Editorial

1. Preamble

Prof. Wilhelm Conrad Röntgen (1845–1923) discovered the X-rays on the 8th November 1895 at the Institute of Physics of the University of Würzburg. This was a major milestone for medical diagnosis. The importance of this discovery was immediately understood by the medical world: “Seeing is believing”. The discipline of Radiology was born and grew up rapidly. Phosphor screens were introduced at the beginning of the twentieth century; in the ‘70s, image intensifiers were introduced; in the ‘80s, radiography became digital and the CT was invented.

The use of ionizing radiation for the treatment of tumors was soon explored, already in 1896, thus initiating a new discipline, i.e., Radiotherapy. In the same year (1896) studies on Uranium salts conducted by Henri Becquerel, Pierre and Marie Curie brought to the discovery of natural radioactivity. The use of gamma, beta and alpha particles for diagnosis and therapy gave birth to the new discipline of Nuclear Medicine.

In the early 1900s, radium was being promoted on a large scale as a cure for virtually all ailments, from cancer to baldness. Radium was added in appreciable quantities in hundreds of commercial health and beauty products (Fig. 1). The name of the inventor of the Tho-Radia powder/cream was Alfred Curie, who had no relation whatsoever with Pierre and Marie Curie! Eben Byers, U.S. Champion Open Golf, (Fig. 2) was a sponsor for “Radithor”, a brand of mineral water with a high concentration of radium. He had been drinking 3 bottles of “Radithor” a day for three years. He died in 1932 due to radionecrosis of the jaw and skull.

It was soon understood that radiation (either X-rays or particles/gamma rays from radioactive sources) could cause ailments to human being going from skin dermatitis up to cancer, e.g., in one-year period (1/1896–12/1896) 23 cases of radiation dermatitis were documented and in three years (1911–1914) 252 cases of radiation-induced cancer (54 deaths) were reported. A lot of concern was raised by the radiologists; many of them had suffered by the harmful effects of radiation. At the 1928 International Congress of Radiology, the International Commission on Radiological Protection (ICRP) was established. This commission issued the first recommendations for the safe use of radiation in Medicine. The new discipline of Radioprotection was born.

All together the use of X-ray and radioactive sources in medicine created the fields of Radiology, Nuclear Medicine, Radiotherapy and Radioprotection. It should be underlined that everything started with the discovery of the X-rays, 125 years ago. To celebrate this anniversary the Editorial Board of EJMP has decided to publish a focus issue dedicated to this event by invited contributions. We were asked to act as Guest Editors. We were much honored and humbly accepted the task.

2. Content of the volume

Seventeen review papers were finally accepted that are the content of this volume. For sake of coherence the invited reviews were limited to the topics of History of Radiology, Advances in X-ray Imaging, X-ray Radiotherapy, X-ray Dosimetry and Radioprotection.

2.1. History of radiology

The end of 19th century and the beginning of 20th century were one of the most fascinating periods for the advance of clinical diagnosis and therapy. F. Nüsslin in his review paper [1] presents a thorough historical view of the pre X-ray physics and of Röntgen’s discovery. A very nice section is that one dedicated to W.C. Röntgen’s personal life and his attitude toward science and academia. A short survey of radiological applications in various fields completes the paper.

R. Behling in his review [2] covers the development of the X-ray technology from Röntgen’s discovery to the present day. It is a fascinating ride from the first X-ray tubes of 1896 and the first rotating tubes of the beginning of the 20th century to the modern X-ray tubes specific for each radiological application, e.g., cardiology, angiography, dental, mammography. The large number of illustrations of the various devices allows the reader to grasp the tremendous impetus that the X-ray technology has experienced in the last 125 years.

The enthusiasm for the new kind of radiation with its broad spectrum of medical applications hid for quite some time the risks associated with X-rays. With the increasing observation of severe sequelae of an unprotected and often long-time exposure of X-rays the need for proper protection measures became obvious. A grand tour d’horizon via all aspects of radiation protection, particularly the development of measurement quantities and techniques, optimization methods and international standardization is provided in the review article of J. Malone [3].

