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Pediatric phantoms

It is very hard to simulate human body from the newborn to the adult with the huge variations of dimensions of the body and organs and different tissues that are supposed to be mimicked. The shape of the organs and tissues and also tissue properties are crucial by body region.

Requirements

Geometry must follow the references from ICRP reports as much as possible. Tissue simulation is the gold standard and is supposed to be within 1%. The reference data are very crucial. To design phantoms you need not only reliable reference data but also complete data to make a complete product. We need to choose some age groups to represent all these ages. Traditionally, from the medicine point of view, we have five age groups: the infant, sometimes the newborn is separated (up to 3 months), the toddler, pre-school child, school age child, and the adolescent (Table 1). For the dosimetry the size of the body and organs is the most important criterion to represent all groups because radiation absorption in the body depends on the size.

First, we took the trunk length to represent the whole body because organs "in general" have a linear relationship to the trunk length (Fig. 1). Using five equal intervals, we divided the whole range for the five age groups, and medium ages for each group are shown here. Trying to be more precise, we took the relative effective size of organ as a representative factor and, using the same concept, we came to a somewhat different result (Table 2). However, they were very close. The final decision is made on the basis of reference data, as they are more reliable. Thus, we chose the newborn baby (0 year old) and the 1-, 5- and 10-year-old child, and the 15-year-old adolescent to represent the age groups (Fig. 2). Each phantom is relatively average in the age group. Children organ dimensions do not vary more than 15% within the age group. The difference covers the sexual and ethnic variations. However, if we are talking about a particular pediatric patient, we need to take in account the patient's size (height) and not the age to find the appropriate age-group phantom for this patient and relate it to some dosimetry data.

This is the final table (Fig. 2). There is the height range in a right column that corresponds to the age goups. For example, the 5-year-old phantom represents children from 3 to 7 years old, boys and girls and all ethnic groups, but more precisely, the children's height is supposed to be from 95 to 124 cm to apply the phantom dosimetry data to this particular patient.

Computational phantoms

There are well-known mathematical types of phantoms, elliptical pediatric models developed by M. Christy in 1980 and improved later (Fig. 3). Later they were highly developed by Yamaguchi. They have five age groups: newborn, 1, 5, 10 and 15 year olds; they also adjustable by size and weight of the person. That is a great improvement.

Tomography models developed by Williams and Maria Zankl in the late 1980 s included 2-month and 7-year-old phantoms because they used particular corpses. They used CT scans to provide 3D representation of a whole body and a variety of tissues. Phantoms are very precise because the pixel sizes are 1.5×1.5 mm in

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Table 1. Traditional age groups

Five traditional age groups	
Infant	0–12 months
Newborn	0–3 m
Toddler	To 3 years
Preschool	To 6 years
School age	To 12 years
Adolescent	To 17 (18) years

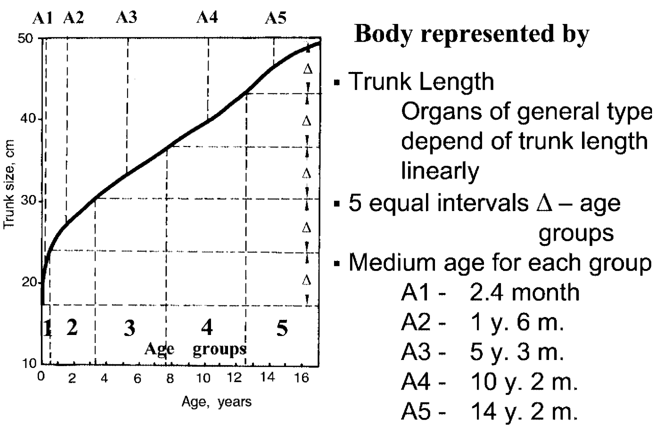
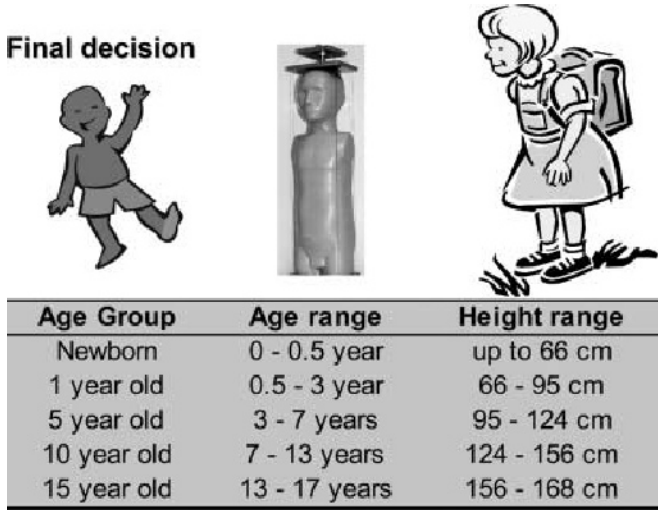


