THE VERIFICATION OF QUALITY INDICATORS IN MRI (AUTOMATIC ANALYSIS VS MANUAL ANALYSIS OF THE IMAGES OF A STANDARD PHANTOM)

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ABSTRACT

After the entry into force of the Ministerial Decree 10/08/2018 and subsequent Ministerial Decree 14/01/2021 which determine the need to specify in the Magnetic Resonance Safety Regulation the methods and frequency provided for the quality checks, a corporate RM quality assurance program has been realized and attached to the Safety Regulations itself. After a review of the indications in the literature, the PRO-Project PRO-MRI phantom built following the criteria and requirements of the ACR was identified. Images were acquired with standard SpinEcho sequences (T1-T2 weighted) verifying the Uniformity – Ghosting – geometric distortion – spatial resolution – low contrast resolution – slice positioning accuracy – layer thickness – SNR (FAT-WATER) indicators. The images were analyzed automatically using the Pro-Project Pro-Control software and manually using the ImageJ software. The results highlighted the need for a very accurate positioning of the phantom inside the reel to overcome problems of non-recognition of the inserts in the automatic analysis and the appearance of artifacts. The conclusions from the automated analysis were then compared with the manual measurements. The checks showed an overlap between the two sets of analyzes but also the evidence that these checks fail to bring out, from the point of view of the pass / fail criteria, the real quality of the images acquired. The MR safety expert, in agreement with the Physician Responsible for Clinical Safety, is considering decreasing the range of acceptability of some limits suggested by the documentation with particular regard to artifacts (ghosting).

INTRODUCTION

The quality assurance of an imaging equipment is an ever-evolving dynamic improvement process that at every level must integrate with the quality assurance processes of the entire system. In Italy the quality assurance of the Magnetic Resonance Equipment is regulated by the legislator and, following the passing of the Ministerial Decree 10/08/2018 (Determination of safety and use standards for magnetic resonance equipment) and the subsequent Ministerial Decree 14/01/2021 which determine how it is necessary to specify in the Magnetic Resonance safety regulation the methods and frequency provided for the quality tests of the equipment, a quality assurance program has been drawn up and formalized for the three MRI and attached to the Security manual. Previously, the measuring method of the quality checks was into an operating instruction within the department.

MATERIALS AND METHODS

after a review of the indications in the literature, regarding the tests and operating limits, the PRO-Project PRO-MRI phantom (Fig. 1) in plastic material, filled with a solution of nickel chloride and sodium chloride and constructed following the criteria and requirements of the ACR (American college Radiology), was identified for use.

The measurement protocol consist in the acquisition of a sagittal localizer and 4 axial series, each consisting of 11 slices positioned as in Figure 2. The Phantom is positioned inside the default Head coil. The scan parameters for the first 2 series are prescribed by the ACR (Table 1) and includes a standard SpinEcho and a double echo in which only the second Echo will be analyzed.

NAME	COIL	MATRIX	FOV	THICKNESS	GAP	TR	TE
ACR T1	HEAD	256X256	25 cm	5 mm	5 mm	500	20
ACR D.E ECHO2	HEAD	256X256	25 cm	5 mm	5 mm	2000	80

Tab. 1 - *Acquisition Sequences*

The third and fourth series of images are based on the protocols used in the MR Site and will not be taken into consideration in this work in order to effectively compare the Resonances in question.

The Figure 2 shows the sagittal locator with the 11 axial slices crossed over it. The positioning of the slices must be very accurate and the first must be set at the vertex of the angle formed by the two crossed wedges so that the last is at the vertex of the upper end. The main indicators were then checked, such as Uniformity, Ghosting, geometric distortion, spatial resolution, low contrast resolution, slice positioning, layer thickness and SNR. The images were analyzed automatically using the proprietary Pro-Project

