X-Ray systems: Radiation protection program in basic research applications

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Abstract. Although the radiation doses involved in basic research radiology are relatively small, the increasing number of radiological procedures makes risks becoming increasingly high. Quality control techniques in radiological practice have to ensure an adequate system of protection for people exposed to radiation. These techniques belong to a quality assurance program for X-ray machines and are designed to correct problems related to equipment and radiological practices, to obtain radiological images of high quality and to reduce the unnecessary exposures.
1. Introduction

X-Rays have come a long way from its origins in a small, dark German laboratory on 1895 when Roentgen discovered X-rays accidentally. In fact, he was doing some basic research in physics using a cathode ray tube (like in the back of your TV or computer monitor) to study electrical discharges in gas and discovered by chance that the device he was using produced X-rays. By doing basic scientific research with no specific practical goal, Roentgen discovered one of modern medicine's most useful diagnostic tools and won the first Nobel Prize in physics in 1901 [1]. By the time, scientists did not yet realize that X-rays were a form of electromagnetic radiation however the medical uses of X-rays were apparent.

X-rays are short-wavelength electromagnetic radiations that can undergo various interactions with matter. Such interactions yield data which, when appropriately analyzed, can provide useful information on the materials irradiated. Machines, typically x-ray diffraction devices and x-ray spectrometers, have been designed to utilize very intense x-ray beams in order to facilitate microscopic examinations or elemental analyses of materials in industry, research laboratories and educational institutions.

One particularly useful property of X-rays is their ability to penetrate solid materials of considerable thickness and they can expose photographic films. Their short wavelength allows for high resolution imaging if appropriate optical components are available. However there are differences in penetration through different materials due to the differences in the material densities. X-rays have been used in a wide range of applications from medical science to industry because of their different properties.

The science of radiation protection grew out of the parallel discoveries of X-rays and radioactivity in the closing years of the 19th century. Radiation burns were recorded within a month of Roentgen’s announcement of his discovery of X-rays. However, it was not until the death of Clarence Dally, Edison’s chief assistant in the manufacture of X-ray apparatus, and the documentation of his struggle with burns and serial amputation of both arms to malignant ulceration and extensive lymph node involvement, that medical observers took seriously the notion that exposure to high doses of X-rays cause carcinogenic effects [2].

In recognition of the widespread applications of ionizing radiation to mankind worldwide and the potential adverse human health effects, it seems clear the necessity that norms for protection against radiation become legal requirements. These norms are developed from several government agencies in all countries worldwide. The International Commission on Radiological Protection (ICRP) and the specific European Union Council commission are the international regulatory bodies and the CSN (Consejo de Seguridad Nacional) is the national counterpart of the ICRP in Spain. The most important Spanish regulation on X-rays is the “Real Decreto 1085/2009, de 3 de julio, por el que se aprueba el Reglamento sobre instalación y utilización de aparatos de rayos X con fines de diagnóstico médico” [3]. These norms describe acceptance testing and Quality Assurance (QA) program, safe dose limits for radiation workers and for the general public, patient dose measurements, the checking of technical parameters from X-ray tubes, and the shielding required for the walls of an X-ray room among others.

This article summarizes the basic tasks of the Technical Unit for Radiation Protection of the University of Barcelona (UTPR-UB), which are carried out at various X-ray facilities, with examples of X-ray applications in research that show the scope of this technique.

2. Radiological Protection methodology

The new regulations require that each facility using X-ray equipment (including any medical diagnostic radiology unit, which can be dental or conventional, fluoroscopic, X-ray bone densitometry and computed tomography) establishes and carries out a quality assurance program. An ineffective quality assurance program can lead to poor quality images that can impair diagnosis or research, increase operating costs and contribute to unnecessary radiation exposure to staff and
mainly to patients, if it is the case of medical diagnostic radiology. Any extension of the basic quality assurance program is the responsibility of each X-ray facility.

The UTPR-UB is in charge to develop and implement a Radiological Protection Program also named QA program at any X-ray facility of UB or external institutions that handle their services. The QA program includes periodic Quality Control (QC) tests of the components in a diagnostic X-ray imaging system using equipment and test tools designed for that specific purpose, radiation levels checking, shielding studies, dosimetry and radiological protection administrative procedures. The latter procedures are aimed at verifying that QC testing is effective, i.e., the tests are performed regularly and correctly, the results evaluated promptly and accurately, and the necessary actions taken. They include recommendations regarding the responsibility for quality assurance action, staff training, equipment standards, and the selection of the appropriate equipment for each examination.

