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Optimization of the cardio-rm study protocol in "critical" patients

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ESSAY

Abstract

Magnetic resonance imaging is a reliable and mature method for almost all organs and systems of the human body. The heart has been for years the most difficult organ to visualize due to its continuous movement. But, following the exceptional advances in technology in this sector, today it is possible to perform a complete evaluation of the heart, giving the possibility of studying the morphology, function and pathophysiology of the heart in an extremely precise way, thus making it possible to diagnose many entities cardiac pathologies. An examination of the heart in Magnetic Resonance, however, generally requires a high level of patient collaboration necessary to acquire images as free of artifacts as possible, and it is for this reason that certain conditions still exist in non-cooperative patients which in fact represent real contraindications to the Magnetic Resonance method. Nonetheless, making the most of the high performance of the equipment and optimizing the technical development of the study protocols, even in critically ill patients, an adequate performance of cardiac imaging with Magnetic Resonance is becoming increasingly possible.

Introduction

The objective of this presentation is to illustrate which are the technical strategies to be used to optimize a cardio MRI study of a critically ill patient, defining it as such a patient who presents problems from the cardiocirculatory and/or respiratory point of view which make it particularly complex it is difficult to study the myocardium and the cardiac chambers, with the risk of obtaining a scan that is poorly diagnostic or, in the most serious cases, impossible to complete. Adequate knowledge and use of equipment and acquisition techniques, in fact, today allow to obtain a significant diagnostic result in correlation to the clinical question of the MRI cardio examination, fundamental for the patient's therapeutic procedure.

Objectives of a cardio MRI

Before talking about how it is possible to optimize the Cardio MRI examination in a "critical" patient, it is first of all necessary to recall what are the fundamental objectives that this examination must guarantee in order to ensure sufficient diagnostic quality in all cases. In fact, an MRI cardio exam must ensure specific standards of:

1. spatial resolution: i.e. the ability to distinguish single elements that are spatially close to each other;
2. contrast resolution: i.e. the ability to distinguish single elements that differ in signal intensity;
3. high temporal resolution: i.e. the ability to observe the heart as if it were a static organ, counteracting the "disturbance" of its movement in cardiac imaging.

Managing and mastering the last parameter is particularly important so that the study falls within the internationally recognized quality standards, in order to prevent any artefacts from invalidating its diagnostic capacity. In all cases, and therefore also in the specific study of a "critical" patient, the acquisition protocol must be adequately managed to maintain the Temporal Resolution within values that are less than or equal to 45 ms.

Methodology and materials

The quality of an MRI cardio study must possess well-defined standard characteristics which are strictly dependent on the performance of the equipment on which it is performed. For this reason, in this presentation, we will deal with how it is possible to optimize the study protocol in the non-cooperative patient using a 1.5 T MR tomograph equipped with a high magnetic field, (1.5 T or higher) performing gradients for power and speed, calculation software and dedicated reconstructions and finally adequate cardiac and respiratory synchronization systems.

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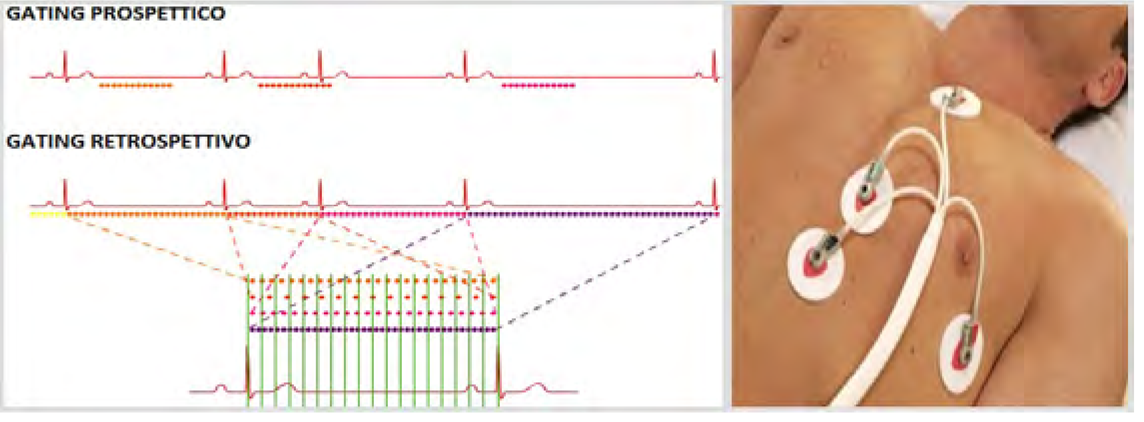
Synchronization systems

