4D FREE-BREATHING SEQUENCE FOR THE STUDY OF PANCREATIC LESIONS IN MRI 3 TESLA

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ABSTRACT

ancreatic cancer is the fourth leading cause of cancer death in both the United States and Europe. A fundamental role in the characterization, early diagnosis, and staging of pancreatic cancer is played by Magnetic Resonance. An innovative and recently implemented sequence, the 4D Free-Breathing sequence, is demonstrating remarkable efficiency in the characterization of pancreatic lesions, as it allows to obtain images with high temporal resolution on the arterial phase, maintaining high spatial and temporal resolution, with the patient free breathing and with compensation of respiratory movement artifacts. The aim of this study was to analyze the 4D Free-Breathing sequence technique and to evaluate its advantages in terms of image quality and diagnostic value in the characterization of pancreatic lesions. The 4D Free Breathing sequence replaces the acquisition of the classic arterial post-contrast phase obtained with the 3D-THRIVE sequence: after a first acquisition of the k-space data in the non-contrast phase (lasting 58 seconds), multiple arterial subphases, each one lasting about 5 seconds, will be acquired with a complete coverage of the post-contrast phase of about 90 seconds. This sequence exploits the k-space sampling technique called "Stack of Stars", based on a radial sampling in the XY plane. In detail, along the slice phase-encoding direction (kz), uniform Cartesian-grid sampling is maintained. Within each kz-encoded plane, radial data is collected with consecutive views (1 per sequence repetition time TR) rotated by a golden-angle of 111.25°, allowing the sampling of a complete circle, also determining a considerably reduced presence of breath artifacts. The inclusion of the 4D Free-Breathing sequence in the MRI study protocol of the pancreas, through the rapid and consequential acquisitions of 18 arterial phases, allows to improve the diagnostic information contained in the arterial phase, with free breathing, also in non-compliant patients and with correction of breath artifacts.

INTRODUCTION

Malignant pancreatic neoplasms, and particularly pancreatic ductal adenocarcinoma, are ranked as the fourth leading cause of cancer death in both the United States and Europe. This high percentage of mortality is due to several factors, including the difficulty of obtaining an early diagnosis. Indeed when lesions cause symptoms, the neoplastic mass in most cases has already reached a considerable size, and it will have already infiltrated adjacent structures. The latter is probably related to the anatomical position: the pancreas is located deep in the abdomen, close to vital vascular structures, which will most likely be involved in the early course of the disease. A fundamental role in the characterization of pancreatic neoplasms is played by diagnostic imaging, which over the years is undergoing a progressive evolution, allowing a diagnosis as early as possible of any malignant lesions needed for appropriate therapies aiming tumors 'regression. The application of Magnetic Resonance Imaging (MRI) allows to obtain images with high spatial and contrast resolution, without the use of ionizing radiation. To date, in the pancreas study protocol, an innovative sequence is used, namely the "4D Free Breathing" which, through the "stack of stars" sampling technique, allows to acquire multiple arterial phases, with free-breathing and compensation of respiratory movement artifacts, obtaining a greater capacity for correct identification and characterization of lesions. A diagnosis as accurate and early as possible translates into the possibility of adopting therapeutic procedures as targeted as possible.
The aim of this study is to analyze the 4D Free-Breathing sequence technique and evaluate the resulting image quality and diagnostic advantages in the identification and characterization of pancreatic lesions.

METHODS AND TECHNICAL DESCRIPTION

We will describe the technical and technological principles of the 4D Free-Breathing sequence and the MRI pancreatic study protocol performed at our Radiology Unit ("Paolo Giaccone" Polyclinic University Hospital of Palermo), using a 3-T MRI scanner (Philips Ingenia, Philips Healthcare, Eindhoven). Representative images of modern 4D Free-Breathing sequences will then be shown. Finally, the main advantages of applying this sequence in MRI protocols for the study of the pancreas emerging from the analysis of the scientific literature will be discussed.