2.1. Quality control
It consists of a series of standardized tests developed to detect changes in X-ray equipment function from its original level of performance. The objective of such tests, when carried out routinely, allows prompt corrective actions to maintain X-ray machines in proper use and with an optimal image quality. Quality controls should be done at least annually or every time that an X-ray equipment has undergone a technical repair. Control test results must be within the tolerance allowed by law; otherwise the appropriate corrective actions must be issued.

2.1.1. Quality of the radiation beam
In X-ray equipments, three main indicators or variables express the essential characteristics as the quality of the X-ray beam, and the time for which they are produced. These are: a) Kilovoltage (kV), which expresses the penetration power and the energy of the photon beam generated in the tube (a higher kV results in a higher energy and level of penetration of the beam); b) Milliamperage (mA), which expresses the "quantity" of photons generated in the tube (i.e. an increase in current causes an increase in the number of X-ray photons generated per unit area and time); c) Time (t), which expresses the time of issuance of the radiation beam (the longer the time, the higher the exposure).

The main control parameters checked in quality control tests are related to the quality of the radiation beam. Table 1 summarizes the main tests developed in the QC with their degree of tolerance allowed by law (data extracted from “Protocolo Español de Control de Calidad en Radiodiagnóstico [4]”).

2.1.2. Image quality
X-ray image quality directly affects the diagnostic results. The X-ray inspection programs concentrate on the measurement of X-ray machine parameters such as kVp and mAs, timer accuracy, collimation, etc. but image quality test enables objective measurement of background density, high-contrast resolution, density uniformity, low-contrast resolution, low-contrast detail, and film contrast. Image noise is the most important quality-limiting factor in radiological imaging, because it sets the limits of the detectability of details and also restricts possibilities to visualize the details by means of image enhancement (e.g., image sharpening and contrast increase). The image sharpness is often evaluated visually by the resolution seen in line-pair test object images and image noise by determining the threshold contrast. As an example, figure 1 shows a TOR CDR test image. The TOR CDR phantom is used, routinely, for conventional and non-subtractive digital radiography image quality tests [5]. It enables the following checks to be made: Sensitometric measurements (10 test point details, 5.6mm diameter), Resolution limit (0.5 to 14.3 LP/mm), Low-contrast large-detail detectability (17 details, 11mm diameter) and High-contrast small-detail detectability (17 details, 0.5mm diameter). In addition to checking the consistency of radiographic performance, the test object can be used to assess the relative performance of different screen-film combinations.
### Table 1: QC tests and degree of tolerance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test</th>
<th>Tolerance allowed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilovoltage Calibration</td>
<td>Accuracy</td>
<td>&lt;±10%</td>
</tr>
<tr>
<td></td>
<td>Reproducibility</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>Radiation Wave form</td>
<td>Radiation Wave form</td>
<td>Ripple percentage indicated in manufacturer specifications</td>
</tr>
<tr>
<td>Exposure Time</td>
<td>Accuracy</td>
<td>Deviations &lt;±10% for times &gt; 20ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deviations specified by the manufacturer for times ≤ 20ms</td>
</tr>
<tr>
<td></td>
<td>Reproducibility</td>
<td>&lt;10%</td>
</tr>
<tr>
<td>Total filtration</td>
<td>HVL</td>
<td>&lt;2.5mm Al for kV &gt; 70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;1.5mm Al for kV ≤ 70</td>
</tr>
<tr>
<td>Performance</td>
<td>Performance value</td>
<td>Orientative 30-65µGy/mAs at 1m for 80kV. (Or indicated in manufacturer specifications)</td>
</tr>
<tr>
<td></td>
<td>Performance reproducibility</td>
<td>Variation rate &lt;10%</td>
</tr>
<tr>
<td></td>
<td>Variation of performance</td>
<td>linearity coefficient &lt;0.1</td>
</tr>
<tr>
<td></td>
<td>with current and charge</td>
<td>&lt;15% for current changes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;20% for charge changes</td>
</tr>
<tr>
<td></td>
<td>Film-focus distance</td>
<td>difference between measured and indicated 4%</td>
</tr>
<tr>
<td>Geometric parameters</td>
<td>X-ray/Light Beam Alignment</td>
<td>&lt;±2% focus-phantom distance on each site of rectangle, being the sum of 4 sites less than &lt;±3%</td>
</tr>
<tr>
<td></td>
<td>(Congruence of Collimators)</td>
<td>Record field alignment &lt;±1% focus-film distance</td>
</tr>
<tr>
<td></td>
<td>Beam Orthogonality or perpendicularity</td>
<td>≤1.5º</td>
</tr>
<tr>
<td>Measurement of radiation leakage</td>
<td>Measurement of radiation leakage</td>
<td>&lt; 1 mGy/h at 1m</td>
</tr>
</tbody>
</table>

**Kilovoltage Calibration** is one of the variables that determine the quality of a beam, a variation (relatively small) in the kVp generates an alteration in the contrast of the image and the transmitted intensity. Accuracy and reproducibility of kV are checked.