Synchronization systems are essential for correct cardiac imaging, even more so in a "critical" patient, as they allow to contain the heartbeat artefacts) and/or the motion artefacts of the chest wall distinguished in physiological involuntary movements, (eg blood flow of the great vessels), voluntary movements and movements caused by the patient's breathing (breathing artefacts)

1. Cardiac gating (fig.2): allows images to be acquired by synchronizing the RF pulses with the patient's ECG. However, to date, the latest generation systems adopt a path calledVectorCardiography (VCG) which we will analyze better later. Cardiac gating can in turn be divided into two different types, the choice of one or the other varies according to the characteristics of the patient and the sequences to be used based on the clinical question:

- prospective gating:in which the acquisition of images begins immediately after the QRS complex and ends with the completion of approximately 80% of the cardiac cycle with the possibility of reconstructing images of the heart in the diastolic phase.
- retrospective gating: in which data is acquired continuously and segmentally throughout the cardiac cycle.



(Fig.2) *cardiac gating*

2. Respiratory gating (fig.3): allows to acquire images during an expiratory apnea (10-15 seconds) of the patient by limiting the artifacts from movement of the chest wall. This synchronization system takes place through the use of a transducer located inside an elastic band placed around the chest which, therefore, monitors the patient's breathing.

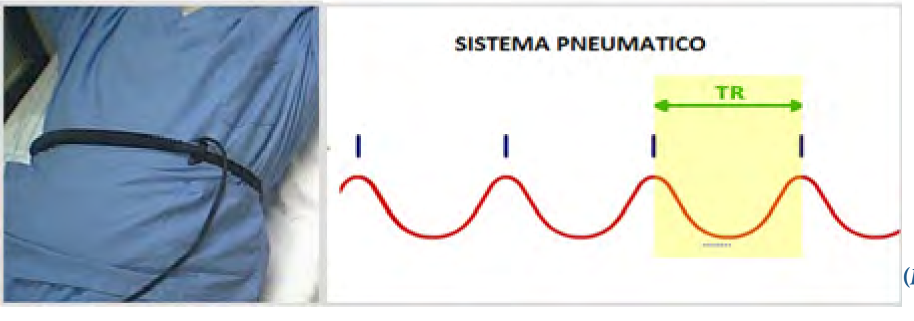
Study protocol

The study protocol that we will analyze in the "critical-non-cooperative" patient must almost always aim to guarantee correctly oriented sequences in the oblique planes of the heart (fig.4), defined by the Journal of cardiovascular Magnetic Resonance and by the Society for cardiovascular Magnetic Resonance, a publication updated among other things in the year 2020, to standardize MRI cardio images worldwide.