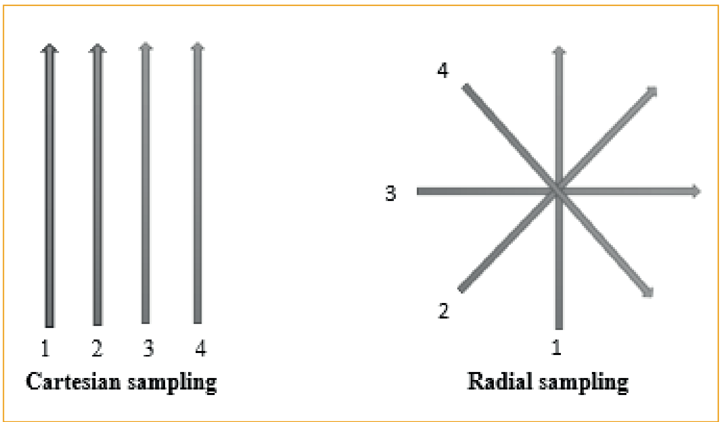

Fig. 1 - *Representation of the two different types of sampling. Respectively "2D Cartesian sampling" (left); "2D radial sampling" (right)*

RESULTS

4D Free-Breathing Sequence: k-space technique and sampling

The 4D Free-Breathing sequence allows to obtain in "Real-Time" different acquisitions in the arterial phase of high quality in terms of Temporal, Contrast and Spatial Resolution, without requesting respiratory apnea, unlike the conventional 3D-THRIVE sequence which employ the Breath-Hold and/or Trigger Gating modalities. This allows a more accurate characterization of pancreatic lesions with the post-contrast study, even in poorly compliant patients.

This sequence uses the sampling technique called "Stack of Stars", based on a radial sampling of the k-space in the XY plane, unlike the "classic" sequences used for the study of dynamics post-contrastographic, such as the 3D-THRIVE, which are based on a Cartesian type k-space sampling in the XY plane with an associated sequential phase shift along the Z axis to sample again in a Cartesian sequential manner on the XY plane (Fig. 1).

The name of the sampling technique called "Stack of Stars", specific to the 4D Free-Breathing sequence, is

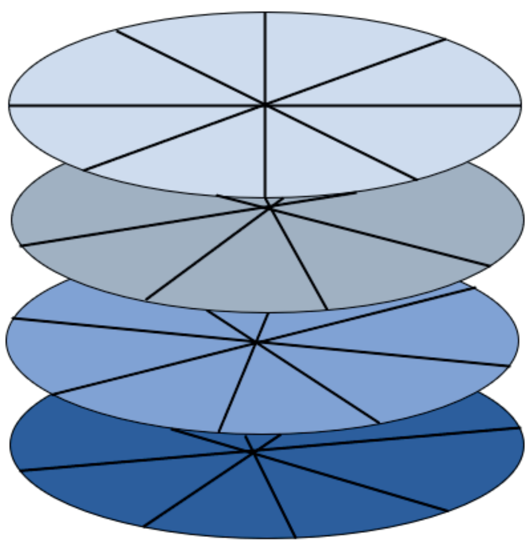

Fig. 2 - *Graphical representation of the "Stack of Star" data sampling method*

due to the way in which the K-space data are sampled (Figs 2 and 3). In fact, unlike the Cartesian sampling which collects data in a sequential manner, this technique allows to collect the K space data, figuratively forming a star, in which each ray will pass rigorously through the center.

It is defined as the golden angle technique, that is a radial sampling with rays always passing through the center, which are spaced from each other with an angle of 111.25 °, defined as **golden angle**, so called because by exploiting this angle it is possible to sample a full circle, covering only 180 °. The golden angle corresponds to 180° multiplied by the golden ratio.

Resuming, along the slice phase-encoding direction (kz), uniform Cartesian-grid sampling is maintained. Within each kz-encoded plane, radial data is collected with consecutive views (1 per sequence repetition time TR) rotated by a golden-angle of 111.25°, allowing the sampling of a complete circle, The center of each continuously sampled K-space will carry with it along the z axis, in addition to the data relating to the contrast resolution, also the information of the data relating to the respiratory movement which, through the Fourier Transform, along the slices, will determine an estimate of the data over time, which will allow the artifacts related to the patient's free breath to be corrected through a data system analysis during the dynamic contrast phase.

The 4D Free-Breathing sequence then uses the core data as the midpoint of respiratory motion estimation. The use of the golden angle, that is a radial sampling with rays always passing through the center, which are spaced from each other by 111.25 °, capable of sampling a complete circle, determines a considerably reduced presence of artifacts from an incorrect respiratory movement.