**Accuracy** sets the level of reliability of X-ray equipment examined. Test procedure: Perform at least 5 exposures with constant mA and ms (milliseconds) but with gradually increasing kVp or with constant mA and kVp but with gradually increasing ms.

**Reproducibility** test is important to assess the ability of the radiology team to reproduce always the same output values that define the radiation beam: voltage, time and dose. Test procedure: make repeated exposures a number of times on constant parameters to be recorded.

**Radiation wave form:** It shows the variation of x-ray intensity with time.

**Exposure time:** For the purposes of this test procedure, accuracy will mean the degree of agreement between the measured and indicated time values. Reproducibility will mean the degree of agreement between several measurements of the exposure time at the same indicated time on the x-ray control panel.

**Half Value Layer (HVL)** is defined as the thickness of material needed, brought in the beam, to reduce beam intensity by half. From the HVL, it can be checked if the beam total filtration is in correspondence with the minimum requirements. Test procedure: Place an ionisation chamber 1 m from the focal spot. Make repeated exposures adding increasing thicknesses of 1 mm aluminium plates every two exposures and record them until the recorded exposure is less than half the exposure without additional filtration.

**Total Filtration (TF)** is assessed by measuring the HVL of the X-ray beam at a known kV, followed by an estimation process based on calculations.

**Performance** corresponds to the value of the dose rate in air per charge unit: µGy/mAs

**Performance reproducibility**: Is the coefficient of variation of different performance measures under the same conditions.
Variation of performance with current and charge: Check the consistency of performance with the variation of the charge and current. It is calculated with the coefficient of linearity between two consecutive measurements.

Film-focus distance: The distance between the focal spot of the x-ray tube, or the radiation source, and the film.

X-ray/Light Beam Alignment (Coincidence): The alignment between the light field and the radiation field permits the technologist to position the field to expose only the anatomy of interest. Misalignment may result in unnecessary or repeat exposure. Test procedure: Adjust the collimator so that the light beam covers exactly one of the inner patterns of the test tool (i.e. 15x15 square of Visi X test tool), perform an exposure and compare with the irradiated fluorescence square appeared. Record its difference in mm.

Beam Orthogonality or perpendicularity: This parameter includes both the possible deviations in angulation (between the central beam radiation and perpendicular to the receiver input image) and displacement.

Radiation leakage: The tube housing is made of lead in order to absorb all radiation, which is not directed at the patient. The amount of radiation, which has “leaked” from the housing should be minimal. Test procedure: Close the X-ray tube diaphragm, Surround the X-ray tube with a lead apron or equivalent shielding and take radiation exposures measurements at different points.

Figure 1. Radiography of a test object model TOR CDR (Leeds test objects Ltd.). This TOR CDR test image shows different test patterns such as low and high contrast objects, test point details for sensitometric measurements, spatial resolution bar phantom, and gray-scale objects. After an initial grey-scale check, image quality is measured simply by counting the number of details detected and the number of bar-patterns resolved in the image (image taken with a TOR CDR radiographic test object from the UTPR-UB).

2.1.3. Radiation levels

In the planning of any X-ray facility the main priority is to ensure that persons in the vicinity of the facility are not exposed to levels of radiations which surpass the current regulatory exposure limits (this means that radiation levels in controlled areas that are occupied routinely by radiation workers must be such that: first, no radiation worker is occupationally exposed to more than 20 mSv per year; and second, non-public person receives more than 1mSv per year). The system of radiation dose limits in use in Spain (and in most other countries) is based on the recommendations of the ICRP. In order to meet these requirements, radiation levels should be monitored in the vicinity of an X-ray unit and if necessary, appropriate actions must be taken to ensure adequate shielding. In general, attention to the basic principles of distance, time and shielding are required to determine shielding needs. In general, the radiation exposure to individuals depends primarily on the amount of radiation produced by the source, the distance between the exposed person and the source of the radiation, the amount of time that an individual spends in the irradiated area, and the amount of protective shielding between the individual and the radiation source.

