The HAMILTON-MR1 in the MRI environment

An evaluation at Primary Children's Hospital, Salt Lake City, Utah / USA

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Introduction

Each year an increasing number of MRI tests are performed on intubated and ventilated ICU patients. A limited number of ventilation devices meet the strict requirements to be used in the MRI suite. A device must first be approved for MRI use as being either MR Safe or MR Conditional. A search for MRI-capable ventilators indicated that most ventilators fall into the MR Conditional group. Hamilton Medical has recently received FDA approval for the HAMILTON-MR1 ventilator for use in the MRI suite. With previously used microprocessor-controlled ventilators, image artifact or "noise" became an issue for Primary Children's Hospital. A particular test sequence was performed on the MR system under the direction of the manufacturer to validate the use of the HAMILTON-MR1 ventilator inside the MR scan room. This test (termed "Coherent Noise" per GE Healthcare) is designed to detect the presence of external electromagnetic frequencies inside the MR scan room that are within the operational bandwidth of the MR system electronics, and thus have the potential to interfere with the diagnostic quality of the MR imaging.

Methods

A HAMILTON-MR1 ventilator (Hamilton Medical, Reno NV) with a shielded power supply and non-ferrous trolley was the tested ventilator. The HAMILTON-MR1 is FDA approved as an MR Conditional device. Setup was completed by a Hamilton Medical technician. A Hamilton Medical coaxial breathing circuit with an adult/pediatric flow sensor was used in the testing. Either a 3.0 m or 4.8 m circuit was used, depending on the required positioning of the ventilator for a successful test. The ventilator was precalibrated outside of the MR scan room according to Hamilton Medical setup instructions.

Hamilton Medical-provided literature states that the HAMILTON-MR1 ventilator must be placed at such a distance from the scanner that the measured magnetic field range is 50 mT or less (approximately 1 m from the front of a 3T MRI scanner). The HAMILTON-MR1 ventilator is unique in that it has an integrated gaussmeter called TeslaSpy. A green indicator denotes the ventilator is at a safe distance from the MRI magnet. A yellow indicator denotes the HAMILTON-MR1 is too close to the MRI magnet.

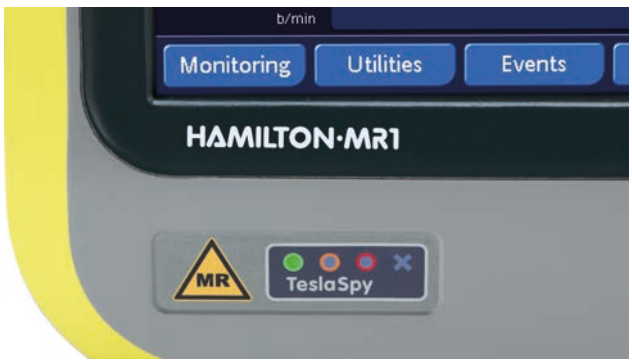

Figure 1: Integrated gaussmeter TeslaSpy

For this test, the HAMILTON-MR1 was moved until the TeslaSpy device changed indicator colors from green to yellow to indicate the device was too close to the MRI magnet. The ventilator was then positioned 1 foot further away from the scanner opening so that the TeslaSpy displayed a green

indicator, denoting the ventilator was at an acceptable distance from the scanner (50 mT or less magnetic field strength).

Each MRI suite was tested without the HAMILTON-MR1 ventilator to verify a passing Coherent Noise test result. The ventilator was then placed in each suite and tested under two load conditions: low load and high load. In each ventilator test, the ventilator was run at 21% oxygen to use the full power of the turbine drive system to create the worst case possible potential EMF noise from the turbine. The ventilator was also plugged into AC wall power in the room. Oxygen was not used so the ventilator was not plugged into the wall oxygen supply.

The first test was a low-load condition with the following settings: Tidal volume 80, respiratory rate 25, PEEP 5. The lung used for this test was a Venti Plus model 2005 pediatric test lung (Respiralogics, San Marcos Ca.) with resistance set to 5 cmH20/l/s and compliance set to .01 l/cmH2O. The second test was a high-load condition with the following settings: Tidal volume 300, respiratory rate 20, PEEP 20. The lung used for this test was a TL2 test lung (South Pacific Biomedical, Temecula Ca.) with resistance set to 5 cmH20/l/s and compliance set to .05 l/cmH20. The test lung and circuit were placed directly in the MRI scanner at the approximate point where the patient's head would be during a scan. Peak pressure for the low-load scan was 19 cmH2O. Peak pressures for the high-load scan were 48 - 50 cmH20.