2.2. Advances in X-ray imaging

It is well-known that one of the limitations of conventional X-ray imaging is its reduced capability of discriminating among biological soft tissues. To overcome this drawback phase contrast X-ray imaging was proposed in early ‘70s and since then many attempts have been done to implement this method, first using synchrotron radiation and later on with conventional X-ray tubes by using X-ray grating interferometry. The review by A. Momose [4] presents at length the theory of phase contrast X-ray imaging and discusses the encouraging results of the first pilot studies on patients in mammography and in the diagnosis of

arthritis and of lung diseases.

Different from the previous contribution, the review by Ando et al. [5] discusses a specific variation of the X-ray contrast imaging. This technique, introduced in early 2000, is based on X-ray refraction imaging and is named X-ray dark field imaging (XDFI). This paper illustrates the last 20 years of theoretical understanding, the instrumentation development and many of the potential ex-vivo and in-vivo clinical applications of XDFI.

The review paper by L. Heck and J. Herzen [6] addresses the specific application of Phase Contrast Imaging to mammography. After a discussion on Phase-Contrast Mammography and on Grating Based Mammography to obtain 2D images of the breast, the authors tackle the possibility of 3-D imaging by using Phase-Contrast Breast Computed Tomography and compare the preliminary results as obtained at synchrotron sources with those obtained with a more standard CT device (Breast Computed Tomography).

The K-edge subtraction (KES) imaging exploits the absorption difference of X-rays above and below the K-edge energy of a contrast agent (usually Iodine). This is best achieved with monochromatic and tunable X-ray beams as obtainable with synchrotron radiation. However, to overcome the complexity of a synchrotron and to bring KES into the clinical environment, the inverse Compton sources have been suggested, based on the principle of inverse Compton scattering. The review paper by S. Kulpe et al. [7] presents an extensive coverage of the advantage of this new technique and describes possible clinical applications.

Lung X-ray imaging both with conventional 2D-radiology and CT is limited to morphology studies, because of the difficulties for having enough signal to noise ratio to study the lung functionality. A high spatial resolution joint to a high temporal resolution would be needed for that purpose. Recently the use of high intensity synchrotron radiation has been suggested because of its monochromaticity and its temporal beam structure. The review paper by S. Bayat et al. [8] presents the principle of the major techniques now available with synchrotron sources, i.e., phase and absorption contrast imaging and K-edge subtraction imaging, and their applications in preclinical animal models. Of particular interest to the actual COVID-19 pandemic appear the in-vivo studies on lung ventilation in rats.

Fig. 2. Photo of the golf player Eben Byers (). adapted from <http://westpenngolffhof.org/ind/2015-byers-eben-wpga-hof.html>

In many CT applications, especially in cardiac studies, there is the need for very short exposure times so as to avoid motion-artifacts in the reconstructed image. This would require to further increase the gantry rotation frequency of a spiral CT that could be rather difficult with the actual technology. As alternative solution the dual source CT has been proposed with two x-ray tubes and two detectors at approximately 90° . The review by B. Schmidt and T. Flohr [9] describes the principles and the clinical benefit of this technique, with an ample coverage of the dual energy imaging, as obtainable by operating the two tubes at different kV-settings. A discussion of the advantages and challenges of dual sources CT concludes the paper.

Photon Counting detectors were originally developed for Nuclear Physics and High Energy Physics experiments. It took a while for this

Fig. 1. Left: Poster for Tho-Radia beauty products with added Radium and Thorium (1933) (<https://www.pinterest.it/pin/212865519867778172/>). Right: Photo of the Tho-Radia Powder (https://commons.wikimedia.org/wiki/File:Tho-Radia-IMG_1228.JPG).

technology to be transferred to X-ray imaging for obvious reason of cost, reliability and too high count-rate. Now it appears mature for CT application so as to increase the signal to noise ratio and overcome the present CT limitations in quantitation capability and in dual-energy applications. The review paper by T. Flohr et al. [10] presents an exhaustive description of the photon counting CT principles and of the last generation of detectors. The encouraging results obtained in ex-vivo applications and in proof of principle studies on patients complete the paper.