Fig. 1. Body represented by trunk length

Table 2. Body represented by relative effective size of organ

$S(t) = \sum W_i(t) * S_i(t)$,	$W_i(t) = \frac{L_i(t)}{L_B(t)}$, weighting factor to represent larger organs, $L_B(t)$ - length of body at age t
$S_i(t) = \frac{L_i(t)}{L_{\max}}$	$L_i(t)$-size of i-organ at age t $L_{\max}$-size of i-organ at age 17.
Using the same concept – Medium age for each groups	A1-2 months A2-1 year A3-5 years,3 months A4-9 years Y5-14 years



Age Group	Age range	Height range
Newborn	0 - 0.5 year	up to 66 cm
1 year old	0.5 - 3 year	66 - 95 cm
5 year old	3 - 7 years	95 - 124 cm
10 year old	7 - 13 years	124 - 156 cm
15 year old	13 - 17 years	156 - 168 cm

Fig. 2. Final decision

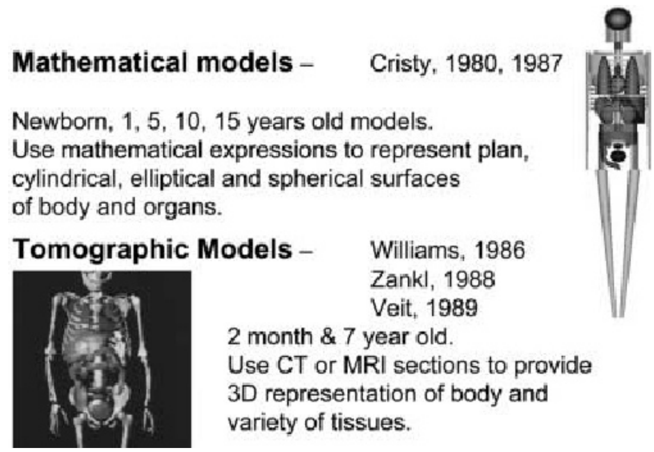


Fig. 3. Computational phantoms. Mathematical and Tomographic Models

area. However, these phantoms depend on the availability of corpses and they do not conform to any age group. They can just be used in research.

Physical Phantoms

As you can see (Table 3) from the 1950s, different researchers used objects of different shapes to represent the body of children and the different age groups; various materials like paraffin and liquids and, finally, epoxy resin were used. A crucial point was reached in 1987 when a well-known scientist Dr. Sam Alderson, presented a 6-year-old phantom with a natural skeleton. In 1988, author published paper about a newborn anthropomorphous phantom with a natural skeleton. In 1993, author published an article describing a set of all five pediatric phantoms with artificial skeletons of simplified shape. The name of this set is "ATOM phantoms." They have been developed in the 1980s in the USSR.

Newborn prototypes were developed in 1986 (Fig. 4). It didn't have a skeleton, but only lungs and soft tissue. The second newborn phantom included a natural skeleton and artificial lungs and, soon, in 1988, three pediatric phantoms were finished (newborn, 1 and 5 year old), and all of them had a natural skeletons (Fig. 5). Soft tissue simulation wasn't so good then. It was ± 2% – no comparison with today's simulation.