Table 1 shows in detail the acquisition parameters of the 4D Free Breathing sequence. This sequence replaces the acquisition of the classic arterial post-contrast phase obtained with the 3D-THRIVE sequence. In particular, after a first acquisition of k-space data in the pre-contrast phase (lasting 58 seconds), with substantially equal in-plane resolution and slice thickness compared to the classic 3D-THRIVE, multiple (18 in our study protocol) arterial subphases, each lasting about 5 seconds, will be acquired, with a complete coverage of the post-contrast dynamics of about 90 seconds.

MRI study protocol of the pancreas with 4D Free-Breathing sequences

The MRI study protocol of the pancreas performed at our Radiology Unit using the Philips Ingenia 3-T Magnetic Resonance Scanner (Philips Healthcare, Netherlands Eindhoven), equipped with combined gradients with 45 mT/m of amplitude and 200 mT / m / ms of slew rate, is reported below.

The receiving coil used is a dStream TORSO coil surface coil, composed of a front and a rear FlexCoverage coil, which allows to obtain a body coverage of 56 cm and to adopt a maximum of 32 channels, positioned centrally to the area of interest so as to capture a signal as broad and homogeneous as possible from the district concerned. The protocol used for a pancreatic study in 3 Tesla Magnetic Resonance, provides the

