Imaging Facilities for Basic Medical Units: A Case in the State of Guerrero, Mexico

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Abstract This work presents the methodology to design a small imaging unit in a small regional hospital that takes into account the real imaging needs in the region regardless of current administrative guidelines. The situation of the imaging facilities in Mexico's states is studied and compared with other countries, and a project plan is designed for the specific state (Guerrero) where the clinic is to be located. The proposal includes the acquisition of a basic suite of modalities that include an ultrasound system, a mammography unit, and a conventional X-ray system in addition to a CT system that is not available anywhere within the state. The system should be primarily digital and should incorporate a simple picture archiving and communications system that can be the basis of a future telemedicine unit. The conclusion of this study also proposes changes in the segmented and pyramidal structure of the Mexican health system in order to provide higher quality care at the lower level, to reduce bottlenecks, and to provide higher quality health care near the patient's home.

Keywords Medical imaging · Healthcare systems · Medical technology assessment · PACS · Diagnostic imaging · Digital imaging · Digital radiography · Medical economics · Health technology · Radiology department · Hospital

Introduction

Health Care in Mexico is based on a mixed system of social security, public health care, and private insurance and

practice, and this leads to an unwieldy system where there are a lot of redundancy in some aspects of health coverage and severe deficiencies in others. [1]

The most important subsystem is the Social Security Institute (IMSS), which is geared towards the registered working population. However, since most of the working population is not registered, this coverage is far from universal. Government workers have their own social security system (ISSSTE), while a large segment of the population is without coverage. In these cases, the federal and local governments provide health care. Federal coverage is now mostly limited to a modest popular insurance system that covers only certain medical procedures (Seguro Popular). The brunt of the load has to be carried by the state governments.

Apart from the fact that health coverage is not homogeneous, there exist economic and social factors which are correlated and have an impact on the health care and which produce enormous contrasts, for example, within a region, there can be high quality private health care facilities, coexisting with a large population without adequate coverage.

"Primary" sources of information on the state of the infrastructure and equipment in medical facilities in Mexico are not very reliable, nor up to date. The most important sources are the statistical compilations by the Social Security Institute (IMSS) [2], the Social Security Institute for government workers (ISSSTE), and the health secretariat. Regarding the situation of imaging equipment, information is available from a variety of sources, but not all of these are up to date, nor complete. However, the information is sufficient to provide a general view of the state of imaging facilities in Mexico.

This paper deals with the methodologies for the design of the imaging facilities in a small provincial hospital in

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southern Mexico. It is based on real world experiences while working as consultants for a private constructing company, which was hired by the state government. The final project underwent several modifications before it was completed, but this experience can be easily reproduced in other health care facilities in order to plan for the installation of more cost-efficient diagnostic services within the hospitals. “[Imaging Facilities in Mexico](#)” deals with the information regarding the type of equipment and state of repair that exists throughout the country, and specifically in the state of Guerrero. “[Design of the Imaging Unit](#)” presents the design of the imaging unit before a discussion on the lessons learned while developing this project is presented in “[Discussion](#).”

Imaging Facilities in Mexico

The most complete information regarding imaging modalities and the situation concerning installations and medical equipment belongs to the IMSS that shows that in the imaging equipment section, there are a total of 4,010 systems listed, where 30% are between 0 and 5 years of age, 30% have an age between 6 and 10 years, and 40% are more than 10 years old [2]. According to IMSS criteria, an imaging system is considered to be obsolete when it is 10 years old, and 58% of X-ray equipment, 27% of ultrasound modalities, and 59% of CT scanners are over this age [2].

Forty percent of the patients spend more than 8 h waiting in the emergency room because of a lack of imaging and laboratory equipment. This state of the infrastructure can be considered as the best of the public health care system, while all the other subsystems have an infrastructure that is below this standard.

With regard to the state of the imaging facilities when compared to other countries, we can see from Table 1 that the number of large imaging modalities in Mexico is lagging behind many industrialized countries [1]. According to the Organization for Economic Cooperation and Development (OECD) Health Data 2008, availability for MRI and CT imagers in the member nations is an average of one MRI scanner per 108,000 inhabitants and one CT per 52,000 persons. In Mexico, the numbers are one MRI per 714,000 inhabitants and one CT per 277,000 inhabitants (five times and 6.6 times less than the average, respectively) [3, 4]. Its infrastructure is similar to that of Iran [5].