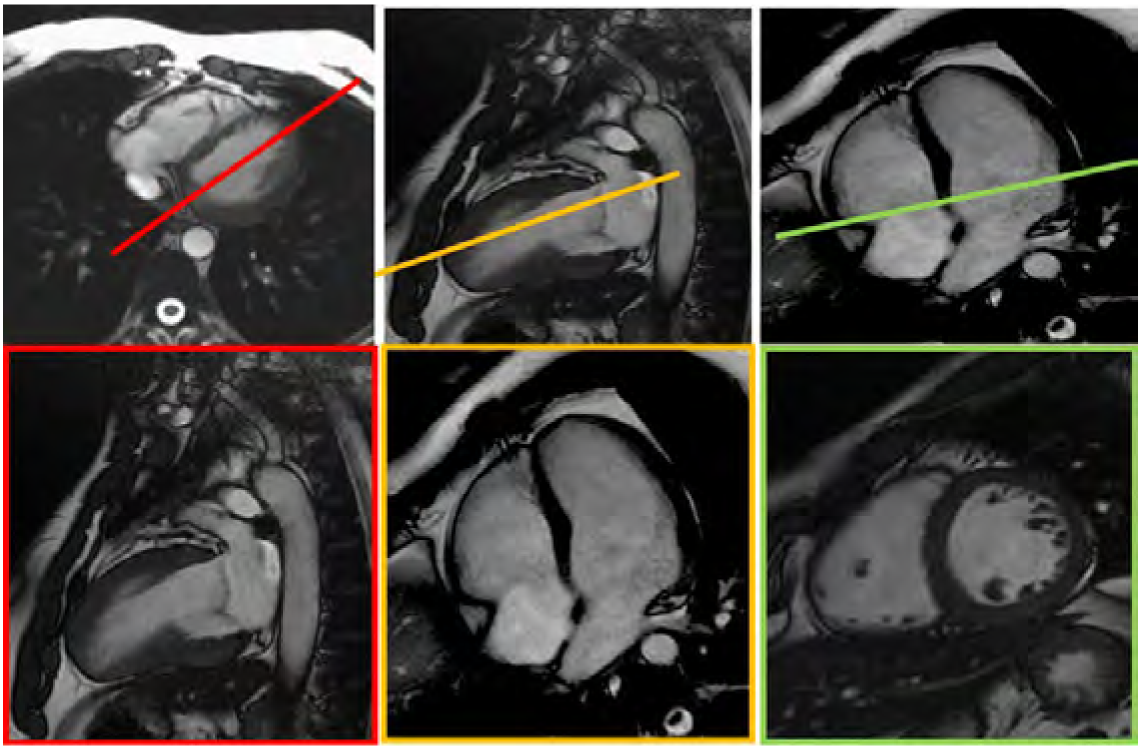
- Long axis 2 Chambers
- Long axis 4 Chambers
- Short Axis 2 Bedrooms

The planned sequences respecting the study plans must allow to obtain information on:

1. morphology: using BBFSE T1 (Black Blood Fast Spin) sequences which, by exploiting a pair of inversion pulses, are able to break down and saturate the blood signal within the section to be acquired. In this way, an adequate visualization of the cardiac chambers is obtained due to the saturation of the contained blood signal
2. For the study of edema: we use sequences of BBFSE T2 fs (Black Blood Fast Spin Echo fat sat) which allow an adequate saturation not only of the blood, but also of the adipose tissue by exploiting the fat spectral saturation technique;
3. For the evaluation of kinesis: Gradient Echo balance steady-state free precession sequences are programmed which exploit a high intrinsic contrast, a high Signal/Noise ratio and a high Time Resolution for the study of cardiac contractility thanks to a signal that strictly



(Fig.3) *respiratory gating*



(Fig.4) *study plans of the Heart*

depends on the T1 ratio /T2 of the tissues studied;

4. For perfusion imaging: we use sequences belonging to the Ultra Fast Gradient Echo IR family, with inversion pre-pulses to attenuate the myocardial signal during contrast medium infusion to evaluate hypothetical areas of organ hypo-perfusion through the evaluation of the wash in and wash out of the perfused organ. In the patient who does not collaborate with breathing, this sequence can also be acquired in free-brething as, in addition to being very fast, it exploits the motion artifact algorithms to correct the movement artifacts of the chest wall;
5. Vitality: also in this case Gradient Echo IR sequences are used and performed from 6-10 min to 20-25 min after injection of Gad-DTPA to evaluate the enhanced accumulation of Contrast Medium in the ischemic/infarcted myocardium. Since this sequence requires a perfect Inversion Time (TI) to obtain the null-point of the "healthy" muscle. To determine its numerical value to be subsequently applied to the GRE IR T1 fs, a sequence called Cine IR is used which allows to visualize the signal intensity of the Myocardium after several TIs in order to find out which one is the most suitable and which can best cancel the myocardial tissue.

Results And Discussion

From what has been said above, it seems easy to understand how a cardio MRI examination can be relatively accessible if the synchronization systems are applied to a cooperative patient.
However, in the case of a "critical" patient, the examination is considerably more complex and, if not suitably optimized by the operator, it can sometimes be particularly difficult to carry out or even impossible to complete, very often representing a real "contraindication". in Magnetic Resonance.
But who is the "critical" patient?
In cardio MRI a "critical" patient is defined as someone who, due to acute or chronic pathologies, surgical interventions and traumas, is partially or totally uncooperative because he is unstable from a point of view:

1. Cardiovascular: patient with heartbeat abnormalities such as arrhythmias and/or ectopic beats that are difficult to synchronize with Cardiac Gating;
2. Respiratory: elderly patient, sedated, comatose or otherwise with conditions such as not to perform frequent, relatively long or otherwise incompatible expiratory apneas with Respiratory Gating.