Quantification of the scatter radiation levels prevalent at X-ray facilities of research areas is necessary to delineate the level of occupational exposure of radiation to which the technician-operators are exposed and to facilitate radiation protection measures. Those areas occupied by any other individual such as visitors or employees who do not work routinely with or around radiation sources are of special attention and cannot exceed 1mSv per year. The measurement of scattering radiation in the vicinity of X-ray offices must be reported annually and recommendations for improving the security level must be suggested if necessary.

In a medical diagnostic radiology unit, the same considerations with regard to working staff and general public must be taken into account but also a special interest in the actions is necessary to ensure that the patient receives doses as low as possible in any diagnostic exposure.
2.2. Shielding study
Shielding requirements are usually specified following the calculation concept of the ICRP. The methodology proposed calculates the exposure levels of primary, scatter and leakage radiation emitted from an X-ray source (figure 2), following the ALARA (as low as reasonably achievable) principle. Each x-ray installation must be assessed for shielding requirements based on the: dimensions of the room, positions of the x-ray control, vertical bucky and operator, proposed construction materials (protective screens, walls, floors, doors), areas adjacent to x-ray room (occupancy, future use), x-ray workload. According to the characteristics of the x-ray room or x-ray equipment, protection may be required for structural materials as lead covered walls or doors. Structural protection plans must be supplied to the UTPR prior to construction or for existing buildings prior to use of the x-ray equipment in the room. In other X-ray facilities will be sufficient to provide a barrier shielding with a mobile x-ray lead barrier and to make available personal protective accessories including: lead aprons, collars, gloves and lead-coated glass products when needed.

![X-ray unit and radiation types](image)

2.3. Dosimetry
Personal dosimeters are intended to monitor occupational doses thereby providing a mechanism for restricting future radiation exposures to an individual, so that the recommended maximum permissible limits are not exceeded. Area dosimetry can be used in some cases so that the dose of exposed personnel shall be estimated from these data using an appropriate protocol. Depending on the analytical X-ray system design, monitoring the extremity doses could be necessary. The dosimeter readings are kept as records for every staff for the purpose of evaluating their radiation history and possible risks involved.

2.4. Staff training
The QA program should include the means to provide appropriate training for all personnel with QA responsibilities and especially those directly involved with QC testing. A continuing education program is necessary to keep personnel up-to-date. UTPR-UB has the qualified personnel to perform adequate QA program in radiology facilities. It also undertakes training courses for personnel involved in handling x-ray equipment.

3. Examples of applications
X-ray imaging is a key technique for medical imaging, non-destructive testing, and basic research applications. Medicine and dentistry remains the most common use of X-rays being employed routinely at doctor offices and hospitals. However, X-rays are also widely used in other applications from airport security to industrial inspection and quality control systems, or in art restoration studies, among others. Researchers use X-ray systems in many different applications.
ranging from pneumology and cardiology studies using pigs and dogs X-ray images to radiographs of small animals (such as mouse, rats, fishes and coral radiographies in biomedicine or marine biology department studies respectively), molecular structure determination by X-ray crystallography (the most famous example along these lines is the double helix structure of the DNA molecule, as determined by Franklin, Crick and Watson) to grain and seed inspection in agriculture department studies.

Although radiographic units exist in a wide variety of configurations we have focused on cabinet X-ray systems and conventional X-ray systems (in the latter case by selecting examples of applications of fluorography, dental and conventional X-ray machines). Herein we report some specific examples of X-ray application developed at the UB.

3.1. Cabinet X-Ray imaging system

The term "cabinet X-ray system" refers to an X-ray system with the X-ray tube installed in an enclosed, interlocked cabinet. The main advantage of the system is that no additional shielding must be added to the facility where the X-ray machine is installed as the cabinet provides the necessary shielding. The cabinet X-Ray unit located at IR-147 (at the Biology Faculty of the UB) is a Faxitron model [6] with maximum operating conditions of 130 kV and 3 mA (figure 3a). This imaging system has very different possibilities for research applications.

First, this unit is used in biomedical and basic research projects, for example to produce highly detailed radiographs of small animals. Radiographic images like that shown in figure 3b allowed to record both shape and meristic characters of axial skeleton and vertical fins of zoarcid fish specimens from the Southern Ocean which provided the necessary information to identified a new species Santelmoa carmenae [7].

