Journal of Electromagnetic Analysis and Applications, 2014, 6, 141-155
Published Online June 2014 in SciRes. http://www.scirp.org/journal/jemaa
http://dx.doi.org/10.4236/jemaa.2014.67014

Scientific Research

Study of Electromagnetic Compatibility in Hospital Environments

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Received 24 February 2014; revised 21 March 2014; accepted 15 April 2014

Abstract

This paper presents a study on the effects of radiation from electronic equipment in hospitals. This study was performed in Argentinean, Colombian and Spanish hospitals. The work consists of two parts: a survey to determine the hospital personnel's knowledge of the problem and a technical part consisting of a measurements campaign to determine the levels of radiated electrical and magnetic fields in several hospitals due to the presence of electromagnetic interferences, such as the use of mobile phones. The study of this problem has been of special interest in countries such as the USA and Canada, and this paper attempts to convey the necessity of creating regulations that can be applied to the hospitals of the countries analyzed. More than fifty hospitals were studied in these three countries, considering the following aspects: the hospital personnel's awareness of the problem, whether the hospitals have performed previous studies of this type, the appearance of problems in medical equipment due to this interference, the origin of the interference, and the failures that have appeared in computers due to electromagnetic interference. The results show that, most hospitals have a lack of knowledge regarding this issue and that field levels above those allowed by international regulations are present. Therefore, a regulation must be established to avoid the problem.

Keywords

Electromagnetic Compatibility, Radiated Emissions, Magnetic Field Measurements, Electric Field Measurements

1. Introduction

The increase in the use of mobile communication systems and wireless devices has created awareness of the

How to cite this paper: Gutiérrez, O., Navarro, M.Á., de Adana, F.S., Escobar, A., Moncada, M.E. and Muñoz, C.M. (2014) Study of Electromagnetic Compatibility in Hospital Environments. *Journal of Electromagnetic Analysis and Applications*, **6**, 141-155. http://dx.doi.org/10.4236/jemaa.2014.67014

possible effects of electromagnetic fields in different environments, including hospitals, in which this topic is of importance because of the possible effects of these fields on patients' lives. Some of this equipment is used to monitor important physiological parameters or even to give life support to the patients, and therefore, the proper function of this equipment at all times and without interferences from external devices is important. With this concern, the FDA published, in 1979, the first regulation to address the effect of electromagnetic interferences on medical equipment [1]. Following this publication, several researchers have performed studies to investigate the electromagnetic interference in medical devices, including pacemakers [2] [3] and other medical equipment [4]-[7]. The evaluation of the effects of new wireless technologies on medical equipment continues to be a subject of study [8]-[11], and more than half of the medical equipment has been shown to present some type of failure due to electromagnetic interference. There was initial concern about the TV and FM radio frequency bands [12]-[14] and later concern regarding the cell phone band [15]-[17] because cell phones have been shown to be a crucial source of electromagnetic interference. Recently, the ISM (Industrial Scientific Medical) band has also been an object of analysis [18].

The main problem is that, even with these studies and regulations, there is a general lack of knowledge among medical personnel regarding aspects related to electromagnetic compatibility, which can affect certain diagnostics that are important to a patients' life. Therefore, these personnel need to be informed about the dangers of electromagnetic interference and a regulation needs to be established to ensure the proper functioning of medical equipment in the presence of wireless devices, which, with increasing use, are a constant problem inside hospitals. For this reason, in countries such as the US, there are regulations regarding electromagnetic interference. However, these regulations are not followed in other countries, including Argentina, Colombia and Spain, leading to a general lack of knowledge in the medical community about this problem, as will be shown in this paper.

Therefore, in this paper, the main objective is to show results that emphasize the necessity of creating a regulation in these three countries (and most likely in other countries with similar environments) to control the emission level of the equipment present in sensitive areas of hospitals. With this idea, this paper is organized as follows. After this introduction, Section 2 states the problem using the results of a survey performed in different Argentinean and Spanish hospitals, which shows the hospital personnel's lack of knowledge regarding the problem. Section 3 describes the measurement procedure used to determine the magnitude of the problem in different hospitals. Section 4 shows the most significant results of the measurements campaign, and finally Section 5 presents the conclusion of this work.

2. Statement of the Problem

Before measuring the field levels at the hospitals, this project aimed to determine the awareness of medical personnel regarding the problem of interference in the performance of the medical equipment and to see if there is any precedent in the study of electromagnetic compatibility in these hospitals and if any security measures are taken to avoid the problem of electromagnetic interference. With these objectives, a survey was performed in 55 hospitals in Argentina and Spain. **Figures 1-9** show the most important results of this survey. The result of the survey for the Spanish hospitals is shown in blue, and the result of the survey for the Argentinian hospitals is shown in red.

As shown, although the problem is slightly larger in Argentina than in Spain, there is a lack of awareness regarding this problem in both countries. Not only are the majority of personnel unaware of the problem but also between a one-quarter and one-third of the hospitals have suffered equipment damage due to interferences or unknown causes. Furthermore, in most hospitals, precaution measurements have not been taken. Therefore, this is clearly an issue that should be analyzed because there are lives at stake if these measurements are not taken.