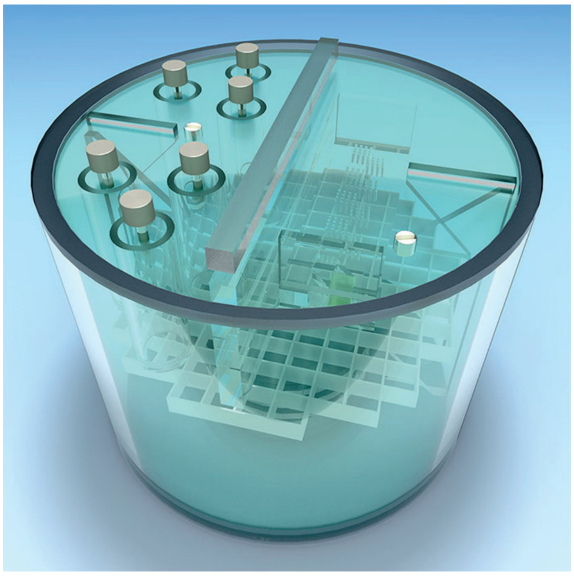

Fig. 1 - *PRO-Project Pro-MRI phantom*

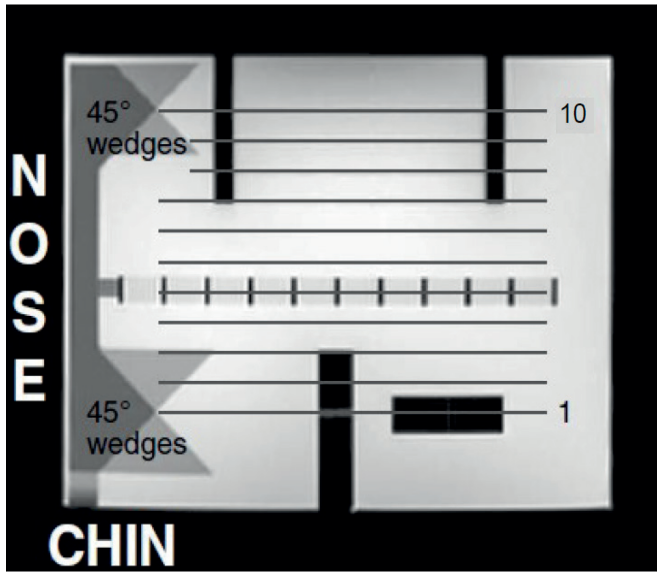

Fig. 2 - *Slice Positioning on the Localizer*

Pro-Control software and manually using the free ImageJ software.

RESULTS

The tests foremost highlighted the need for a very accurate positioning of the phantom inside the Head coil to avoid problems of non-recognition of the inserts in the automatic analysis using the proprietary software. The automated verification may in fact not recognize the thin band for the geometric verification (Fig. 3-b) if there is not a correct alignment of the slices. The manual analysis was performed following the instructions in the manual provided by the manufacturer.

Below is the detailed report of the performed measurements and the results obtained for each parameter taken into consideration.

Image uniformity (PIU%): This analysis measures the uniformity of the image intensity on a water-only region of the phantom first by recording a large ROI near the center of the volume and then another near the center of the coil. Failure to pass the test indicates a possible head coil defect (incorrect calibration, gradients, eddy currents or a problem in the radiofrequency subsystems) or B_0 field instability. (Fig. 3-c. Tab.3). The Limit for consistency checks is PIU% ≥ 87.5%.

Ghost - Artifacts: The parameter evaluates the artifacts for which a copy (ghost) of the object appears superimposed on the image, but displaced from its true position (in the direction of the phase encoding). Many artifacts may not be recognizable as copies of the object but simply appear as a patch of signal emanating in the direction of the phase encoding from the brightest regions of the actual image. It can be a consequence of the instability of the signal between the repetitions of the pulse cycle or causes that can be the same on those of the previous test. (Fig. 3-c. Tab. 4). Limit for constancy checks: ghosting ratio ≤ 0.025.

Geometric Distortion

This test examine the accuracy with which the image represents the lengths of the object and predicts 7 measurements of known lengths inside the phantom. The most common cause of failure of this test is that one or more gradients are not calibrated correctly. A poorly calibrated gradient causes an incorrect measurement of its associated size (x, y or z). This can also cause section position errors. (Fig. 3-b. Tab. 5). The maximum deviation shown in the table also refers to the measurements taken in the left and right quadrants of the slice. Limit for consistency checks: Maximum measurement difference = ± 2 mm.

Slice Placement Accuracy: The analysis evaluates the accuracy with which slices are acquired after placement through the locator. Exceeding the limits for this test means that the actually obtained positions of the acquired slices differ too much from the prescribed positions. (Fig.3 – a-d. Tab. 6) and may be due to an error in the gradients or to instability in the B_0 field. Limit for consistency checks: Slice deviation from the vertex of the cross wedges <2 mm.