An additional handicap is the fact that the traditional structure of health care in Mexico follows a pyramidal scheme—where at the basic level, clinics do not even have physicians for consultation. Only health care technicians are provided. At the second level, there are general hospitals, which provide basic hospital care, but high-level specialized medical attention exists only in third-level or regional hospitals. The problem with this structure is that all types of consultations have to proceed from the least sophisticated facility up to the regional hospitals through referrals. This includes situations like broken bones (first-level clinics do not have imaging equipment) and obstetrical/gynecological emergencies. Of course, the population often bypasses first-level clinics and thus emergency services at the higher levels are saturated. As a matter of policy, IMSS has planned to invest mostly on equipment for first-level clinics to improve the quality of health care.

The state of Guerrero is one of the three poorest states in the country and has 3 million inhabitants. Health care coverage is consequently lacking with respect to other richer states. Private infrastructure including hospitals with high technology exists in the city of Acapulco, but this is the sole city within the state with such characteristics and this type of care is not available to the majority of the population.

In 2002, for example, the population of the state without health coverage was 82% when compared to 60% in the whole country and 28% in the state of Nuevo León. In Guerrero, out of 3 million inhabitants, only 711,000 carry any type of insurance (23%) of the population. The total breakdown of those insured is 50% IMSS, 32% ISSSTE, and 13% Seguro Popular, which leaves 2.3 million inhabitants without coverage. [3, 7]

More recent data point to change. In 2005, the population of the state without health coverage was 62% when compared to 40% in the whole country and 23% in the state of Nuevo León. [6] Unfortunately, these data are not as complete as in [3], and further information on how the systems are distributed is not available.

From the point of view of high-technology diagnostic systems, the distribution is not homogeneous, for example, Table 2 shows the number of different types of imaging equipment that is available for different regions in the country. The state of Aguascalientes is representative of the type of infrastructure available throughout the country. Mexico City has a fragmented distribution of resources, with the poorest regions having the least efficient coverage.

Table 1 Number of MRI and CT systems per million inhabitants in different countries

	Canada	Germany	France	Greece	Portugal	Spain	UK	Mexico
MRI	6	6	5	13	4	8	5	1.4
CT	11	15	10	25	25	13	7	3.6

Table 2 Number of inhabitants (thousands) per imaging modality

	X-Ray	CT	Ultrasound	Mammography units
Aguascalientes	60	241	68	0
MexCity best	20	168	21	400
MexCity worst	67	400	53	4000
Guerrero	40	527	41	263

From these studies, a conclusion is drawn that there does not exist a common methodology in different states and subsectors to analyze the productivity, age, and state of repair of the different imaging systems. There is no policy for the distribution and priority assignment of imaging resources. There is no clear-cut method to determine when the systems are no longer financially viable.

As it can be seen, there is a need to generate strategies to minimize these inequalities. Some examples of solutions being tried is the creation of specialized medical units (UNEMES), which are oriented towards providing specific solutions to problems that are locally predominant. An example has been the installation of hemodialysis clinics where this coverage is not adequate. In this case, these specialized medical units are privately owned, but run jointly with public hospitals, where part of the private patient fees are devoted to defray the costs of the public health system patients.

With regard to imaging systems, this study undertook the analysis of the information available on the infrastructure in the state of Guerrero. According to this, the state public health infrastructure comprises, on one hand, 17 general hospitals with a total of 18 ultrasound systems, 28 X-ray machines, and a mammography unit and, on the other, 15 health care centers without ultrasound or mammography units but having 14 X-ray systems. There is only one CT system in the whole state, and it is installed in the Naval Hospital, which is unavailable to the general population. Table 3 shows the entire imaging capacity of the public health system in Guerrero.

Design of the Imaging Unit

Based on all of this available information, the design and construction of a specialized unit of medical imaging within the state was proposed. It was expected that, on one hand, the official requirements for the installation of such a unit would be met, as a result of a very careful appraisal of the

specific needs of the region to be served. On the other hand, the design considered the technological aspects tied together with the architectural designs and aspects of information management in order to control all of the patient data.

Design Criteria

The idea behind the equipment specifications is that regardless of the size and quality of installations belonging to the different sectors of the health system, the state's infrastructure is woefully inadequate and any system that is installed at this hospital will be used to its fullest capacity. The idea is to make this imaging unit available to all of the different subsectors of the health care system, so anyone with the need for an imaging study will be able to have his/her needs served. This leads to the design of a unit with moderate capabilities for expansion. In short, this proposal bypasses the traditional pyramidal structure of the Mexican health care facilities and is designed to make the imaging systems available horizontally to all of the subdivisions of the health care system.