3. Measurements

Once the problem has been identified from a qualitative perspective, its magnitude must be quantified. With this objective, several measurements were performed in hospitals in Colombia and in Spain (in Argentina, a measurement campaign could not be performed due to budget constraints). In this paper, the results of the measurements in several hospitals have been selected to illustrate the problem. Hospital Buenos Aires and Hospital San Javier in Colombia and Hospital Principe de Asturias in Spain were selected. These hospitals have been selected for the sake of brevity, and they are sufficiently representative of the tendency of other hospitals. Both the radiated electric field in radiofrequency and the magnetic field at low frequency or industrial frequency (50/60 Hz)

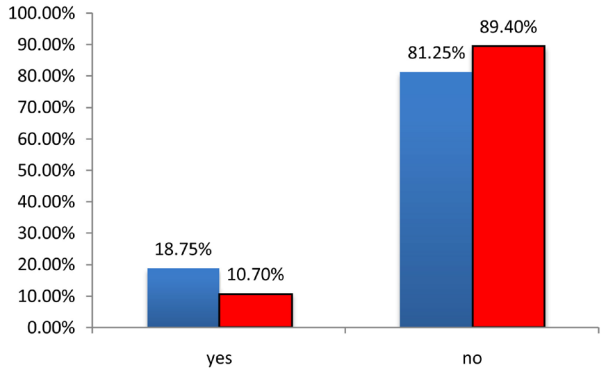


Figure 1. Hospitals with previous studies of electromagnetic compatibility.

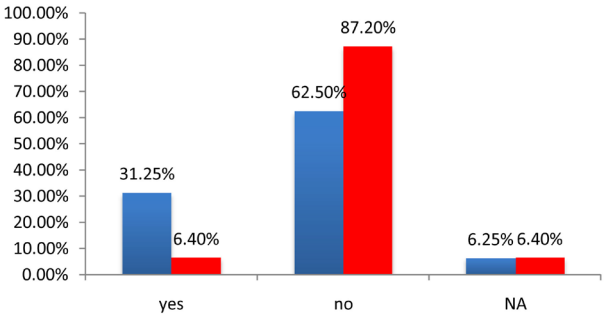


Figure 2. Hospitals with personnel familiarized with electromagnetic compatibility problems.

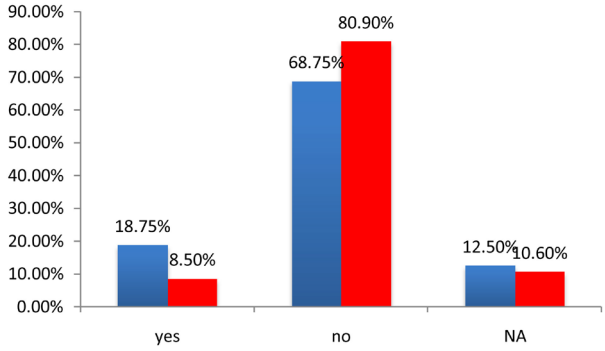


Figure 3. Hospitals with information about the emission levels of the devices.

are analyzed because the equipment in hospitals is complex and the magnetic field generated by cables or external sources, such as transmission and distribution lines or transformers, must be considered. This section describes the procedure for the measurements, the places measured in the different hospitals, and an analysis of the obtained results.

3.1. Measurements at Industrial Frequencies (50/60 Hz)

The low frequency measurements were performed with a magnetic field probe, EMDEX II in Colombia and a PMM, model EHP-50C, in Spain (**Figure 10** and **Figure 11**). In an area, the mapping method can be used to evaluate the spatial variation of the magnetic field. This method involves performing a continuous trajectory along the measurement site (covering the largest area possible) to identify the areas with the same mag-

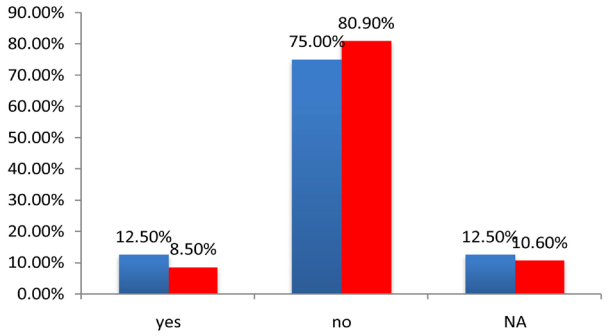


Figure 4. Hospitals with information about susceptibility levels of the devices.

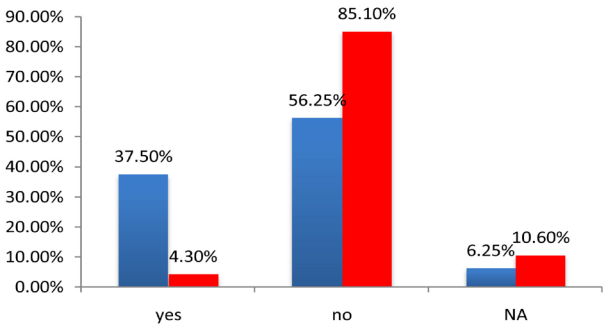


Figure 5. Hospitals with a place isolated from radio frequency signals.

