European Journal of Radiology 84 (2015) 1579–1585

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Construction of pediatric homogeneous phantoms for optimization of chest and skull radiographs

Allan Felipe Fattori Alves [a,*], José Ricardo de Arruda Miranda [c,2], Fernando Antonio Bacchim Neto [c,2], Sérgio Barbosa Duarte [d,3], Diana Rodrigues de Pina [b,1]

[a] Instituto de Biociências de Botucatu, P.O. BOX 510, Departamento de Física e Biofísica, UNESP—Universidade Estadual Paulista, Distrito de Rubião Junior S/N, Botucatu, 18618-000 São Paulo, Brazil
[b] Departamento de Doenças Tropicais e Diagnóstico por Imagem, Faculdade de Medicina de Botucatu, UNESP—Universidade Estadual Paulista, Distrito de Rubião Junior S/N, Botucatu, 18618-000 São Paulo, Brazil
[c] Instituto de Biociências de Botucatu, Departamento de Física e Biofísica, UNESP—Universidade Estadual Paulista, Distrito de Rubião Junior S/N, Botucatu, 18618-000 São Paulo, Brazil
[d] Centro Brasileiro de Pesquisas Físicas, Laboratório de Altas Energias, Dr. Xavier Sigaud, 150, Rio de Janeiro, 22290-180 Rio de Janeiro, Brazil

ARTICLE INFO

Article history:
Received 26 September 2014
Received in revised form 6 April 2015
Accepted 8 May 2015

Keywords:
Chest and skull
Pediatric homogenous phantom
Image quality
Dose optimization

ABSTRACT

Objectives: To develop two pediatric patient-equivalent phantoms, the Pediatric Chest Equivalent Patient (PCEP) and the Pediatric Skull Equivalent Patient (PSEP) for children aged 1 to 5 years. We also used both phantoms for image quality evaluations in computed radiography systems to determine Gold Standard (GS) techniques for pediatric patients.
Methods: To determine the simulator materials thickness (Lucite and aluminum), we quantified biological tissues (lung, soft, and bone) using an automatic computational algorithm. To objectively establish image quality levels, two physical quantities were used: effective detective quantum efficiency and contrast-to-noise ratio. These quantities were associated to values obtained for standard patients from previous studies.
Results: For chest radiographies, the GS technique applied was 81 kVp, associated to 2.0 mAs and 83.6 μGy of entrance skin dose (ESD), while for skull radiographies, the GS technique was 70 kVp, associated to 5 mAs and 339 μGy of ESD.
Conclusion: This procedure allowed us to choose optimized techniques for pediatric protocols, thus improving quality of diagnosis for pediatric population and reducing diagnostic costs to our institution. These results could also be easily applied to other services with different equipment technologies.

1. Introduction

Because of increased mitotic activity and longer life expectancy, children are more radiosensitive than middle-aged adults. Children are two- to three-times more susceptible to radiation and the consequent development of leukemia, and adults who are exposed to radiation during childhood have an increased probability of developing breast or thyroid cancer [1]. Chest and skull radiography are the most commonly performed examinations in pediatric patients aged 1 to 5 years because of head trauma [2,3] and pneumonia [4].

The optimization of radiographic techniques for pediatric patients is especially important when using digital systems because of an imperceptible increase in dose with time [5]. Homogeneous phantoms are important tools to establish optimized techniques [6–9], especially in medical departments with restricted resources, which can easily simulate realistic anatomical regions [10]. Two homogeneous phantoms are currently used: LucAl phantom (which provides accurate simulation of primary and scatter transmission through the lung field) [11] and patient equivalent phantom (PEP; also known as the ANSI phantom [6,10,12] for the chest, skull, and extremities). The PEP is lightweight and transportable. It is constructed of readily available materials and accurately simulates the standard patient's attenuation properties [13,14].

The present study presents a methodology for constructing pediatric homogeneous phantoms, namely the Pediatric Chest

* Corresponding author. Tel.: +55 14 3880 0285; fax: +55 14 3880 0285.
E-mail addresses: allan@ibb.unesp.br (A.F.F. Alves), jmiranda@ibb.unesp.br (J.R.d.A. Miranda), fernando.bacchim@gmail.com (F.A. Bacchim Neto), sbd@cbpf.br (S.B. Duarte), drpina@fmb.unesp.br (D.R.d. Pina).
1 Tel: +55 14 3811 6254, Fax: +55 14 3811 6254.
2 Tel: +55 14 3880 0285, Fax: +55 14 3880 0285.
3 Tel: +55 21 2141 7328, Fax: +55 21 2141 7328.

http://dx.doi.org/10.1016/j.ejrad.2015.05.015
0720-048X/

Equivalent Patient (PCEP) and Pediatric Skull Equivalent Patient (PSEP). Both phantoms were based on the Infant Patient Equivalent Phantom (IPEP) that was built for newborn patients (age <1 year) [8]. We also based our work on a methodology for estimating the amount of biological tissues in computed tomography examinations and then converting them in simulator materials, such as Lucite and aluminum [8]. We also used both phantoms for image quality evaluations based on objective physical quantities, including effective detective quantum efficiency (eDQE) and the contrast-to-noise ratio (CNR). These quantities were associated with values obtained for optimal techniques for standard adult patients in a previous work. This procedure permitted us to choose optimized techniques for pediatric protocols, improve the quality of diagnosis for the pediatric population, and reduce the cost of diagnosis.

