

Electromagnetic Interference from Auto Identification Systems May be Diminished Using IEEE 1902.1, A Low Frequency, Magnetic Field Based Protocol, in Healthcare Settings

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ABSTRACT

Background

Utilization of automatic identification systems for patient care and hospital assets has been suggested to improve patient safety and reduce medical costs. However, prior studies have suggested a high risk of electromagnetic interference (EMI) from radiofrequency identification (RFID)-based technologies on hospital equipment. We sought to evaluate the likelihood of EMI on medical equipment with a novel low frequency, magnetic-field based autoidentification protocol.

Methods

Testing was performed with an FDA-approved non-significant risk low-frequency autoidentification system (RuBee, Visible Assets, Incorporated). Thirty-three medical devices were tested for EMI by a biomedical engineer skilled in use of the equipment and a clinician knowledgeable in operation of the various devices. Testing was started at 4 feet and the device was approached in 1 foot increments with the signal antenna during which the clinician watched for any evidence of EMI. If EMI occurred, the type of EMI, distance at which EMI occurred, and magnetic field strength at the time of EMI were recorded. EMI was characterized as light, significant, hazardous, or none. All devices were tested to ensure normal operation prior to and after testing.

Results

Of 32 tested devices, light to hazardous EMI was seen in 8 (25%). Hazardous EMI was seen in 2 12-lead ECG machines, significant EMI in fluoroscopy, echocardiograms, and one of five cardiac monitors, and light EMI in a defibrillator and a cardiac monitor. Average magnetic field strengths were similar at each distance regardless of the presence of EMI. No EMI was recorded with any device at distances greater than 4 feet, with no loss of signal fidelity at distances up to 17 feet.

Conclusions

A low frequency, magnetic field based autoidentification system induced minimal EMI in a healthcare environment and all EMI was distance dependent. Thus, this system may provide a safe alternative to existing higher frequency RFID-based protocols. However, implementation in critical care, operative, or other high technology areas require *in vivo* testing with a patient or patient simulator connected to ensure the antenna is located at a safe distance from medical equipment.

KEY WORDS: Autoidentification system, Electromagnetic interference,

INTRODUCTION

Technological advances over the past decade have improved patient safety and outcomes, though at the expense of healthcare costs, which have increased from \$75 billion in 1970 to \$2 trillion in 2005 and are estimated to increase to \$4 trillion by 2015. [1-4] Autoidentification technologies such as radiofrequency identification (RFID) have been proposed as a means by which to potentially decrease costs and further improve patient safety. [5-9] In fact, the 2008 Fifth Annual Survey of Health Information Exchange at the State and Local Levels suggested a direct link between the exchange of health information electronically and improved efficiency, reduced costs, and better patient outcomes. [10] Thus, total expenditures on RFID-based electronic systems are expected to grow significantly to a projected \$2 billion in 10 years. [11, 12]

One reason autoidentification protocols may offer safety and cost benefits is the ability to individually track patients, medical equipment, and devices. Thus, product-encoded tags may be used to “mark” devices, equipment, or pharmaceuticals for specific patients, which may then be tracked through a central hub, thereby reducing risks of inappropriate administration and reducing costs from manual data entry. Furthermore, advances in technology may permit incorporation into products or patients to automatically sense a variety of patient, product, or climate parameters, such as the temperature of stored blood products [9] or a patient’s glucose via an implanted intravenous line. [13]

However, one of the inherent difficulties with the establishment of novel technology, particularly wireless technology, in the healthcare setting is the potential for interference with other electronically complex devices and equipment. In many cases, the risk of electromagnetic interference (EMI) may unpredictably vary between devices, as in the case of cell phones. [14-16] Both assumptions and published data regarding the risk of EMI of novel technology with medical equipment have the potential to alter practice patterns and regulations regarding the use of these devices.