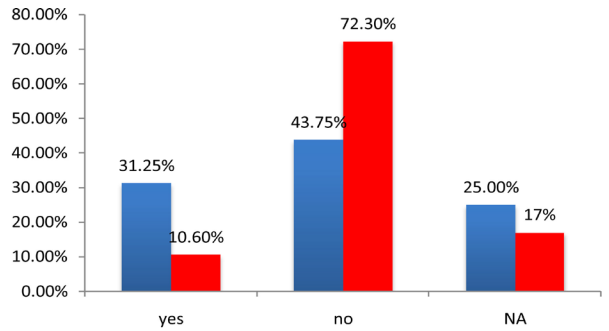


Figure 6. Hospitals that have line filters in certain places.

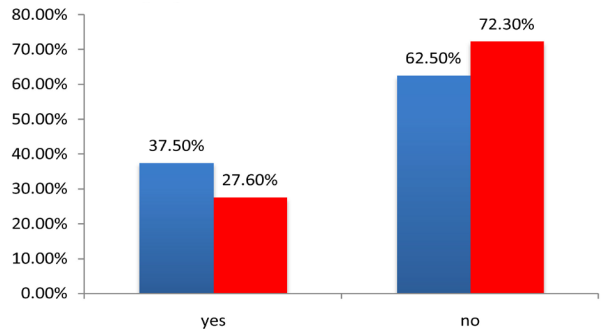


Figure 7. Damages or failures in medical equipment due to interference.

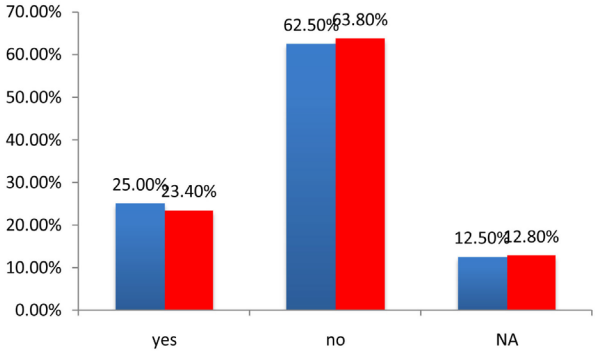


Figure 8. Damages or failures in medical equipment without identifying the causes.

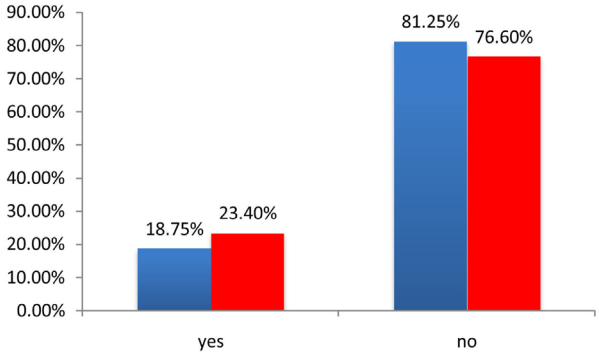


Figure 9. Hospitals with equipment or computer failures that required filtering or isolating.

Figure 10. Magnetic field probe EMDEX II used in Colombia.

Figure 11. Magnetic field probe EHP-50C used in Spain.

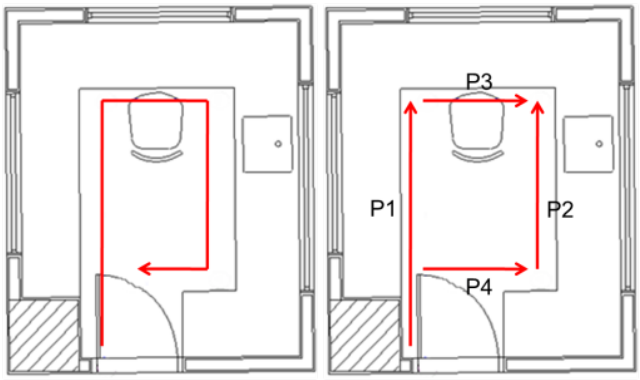
netic field values. However, due to the complexity of the hospital environment, rather than performing a continuous trajectory, profiles were measured inside the rooms (**Figure 12**). However, the profiles were limited by the amounts and positions of the various elements located inside (medical equipment, furniture, etc.). **Figure 13** shows an image of the low frequency measurement process performed in one of the birthing rooms of the obstetrics department at Hospital Buenos Aires in Colombia.

