

Dosimetry and quality control in medical imaging applications

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Abstract— Radiation exposure to medical diagnostic procedures is becoming a topic of increasing relevance and social interest. A primary aim of modern diagnostic procedures is to provide sufficient information for a particular diagnostic task with exposures kept as low as practicable. The ALARP principle (As Low As Reasonably Practicable) is the driving force behind a number of innovations and ongoing research activities over the past 30–40 years.

To evaluate the performance of diagnostic imaging systems it is necessary to correlate image quality and dose and, therefore, be able to evaluate both. This can, on the one hand, involve advanced measurement tools and methods that attempt to measure imaging system parameters such as MTF, NPS, and NEQ as well as dose (quanta) dependent image/information quality parameters such as DQE. However, whilst such measurements provide information concerning the physical performance capabilities of systems employed in diagnostic procedures under well defined exposure conditions, they do not permit us to verify optimal performance in daily clinical use. For this latter purpose it would be necessary to routinely perform measurements of image quality and associated dosimetric evaluations, ideally for every patient. Under such circumstances the ALARP principle could then be said to apply to each and every patient or group of patients.

In this paper the development of meaningful patient dosimetry methods and techniques for various patient specific radiological applications, as well as image quality control procedures will be reviewed. The importance of ongoing technological developments will be discussed in relation to the present situation and future progress that might be possible in the field of patient radiation protection. For example in the UK during the past 5 years there has been a complete transfer from film based to digital radiographic techniques. Equally, ongoing developments in CT technology continue to create increased imaging information albeit at much higher doses. The effects of these changes on scientific support to patient dosimetry and quality control in diagnostic radiology as well as future possibilities for improved application of the ALARP principle will be highlighted.

Keywords— Radiation protection, patient dosimetry, quality control

I. INTRODUCTION

Over the past 40 years collective effective doses arising from diagnostic radiology have risen consistently as the diagnostic power and availability of radiological imaging methods has continued to grow. Consequently increases in image quality (diagnostic power) rather than a reduction in patient dose continues to underpin modern practice. CT examinations, now considered to represent the “gold” standard for diagnostic outcomes continue to grow as a percentage of overall x-ray examinations as well as in terms of their overall contribution to population exposures [1]. Indeed a recent report released recently by the National Council on Radiation Protection and Measurements (NCRP) [2] indicates that in the US the population exposure to ionising radiation from medical procedures grew more than seven-fold between the early 1980’s and 2006. This corresponds to a doubling time of roughly 8 years. What is the relevance and meaning of the fundamental aspects of radiation protection embodied in the ALARP and ALARA (As Low As Reasonably Achievable) principles in the face of such growth?

The field of general radiation protection is built upon the foundation of controlling exposures (minimisation of risks). However, in the field of healthcare, reduction of radiation exposures can be counterproductive and may actually lower benefits. The control of radiation exposure cannot be treated in isolation from the need to improve and/or maximize diagnostic outcomes. Thus we need to consider the total risk (R_T) arising from diagnostic radiology, given by:

$$R_T = R_R + R_D \quad (1)$$

Where R_R is the radiation risk and R_D is the diagnostic risk associated with false positive/false negative outcomes [3, 4]. Decreasing the radiation dose in order to reduce R_R may have a much greater deleterious effect on R_D . Also, both the diagnostic risks and benefits can vary from patient to patient (age, sex, weight) as well as disease process and anatomical region.

Given this extremely complex and varied situation medical scientists have attempted to create a scientific framework for radiation protection, including quality control and patient dosimetry. This framework has largely been driven by ongoing technical developments within the field of diagnostic radiology as well as the integration of developments from outside. Before attempting to indicate how such a scientific framework might continue to evolve it is worthwhile considering historical developments in this field over the past 50 years.

II. DEVELOPMENT OF TEST PROCEDURES AND STANDARDISATION OF PRACTICES (1950 – 1980)

The roots of quality assurance in diagnostic radiology, including quality control, radiation protection and patient dose, may be traced back to the 1950s. At this time there was just three X-ray imaging modalities; radiography, fluoroscopy and conventional tomography. A growing interest was developing throughout Europe and North America in developing a more scientific framework for diagnostic radiology including an improved understanding of its limitations. There was also a growing awareness of the need to quantify and assess the levels of radiation employed diagnostically.

These early initiatives were pursued by a relatively small group of radiologists, physicists and engineers working in industry and healthcare throughout Europe and North America. Concepts such as noise, resolution and visual performance that had been developed elsewhere for quantifying/assessing system performance, were being applied to the radiological image [5,6,7,8]. Also technical developments in image intensification for medical applications were receiving increased attention [9,10].

As well as the scientific and technical aspects of X-ray image production, interest was growing in the levels of radiation employed in diagnostic radiology and dosimetric measurement methods [11,12]. During the late 1950s in the UK the Adrian Committee organized a survey of the extent of medical and dental radiology in Great Britain in order to assess the levels of radiation dose employed and make recommendations for its reduction. The findings of the committee were published in three parts between 1959 and 1966 [13,14,15]. The reports included recommendations for reducing the genetically significant doses from diagnostic radiological practices since genetic risks were considered, at this time to be, the major hazard.

The early initiatives led to three meetings held in Washington [16] and Chicago [17,18]. These meetings brought together experts, from both Europe and North America and included radiologists, engineers and scientists and involved a transfer of information between the manufacturers and users of X-ray equipment. Also, the meetings were not only concerned with the technical basis of X-ray imaging methods but also methods for reducing patient dose by instrumentation and technological developments. However, over the intervening 40-year period, technological developments have led to the completely opposite outcome based upon a desire and capability for improved information.