Computed Tomography is the most revolutionary technique born from X-ray discovery, and yet today a story of breaking developments. Singh et al. [11] look back at the milestones of this route of fascinating innovations in hardware and software design aiming at faster image acquisition, more information extraction, higher image quality and, due to its wide dissemination, an efficient strategy for dose reduction. The progress in spectral CT and the recent techniques of dose reduction based on photon-counting detectors (PCD) as a promising approach for dose reduction is described. Finally, the potential of Deep-Learning (DL) methods in medical/biological applications are outlined both in image reconstruction and in combination with PCD in dose reduction. Interesting novelties appear at the horizon such as phase contrast and dark-field CT.

2.3. X-ray radiotherapy

Although kV-X-ray lost its importance with the advent of high-energy photon beam techniques, there is a kind of renaissance of this field during the recent years. It is not only the technical progress in X-ray tube design, but the variety of special applications up to even IMRT and not least the cost-effectiveness which brings back the interest of kV-X-ray radiotherapy beyond the established indications of treatment of superficial tumors and benign diseases. The article of D. Breikreutz et al. [12] presents a comprehensive review of the current status and an overview of promising developments.

2.4. X-ray dosimetry and radioprotection

As already emphasized by several authors in this Focus Issue, dosimetry is the key in all efforts of radiological procedure optimization. The classical approach is dose measurement in a phantom. Addressing one of the most critical issues in radiological practising, i.e., the X-ray imaging of the breast, K. Bliznakova [13] takes us on an exciting historical tour giving an overview how to mimic the breast by anthropomorphic phantoms. The different solutions for physical and computational phantoms and their advantages and limitations are discussed. The available materials and manufacturing processes for the design of physical phantoms up to most recent developments such as 3D-printing are covered. Less expensive and more versatile are the computational phantoms, particularly when individual image-based data are included.

A specific aspect of radiation protection is addressed in the article of C.J. Martin et al. [14] who describes the way towards the introduction of the Effective Dose (E) concept by the International Commission on Radiological Protection (ICRP). In particular, the yet often debated application of this concept in medicine is carefully discussed including hints to the new techniques how to calculate a patient specific effective dose.

It is always a dilemma in all radiation practicing to balance the benefits against the risks. The article of M. Rehani and D. Nacouzi [15] highlights this problem emphasizing the concerns with the cumulative dose absorbed from multiple examination procedures. This requires focussing even more on dose minimizing technical solutions in the equipment, for instance with the recent development of the monochromatic X-ray sources, may be in the future also with the application of robotics.

CT is a powerful and most frequently used X-ray imager today which

however is still associated with a significant exposure. Therefore, careful optimization of examination procedures as well as technical measures for dose reduction is an essential requirement. I.A. Tsalaifoutas et al. [16] review the various steps of the introduction of the specific CT-dose quantities, their definition, measurement and recording. Recent solutions are presented like the concept of computer-based dose monitoring systems (DMS) which enables automatization of dose monitoring and recording for each examination, and beyond that a systematic analysis of the captured data to optimize the examination protocols.

Compared to the previous paper, V. Tsapaki [17] addresses in her article the whole spectrum of radiological examinations when outlining her challenging 5-step approach of suitable measures for dose reduction. She emphasizes the need of a valid QA programme, establishment of a multidisciplinary dose optimization team, determination of base-line dose levels for all practices, involvement of a medical physicist for modification of protocols and an evaluation of the entire optimization process with respect to the effect on patient dose and image quality.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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