3.2. Measurements at High Frequency

An ARONIA SPECTRAN HF6015 portable spectrum analyzer with a Hyperlog 60100 antenna in Colombia and a Rodhe & Schwarz FSH4 spectrum analyzer with a Chase Bilog CCBL6112B antenna in Spain were used for the high-frequency measurements (**Figure 14** and **Figure 15**). A classical method to characterize the electromagnetic environment at high frequencies is to measure the electrical field as a function of the frequency for the frequency region of interest. The advantage of this method is that a general overview of the perturbations is obtained. For this method, the analyzer was placed in the central point of the room and a frequency sweep was performed from 800 MHz to 5.5 GHz, both for the horizontal and vertical polarizations of the antenna, which was placed one meter above the floor (**Figure 16**). **Figure 17** shows an image of the high-frequency measurement process performed in one of the birthing rooms of the obstetrics department at Hospital Buenos Aires in Colombia.

3.3. Measurement Locations

The electromagnetic field measurements at low and high frequencies were performed at different departments of several hospitals in Colombia and Spain. The results from three of these hospitals have been selected because they are representative of the results obtained. The departments in each hospital were selected according to the services provided in each department and according to the medical equipment placed inside them. **Table 1** indi-



(a) (b)

Figure 12. Different trajectories: (a) Continuous; (b) Using profiles.

Figure 13. Measurement procedure at low frequency.

Figure 14. Spectrum analyzer HF60105 and Hyperlog Antenna 60100 used in Colombia.

Figure 15. Rohde & Schwarz FSH4 spectrum analyzer used in Spain.

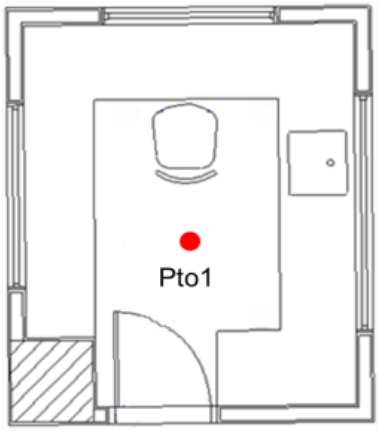


Figure 16. Example of the measurement position in the room.

cates the departments in which the measurements were performed and the number of rooms measured in each department.

4. Measurement Results

The results of the measurements were compared with the field level required by the IEC 60601-1-2 standard.

Figure 17. Measurement procedure at high frequency.

Table 1. Different departments in which the measurements were performed.

Hospital	Department	No. of rooms measured
Buenos Aires (Colombia)	Hospitalization	08
	Obstetrics	11
	Dentistry	08
	Clinical Laboratory	09
	Emergency	16
San Javier (Colombia)	Hospitalization (Plants 2 and 3)	28
	Obstetrics	15
	Dentistry	04
	Clinical Laboratory	05
	X-Ray	03
	Emergency	14
Principe de Asturias (Spain)	Hospitalization (Plant 3)	08
	Radiology	07
	Electromyography	01
	Techniques Area	06
	Consulting Rooms	04
	Emergency	04

This standard defines that all the equipment of vital assistance (critical equipment) must support a 10 V/m electrical field and that the rest of the equipment (non-critical) support a value of 3 V/m at a frequency in the range from 80 MHz to 2.5 GHz. Similarly, the standard establishes that the medical equipment must support a magnetic field of 37.8 mG at the industrial frequency (60 Hz). In the following sections, the results obtained in the three hospitals mentioned above are shown. These results are compared with the values of the standard. At high frequencies, the lowest value established by the standard is considered (3 V/m, equivalent to 129.5 dBμV/ m) due to the simultaneous presence of critical and non-critical equipment.

4.1. Hospital Buenos Aires (Colombia)

Table 2 shows the minimum, maximum and average magnetic field values at low frequency measured in the different departments of Hospital Buenos Aires. **Figure 18** shows the maximum and average values compared with the immunity level established by the IEC standard.

According to the measurement results, in the clinical laboratory and in the emergency care departments of this hospital, the immunity level was surpassed. **Figure 19** shows a contour map of the magnetic field measured in

the clinical laboratory. Two areas where the reference level is surpassed (indicated in red) can be observed. The high levels in area 1 are due to the presence of several pieces of equipment (UPS, computer, printer) in a reduced space, and the high levels in area 2 are due to a subterranean box through which electrical cables pass.

Figure 20 shows the contour map obtained from the emergency care departments. Two areas where the reference level is surpassed can be observed. The high values in area 1 are due to an infusion bomb, and the high values in area 2 are due to the development of radiographs.

Table 3 presents the maximum electric field values measured in each department of Hospital Buenos Aires. **Figure 21** shows these values compared with the immunity level established by the IEC standard. In all the departments, the measured levels are below those established by the international standard.

4.2. Hospital San Javier (Colombia)

Table 4 shows the minimum, maximum and average magnetic field values at low frequency measured in the different departments of Hospital San Javier. **Figure 22** shows the maximum and average values compared with the immunity level established by the IEC standard.

According to the measurement results, the immunity level was surpassed in the clinical laboratory and in the obstetrics, dentistry and hospitalization sections of this hospital. **Figure 23** shows the contour map of the magnetic field measured in the hospitalization section, plant 3. One area where the reference level is surpassed (indicated in red) can be observed. The high levels in this area are due to the presence of a communication system placed at the nurses' station.

Figure 24 shows the contour map obtained in the obstetrics section. One area where the reference level is surpassed can be observed. The high levels in this area are due to the presence of a distribution line, which passes outside the hospital.