Second, the non-destructive nature of X-rays generated at selected excitation voltages, may be used to reveal internal details of any items, from thin low density objects such as documents (those made of paper or cardboard can be viewed through soft X-rays), to more dense objects such as those made of heavy metals. This may be useful to reveal latent fingerprints from difficult surfaces and to inspect overwritten watermarks, obliterated serial numbers and other markings or ink components such as transition metals in the context, for example, of detecting differences between a counterfeit banknote and a genuine one as shown in figure 3c. Moreover, numerous examples illustrate the usefulness of a simple and compact cabinet X-ray system in forensic laboratories, particularly when preservation of evidence is important and because X-ray analysis is used to screen objects non-invasively. It allows doing radiography of excised organs to determine cause of death, and spatter patterns on clothing to determine firing distance.

Third, radiography, in general, and cabinet X-ray systems, in particular, have their applications in industry where they are valuable for non destructive testing of products for defects. Because the industry attaches great importance to the quality assurance, X-ray imaging is used in the research and development, as well as in the production departments. A very good application is to check, for example, electrical components by digital X-ray inspection on completeness and a correct assembly of the single components. Electronic components are becoming increasingly miniaturized. Only high-resolution and high-magnification X-ray technology provides the necessary means to inspect such components. Cabinet X-ray systems offer manufacturers and industrial service providers a tool to investigate, in a non-destructive manner, objects and object properties that cannot be inspected optically. Typical inspection tasks includes: Inspection of bond wires and bonding areas, void analysis of conductive and non-conductive die bonds, inspection of flip-chip solder joints in processor cases and analysis of discrete components such as capacitors and inductors (figure 3d).

Also, X-ray inspection in industry offers the capability to confirm the integrity of a product and so ensure compliance with quality standards. X-ray images can reveal contaminants (such as metals, bone, glass, plastics, ceramic, cement, etc) and product defects (such as missing, cracked or broken parts) that can not be seen with the naked eye. I.e.: In quality control of the food industry, thanks to the use of X-rays, metal contaminants can be seen such as a screw in a glass container containing prepared food for infants that may, otherwise, go unnoticed (figure 3e).
Figure 3: Applications with Faxitron cabinet X-ray system. A) Faxitron cabinet X-ray system at IR-147 facilities of UB. B) Radiographic and photographic image of Santelmoa carmenae [7]. Holotype, UAB: B03GSZ51, male, 264 mm SL, from Gerlache Strait, Southern Ocean (Images kindly provided by Jesus Matallanas) C) Left: counterfeit (top) and genuine (bottom) £10 notes. Right: soft X-radiographs that have been scanned and inverted to enhance contrast. Radiographic image for original and counterfeit banknote was obtained with 12Kv during 40sec radiation and using Kodak film. The major difference between the two notes is the absence of the strip of metal, Queen’s head, and the rest of the script on a £10. D) Electronic microchip and its radiography. With X-ray inspection systems, weld and solder joint quality can be easily and quickly inspected. E) Radiography of a glass container containing prepared food for infants with a screw inside.

The X-ray baggage inspection system similar to the Faxitron cabinet X-ray system is a particular example used to examine luggage at airports and people baggage at some official building control access for possible weapons, contraband and bombs detection.

Finally, once again for its simplicity and for being compact and shielded, the cabinet X-ray system can be used as an alternative to a conventional X-ray unit for applications in agriculture and Ecology studies (e.g., radiography inspection of grain and seeds with radiographic images provides information about viability, infestation, damage or contamination, radiography of wood rings is used to evaluate seasonal growth characteristics), in Archaeology studies (i.e. to visualize
archaeological artefacts to aid in the preparation and cleaning of rare and often delicate structures) or in Art restoration (for works of art in small format to reveal previous works and changes that have been painted over).

3.2. Conventional X-Ray systems

Conventional X-ray systems offer many possibilities of applications being the medical diagnostic the most commonly used. However, here we have focused our attention on research applications developed at different departments of the UB. We present three examples of X-ray applications in research projects with three different X-ray units: a mobile conventional X-ray unit, a dental intraoral X-ray and a C-arm fluoroscopy unit.

3.2.1. Conventional X-ray applications in Art Restoration

The Department of conservation and restoration at the Fine Arts School (UB) uses a mobile conventional X-rays, located at IR-2376 which operating from 40 kV to 80 kV has revealed some interesting discoveries hidden in works of art.