Once the objectives, instruments, acquisition plans and sequences useful for the creation of a correct imaging of the heart in Magnetic Resonance have been defined, to clarify how to behave when we find ourselves in front of a "critical" patient and to optimize the acquisition protocol in order to make it as much as possible, adequately diagnostic, we will cover 5 different scenarios; each of which involves different optimization strategies.

SCENARIO I: CLAUTROPHOBIC PATIENT

The Claustrophobic patient is the one who, due to an irrational phobia of enclosed spaces, does not tolerate the positioning of the MRI inside the gantry, making the development of the exam almost impossible. In the most severe cases of claustrophobia, the only solution is sedation, but in cases of milder claustrophobia, however, a valid alternative is to acquire the examination in the prone position because it provides the patient with the possibility of being able to have a projected gaze towards the outside of the appliance and not actually feel "constipated" inside. The electrodes will be positioned posteriorly close to the medial border of the scapula and the small loss of ECG signal deviated by a "removal" of them from the heart, can be easily compensated by setting some cardiac gating parameters (eg arrhythmia rejection window)

(Fig.5) *Positioning of the claustrophobic patient in prone decubitus*

SCENARIO II: PATIENT NOT HOLDING BREATH

If the patient, due to age, or in any case due to respiratory problems, is unable to sustain long or frequent apneas, even if we are not dealing with particular heartbeat abnormalities, we will still get serious artefacts from movement of the chest wall which do not allow us to obtain images of adequate quality. In this case, to reduce the number and times of apneas, it would be possible to act on parameters such as slice thickness and phase encoding and/or frequency, or to use morphological sequences that drastically reduce acquisition times such as the T2 Single Shot. Nonetheless, the gain we will obtain in terms of frequency and duration of expiratory apneas would be inconvenient since, in addition to having a significant reduction in image quality, it is not certain that the patient will derive real benefit from it. Therefore, a truly useful parameter in patients who have little autonomy during apnea is certainly the Acquisition Before Pause thanks to which, by increasing the pauses between one acquisition and the next, the time of each single apnea can be considerably reduced, causing, however , inevitably an increase in their frequency in order to guarantee the acquisition of all the lines necessary to fill the space K.
Another expedient, which, as in the cases, affects the average quality of the useful images, to minimize the times and frequencies of the apneas is to reduce the RR sampling intervals from 2RR to 1RR in the #RR Interval section; in doing so, in fact, we sample the lines of the K space in a single RR interval, creating less quality in the images but reducing the apnea times.
On the other hand, the case in which a patient has problems such as not to collaborate in any way with the expiratory apnea is different, for example in the case of patients with obvious neurological

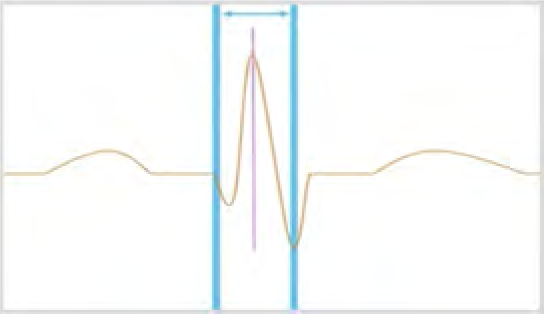
(Fig.6) *operator interface - and related Optimization Parameters of a latest generation RM Tomograph* deficits or in a state of unconsciousness. Faced with this scenario, the only possible solution is certainly the acquisition of Respiro Libero. As is known, a free-breathing acquisition would cause significant chest wall motion artifacts; therefore, to limit the damage it is possible to optimize the intrinsic quality of the image in terms of spatial resolution by exploiting the NEX. The NEXs, in fact, are nothing more than the number of samplings that are carried out for each acquisition, as these increase, the quality of each single image increases, however at the expense of acquisition times which lengthen exponentially. So,the software shown in fig.6 does not allow the operator, in RM cardio exams, to increase the NEX value in combination with parallel imaging. Therefore, in these cases, it is necessary to tick the ASSET item in the Imaging Options box of the sequence to be set.

