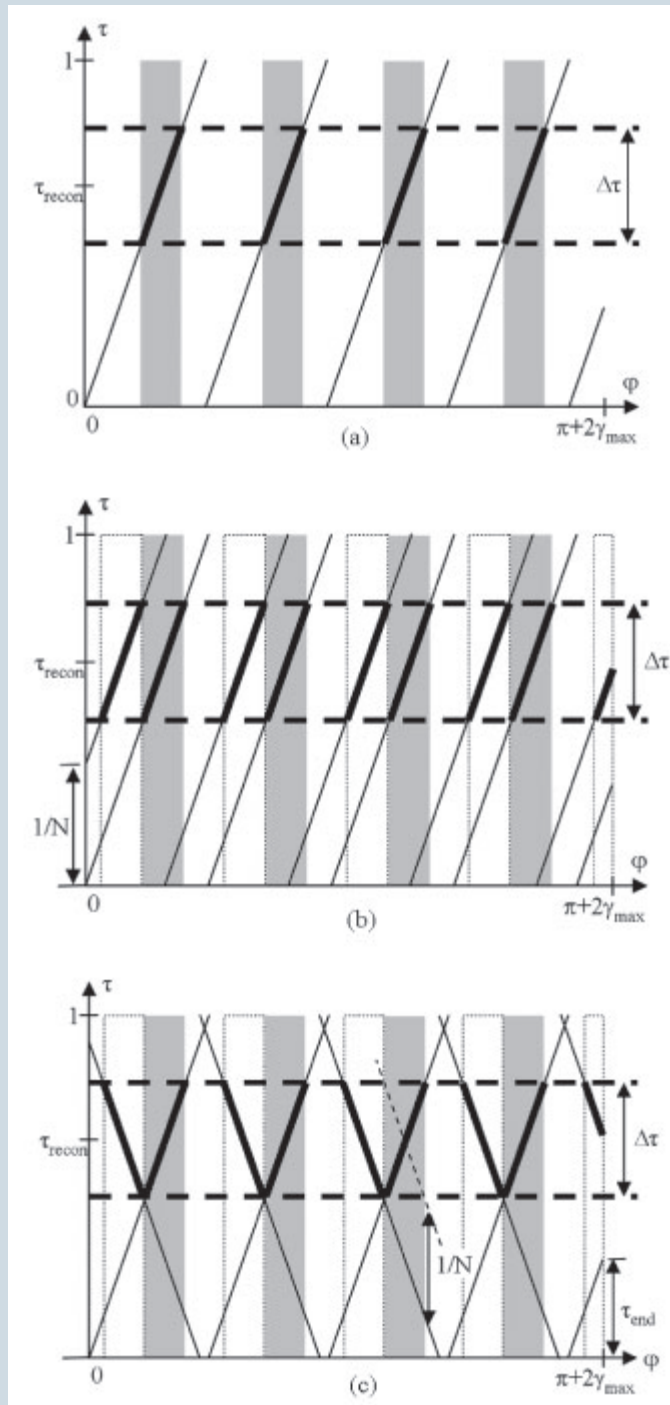


Fig. 1
 (a) ECG-gated data selection. Only those projection data are used for image reconstruction that are acquired in a preselected time window of the relative heart cycle time (gray shaded area). The time window is centered at the reconstruction phase τ_{recon} and has width $\Delta\tau$.
 (b) A second forward run is performed to extend the valid angular range of source positions. In this illustration, the second run is triggered with the heart phase such that the valid angular range is disjointed and seamlessly positioned to the left of the gray shaded area acquired by the precursor run.
 (c) A second run is performed in the backward direction to extend the valid angular range of source positions. Equivalent to Fig. 1(b), the backward run is triggered with the heart phase such that the valid angular range is disjointed and seamlessly positioned to the left of the gray shaded area acquired by the precursor forward run.