Whilst these more fundamental initiatives were underway, interested individuals, who were working within the healthcare sector, continued to develop methods for assessing the performance of radiological systems and the application of imaging sciences to diagnostic radiology. Research, including methods for making measurements on X-ray beams, radiological imaging systems, image quality and perception, were all pursued. In 1974 the Hospital Physicist's Association (HPA) in the UK published in a single document what had previously been four individual reports dealing with the physical aspects of the important imaging components [19]. This has been subsequently revised on a number of occasions. Particular attention was paid to those aspects of performance that could be quantified. The transfer of basic research on systems performance and methods of measurement, into routine application within the clinical domain had now begun. However, test methods were extremely varied and in most instances test equipment was manufactured locally to personal design so that results could not easily be compared.

The momentum was maintained throughout the 1970s as individuals continued to develop, implement and refine methods for measuring X-ray system performance. Results of this effort in the UK led to the publication by the Hospital Physicists' Association (HPA) of standard test protocols of methods and procedures, for assessing the performance of radiological systems. The first protocol dealing with X-ray tubes and generators was published in 1980 [20]. This was followed almost immediately by protocols dealing with image intensifier/TV systems, screen-films and automatic processors, CT scanners and conventional tomographic units.

However, whilst these activities were underway, there was continued technological development and ongoing basic research in diagnostic imaging methods being pursued including rare earth intensifying screens, CsI image intensifiers, digital (subtraction) fluoroscopy, mammography,

xeroradiography and ionography. There was a need for a dynamic scientific process within quality assurance in diagnostic radiology based upon the application of research and development methods. Also, up until this point the routine application of patient dose measurements was somewhat peripheral to the assessments of equipment performance.

III. HARMONISATION OF INITIATIVES AND CREATION OF A EUROPEAN DIMENSION (1980 – PRESENT)

The beginning of a truly European dimension to quality assurance in diagnostic radiology can be traced to a meeting held in Munich-Neuherberg in April 1981 organized by the Commission of European Communities. The purpose of this meeting was to discuss with a group of European experts the possibility of reducing patient doses from medical X-ray diagnosis [21]. This meeting highlighted the need for a separate EU Directive on radiological protection of the patient and the need for an EC research effort to reduce patient exposure.

Following this preliminary meeting a Council Directive concerned with protection of the patient was issued in 1984 (84/466/EURATOM). As part of the underpinning initiatives to support the Directive experts from research, industry and public health services involved in medicine came together to participate in a seminar on “Criteria and methods for quality assurance in medical X-ray diagnosis” held in Udine, Italy [22]. This meeting coincided with the commencement of an extended research programme in the field of radiation protection in diagnostic radiology. Prior to this contractors had been representatives from Government Laboratories and major University Hospitals. However, much of the expertise in this area lay with individuals working in routine medical practice and these were now included in the programme. A comprehensive radiation protection research programme including quality assurance and patient dosimetry has been ongoing throughout Europe over the past 20 years and has produced many notable outcomes.

Findings and outcomes from the European research programme in the field of radiation protection, including quality assurance and patient dosimetry, have been published in the proceedings of numerous meetings over the years, for example [23,24,25]. However, such programmes have had to constantly cope with and reflect the ongoing technological changes that are being implemented within the field of diagnostic radiology. For example in the UK there has been a complete replacement of film based radiographic imaging by digital technology. This has led to a completely electronic radiological environment that itself offers a number

of exciting possibilities for developing more patient oriented scientific support mechanisms.

IV. CURRENT STATUS AND FUTURE NEEDS

There is no doubt that quality assurance including quality control, radiation protection and patient dose measurement in diagnostic radiology has evolved significantly both philosophically and practically over the past 50 years. It is now an accepted part of routine radiological practice and has helped to introduce a more scientific approach to this activity. It has led the way in terms of the application of quality assurance in healthcare. Also, given the increasing importance of imaging in therapeutic applications it is influencing scientific practice outside diagnostic radiology.

Research based activities in the field of quality assurance continue to underpin the ongoing development of the field. Thus new test methods are continuously being required to evaluate and assess new forms of X-ray imaging particularly in the field of 3 dimensional imaging methods such as tomosynthesis. This includes new techniques and methods for assessing patient dose. The impact of IT on the diagnostic imaging process, through the introduction of new detectors and PACS systems continues to open up new possibilities for automated quality assurance processes including improved data analysis and centralized management systems. The use of clinical images in routine quality control methods driven by the application of computer aided diagnostic methods [26] is also becoming a reality. These developments can have a major impact on the optimization of radiological practices throughout Europe.

Of particular interest is a web-based approach to the centralized collection, analysis, management and storage of x-ray exposure information accessed from a Hospital’s Radiology Information System (RIS) [27]. Such an approach can permit ongoing patient dose audits as part of a routine automated QA programme [28]. For example the differences in mean dose for male and female patient populations provides valuable information on the performance of AEC devices. This approach can permit more detailed assessments of radiological practices as part of an optimization programme involving all patient records. It can also form the basis for ongoing international collection and comparison exercises of patient doses and radiological practices. Where data is collected to a standard format.

The application of IT to radiation protection in diagnostic radiology can provide new and improved scientific support mechanisms. Information generated can underpin the devel-

opment of a more quantitative risk-benefit framework for diagnostic radiology as well as optimized feedback loops or expert system support for operators.

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Format the Acknowledgment and References headlines without numbering.

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