SCENARIO III: PATIENT WITH ARRHYTHMIA

Arrhythmia is an alteration in the frequency or regularity of the heartbeat which normally ranges from 60 to 100 beats per minute (BPM) with regular cadences. Before understanding how to optimize the synchronization problems due to the patient's heartbeat abnormalities, it is essential to remember how important proper electrode placement and Cardiac Gating are as, if not positioned correctly, they could cause an altered ECG signal making the exam particularly difficult.
First of all, to obtain a correct electrical contact, the patient's skin must be cleaned and degreased and, when necessary, a hair removal is also performed. The positioning of the electrodes is critical, as it is necessary to avoid, as far as possible, that the ECG cables describe loops and that the electrodes themselves are perfectly adherent to the skin. To demonstrate correct positioning of the electrodes, it is essential to observe that the R wave on the tracing is clearly recognizable and that the T wave is not particularly high (fig.7).

Since within a high magnetic field, due to an effect called Magneto-Hydrodynamic, the electric currents induced by the movement of the electric charges in the blood can cause a distortion of the ECG; the GE Tomograph, as well as almost all the latest generation equipment, uses a Gating called Vectorcardiographic (VCG) which is considerably more stable as the orientation of the electrical axis of the heart on which it is based is not affected by the Magneto effect - Hydrodynamic. The patient's VCG tracing consists of two different cardiac vectors strictly dependent on electrode placement. The first heart vector is marked by the white-red line of the electrodes, the second by the black-green line. The quality of the synchronization depends on both vector directions, the fact remains that if one of the two is particularly noisy it is possible to tick it by relying on the "cleaner" VCG path. Assuming therefore that the VCG tracing is faithful to the real condition of the patient's heartbeat, what are the strategies that allow an optimization of the acquisition in case of Arrhythmia? Since the sequences on the Tomograph in question are usually set up to acquire with a Retrospective synchronization system, the cardiac acquisition is continuous within one RR interval of the cardiac cycle and ends only when all the data of the cardiac cycle are recorded. K space. In order to acquire all the necessary data, it will therefore be first of all it is fundamental to set a parameter called Minimum Trigger Delay: that is the delay from the peak of the R wave and the acquisition of the images which, generally, is always the minimum possible established by the machine. In the event that due to a cardiac arrhythmia we have an always variable RR cycle length, naturally the machine will reject all those RR cycles that deviate considerably from an average value making the exam times too long or, sometimes, aborting the acquisition itself. Therefore, the most important parameter to use in these cases is definitely the Trigger Window. This parameter corresponds to a sort of more or less wide "acceptance window" which is set on the peak of the R wave and which, therefore, it has the function of accepting and acquiring all cardiac cycles that fall within this window, while the remaining cycles are automatically rejected. In an arrhythmic

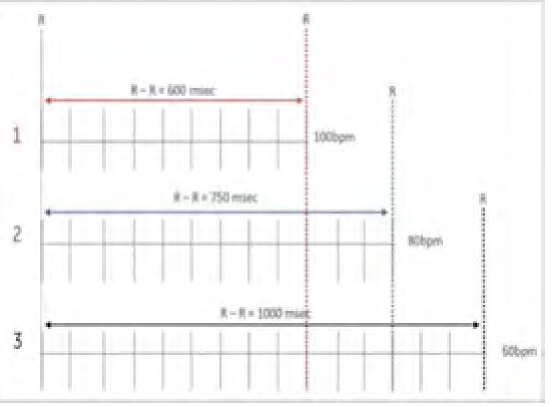
(*Fig.7*) *VectorCardiography tracing in ideal conditions* patient, who will therefore significantly increase the possibility of heartbeat rejection, it is therefore essential to increase this parameter from a standard value of 20% up to a maximum of 40%; in this way we optimize the possibility that the peak R of the cardiac cycle discordant with the average values is not rejected but in any case sampled and acquired, consequently reducing the synchronization anomalies with the Retrospective Cardiac Gating (fig.8). it is therefore essential to increase this parameter from a standard value of 20% up to a maximum of 40%; in this way we optimize the possibility that the peak R of the cardiac cycle discordant with the average values is not rejected but in any case sampled and acquired, consequently reducing the synchronization anomalies with the Retrospective Cardiac Gating (fig.8). it is therefore essential to increase this parameter from a standard value of 20% up to a maximum of 40%; in this way we optimize the possibility that the peak R of the cardiac cycle discordant with the average values is not rejected but in any case sampled and acquired, consequently reducing the synchronization anomalies with the Retrospective Cardiac Gating (fig.8).