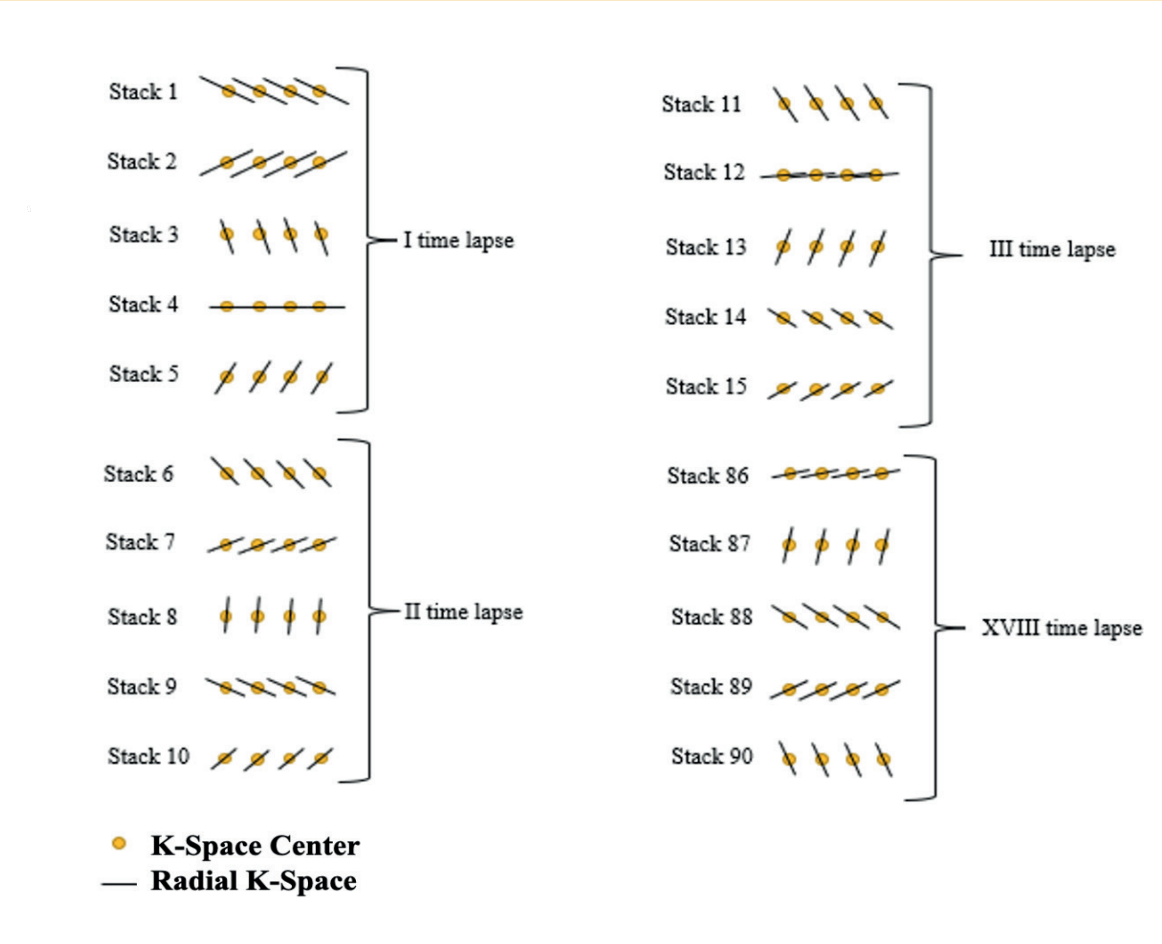

Fig. 3 *- Graphic representation of the golden angle in the various "stacks" in the various time intervals. It can be seen that, from one "stack" to the next, the gradation of the orientation varies by 111.25 ° (value of the golden angle).*

4D Free Breathing	
FOV: FH (mm) 225 RL (mm) 430 AP (mm) 430 *Voxel:* FH (mm) 5/-2.5 RL (mm) 1.6 AP (mm) 1.6 *Slice thickness recon* (mm): 2.5 *Slices:* 90 *TSE factor:* 35 *TE:* 1.32	*TR:* 3.3 *Flip Angle:* 15° *TA:* 02:28 *Factor SENSE:* yes *Parallel Immaging Factor:* P (1); S (1.7) *Temporal Resolution (ref. Scan/Phase):* 58/5sec *Radial Percentage %:* 160 *NSA:* 1 *Fat Suppression:* SPAIR

Tab. 1 - *Acquisition parameters for the sequence 4D Free-Breathing in the pancreas MRI study (MRI 3T, Philips Ingenia, Philips Healthcare, Eindhoven).*