Slice thickness: This parameter is measured through

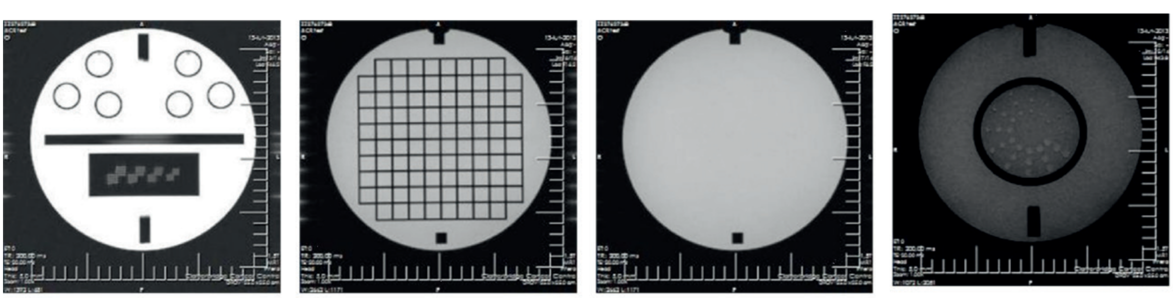

Fig. 3 - *a) b) c) d) Slice images - Pro MRI phantom*

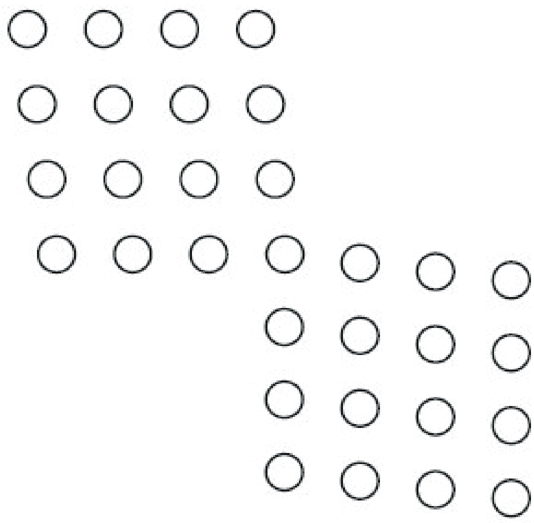

Fig. 4 - *High contrast detail positioning*

an image of two inclined slits present on the plastic material with a width of 1mm and a depth of 5mm. The cause of failure in this test may be caused by radio frequency (RF) non-linearity which can produce distorted RF pulse shapes (Fig. 3-a. Tab. 7). Limit for consistency checks: Slice thickness = 5.0 mm ± 0.7 mm.

SNR of FAT and WATER: a degradation of the system's signal-to-noise ratio is usually due to an instability of the B_0 field or to an incorrect setting of the flip angle in the sequences. In our measurements, we found an imperfect correspondence of the pixel value in the ROIs within the inserts compared to those of the automatic analysis, probably due to the incorrect positioning of the ROIs by the software. (Fig. 3-a. Tab 8). Limit for consistency checks: SNR deviation from acceptance test ≤ 10%.

Low Contrast Resolution: The ability to detect objects with low contrast differential to the background is determined by the contrast-to-noise ratio (CNR) of the image and can be affected by the presence of ghost artifacts. The phantom consists of a series of 4 polycarbonate discs with thickness 0.05-0.1-0.15 and 0.2 mm whose contribution in partial volume with respect to the filling solution produces a differential contrast of 1.4- 2.5- 3.6 and 5.1% respectively. Each disc contains 12 groups of 3 holes arranged in a radial pattern in which the holes of each spoke have the same diameter and the range of diameters goes from 7.0 to 1.5 mm (0.5 mm pitch). Manual evaluation is performed by counting on the monitor the visible details and adding up the number of complete rays in each slice. The number such possible is 12 * 4 = 48 rays. Given the inter-observer variability, the report is not included in the present work (Fig.3-d). Limit for consistency checks: total score> 9 for MRI <3 Tesla.

Spatial resolution: The high contrast resolution represents the ability of a system to distinguish two single elements close to each other. The manual evaluation of this is performed by evaluating on the monitor the visibility of four matrices of holes with decreasing diameters (1.1, 1.0, 9.0, 0.8 mm).

Given the inter-observer variability, the report is not included in this paper. (Fig. 3 – a). Failure of this test means that for that FOV and Matrix the scanner cannot distinguish details. Limit for constancy checks: Spatial resolution> 1mm.

As explained in the following table, each verified parameter indicates different characteristics of the system and often it is not immediate to identify the real problems starting from the failure of one of the tests described above.

CONCLUSIONS

The analisys showed a substantial overlap of the values found manually with respect to the automatic reports of the dedicated software but also the evidence that these checks fail to bring out, from the point of view only of the pass / fail criteria, the real quality of the images. In fact, although it is clear (especially from the measurements relating to the uniformity -Tab3 and the Ghosting ratio Tab4) that the RM3 is qualitatively lower, it is still well within the tolerance ranges to allow for clinical use. The MR safety expert, in agreement with the Physician Responsible for Clinical Safety, is evaluating to decrease the range of acceptability of some limits suggested by the reference documentation with particular regard to the artefacts (ghosting) in the images in order to be able to suggest interventions by the company manufacturer for the restoration of the conditions of acceptance of the equipment.