(*Fig.8*) *Trigger Window*

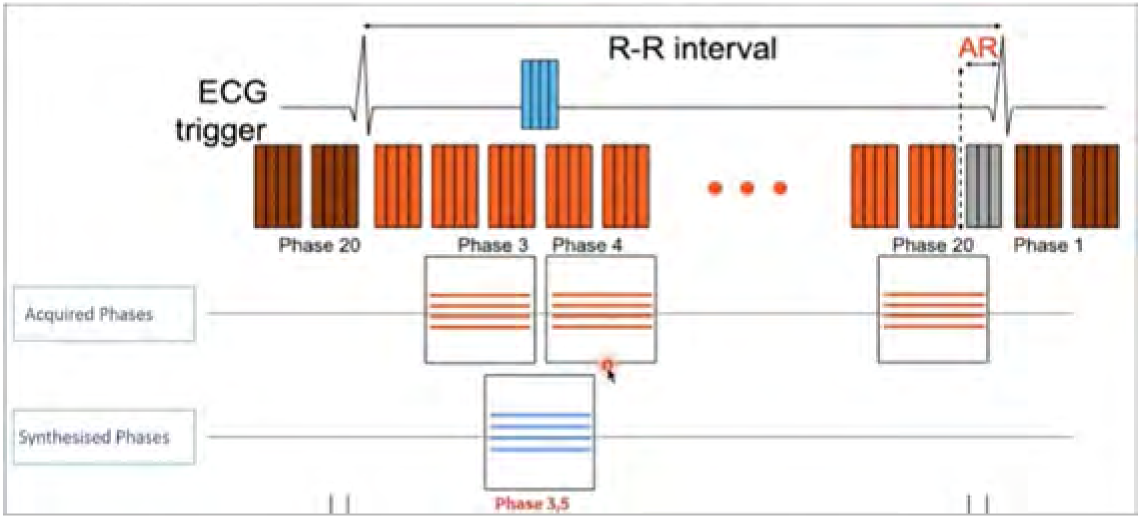
SCENARIO IV: PATIENT WITH SEVERE ARRHYTHMIA

In patients affected by a serious arrhythmia, therefore rich in extrasystoles and/or ectopic beats that are difficult to compensate for by modifying the Trigger Window alone, a valid alternative is to exploit the acquisition technique with Prospective Gating. Before presenting this scenario, however, it is essential to know how the equipment acquires with the Retrospective technique, and why this technique is less compatible with serious arrhythmias in the patient.
We know that the RR length of a single cardiac cycle varies according to the patient's BPM: as the BPM increases, the RR length decreases, as the BPM decreases, the RR length increases (fig. 9).
However, it is essential to remember that for the GE machine the RR length is standardized on what is an average value and, therefore, it expects to acquire the cardiac cycle data on this pre-set length. Whenever the RR length deviates from the average value, there will be anomalies in the acquisition, just like in the case of arrhythmias: in short, the GE system ensures that the acquired data are as similar as possible to what is expected.
If during the acquisition of the morphological se-