Farther phantom development included the developing of pediatric phantoms of five sizes with artificial skeletons. Skeletons were simplified because it was a huge problem to make them natural. All phantom

Table 3. Physical phantoms

1957, Billings	Rectangular blocks 0–2, 2–7, 7–11 years old
1957, Webster	Blocks 3 and 10 years old
1972, Hashizume	Paraffin-based 0–2, 2–7, 8–14 years old
1978, Chen	Liquid mix 1 and 5 years old
1986, Kostenetcky	Paraffin 1, 7, and 12years old
1986, Harnet	Epoxy-resin head 4–5 yearsold
1987, Aldreson	Anthropomorphous, natural skeleton, 6 years old
1988, Varchena	Anthropomorphous, natural skeleton, newborn
1993, Varchena	Anthropomorphous, artificial skeleton, 0, 1, 5, 10, 15 years old

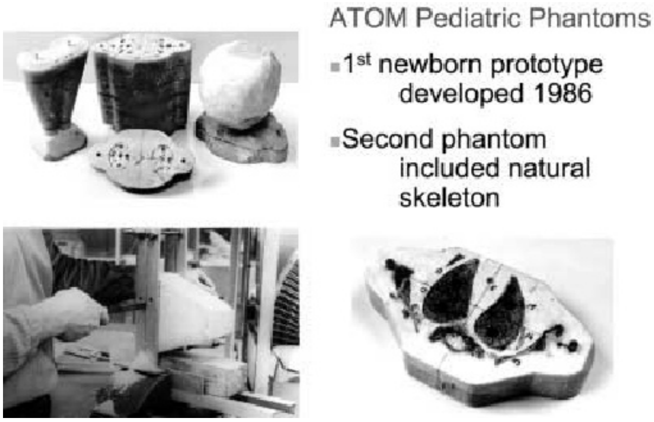


Fig. 4. Physical phantoms. ATOM pediatric phantoms. - 1st newborn prototype developed in 1986. - Second phantom included natural skeleton

development was based on extensive anatomical research. The position of 19 internal organs was specified in the phantoms, which was very important for research in pediatric radiology (Fig. 6). The locations of TLD in these organs were optimized to decrease the time and cost.

The final improvement was done in Norfolk, Virginia (Fig. 7). All the skeletons became anthropomorphous. The bone materials of each age group depended on the group and shape was much more realistic. Six tissues were simulated in each model, and the lung density varies from full inhalation to exhalation. It could be also customized. Great improvement in 10 years (Fig. 8)!

The tissue simulation in ATOM Phantoms is perfectly done today and all tissue except for the lungs mimics the reference within 1%, starting with 40 KeV to 25 MeV for the photon beam, which makes these phantoms very useful in both diagnostic radiology and therapy. Artificial skeletons provide no variation in size, position, or density.

Figure 9 is representing a female head phantom image of a well-known brand name (left), and ATOM

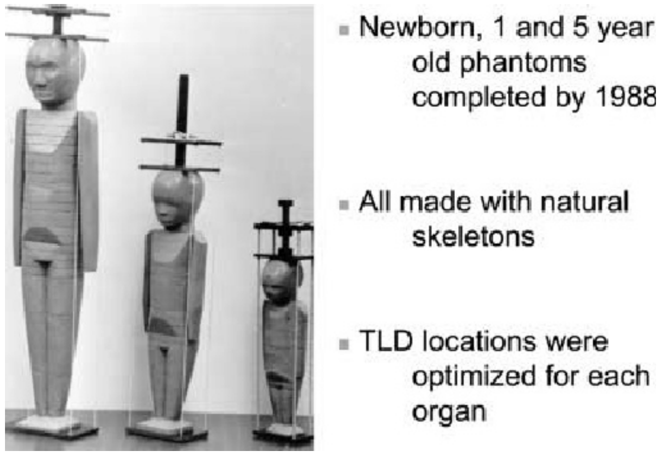


Fig. 5. Newborn, 1- and 5-year-old phantoms completed by 1988. All made with natural skeletons. TLD locations were optimized for each organ