Table 5 presents the maximum electric field values measured in each department of Hospital San Javier. **Figure 25** shows these values compared with the immunity level established by the IEC standard. In all the de-

Table 2. Magnetic field values at low frequency measured in the different departments of Hospital Buenos Aires.

Department	Magnetic Field (mG)		
	Maximum	Average	Minimum
Hospitalization	14.40	4.56	0.44
Obstetrics	18.50	2.96	0.64
Dentistry	5.99	1.84	1.13
Clinical Laboratory	71.90	10.90	1.18
Emergency	49.10	1.41	0.58

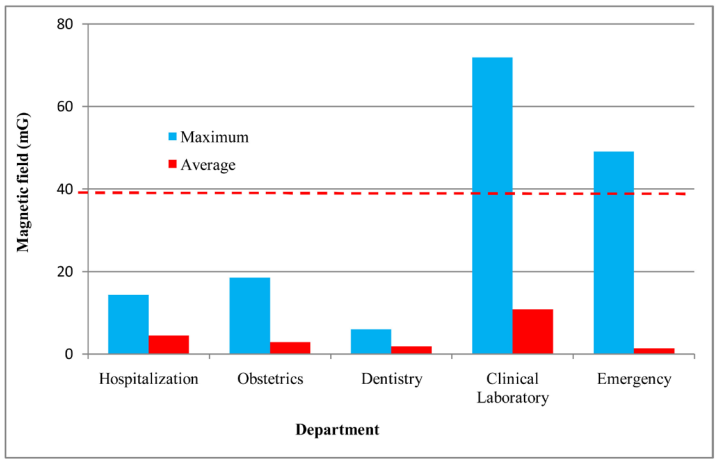


Figure 18. Maximum and average magnetic field levels at low frequency measured at Hospital Buenos Aires and level established by the IEC standard (dash line).

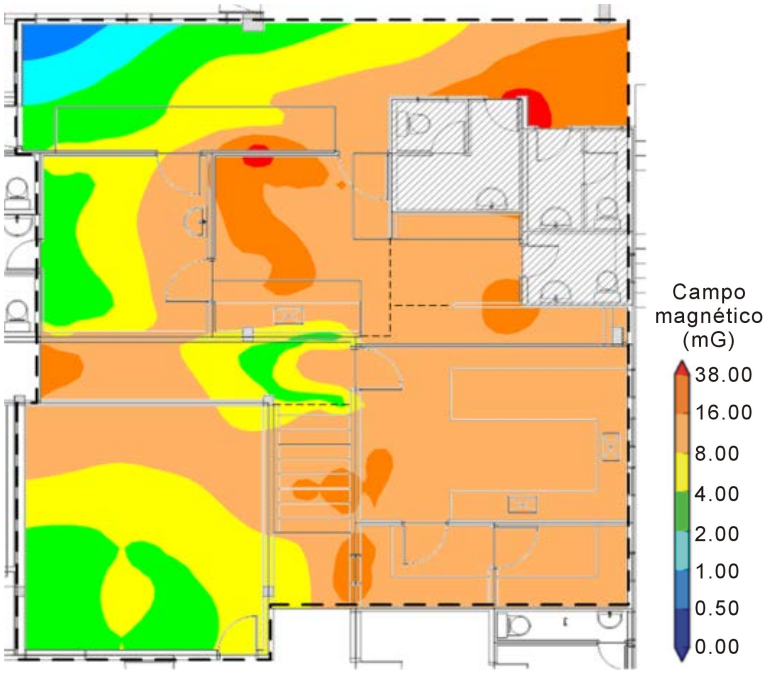


Figure 19. Magnetic field measured in the clinical laboratory.

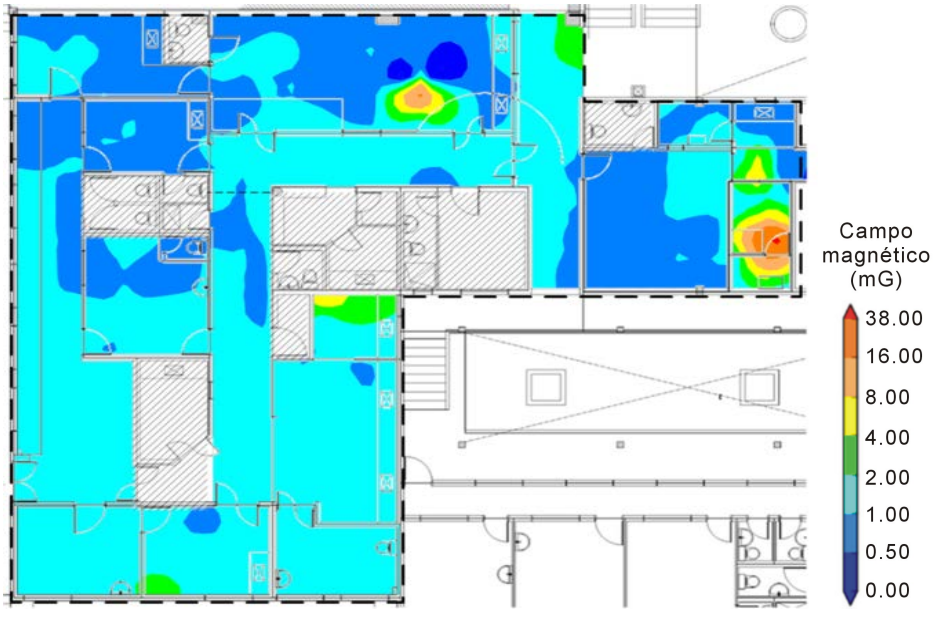


Figure 20. Magnetic field measured in the emergency care department.