The risk of EMI with autoidentification technologies such as RFID is unclear due to the dearth of research on the safety of such technology in the healthcare setting. [17,18] One recent study suggested that there may be significant EMI from RFID in critical care medical equipment. [18] EMI was judged to be distance and frequency dependent with the most significant EMI occurring at higher frequency (868 MHz versus 125 MHz) at almost direct contact. However, this study used only 2 RFID systems that may have had differences in shielding and did not take into account newer protocols which may offer alternatives to RFID.

One technology that is being studied for application to healthcare systems is lower frequency, Long Wave (LW) magnetic signal based protocols. [19, 20] These differ from RFID in that they work in the low frequency (131 kHz) band and primarily use the magnetic field, thereby offering the benefits of longer battery life and diminished signal effects of liquids or steel. However, the likelihood of EMI with low frequency, magnetic field-based systems on medical equipment is unknown. Thus, we sought to identify and characterize potential EMI with this autoidentification system.

METHODS

Autoidentification System

The low frequency, magnetic field based autoidentification system chosen was RuBee (IEEE 1902.1, Visible Assets, Incorporated), which is currently used principally in non-healthcare systems such as the Department of Energy and Department of Defense. The RuBee protocol was recently awarded FDA approval for use in healthcare settings after being judged as non-significant risk, having met power and human safety recommendations. [19] The system uses a

two-way radio tag and a 131 kHz data carrier. Due to the long wavelength, minimal energy is dissipated in the form of an electric field (0.01%) with most radiated energy in the form of a magnetic field (99.99%). To ensure reliable communication, a signal range of 0.1 to 3 mGauss is needed. The strongest field generated when in direct contact with a RuBee antenna is 800 mGauss, which decreases to 2 mGauss at about one meter from the antenna. Thus, RuBee meets government and published specifications for safe electric and magnetic field levels when used in close proximity to medical devices and equipment.

A standard autoidentification system is composed of tags and readers. In RFID systems, tags may be passive, in which case they have no internal power and are activated by the electromagnetic field generated by the reader, or active, in which case they are operated by batteries and can broadcast information such as identity without being activated by the reader. [21] The RuBee system's tags, similar to active RFID tags, have their own power supply and thus do not rely on an external field to operate. Part of the reason for choice of this system lies in its current use in asset visibility tracking in similar environments to those used for RFID systems.

Medical Equipment

A total of 32 devices were evaluated according to American National Standard Institute recommendations (ANSI C63.18). [22] **[Table 1]** In most cases, EMI testing was performed during full operation with inputted nominal parameters without a patient connected. Exceptions included 12-lead electrocardiogram acquisition, echocardiogram acquisition and heart rate monitoring in which case testing was performed with a simulator and/or patient connected. IRB approval was obtained prior to testing with an adult patient. All equipment was tested in an operating room (Holy Cross Medical Center, Miami, FL USA), post-anesthesia care unit (Mayo Clinic, Rochester, MN USA) or cardiac electrophysiology lab (Mayo Clinic, Rochester, MN USA). All equipment not involved in testing was turned off to minimize background noise.

Testing Protocol

Prior to testing, all devices were checked for normal operation and inputted with nominal parameters. In the case of echocardiography, ultrasound, 12-lead electrocardiogram, or cardiac monitors, either a simulator or actual patient was connected to the device. Upon ensuring normal baseline operation, the RuBee system was oriented relative to the device as shown in **Figure 1**. The testing system consisted of a DIMETIX laser which emitted a standard beam of energy against either a ranger or RPM transceiver antenna that was placed between the laser and the device. Either an asset tag in the case of devices or patient tag when working with devices to which a patient was connected was attached to the device and/or patient. **[Figure 2]**

Initial tests were performed at 4 feet away from the medical device and then the antenna was brought towards the device, simulator, or patient at 1 foot increments up to direct contact. At each distance, the average magnetic field strength was recorded. If EMI occurred, the type of EMI was recorded in a spreadsheet. A maximum of nine tests was performed for each device with the RuBee tag placed on the left, right, and top of the medical device and with the antenna oriented in any of 3 spatial planes (coronal, sagittal, or transverse). The laser and antenna were connected to a central computer via a transceiver blaster and signal fidelity and magnetic field strength were recorded at each distance between the laser and antenna. If EMI was seen at greater than 1 foot from the device, then both antenna and laser were placed a maximal distance from the tag and device (about 9 feet) to determine signal fidelity and the maximal distance at which EMI may still be present.