Technological Requirements

Based on the data presented previously, and taking into consideration the fact that the state has very deficient installations in general, practically any imaging equipment that is proposed for the hospital will be fully used to the benefit of the population neighboring the hospital. However, since breast cancer screening and gynecological examinations still present important imaging needs in the region, in addition to the installation of a new X-ray machine, the use of an ultrasound and a mammography unit is necessary. Furthermore, based on the fact that there are an important number of trauma injuries in the region, the installation of a general-purpose CT is strongly suggested.

Even though the hospital has modest resources, a decision was reached for the use of digital imaging

Table 3 Imaging capacity in the public health services of the state of Guerrero (number of units)

State of Guerrero	X-ray	CT	Ultrasound	Mammography units
General hospitals (17)	28	0	18	1
Health care centers (15)	14	0	0	0

modalities everywhere. An important factor for this decision was the fact that printing, storing, and developing of conventional X-ray film was too inefficient in public hospitals belonging to the health care system [8]. In general, the use of wet developing methods regularly turns into important bottlenecks in the system, as there are too many variables to control that depend on the developing room technician that is sometimes not well trained in these locations. In the case of digital modalities, the job description for the person in charge will have to change from a technician to an engineer in charge of several jobs dealing with medical imaging and information technology in addition to the training of physicians, nurses, and technicians. This digital imaging site can later be developed into a telemedicine hub, servicing several clinics in the general area, as it will already have the necessary infrastructure and personnel to provide diagnoses based on digital imaging.

Regarding the imaging modalities, these should include the Digital Imaging and Communication in Medicine (DICOM) communication services in order to be able to store all the images from the different modalities in an imaging database server that includes redundancy and security. This would require the installation of a picture archiving and communications system (PACS). Images should be presented in large high-resolution flat screen monitors instead of alternators, and the viewing station should be able to handle image processing algorithms and 3D rendering as an aid to radiologists. However, in order to preserve the viewing capability for old films and to provide hard copies of the studies, a low-throughput laser printer and alternators should also be installed.

Selection of a Viewing Station

One of the most important considerations in the design of the imaging department is the cost of the image modalities and the viewing stations. As it has already been noted, the proposal for this hospital is to have a basic imaging system, interfaced to a basic PACS. This led us to consider different solutions ranging from open-source systems to proprietary designs. Our group has designed and constructed an open-sourced PACS for the National Biomedical Instrumentation and Imaging Research Laboratory (CI3M) that is based in the OsiriX viewing station software, together with DCM4CHEE medical image database. Using this system as a basic design, and taking advantage of the interest of the radiologist and technician responsible for CT studies at a large private hospital in Mexico City in carrying out a side-by-side performance evaluation of OsiriX 3.2.1 and G.E. AW4.2 imaging workstations, a comparison of both systems was performed at their location.

Three different aspects were evaluated:

1. Technical requirements and functional characteristics regarding file manipulation;
2. Diagnostic, editing, and image manipulation tools; and
3. Special functions.

Table 4 shows the results for file manipulation and technical characteristics for both viewing stations. Each system has its advantages and disadvantages, but in general, the issues are not serious enough to make one system stand out as superior to the other and can generally be solved in an acceptable manner (for example, data security can be enhanced in the OsiriX workstation by the use of specific IP addresses that are authorized and by the use of RAID systems in the database server). Table 5 shows the characteristics regarding the tools for image measurement and enhancement. In this instance, the similarity is striking. The conclusion of the evaluation was that the OsiriX viewing station performed well; provided most if not all of the tasks regarding image manipulation, enhancement, and measurements required in the regular clinical setting at the hospital; and can provide a cost-effective alternative to imaging workstations provided by the large image modality manufacturers.

Based on these results and on the previous design experience of a PACS in our laboratory facilities, it was decided to propose a similar design for the clinic, where the OsiriX viewing station would be a good complement to the basic viewing system of the CT. With respect to DICOM services provided by OsiriX, C-STORE, C-MOVE as well as C-FIND and C-GET services are available. Basic printing services, C-PRINT CSI and C-PRINT SCP, are provided. OsiriX does not provide a modality worklist, but this is available from various software vendors.