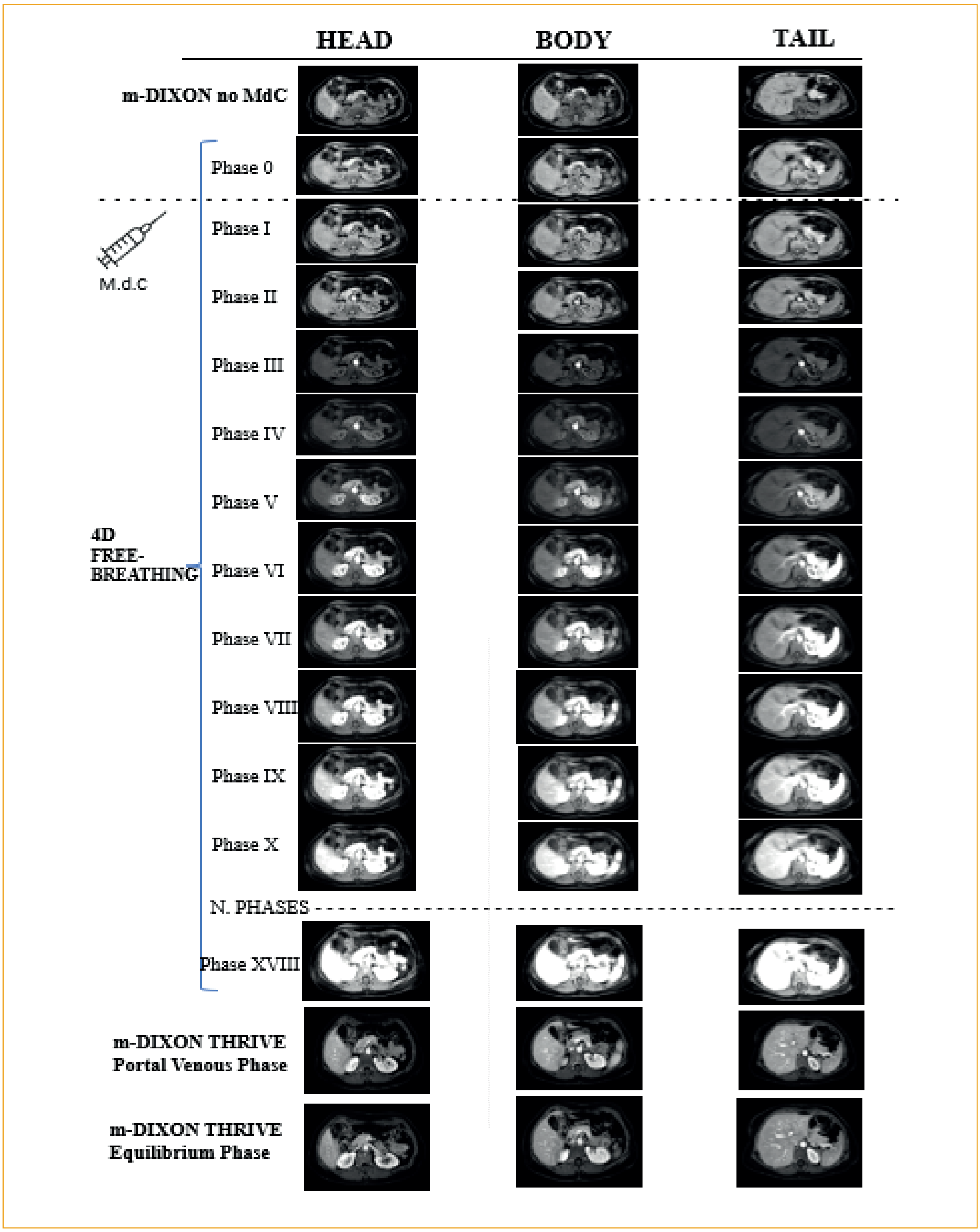

Fig. 4 - *Graphic representation of the non- and post-contrast phases in the sequences: m-DIXON basal, 4D FreeBreathing, m-DIXON Thrive PORTAL, m-DIXON Thrive LATE 3 minutes, distinguishing the three main sections of the pancreas: head, body and tail*

following sequences: coronal T2 TSE-SSh, axial T2 MVXD, axial T2 SPIR MVXD, axial dual FFE OP-IP (BH), 3D MRCP RT, 2D MRCP Radial, mDIXON-Quant (BH), axial DWI, and finally DIXON dynamic and 4D Free-Breathing after the administration of an extracellular gadolinium-based contrast agent, these latter with the temporal scheme described in detail in Figure 4.

DISCUSSION AND CONCLUSIONS

The use of the 4D Free-Breathing sequence in the pancreatic study protocol means that radial acquisitions are significantly less susceptible to movement, thus allowing examinations to be performed without the usual respiratory apneas. Furthermore, this free-breathing technique, eliminating problems related to the patients' possible difficulties in holding their breath correctly, allows to minimize the failure rates, related to breath artifacts, especially for non-compliant or elderly patients, or patients with respiratory pathologies, allowing to obtain an imaging with high contrast, spatial and temporal resolution. The rapid acquisition allows to optimally compensate for all types of movements, such as those due to the physiological intestinal peristalsis or to the patient's difficulty in maintaining the necessary immobility. The image artifacts, which can appear as streaks, or as blurring, in particular in a restricted anatomical volume and particular in its morphology, such as that of the pancreas, can in fact invalidate the diagnostic evaluation, making it difficult to identify and distinguish the anatomical structures and any focal pancreatic tumor lesions. The arterial post-contrast phase is a crucial phase, which allows for example the differential diagnosis between neuroendocrine tumors, which frequently show early arterial enhancement and subsequent rapid wash-out, and adenocarcinomas, which are hypointense compared to the remaining pancreatic parenchyma.

Routine clinical use of sequences employing stack of star sampling techniques is feasible with current MRI systems and can serve as a replacement for conventional T1-weighted fat-suppressed sequences in applications where motion is likely to degrade the image quality.

This particular sequence plays an important role not only in pancreatic imaging, but more generally in abdominal imaging considering that the information of the arterial phase is frequently fundamental for a correct and accurate diagnosis of pathologies and that the conventional single arterial phase obtained with 3D THRIVE sequence is not infrequently inadequate for small movements of the patient or for errors in the temporal acquisition of the sequence.

These problems mentioned so far are therefore overcome by including the 4D Free-Breathing sequence in the examination protocol, since through the rapid and consequential acquisitions of 18 arterial phases, each one lasting 5 seconds, it is possible to capture and identify the maximum saturation point of the contrast media in the arterial circulation, with free-breathing, therefore also suitable for non-compliant patients and with correction of breathing artifacts.

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