Table 3. Maximum electric field values at high frequency measured in the different departments of Hospital Buenos Aires.

Department	Maximum EF (dBµV/m)
Hospitalization	87.55
Obstetrics	77.81
Dentistry	93.74
Clinical Laboratory	77.58
Emergency	93.90

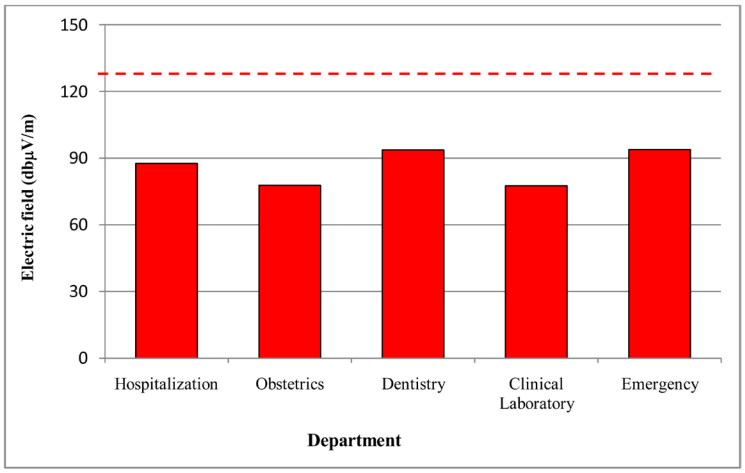


Figure 21. Maximum electric field levels at low frequency measured at Hospital Buenos Aires and level established by the IEC standard (dash line).

Table 4. Magnetic field values at low frequency measured in the different departments of Hospital San Javier.

Department	Magnetic Field (mG)		
	Maximum	Average	Minimum
Hospitalization (Plants 2 and 3)	91.10	2.09	0.31
Obstetrics	38.90	3.04	0.34
Dentistry	990.40	19.32	0.58
Clinical Laboratory	70.50	2.12	0.76
X-Ray	7.41	2.00	0.73
Emergency	16.70	2.38	1.11

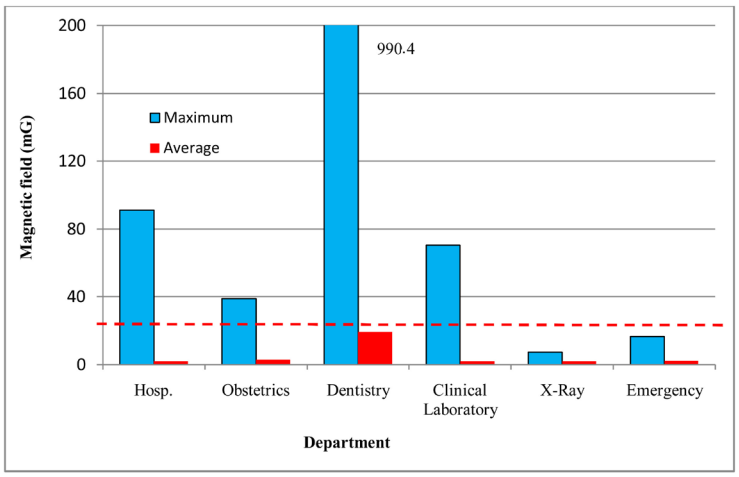


Figure 22. Maximum and average magnetic field levels at low frequency measured at Hospital San Javier and level established by the IEC standard (dash line).

partments, the measured levels are below those established by the international standard.

4.3. Hospital Príncipe de Asturias (Spain)

Table 6 shows the minimum, maximum and average magnetic field values at low frequency measured in the