Space Distributions

One of the major considerations when the design of the imaging facilities shifts to the use of digital modalities is that the space allocation under this supposition is quite different from the conventional wet film processing and storage. In the conventional system, there are spaces dedicated to film processing (darkrooms) and waste recycling. In addition, storage of film takes place in an archive that uses up a significant amount of space. With the use of digital technologies, the proposal has been to use the spaces formerly considered for film into library and telemedicine centers. The whole archive can now fit in the space of a refrigerator instead of a whole room. The original imaging facilities within this hospital, where the design included spaces for the handling of traditional film-based imaging equipment, have been redesigned to accommodate the digital infrastructure. The spaces

Table 4 Comparison of the technical characteristics and functions for file manipulation between the General Electric AW4.2 and the OsiriX viewing stations

Function	Platform		Observations
	OsiriX	AW4.2 G.E.	O: OsiriX; A: AW4.2 G.E.
Expansion and updating of platform	Yes	Yes	A: limited and high-cost
Technical support	Yes	Yes	
System restoration	No	Yes	O: general system restoration
Hardware optimization	Yes	Yes	A: limited and high-cost
Local storage expansion	Yes	Yes	
Storage in extractible media	Yes	Yes	A: limited to CD, DVD O: includes new technologies: USB, iPhone, cards
Data protection	No	Yes	O: can use RAID
Can receive data from other systems (angio, masto, etc.)	Yes	No	
Data importing	Yes	Yes	A: limited to manufacturer's characteristics
Data exporting	Yes	Yes	A: limited to manufacturer's characteristics
Multiple data read (multiple studies)	Yes	Yes	
Database management	Yes	Yes	
File migration to other systems	Yes	Yes	A: limited to manufacturer's characteristics
Multiple image viewing	Yes	Yes	A: limited to 16 images per monitor
User configurable interface	Yes	No	
Automatic file elimination	No	Yes	O: manual elimination
DICOM network support	Yes	Yes	
DICOM printer support	Yes	Yes	
Non-DICOM file support	Yes	No	A: limited to the manufacturer's protocol

Table 5 Comparison of the diagnostic, editing, and image manipulation tools between the General Electric AW4.2 and the OsiriX viewing stations

Function	Platform		Observations
	OsiriX	AW4.2 G.E.	O: OsiriX; A: AW4.2 G.E.
Measurements and angles	Yes	Yes	
Region of interest selection (ROI)	Yes	Yes	
Calibration (real measurements)	Yes	Yes	
Annotations	Yes	Yes	
Erase annotations	Yes	Yes	
Cut and paste annotations	Yes	Yes	
Save editing as part of image	Yes	Yes	
Manual width/level adjustment	Yes	Yes	
Automatic width/level adjustment	Yes	Yes	
Zoom adjustment	Yes	Yes	
Image rotation	Yes	Yes	
Virtual collimator	Yes	Yes	
Image series to video	Yes	Yes	
Acquisition protocols	Yes	Yes	
Configuration of acquisition protocols	No	Yes	A: acquisition configuration
Configuration of width/level acquisition	No	Yes	A: acquisition configuration
Filters and edge enhancement	Yes	Yes	
Invert image	Yes	Yes	

previously devoted to film archives will now be used as a viewing room where the high-resolution imaging stations (and eventually the telemedicine remote stations) will be sited. The CT scanner will also have a viewing station in the control room while the ultrasound room will contain a medium resolution station [9]. In the case of X-ray and CT systems, either single or double 30-in. $2,500 \times 1,660$ -pixel monitors can be employed, while ultrasound images can be adequately displayed in smaller monitors. In the case of the mammography units, either single or double monitors with 3 to 5-megapixel resolution and a 12-bit grayscale depth can be employed which provide an advantage over conventional 8-bit windows-based systems.

Discussion

The design of an imaging unit for a small provincial hospital might seem a straightforward affair, but when all of the factors that are involved in the planning of the services are included, this exercise turns out to be remarkably complex. In the first place, information regarding the infrastructure in neighboring districts within the same state is difficult to obtain and is not very reliable. Official data are incomplete, and in the case where information is available, it must be complemented by on the field inspections, as many of the imaging modalities that are reported are not functional. In the case of the imaging infrastructure in the whole country, the installed infrastructure that is available for the whole of the population is approximately four times lower than in the OECD countries. Up to now, there are no CT or MRI units available for the general population in the state of Guerrero, and the availability of other imaging equipment when compared to the rest of the country is much less. In the case of this small hospital, the acquisitions of the three fundamental modalities—X-ray, ultrasound, and mammography units—were easy to justify and to complete. However, in the case of the CT system, there have been problems in obtaining the appropriate official permits. On one hand, the hospital is too small to warrant the installation of a CT according to the commission in charge in granting these permits, while on the other, there are no CTs available for the general population within a 200-mile radius. In the meantime, the hospital has been designed and built with spaces purposely constructed for this type of equipment. In spite of this, the decision at the state's ministry of health has been to pursue all possibilities to obtain a CT system through either donations or special budgetary allocations.