2. Methodology

2.1. *Quantification of biological tissues and phantom development*

We used an established methodology [8] to develop an automatic computational algorithm that is able to classify and make quantifications for biological tissues based on retrospective computed tomography (CT) examinations. We retrospectively analyzed 148 CT examinations of patients aged 1 to 5 years, of which 92 were chest examinations and 56 were skull examinations. The algorithm steps are summarized as the following:

- Read the Digital Imaging and Communications in Medicine (DICOM) images and the attributes present in the DICOM header.
- Delimit the image region of interest (ROI) and eliminate artifacts.
- Estimate the mean anterior-posterior diameter (APD) and lateral diameter (LD) of the images by averaging the APD and LD in each delimited image.
- Generate the patient examination histogram (number of voxels $\times$ CT number).
- Make a Gaussian fitting of each tissue type in the patient examination histogram (bone, soft, fat, and lung).
- Quantify the number of voxels under each Gaussian curve.
- Determine the mean thicknesses of the biological tissues.
- Convert the mean thicknesses of the biological tissues into the corresponding thicknesses of the simulator material plates (aluminum and Lucite).

Both phantoms were constructed using similar structures to the conventional PEP for standard patients [12], with plates areas of 15.0 cm $\times$ 15.0 cm. However, in our case, the PCEP and PSEP have different thicknesses because of the patient characteristics in the age range of 1 to 5 years.

In the PCEP, the first Lucite pair (at the top) sandwiched an aluminum (type 1100) plate. The second Lucite pair (at the bottom) contained a slightly wider aluminum slab inside. The second aluminum plate was designed to account for the greater amount of bone tissue, which results from the presence of the vertebral column (Fig. 1a and b). Between the upper and lower pairs of plates, we inserted spacers that represented lung tissue as an air gap.

The PSEP (Fig. 1c and d) was constructed from five Lucite plates of equal thickness. Two aluminum plates were inserted between the first and second plates and between the fourth and fifth Lucite plates.

2.2. *Setup description and physical quantities used to define test techniques*

The X-ray beam was generated with three-phase X-ray equipment (Multix B, Siemens AG Medical Engineering, Germany). The total inherent filtration of the X-ray tube was 2.5 mm aluminum. We used a CR-85X Reader (Agfa-Gevaert Group, Mortsel, Belgium) with MD 4.0 general cassette plates (18 cm $\times$ 24 cm; effective pixel pitch, 0.1 mm). To achieve maximum reproducibility, one image plate (IP) was used for chest and skull examinations, and all of the procedures were repeated three times. We ensured a delay of 10 min between exposure and reading the image plate.

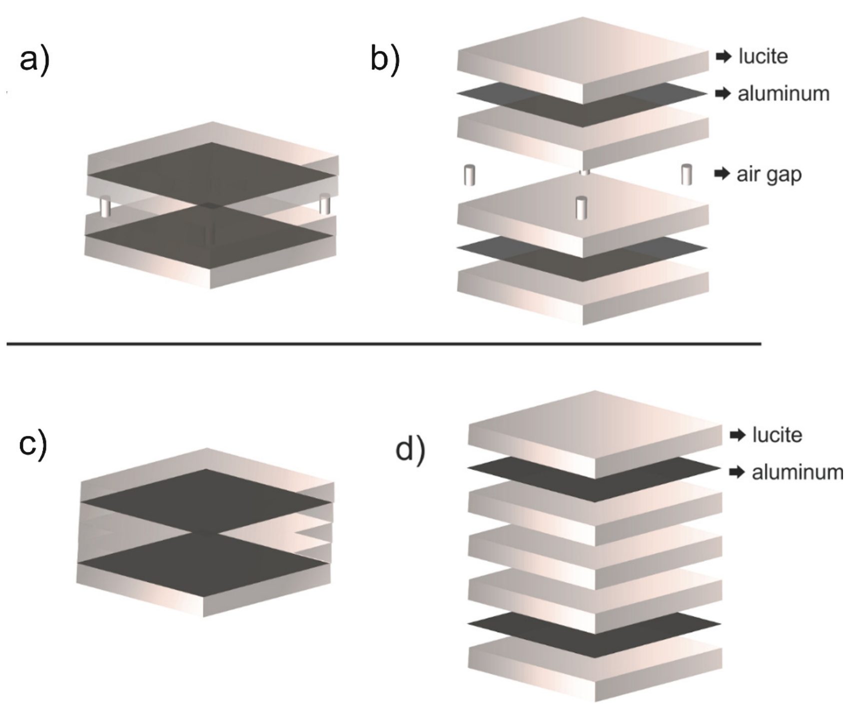

Fig. 1. Illustration of the pediatric homogeneous phantoms. (a) Assembly of the pediatric chest equivalent patient (PCEP). (b) Expanded view of the PCEP. (c) Assembly of the pediatric skull equivalent patient (PSEP). (d) Expanded view of the PSEP.