Testing was performed using both a 3.0T MRI HDXt scanner running software 23.1 (GE Medical, Waukesha Wi.) and a 1.5T MRI HDXt scanner running software 16 v02 (GE Medical Milwaukee Wi.). The standard head coil and internal body coil for both machines were used. The test type used was a Coherent Noise test. Each Coherent Noise test was completed twice for each load condition in each MRI suite. To pass a test, the ventilator had to successfully complete both runs of the Coherent Noise test.

Results

In the low-load condition settings, the device was placed approximately 1 m from the opening of the MRI scanner according to the TeslaSpy gaussmeter indicators. A 3.0 m breathing circuit was used. This setup, settings, and ventilator position passed the Coherent Noise test.

The ventilator was then placed into the high-load conditions. The ventilator was positioned 1 m from the MRI scanner opening. This setup, settings, and ventilator position failed the Coherent Noise test. A second test was completed with the AC power disconnected from the wall using only internal battery power. The ventilator was positioned 1 m from the MRI scanner opening. This setup, settings, and ventilator position also failed the Coherent Noise test. Note that AC power noise was also in evidence using other MRI-compatible ventilators in this MRI suite during clinical use. For the next set of tests, the longer 4.8 m circuit was connected to the ventilator, and the ventilator was plugged back into AC power. The ventilator was moved to the end of the bed platform, approximately 2 m from the MRI scanner opening. This setup, settings, and ventilator position passed the Coherent Noise test.

Figure 2: Ventilator positioning for low-load test with 3T scanner

In low-load conditions with the 1.5T scanner, the device was placed directly next to the MRI scanner opening. The ventilator was plugged into AC power. This setup, settings, and ventilator position passed the Coherent Noise test.

Figure 3: Ventilator positioning for high-load test with 3T scanner

The ventilator was then changed to high-load settings. The positioning of the ventilator was not changed. This setup, settings, and ventilator position failed the Coherent Noise test. The ventilator was then moved to the end of the bed

platform, approximately 2 m from the MRI scanner opening. This setup, settings, and ventilator position passed the Coherent Noise test.

Conclusion

The HAMILTON-MR1 passed all Coherent Noise testing after adjusting the placement of the device. In the 3.0T and 1.5T environments, the best placement for the ventilator using adult or high-load patient settings may be at the foot of the bed, approximately 2 m from the MRI scanner opening. It may be possible to place the ventilator between 1 and 2 m from the scanner opening, but we did not test those distances. With the 3T scanner, the ventilator should be placed a minimum of 1 m away from the scanner opening. With the 1.5T scanner, the ventilator can be placed directly next to the scanner opening. The ventilator delivered all breaths without alarms or other breath-delivery issues at both the low- and high-load settings.

Discussion

The purpose of this test was to determine whether the HAMILTON-MR1 ventilator could pass the Coherent Noise test. The Coherent Noise test was designed by GE Healthcare (the manufacturer of the MR systems used at Primary Children's Hospital) and serves to establish a baseline for acceptable levels of electromagnetic interference within the MR scan room. The test listens for the presence of external electromagnetic frequencies inside the MR scan room that are within the operational bandwidth of the MR scanner electronics. In the event that a device being used inside the scan room is emitting such frequencies, it could result in image artifacts (specifically "zipper" artifacts as termed by the diagnostic imaging industry), which could interfere with the diagnostic significance of the patient images. A passing or successful result of the Coherent Noise test validates that no such frequencies exist inside the scan room, and thus proves that any device(s) inside the scan room (such as the HAMILTON-MR1 ventilator) are cleared for use without suspicion of interfering with the MR system.

In the testing of the 3T and 1.5T scanners, it was noted that placement of the ventilator at a distance of 1 m from the center of the scanner magnet resulted in the ventilator failing the Coherent Noise test during high-load testing. In actual patient scenarios, a PEEP of 20, peak pressure of 50 cm, and an FiO2 of 21% would not be clinically applicable. The test parameters called for the highest ventilator power output possible with available lung-testing equipment. There could potentially be a point closer than 2 m at which an acceptable image could be acquired for high ventilator load conditions. Proper placement for adequate image acquisition depends on several nonventilator factors, including brand and type of scanner, test being performed, and image quality required. If unacceptable visual noise is noted on a scan, the 4.8 m circuit must be available to allow the HAMILTON-MR1 to be placed further from the scanner opening. There was additional length available to move the ventilator further away from the scanner opening during testing. Due to Hamilton Medical's use of proximal flow sensor technology, lengthening the circuit should have minimal effect on increased work of breathing or additional dead space issues. The other consideration is that while the TeslaSpy indicator provides information on protection of the ventilator from possible damage, it is not intended to correlate to image acquisition quality. The Tesla spy showed green, or within an acceptable range, for all tests throughout the testing phases.

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