When the university was taken on as a consultant, the facilities were almost entirely built, and so the initial task was to verify that the spaces and preinstallations complied with the norms for the type of equipment that was to be

installed. The most innovative part of the project was to transform the imaging facilities from a traditional late twentieth century design into a modern facility, incorporating up-to-date technology that will place this small hospital in the hub of a telemedicine center, where different local facilities will be able to transmit imaging results to the hospital in order to get an accurate interpretation by experts (fortunately telecommunications infrastructure both by fiber cable and wireless are available). Additionally, the use of digital imaging technologies will cut down on the need for maintenance of equipment, mostly because the most vulnerable piece of equipment in the image production chain, the wet film developing subsystem, will be substituted by digital means.

Conclusions

We have presented an example of a design of an imaging unit that can be installed in small provincial hospitals, regardless of current acquisition guidelines by National Centre for Technological Excellence in Health Care (CENETEC). These guidelines take into account first the size of the facility being built (quantified by the number of beds) and then the infrastructure that is available in the region. An important factor in this approach is the number of imaging units in Mexico, which is very low, especially when compared with OECD countries. In advanced imaging modalities, the number of CTs and MRI units is five times less than the mean for these countries. In addition to this, the distribution of these resources and the number of inhabitants with adequate health care vary widely from state to state. Because of these circumstances, the idea has been to propose the construction of imaging departments in small facilities that contain a wide variety of complementary modalities. These imaging suites will be more successful than the installation of a stand-alone scanner. The existence of a structured technological “critical mass” will assure that a common group of servicing and maintenance providers can preserve the infrastructure in a good state of repair. In addition, the employment of digital technology and the existence of an adequate telecommunications structure will allow these small centers to work as nuclei for the existence of teleradiology centers.

Perspectives

There are two conditions to be dealt with before this system can work; first, the fragmentation of the Mexican health system must be resolved in practice. Inhabitants with different kinds of insurance, public and private, should have access to these facilities. Each sector of the health system should cover the expenses of their insured citizens.

The second aspect deals with changing the traditional way of looking at the hospital infrastructure in Mexico. Normally, there are three levels of complexity in the health care facilities. The lowest level is a clinic with little or no instrumentation. The second level has general hospitals with conventional equipment, and the third level has large regional hospitals with different specialized departments and equipment. Theoretically, all patients have to pass through the three levels in order to get specialized care, should it be needed, but in practice, most second- and third-level facilities are filled with patients that enter through the emergency rooms. The general population largely bypasses first-level clinics. Our proposal to offer a more complete suite of imaging modalities in small hospitals would eliminate the need for patients to pass through several kinds of facilities before they travel to the regional third-level hospital in order to have an imaging procedure done. These changes which will help increase the quality of health care in the case of medical imaging procedures can be brought about quickly, if the different health care subsystems agree on a cost sharing system.

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References

1. C. Schwellnus. Achieving Higher Performance Enhancing Spending Efficiency in Health and Education in Mexico. OECD Economics Department Working Paper No. 732. Available at <http://www.oecd.org/dataoecd/5/17/42865347.pdf>. Accessed October 2010.
2. División Técnica de Información estadística en salud, IMSS. Inventario funcional del equipo médico de imagenología, 2003. *Revista Médica del IMSS* 43(1): 75–81, 2005.
3. OECD Directorate for Employment, Labor and Social Affairs. Health Policy in Mexico. September 2006.
4. I. Borretzen. Diagnostic Radiology in Norway. *Radiation Protection Dosimetry* 124(4):339–347, 2007.
5. M. Palesh, S. Fredrikson, H. Jamshidi, P. Jonsson, G. Tomson. Diffusion of magnetic resonance imaging in Iran. *Int. J. Tech. Assess in health care* 23(2): 278–285, 2007.
6. Secretaría de Salud. Plan Nacional de Salud 2007–2012. Available at http://alianza.salud.gob.mx/descargas/pdf/pns_version_completa.pdf. Accessed October 2005.
7. E. Puentes Rosas, S. Sesma, O. Gómez Dantés. Estimación de la población con seguro de salud en México mediante una encuesta nacional. *Salud Pública Mex.* 47(sup 1):22–26, 2005.
8. F. Martínez L., J. Azpiroz L., M. Cadena M., S. Duarte Y., A. Terán G. Knowledge Network for Medical Technology Management in Mexico. *Int. J. Technology Assessment in Health Care* 25(4):564–569, 2009.
9. J. Azpiroz Lehan, S. Vides Cañas, F. Martínez Licona, M. Cadena Méndez. Methodology for the Design of a PACS in a Small Provincial Hospital. *IEEE Proceedings of the 30th Annual International Conference of the IEEE EMBS, Vancouver, BC Canada*, 386–389, 2008.