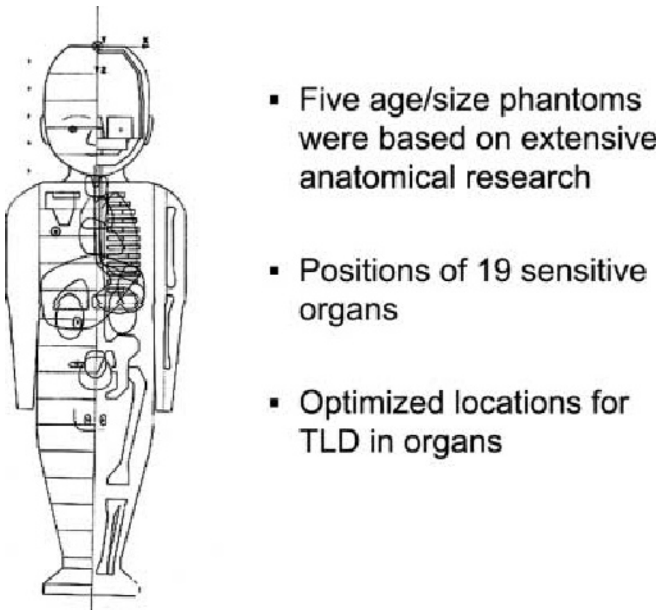


Fig. 6. Five age/size phantoms were based on extensive anatomical research. Positions of 19 sensitive organs. Optimized locations for TLD in organs

Phantom. The huge difference coming from the fact that we do not coat slab surfaces as a result ATOM Phantoms have very good continuity of internal anatomy. You can barely see the interfaces between slabs that makes the dosimetry more precise and reliable.

Different types of dosimeters are applicable to the phantoms. TLD holes are available in different grids and locations in organs. Holes have supportive numbers on a slab and physicist also has a map of each slab and the list of organs with the hole numbers for easy use of the phantom (Fig. 10).

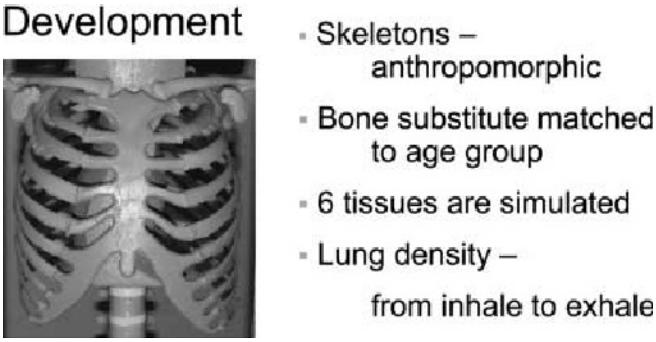


Fig. 7. Development. Skeletons – anthropomorphic. Bone substitute matched to age group. Six tissues are simulated. -Lung density – from inhalation to exhalation

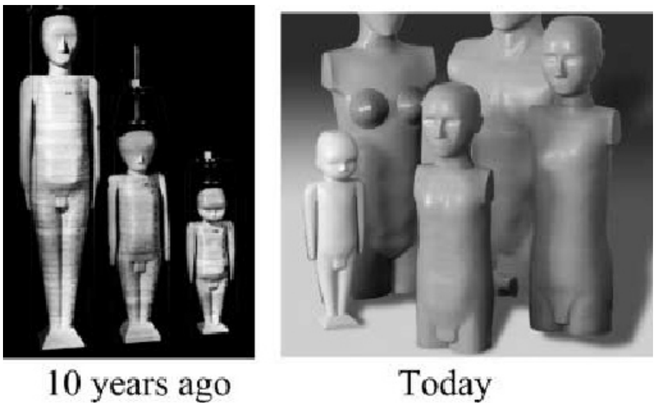


Fig. 8. Ten years ago and today

There are well-known standard acrylic phantoms for the adult abdomen and head. They are used for CTDI evaluation and are made according to FDA and international standards (Fig. 11). As reported by Dr. Nickoloff, it is clear idea to use cylinders of different diameters to represent pediatric patients, but Dr. Nickoloff has also shown that it is useful but it is not standard. Dr. G. Barne went even farther to get the standard with more realistic shaped abdominal phantoms for different ages, with the spine inside. The CTDI concept is still applicable for these phantoms for research purposes.