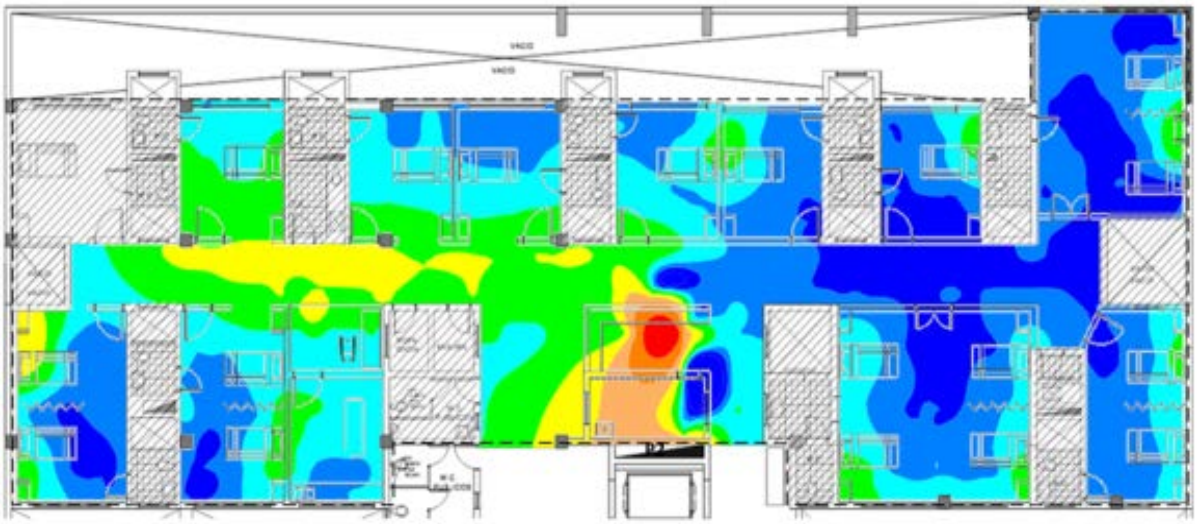


Figure 23. Magnetic field measured in the hospitalization section (plant 3).

Figure 24. Magnetic field measured in the obstetrics section.

Table 5. Maximum electric field values at high frequency measured in the different departments of Hospital San Javier.

Department	Maximum EF (dBμV/m)
Hospitalization (Plants 2 and 3)	90.16
Obstetrics	86.55
Dentistry	77.69
Clinical Laboratory	90.57
Emergency	80.01

different departments of Hospital San Javier. **Figure 26** shows the maximum and average values compared with the immunity level established by the IEC standard. In this case, there is no place in which the standard is surpasses, although there are fluctuations in the levels between the rooms.

Table 7 presents the maximum electric field values measured in each department of Hospital Buenos Aires. **Figure 27** shows these values compared with the immunity level established by the IEC standard. In all the departments, the measured levels are below those established by the international standard, although, in the urgen-

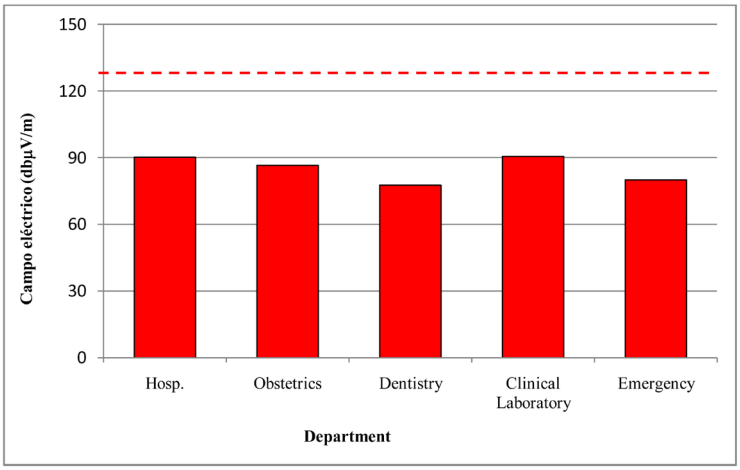


Figure 25. Maximum electric field levels at low frequency measured at Hospital San Javier and level established by the IEC standard (dash line).

Table 6. Magnetic field values at low frequency measured in the different departments of Hospital Príncipe de Asturias.

Department	Magnetic Field (mG)		
	Maximum	Average	Minimum
Hospitalization	2.89	1.97	0.04
Electromyography	8.80	0.18	0.05
Techniques Room	10.64	3.26	0.03
Consulting Rooms	31.30	10.87	0.04
Radiology	1.80	1.59	0.04
Emergency	1.86	1.43	0.00

Table 7. Maximum electric field values at high frequency measured in the different departments of Hospital Príncipe de Asturias.

Department	Maximum EF (dBµV/m)
Hospitalization	102.10
Electromyography	103.75
Techniques Room	106.41
Consulting Rooms	101.79
Radiology	105.83
Emergency	121.14

cies area, the level is very close to it.

5. Conclusion

In this paper, the total lack of awareness regarding the problem of electromagnetic compatibility in Argentina, Colombia and Spain has been demonstrated. A survey was conducted to show that the personnel in these hospitals are not aware of the situation, even if problems due to electromagnetic interference occur. These problems can affect critical or vital equipment, but security measures are not being taken to avoid the problem. After the survey, when a problem was detected, a quantitative analysis was performed to determine the magnitude of the problem. The measurement results show that there is no standard that fixes the position of the various pieces of equipment, including the cables and the other electromagnetic elements, to avoid surpassing the immunity levels defined by the international standards. The lack of this standard results in strong fluctuations in the electric and magnetic field radiation levels, including some areas where these levels are surpassed. The results obtained show that this problem is more important at industrial frequencies (60 Hz) because the levels at radio frequen-