Upon completion of EMI testing, all devices were re-evaluated at initial parameter settings in order to ensure proper operation and if there were any after-effects from the testing.

Interference Classification

Interference was classified as hazardous (unintended change in equipment function with direct effect on patient outcome, eg, total stop of a syringe pump, a device turning off, or unexpected alteration in parameters from initial settings), significant (influence on monitoring with significant level of attention needed causing substantial distraction from patient care, eg, incorrect alarm or inaccurate monitoring), light (influence on monitoring without significant level of attention needed, eg, a display abnormality), and no effect. [18, 23, 24] When interference was seen, additional testing was performed to verify the interference including adjustment of equipment orientation and determining maximum possible distance the antenna could be placed from the medical device without loss of signal fidelity.

Pictures or print outs were taken of all equipment during active operation. An internist and/or technician with experience with the equipment was present at the time of testing in order to determine if any EMI was present.

Statistical Analysis

In order to determine if a significant difference was present in magnetic field strength between devices where light EMI, significant EMI, hazardous EMI, and no EMI was seen, an independent value t-test was performed. A 2-sided P value <0.05 was considered significant.

RESULTS

A total of 32 devices were subjected to testing [Table 1] and a total of 8 (25%) encountered EMI at some time during testing. [Table 2] Of these, 2 experienced hazardous interference, 3 experienced significant interference, and 3 experienced light interference. Only 1 device experienced interference at >3 feet away and this device was re-tested at distances up to 9 feet and no EMI was noted at 5 feet though light interference was consistently encountered at 4 feet. All EMI incidents were reproducible on testing regardless of location of the tag on the device or of the orientation of the antenna in the sagittal, coronal, or transverse plane.

The majority of devices were tested without a simulator or patient connected. The exceptions to this were the cardiac monitors (2a, 2b, 2e), 12-lead ECG machines (11a, 11b), and echocardiogram/ultrasound machines (9a, 9b, 9c), and fluoroscopy systems (10a, 10b). [Table 1] The only episode of EMI noted amongst these devices was a flickering monitor on a HP CodeMaster defibrillator, though no EMI was encountered with the Zoll defibrillator. The other devices tested without an attached simulator or patient did not exhibit any EMI. Specifically, no change in nominal parameters inputted into the system, monitor function or other alteration in normal functioning was seen.

The only devices in which hazardous EMI was encountered were the 12-lead ECG machines. (Figure 4). At distances up to 4 feet, light EMI was recorded which consisted of extra waves noted on the ECG strip (Figure 4b). EMI testing was repeated from 9 feet away 9 separate times from different orientations. In all cases, no EMI was encountered greater than 4 feet from the device or electrodes. When the ECG machine was moved 7 feet away from the patient with electrodes still attached, no EMI was encountered when the antenna was brought towards the ECG machine but only when the antenna was brought towards the electrodes. To further determine if this was principally an issue with EMI with the sensing electrodes rather than the ECG machine, V1 and V6 were removed and the extra waves were encountered in all leads except V1 and V6. Thus, the EMI was felt to be caused by interference with the sensing electrodes rather than the device itself. Similar findings were noted with the 3-lead ECG

acquired using the Datex-Ohmeda monitor, though EMI only occurred at direct contact and was considered significant rather than hazardous. [Figure 4a]

Other examples of EMI included loss of image integrity with echocardiography and image artifact with fluoroscopy. [Figure 5] These episodes were considered light to significant depending on the degree of loss of image quality.