(*Fig.9*) *Changes of RR length according to the variation of Heart Beat Rate*

quences we acquire the images of the heart in a phase that strictly depends on the Minimum Trigger Delay, in the Cine sequences which are fundamental for the information on myocardial contractility we instead acquire a large number of phases for each single slice by exploiting the Gating Retrospective. In this case the number of phases is usually chosen by the operator and corresponds to about 30 phases placed within a parameter called # Phases to Reconstruction and, the more stable the patient's frequency is, the more the acquired data will correspond to the same phases of the cardiac cycle. Furthermore, the lines of Spazio K are acquired in a continuous and segmental way: that is, for each phase of the cardiac cycle only some lines of Space K are acquired and the acquisition will not end if we do not fill the whole matrix; this is why several apneas are needed to complete the acquisition of the volume to be studied. Now the number of segments of Space K that are acquired for each phase strictly depends on a "turbo" factor called by GE Views per Segment (VPS); it seems natural to understand how as this parameter increases, the K Space lines acquired for each single phase of the cardiac cycle decrease, causing a shorter apnea and global acquisition time but at the expense of image quality. The systems, however, are unable to acquire correctly all the lines of the K space coming from the same identical phase of the RR cycle; therefore,
(NB) Assuming that a good Spatial and Contrast resolution is obtained, it is also essential to carefully observe the Temporal Resolution of the image which, if higher than 45 ms, could create blurring artifacts which invalidate the diagnostic quality of the acquisitions.
In fact, to predict the temporal resolution of an image before acting on the parameters indicated, it is possible to multiply the TR x VPS making sure to obtain a value within the range of 45ms.
In the same way it is essential to pay attention that, for each cardiac cycle, it is necessary to have at least 15 images acquired NOT BY INTERPOLATION. In this regard, in order to predict its acquisition, the duration of a single RR cycle of the patient that is given to us by the BPMs must be known. In fact, by dividing the duration of a RR by the time resolution value we will obtain the number of phases acquired not by interpolation.
Usually, as the BPM increases, the number of pha-



(Fig.10) *Reconstruction of the "hybrid" phases in the Cine Sequences thanks to Views Sharing*

ses acquired not by interpolation decreases; the latter to be at least 15 need an optimization of the TR or Views per Segment.
From the difficulties set forth above, it is understood thatwe guess how it is particularly difficult to acquire images in Retrospective mode in a patient with severe arrhythmia; therefore, as previously mentioned, a valid alternative is to use Perspective synchronization by ticking the Prospective box in the Cardiac section of the sequence to be acquired. In doing so we will no longer acquire the whole cardiac cycle, but only the diastolic phase which physiologically turns out to be much more stable and, therefore, less affected by the artifacts of Cardiac Pulsatility.
This type of acquisition will be less sensitive to arrhythmias ensuring a good diagnostic result. Clearly, a careful eye will intuit that there will still be fewer phases in the cardiac cycle than in the acquisitions in Retrospective mode; nevertheless, we know that Magnetic Resonance is a "compromise" method, and this is more than valid for obtaining high quality images in critical patient conditions.

SCENARIO V: PATIENT WITH MIXED CRITICALITIES

The mixed criticality patient has difficulties with both cardiac and respiratory synchronization. Therefore, in these cases, the goal is to compensate for both heartbeat and breathing abnormalities by adopting appropriate technical expedients.
It actually represents a synthesis scenario of everything they have said up to now; therefore, in the event that an acquisition with Retrospective Gating is possible in a patient with arrhythmia associated with poor collaboration in expiratory apneas:
In the Morphological Sequences, the Trigger Window is increased in case of mild arrhythmias, the Acquisitions Before Pauses are decreased to reduce the duration of expiratory apneas and, where possible, the Slice Thikness is increased (maximum 8mm) to reduce the number of expiratory apneas;
In Cine sequences it is also possible to increase the Turbo factor of the Views per Segment to reduce, where possible, apneas and acquisition times; knowing however that, as a result, the number of Phases reconstructed by Interpolation will increase.
Free breathing acquisition is generally used in critical cases in which the patient is unable to cooperate in any way with the expiratory apneas. As we have already said, to compensate for the artifacts typical of free breathing acquisitions, it is necessary to increase the NEX (up to a maximum of 4) in order to increase the intrinsic quality of the images to be acquired;
Regardless of the level of collaboration that the patient others with expiratory apneas, in cases of serious arrhythmias that cannot be compensated by only modifying the Trigger Window, use the acquisition mode with Prospective Gating.

Conclusions

In conclusion, even in critical cases in which the patient is not adequately cooperative, it is possible to conclude with dignity an MRI examination that is as complex as it is fundamental for the diagnostic and therapeutic iter of the patient with cardiac pathologies. In fact, if adequately trained, the operator will be able to acquire a cardiac imaging that respects the quality standards in terms of Spatial, Contrast and Temporal Resolution by optimizing the protocol. Nonetheless, it is however necessary to remember that generally the critical conditions of a non-cooperative patient still represent a Contraindication Relative to Magnetic Resonance which, therefore,

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