	Signal to Noise Ratio	Geometric Distortion	Uniformity	Spatial Resolution	SliceThickness - Slice Positioning	Artifacts - Ghosting	T1 and T2 Accuracy
Frequency Resonance	x						x
Stability Field B0	x	x	x		x	x	x
Calibration, intensity linearity gradients		x	x	x	x	x	
Eddy currents			x			x	
Flip Angle Accuracy	x						x
Radio frequency calibration			x			x	

Tab. 2 - *Verified parameters / System characteristics*

	MR1			MR2			MR3		
	SW Calc.	manual Calc.	DEV %	SW Calc.	manual Calc.	DEV %	SW Calc.	manual Calc.	DEV %
ACR T1	96,78	96,49	-0,30%	95,45	94,10	-1,41%	92,46	90,60	-2,01%
ACR D.E. ECHO2	96,99	95,66	-1,37%	95,79	94,64	-1,20%	92,63	90,69	-2,10%

Tab. 3 - *Uniformity - PIU%*

	MR1		MR2		MR3	
	SW Calc.	manual Calc.	SW Calc.	manual Calc.	SW Calc.	manual Calc.
ACR T1	0,0001039	0,0001122	0,000034	0,00007533	0,004782	0,003074
ACR D.E. ECHO2	0,0001832	0,0001909	0,00003	0,00004800	0,001015	0,001261

Tab. 4 - *Ghosting Ratio*

MR1					MR2					MR3				
SW Calc.		manual Calc.		Dev	SW Calc.		manual Calc.		Dev	SW Calc.		manual Calc.		DEV
Horizontal [mm]	Vertical [mm]	Horizontal [mm]	Vertical [mm]	MAX	Horizontal [mm]	Vertical [mm]	Horizontal [mm]	Vertical [mm]	MAX	Horizontal [mm]	Vertical [mm]	Horizontal [mm]	Vertical [mm]	MAX
173,68	173,46	173,74	173,98	0,56%	174,20	172,80	174,56	173,83	0,60%	172,93	172,34	172,36	173,34	0,88%
173,65	173,49	173,73	173,96	0,56%	174,14	172,98	174,22	173,86	0,51%	172,86	172,42	172,29	172,91	0,69%

Tab. 5 - *Geometric Distortion*

MR1					MR2					MR3				
SW Calc.		manual Calc.		DEV	SW Calc.		manual Calc.		dev	SW Calc.		manual Calc.		DEV
first slice	last slice	first slice	last slice	MAX	first slice	last slice	first slice	last slice	MAX	first slice	last slice	first slice	last slice	MAX
0,98	0	0,92	-0,94	1,86	0,98	0	0,9	0,95	0,98	0,98	0	0,94	0,94	0,98
0,98	0	0,92	0	0,98	0,98	0	0,9	0,9	0,98	0,98	0	0,94	0	0,98

Tab. 6 - *Slice positioning*

	MR1			MR2			MR3		
	SW Calc.	manual Calc.	Dev mm	SW Calc.	manual Calc.	Dev mm	SW Calc.	manual Calc.	Dev mm
ACR T1	4,89	4,71	0,18	5,22	5,59	-0,37	5,22	5,56	-0,34
ACR D.E. ECHO2	4,79	4,62	0,17	4,83	5,29	-0,46	4,83	5,27	-0,44

Tab. 7 - *Slice Thickness*

	MR1						MR2						MR3					
	SW Calc.		manual Calc.				SW Calc.		manual Calc.				SW Calc.		manual Calc.			
	FAT MEAN	FAT SD	FAT MEAN	FAT SD	SNR sw	SNR man	FAT MEAN	FAT SD	FAT MEAN	FAT SD	SNR sw	SNR man	FAT MEAN	FAT SD	FAT MEAN	FAT SD	SNR sw	SNR man
ACR T1	144,96	6,83	183,00	9,80	21,22	18,67	251,20	11,13	250,00	10,00	22,57	25,00	126,32	27,82	102,30	11,74	4,54	8,71
ACR D.E. ECHO2	196,32	6,04	272,00	7,90	32,50	34,43	324,71	11,89	321,00	9,80	27,31	32,76	355,80	106,66	263,00	12,00	3,34	21,92
	WATER MEAN	WATER SD	WATER MEAN	WATER SD	SNR sw	SNR man	WATER MEAN	WATER SD	WATER MEAN	WATER SD	SNR sw	SNR man	WATER MEAN	WATER SD	WATER MEAN	WATER SD	SNR sw	SNR man
ACR T1	836,03	21,34	1098,00	47,00	39,18	23,36	1291,74	32,50	1272,00	29,00	39,75	43,86	587,00	26,73	490,80	15,50	21,96	31,66
ACR D.E. ECHO2	630,14	83,21	903,00	42,00	7,57	21,50	1044,50	54,18	1020,00	43,60	19,28	23,39	540,91	32,98	857,00	94,00	16,40	9,12

Tab. 8 - *SNR Fat e Water*

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