In all cases, signal fidelity from the tag to the antenna remained intact 9 feet from the device. Further testing confirmed that signal fidelity could be maintained as far as 17 feet. For each EMI test performed, the average magnetic field strength was calculated at each incremental distance between the device and the antenna. Average field strengths in mGauss are summarized in Table 3. There were no significant differences in field strength between EMI types at any given distance.

DISCUSSION

While there is some risk of EMI with low-frequency, magnetic-field based protocols on medical equipment, this appears to be rare and only at close range. Furthermore, unlike previous studies on EMI with higher frequency RFID protocols [18], the only episodes of hazardous interference occurred with the 12-lead electrocardiogram electrodes in the form of signal artifact. These findings are consistent with prior tests performed on implantable cardiac devices where no EMI was seen. [25]

The EMI effects in our study were distance-dependent, with much greater EMI seen at direct contact with the electrodes used for 12-lead acquisition, where the interference was hazardous, than at 4 feet away, where the interference was light. Other interference principally occurred at direct contact with the electrodes in the case of the cardiac monitors or with the fluoroscopic head in the case of fluoroscopy. Furthermore, EMI was seen with only one of two separately tested fluoroscopes, suggesting that different models of the same type of device may have different susceptibilities to EMI.

Based on our results, it would appear that a low-frequency, magnetic-field based autoidentification system is relatively safe in the clinical setting, as long as precautions are taken to maintain the antenna at a minimum of 4 feet from medical equipment and the patient. However, because there is some variability in EMI, ranging from none to hazardous, it would appear necessary that care be taken in any new clinical setting where such a system is implemented. These considerations, however, should extend to the clinical adoption of any medical equipment which relies on wireless technology or may generate significant electrical or magnetic fields because there will always exist some risk of novel EMI. [26]

Furthermore, our study and the study by van der Togt et al [18] raise the importance of systematically testing autoidentification systems as unique entities. Namely, each system should be tested separately with the recognition that there is a potential for EMI with any new wireless system, especially with higher frequency systems.

Finally, while our study was adapted for application of an autoidentification system to a clinical setting, the potential implications for use of such systems in retail and industrial outlets must also be considered. An increasing number of patients carry increasingly complex implanted devices, either located internally or externally. The risk of EMI with certain autoidentification systems at close range with these patients' medical devices should be a consideration when deciding on choice of autoidentification system, antenna placement and implementation. It would appear that

lower frequency systems, such as the one used in our protocol, would be safer than higher frequency protocols, such as those used in previous studies. [18]

However, the benefits of autoidentification systems in healthcare cannot be discounted. [12, 27] Autoidentification systems may improve patient safety and reduce costs by reducing the need for manual data entry, which may often lead to clerical, accounting, and medical errors. The goal of implementation should include consideration of the real possibility for EMI in either designing the equipment or application of already designed elements to the clinical arena.

Limitations

It is not clear if these results extend to other low-frequency or magnetic-field based protocols because only one set of chips was used for testing. Furthermore, it is unclear how the EMI identified in our study may extend to medical equipment not included in our study. As EMI was only identified with active clinical use of medical equipment, it is possible that other significant EMI may occur in the clinical setting that was not noted during *in vitro* testing of some equipment.

Another limitation is we did not test how the presence of multiple RFID tags or operation of multiple different pieces of medical equipment may affect EMI. Thus, in clinical settings where multiple pieces of equipment (monitors, infusion pumps, anesthesia machines) may be operating simultaneously, it is possible that perceived EMI during single-equipment testing may be altered. This raises the importance of testing autoidentification protocols in active clinical settings to determine how a more complex electronic environment may alter both operation of the autoidentification system and its effects on surrounding medical equipment.

Conclusion

A low-frequency, magnetic field based autoidentification system appears to be a safe alternative to higher frequency RFID based systems for use in clinical healthcare settings. However, the potential for light to hazardous EMI at close distances to the patient or medical equipment raises the importance of implementing these systems with consideration for EMI in mind. Since the antenna may be located at distances up to 17 feet away from the tag without any loss of signal fidelity, it would seem reasonable to assume that a low frequency, magnetic field based system could be safely implemented in most healthcare settings.