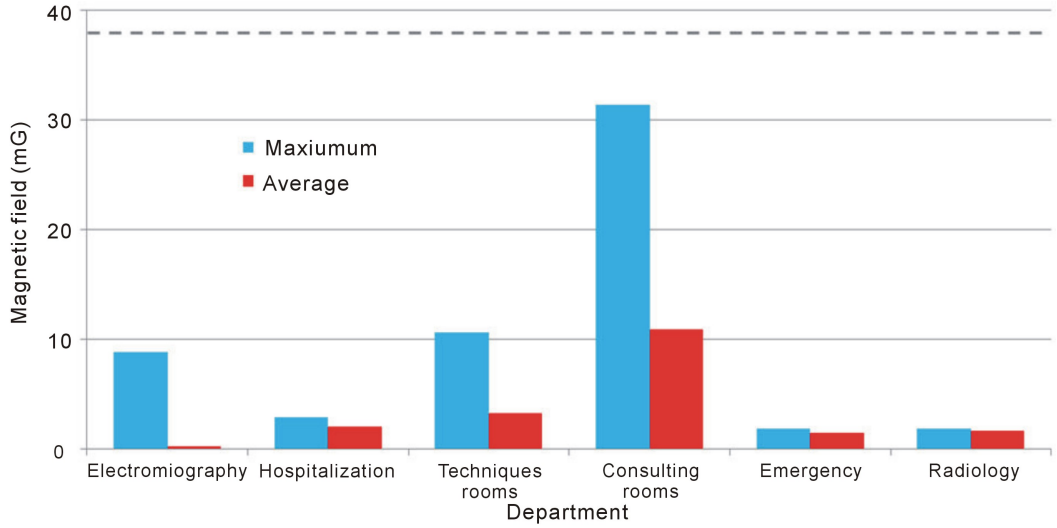


Figure 26. Maximum and average magnetic field levels at low frequency measured at Hospital Príncipe de Asturias and level established by the IEC standard (dash line).

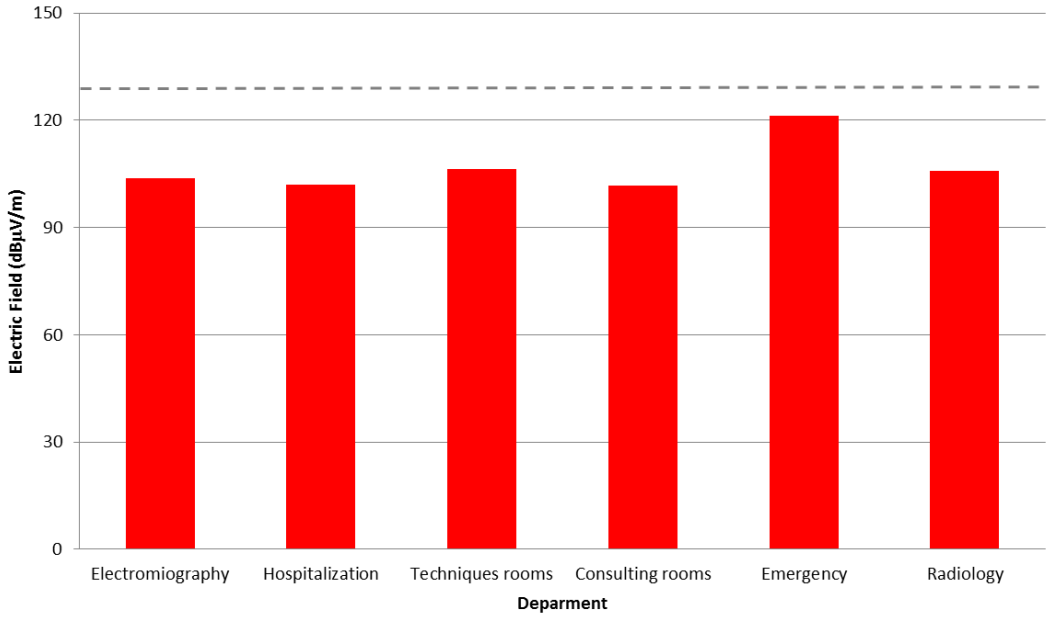


Figure 27. Maximum electric field levels at low frequency measured at Hospital Príncipe de Asturias and level established by the IEC standard (dash line).

cies are generally below the standard. This study shows the necessity of establishing an electromagnetic compatibility standard in hospital environments to avoid the problems described above, especially in areas where lives are at stake.

Acknowledgements

Oscar Gutiérrez, Miguel Ángel Navarro and Francisco Saez de Adana would to like to thank the CATECHOM (Centro de Alta Tecnología y Homologación) of the Universidad de Alcalá, the Hospital Principe de Asturias, and Juan J. Martínez in particular, for his efforts in coordinating the hospital staff, as well as Lucía Engo for her work in the measurements.

Adolfo Escobar and María E. Moncada thank Liliana Sierra and the E.S.E Metrosalud staff for their support

in the realization of this project. This research was supported by E.S.E METROSALUD and Instituto Tecnológico Metropolitano—ITM.

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