I'd like to follow up the previous discussion, especially Dr. Brody's talk. The dose problem is a complex problem in CT. Pediatric doses are directly related to image quality. I should have another topic regarding QC phantoms for pediatric CT, but they do not exist. I am working on the set of QC pediatric phantoms. It will be an additional section to each size of the abdominal set. It will allow to make a quantitative judgment about the quality of the image using high-contrast and low-contrast resolution targets, as well as a noise-to-signal ratio.

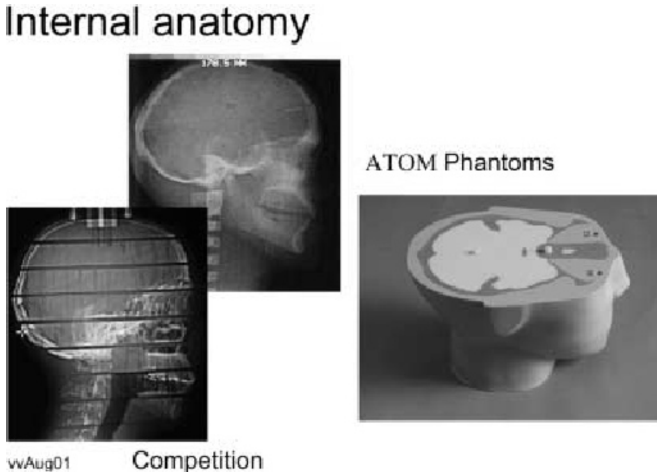


Fig. 9. Internal anatomy, ATOM phantoms, Competition

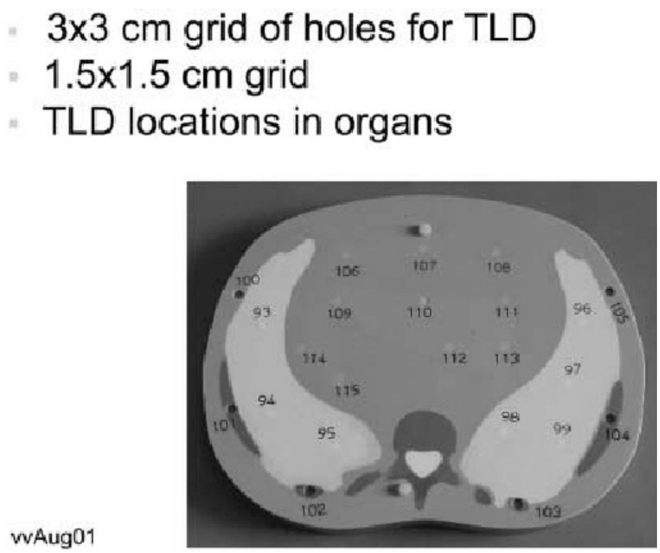


Fig. 10. Dosimeter distribution. TLD locations in organs

Conclusion

In conclusion, pediatric computational phantoms have been available since the 1980s and physical phantoms since the 1990s. Today they are highly developed and precise tool, for research in diagnostic radiology, radiation therapy, and radiation protection.

Dr. Tom Slovis: One of the major issues that I've heard for a long time is that phantoms are so expensive. I think the issue that we have to get to is: if you are spending a half a million dollars or more for equipment,

Fig. 11. CT dosimetry phantoms for CT Dose Index evaluation

and you are keeping it for 5 years, why don't we have the proper way to learn about dose and to do QC? Maybe you could give us an overall estimate of the cost range of the various phantoms.

Dr. Vladimir Varchena: The price basically depends on what dosimetry you want and the hole distribution. The bottom line is, if the phantom is not drilled at all, the newborn is $6,000 and the adult phantom around $15,000. However, I don't want to sell phantoms here. I want to bring up other issues. The phantoms are not ideal, but they are very good and they are still being developed.