REFERENCES

1. Testimony on Technology, Innovation, and the Costs of Health Care, Carolyn M. Clancy, MD, Directory, AHRQ before the Joint Economic Committee, July 9, 2003.
2. How changes in medical technology affect health care costs (March 2008) – The Henry J. Kaiser Foundation Publication.
3. Newhouse JP. Medicare care costs: How much welfare loss? *Journal of Economic Perspectives*. 1992; 6: 3-21.
4. Rettig RA. Medical innovation duels cost containment. *Health Affairs*. 1994.
5. Egan MT, Sandberg WS. Auto identification technology and its impact on patient safety in the operating room of the future. *Surg Innov*. 2007; 14: 41-50.
6. Nagy P, George I, Bernstein W, et al. Radiofrequency identification systems technology in the surgical setting. *Surg Innov*. 2006; 13: 61-7.
7. Young D. RFID implementation not moving fast enough, FDA says. *Am J Health Syst Pharm*. 2006; 63: 500-2.
8. Wicks AM, Visich JK, Li S. Radio frequency identification applications in hospital environments. *Hosp Top*. 2006; 84: 3-8.
9. Dzik S. Radio frequency identification for prevention of bedside errors. *Transfusion*. 2007; 47: 125S-129S.
10. Fifth annual survey of health information exchange at the state and local levels. 2008.
11. Harrop P, Das R. RFID for healthcare and pharmaceuticals 2008-2018. IDTechEx Web site. <http://www.idtechex.com/products/en/view.asp?productcategoryid=101>. Accessed March 10, 2009.
12. Ashar BS, Ferriter A. Radiofrequency identification technology in health care: benefits and potential risks. *JAMA*. 2007; 298: 2305-7.
13. Tomek A. Implantable RFID glucose-sensing microchip for humans. 2007. VeriChip Web site. <http://www.verichipcorp.com/news/1195161153>. Accessed March 10, 2009.
14. van Lieshout EJ, van der Veer SN, Hensbroek R, Korevaar JC, Vroom MB, Schultz MJ. Interference by new-generation mobile phones on critical care medical equipment. *Crit Care*. 2007; 11: R98.
15. Tri JL, Severson RP, Firi AR, Hayes DL, Abenstein JP. Cellular telephone interference with medical equipment. *Mayo Clin Proc*. 2005; 80: 1286-90.
16. Lawrentschuk N, Bolton DM. Mobile phone interference with medical equipment and its clinical relevance: a systematic review. *Med J Aust*. 2004; 181: 145-9.
17. Saito Y, Hasegawa T, Sakamaki T. Efficiency and safety of new radiofrequency identification system in Japanese hospital. In: Kuhn KA, Warren JR, Leong TY, eds. *Studies in Health Technology and Informatics: MEDINFO 2007 Proceedings of the 12th World Congress on Health (Medical) Informatics, Building Sustainable Health Systems*. Washington, DC: IOS Press; 2007: 1478.
18. van der Togt R, van Lieshout EJ, Hensbroek R, et al. Electromagnetic interference from radio frequency identification inducing potentially hazardous incidents in critical care medical equipment. *JAMA*. 2008; 299: 2884-90.
19. Wyld DC. RuBee: applying low-frequency technology for retail and medical uses. *Management Research News*. 2008; 31: 549-54.
20. Weich C. RuBee (IEEE P1902.1) Fact Sheet. 2009. RuBee Web site. <http://www.rubee.com/Sales-SEC/RuBee-FactSheet-070109v1-6.pdf>. Accessed April 5, 2009.
21. Kabachinski J. An introduction to RFID. *Biomed Instrum Technol*. 2005; 39: 131-4.
22. Institute of Electrical and Electronics Engineers. American National Standard Recommended Practice for On-Site Ad Hoc Test Method for Estimating Radiated Electromagnetic Immunity of Medical Devices to Specific Radio-Frequency Transmitters (Standard C63.18). Piscataway, NJ: IEEE; 1997.