Thus, the most commonly used method of holistic art conservation and art restoration science is X-ray radiography. The latter technique is useful for inspection in maintenance and preservation of works of art, their protection from future damage, deterioration, or neglect, and repair or renovation of works that have deteriorated or been damaged. For example, in the past, historical paintings have sometimes been painted over by other artists. But also, old paintings have often been painted over in order to manufacture fakes on chronological authentic canvas. The goal of the modern conservator is to determine in a non-invasive way, like X-ray radiography, the remaining original portions of the painting and to gain an understanding of how the painting had been treated over the years or to find out whether there is an older painting behind the visible one (as the examples shown in figure 4 and figure 5).

Figure 4: One of the most remarkable finds by the Department of conservation and restoration of the Fine Arts School (UB), was an image of Sta. Barbara observed, thanks to the X-rays, beneath a completely different painting in which were men playing cards. (Images kindly provided by Anna Nualart from the Department of conservation and restoration of the Fine Arts School (UB))

3.2.2. Dental X-Ray machine applications in preclinical practices and research

Dental X-ray units are a basic technique for pre-clinical practices at the Faculty of Dentistry. Undergraduate students learn the technique of intraoral radiography practicing isolated teeth. This enables them to become familiar with the dental diagnosis and started in the early invasive practices to rebuild a tooth or eliminate a cavity (figure 6a).
Figure 5: Christ photographic and radiographic images. In polychrome wood carvings, it can be basically seen the number of pieces of wood that comprises the support (most sizes are not made of one piece of wood) between the type of lace pieces and anchors (especially metal pins). In the case of Christ, we see several layers of overlapping colors, with numerous losses of pictorial material. Notice that there is a radiological contrast of pigments in the area of the cloth, with less contrast than the skin. This is due to the presence of metallic pigments in pictorial layers of the skin of Christ, which consists of, very likely, lead white. The overlap of paint layers (different thicknesses) and the fact that the obverse and reverse of the piece remain on the same plane make the resulting X-ray image both spectacular and difficult to understand without having the original side. (Images kindly provided by Anna Nualart from the Department of conservation and restoration of the Fine Arts School (UB)).

Dental X-ray units have also a wide range of applications in clinical research studies. For example, the X-ray image is crucial for the monitoring of dental implant techniques. The dental implant’s surfaces, shapes and sizes are usually submitted to animal experimental assays (usually in dogs) in order to assess their characteristics: osteointegration, resistance, tisular adaptation, etc. (figure 6b).

Figure 6. A) Left image: radiography to visualize the opening cameral of a lower premolar. Right image: Diagnostic imaging to check the anatomy of the tooth and see the number of lines of this molar pieces as their pulp chamber. B) Intra oral radiography. Intra-operative radiography from implants, 3 months post-operative control in a dog. (Image kindly provided by the Human Anatomy and Embryology Unit Laboratory, Faculty of Dentistry, UB)
3.2.3. Studies of experimental animal models with a C-arm fluoroscopy unit

The C-arm fluoroscopy unit installed at RX/30639 in the animal facilities of the Medicine College is an Arcadis Avantic model from Siemens with a maximum operating conditions of 120 kV and 15.2 mA (figure 7a). It is a surgical mobile X-ray unit that can produce images continuously. In continuous fluoroscopy, X-rays are continuously applied to the patient (a pig in this case of angiographic studies) to produce dynamic clinical images that may be recorded on videotape.

X-ray animal imaging has been recognized as an important tool in preclinical research and the development of novel diagnostic probes and imaging tools for a disease specific diagnosis and therapy monitoring. Most of this therapeutic and diagnosis studies have to be assayed in animal models before to achieve clinical trials in humans. In this context, nowadays, one of the main focus is on the investigation of angiogenesis related processes using pigs as experimental animal models.

![Figure 7: C-arm fluoroscopy applications](image_url)

**Figure 7: C-arm fluoroscopy applications** A) C-arm fluoroscopy unit installed at RX/30639 in animal facilities of the medicine college. B) Angiography showing a myocardial infarction in pig, induced by placing an angioplasty catheter into the middle segment of the left anterior descending (LAD) artery and inflating it for 90 minutes, to later study therapeutic strategies. In this image a iodine contrast media has been injected into blood vessels or the chambers of the heart to produce the angiogram. (Image kindly provided by M. Rigol and N. Solanes). C) Injection of radio-opaque contrast substance of the entire tree to draw blood from the pig’s coronary arteries. Contrast compounds containing iodine, which are radiopaque are injected in the artery or veins to highlight these vessels. The contrast compounds consist of highatomic number elements that largely attenuate X-rays and hence the hollow vessel can be more readily observed. (Image kindly provided by M. Rigol and N. Solanes)
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