23. Kivlahan C, Sangster W, Nelson K, Buddenbaum J, Lobenstein K. Developing a comprehensive electronic adverse event reporting system in an academic health center. *Jt Comm J Qual Improv.* 2002; 28: 583-94.
24. US Food and Drug Administration. Draft guidance for industry and FDA staff – radiofrequency wireless technology in medical devices: issued January 3, 2007. Center for Devices and Radiological Health Webs site.
<http://www.fda.gov/cdrh/osel/guidance/1618.html>. Accessed April 3, 2009.
25. Hayes DL, Eisinger G, Hyberger L, Stevens JK. Electromagnetic interference (EMI) and compatibility of an active 131 kHz radio tag (RuBee, IEEE P1902.1) with pacemakers (PM) and ICDs. *Heart Rhythm.* 2007; 4: S398.
26. Berwick DM. Taming the technology beast. *JAMA.* 2008; 299: 2898-9.
27. Radiofrequency-identification: Its potential in healthcare. *Health Devices.* 2005; 34: 149-60.

TABLE 1 – Devices Tested

Device Category	Device Tested
1. Anesthesia Devices	a. GE Healthcare Avance S/5 Anesthesia Machine
2. Cardiac / vital sign monitors	a. Datex-Ohmeda Monitor b. Edwards Lifesciences – Vigilance Monitor c. Somanetics – Invos Oximeter – Cerebral/Somatic d. HP OmniCare e. Phillips Monitor System
3. Tourniquet system	a. Zimmer ATS 2000 Tourniquet System
4. Generator equipment for electronic operative tools	a. Stryker Core Powered Instrument Driver b. Valley Lab Force FX Electrosurgical Generator c. Arthrocare Atlas – Shaver System
5. Fluid warmer	a. Ranger Fluid Warmer
6. Patient warmer	a. Arizant Bair Hugger
7. Cardiac perfusion devices	a. Sarns-Terumo 8000 Roller Pump – 4 unit b. Medtronic S50 Bio-Console Extracorporeal Blood pump speed controller c. Sarns 8000 Cardioplegia, Arterial safety monitor
8. Laboratory systems	a. Medtronic BioTrend b. GEM Premier 3000 – Blood gas / Electrolyte Analyzer
9. Echocardiogram / Ultrasound	a. Siemens Acuson Sequoia C512 b. Siemens Acuson Sequoia C256 c. Sonosite Micro Maxx
10. Fluoroscopy	a. Siemens Artis Zee angiography system b. GE cardio angiography system
11. 12-Lead ECG Device	a. GE MAC 5000 b. GE MAC 5500
12. Operating table	a. Siemens electronic operating table
13. Infusion pumps	a. Hospira Symbiq IV pump
14. Defibrillators	a. HP CodeMaster XLT – Defibrillator b. Zoll M Series biphasic 2003 max defibrillator
15. Autologous blood recovery device	a. Haemonetics – Cell Saver 5
16. Electrophysiology ablation devices	a. Boston Scientific Maestro 3000 b. JNJ Biosense Webster Stockert 70 RF generator c. JNJ Biosense Webster Cool Flow irrigation pump

List of devices included in the study. The left column offers the device type/category and the right column the brand and device model.

TABLE 2 – EMI Encountered During Testing

Device category ¹	Device ID ²	EMI	Distance at which EMI first seen		
			<i>Hazardous</i>	<i>Significant</i>	<i>Light</i>
Anesthesia	1a	None			
Monitors	2a	Yes ³	N/A	Direct contact	N/A
	2b	Yes ⁴	N/A	N/A	1 foot
	2c	None			
	2d	None			
	2e	None			
Tourniquet	3a	None			
Generators	4a	None			
	4b	None			
	4c	None			
Fluid warmer	5a	None			
Patient warmer	6a	None			
Perfusion devices	7a	None			
	7b	None			
	7c	None			
Lab systems	8a	None			
	8b	None			
Echocardiogram / Ultrasound	9a	Yes ⁵	N/A	Direct contact	2 feet
	9b	Yes ⁵	N/A	1 foot	3 feet
	9c	None			
Fluoroscopy	10a	Yes ⁶	N/A	N/A	Direct contact
	10b	None			
12-lead ECG	11a	Yes ³	1 foot	2 feet	4 feet
	11b	Yes ³	1 foot	2 feet	3 feet
Operating table	12a	None			
Infusion pumps	13a	None			
Defibrillator	14a	Yes ⁴	N/A	N/A	1 foot
	14b	None			
Blood recovery device	15a	None			
Electrophysiology ablation device	16a	None			
	16b	None			
	16c	None			

Shown is the devices with which EMI was encountered, at how many feet, and the type of EMI. Device category and device ID are as listed in **Table 1**. ¹Categories from **Table 1**. ²Device tested from **Table 1**. ³Saw multiple spikes on ECG strip when ECG sensors approached while connected to patient; no EMI seen when approaching the monitor or ECG machine (**Figure 4**). ⁴EMI was flickering of the screen. ⁵EMI seen consisted of decreased image clarity; only seen when approached ultrasound probe, not the actual echocardiogram device. ⁶EMI was multiple lines across the screen impairing image quality (**Figure 5**) N/A = not applicable (no EMI of this type seen)

TABLE 3 – Magnetic Field Strength with EMI

Type of EMI	Distance				
	Direct contact	1 foot	2 feet	3 feet	4 feet
None	440 $\pm$ 97	445 $\pm$ 95	399 $\pm$ 157	262 $\pm$ 141	157 $\pm$ 91
Light	438 $\pm$ 180	411 $\pm$ 205	475 $\pm$ 45	323 $\pm$ 100	209 ¹
Significant	479 $\pm$ 23	451 ¹	457 $\pm$ 7		
Hazardous	446 $\pm$ 4	465 $\pm$ 28			

Shown is the average magnetic field strength (mgauss) at each distance between the antenna and device with each type of EMI. There was no significant difference in average magnetic field strength between types of EMI at any distance.

FIGURE LEGENDS

Figure 1 – Testing Procedure

Shown is a schematic diagram of the testing procedure (A) and a representative picture of the test being performed in a hospital operating room (B).

Figure 2 – Components of Autoidentification System Used for Testing

Shown are the different components of the autoidentification system used for testing. (1) The base station is connected to the laser, antenna, and computer as a relay station. (2) The asset tag (left) and patient tag (right) were applied to assets and/or patients, respectively, depending on whether or not a patient was included in the testing procedure. (3) Either a ranger (transceiver) (left) or RPM (right) antenna was used to perform testing and located between the device/tag and the laser. (4) The DIMETIX laser was aimed at the tag with the antenna separating the laser from the device. (5) The stand was used to elevate the laser to the level of the device/tag and antenna.

Figure 3 – Magnetic Field Strength / Signal Measurement

Shown is a representative graph of how magnetic field strength and signal fidelity were evaluated. Green denotes high signal fidelity while red denotes low signal fidelity. The magnetic field strength is displayed as a function of distance of the antenna from the medical device (in this case, 17' is direct contact with the device while 1' is 16' away from the device).

Figure 4 – Example of Electrocardiographic EMI

Shown are examples of EMI using the Datex-Ohmeda Monitor 3-lead system with standard 3M leads (A) and the GE MAC 5500 12-lead ECG machine (B). Note that in (A) EMI was not seen until direct contact between the antenna and the subject whereas with (B) EMI was noted as far as 4 feet away from the subject.

Figure 5 – Example of Fluoroscopic EMI

Shown is an example of EMI using the Siemens Artis Zee fluoroscopic system. At direct contact between the antenna and subject, a series of vertical or horizontal lines (depending on positioning of the antenna in the coronal versus sagittal plane) developed on the monitor. These lines disappeared with turning off of the laser and antenna.