Purpose

This was an experimental quantitative research with the following purposes:

• Measure the equivalent radiation dose in the lens, breast, thyroid and gonads when performing head, thorax, abdomen and lower limb Computed Tomography (CT) examinations.
• Compare the dose with and without use of radioprotection dedicated to the lens, thyroid, breast and gonads (pelvic region).
• Evaluate the effect of using bismuth breast radiation protection in the image quality.

Methods and materials

MATERIALS

The materials used in order to conduct this research were:

• 1 plain ionization chamber PTW®
• 1 electrometer PTW® Unidos E®
• 16 optically stimulated luminescence (OSL) dosimeters
• 1 bismuth breast protection KIRAN®
• (equivalent to 0.08mm of lead)
• 1 lens barium protection GRAYSHIELD®
• (equivalent to 0.075mm of lead)
• 1 thyroid lead protection GUIDANT®
• (equivalent to 0.5mm of lead)
• 1 gonads lead apron protection GUIDANT®
• (equivalent to 0.25mm of lead)
• 1 anthropomorphic phantom ADAMROUILLY®
• 1 computed tomography (CT) equipment SIEMENS® SOMATOM® EMOTION® 16
• 1 image control phantom GAMMEX 464®

METHODS

The methods developed to achieve the purposes of this research started by choosing the acquisition protocols to use. The chosen protocols were routine head CT, routine thorax CT, routine abdomen CT and routine lower limb CT. One of the most important aspects were to check which of the measuring instruments is more sensitive for primary or
secundary radiation. It is known that the plain ionization chamber only detects radiation that incides directly to it (anisotropic detection), and the OSL dosimeters detect radiation from any direction (isotropic detection).

The dosimetry on the routine head CT was made according to the following protocol:

1. The anthropomorphic phantom was positioned in the isocenter to the CT gantry;
2. The plain ionization chamber was placed in the right eye (Fig. 1 on page 5);
3. 1 OSL dosimeter was placed in the left eye, another was placed in the thyroid and another was placed in the thorax (Fig. 1 on page 5);
4. 5 sequential acquisitions of the head (routine head CT) were made, angled by the orbitomeatal line (Fig. 2 on page 7) with the technical parameters of Table 2;
5. The Air Kerma values were anotated for each exposition;
6. The OSL dosimeters were sent to reading;
7. The barium, lead and bismuth protections were placed in the lens, thyroid and thorax, respectively. Also, new OSL dosimeters were placed in the same positions as before (Fig. 3 on page 7).
8. 5 sequential acquisitions of the head (routine head CT) were repeated, angled by the orbitomeatal line (Fig. 2 on page 7) with the same technical parameters of Table 2;

The dosimetry on the routine thorax CT was made according to the following protocol:

1. The anthropomorphic phantom was positioned in the isocenter to the CT gantry;
2. The plain ionization chamber was placed in the middle anterior region of thorax, at the breast level (Fig. 4 on page 9);
3. 1 OSL dosimeter was placed in the middle anterior region of thorax, at the breast level, another was placed in the left eye, and another was placed in the thyroid (Fig. 4 on page 9);
4. 5 volumetric acquisitions of the thorax (routine thorax CT) were made (Fig. 5 on page 10), with the technical parameters of Table 2 on page 13;
5. The Air-Kerma values were anotated for each exposition;
6. The OSL dosimeters were sent to reading;
7. The barium, lead and bismuth protections were placed in the lens, thyroid and thorax, respectivelly. Also, new OSL dosimeters were placed in the same positions as before (Fig. 6 on page 11).
8. 5 volumetric acquisitions of the thorax (routine thorax CT) were repeated (Fig. 5 on page 10), with the same technical parameters of Table 2 on page 13;

The dosimetry on the routine abdomen CT was made according to the following protocol:
1. The anthropomorphic phantom was positioned in the isocenter to the CT gantry;
2. The plain ionization chamber was kept in the middle anterior region of thorax, at the breast level (Fig. 4 on page 9);
3. 1 new OSL dosimeter was placed in the middle anterior region of thorax, as in the previous dosimetry plan, at the breast level (Fig. 4 on page 9);
4. 5 volumetric acquisitions of the abdomen (routine abdomen CT) were made (Fig. 7 on page 13), with the technical parameters of Table 3 on page 15;
5. The Air-Kerma values were annotated for each exposition;
6. The OSL dosimeter were sent to reading;
7. The bismuth protection were placed in the thorax. Also, 1 new OSL dosimeter were placed in the same position as before (Fig. 8 on page 14).
8. 5 volumetric acquisitions of the abdomen (routine abdomen CT) were repeated (Fig. 7 on page 13), with the same technical parameters of Table 3 on page 15;

The dosimetry on the routine lower limb CT was made according to the following protocol:

1. The anthropomorphic phantom was positioned in the isocenter to the CT gantry, at the knees level;
2. The plain ionization chamber was placed in the pelvic region, at the female gonads level (Fig. 9 on page 16);
3. 1 OSL was placed in the pelvic region, at the female gonads level (Image 9);
4. 5 volumetric acquisitions of the left knee (routine lower limb CT of the knee) were made (Fig. 10 on page 17), with the technical parameters of Table 4 on page 19;
5. The Air-Kerma values were annotated for each exposition;
6. The OSL dosimeter was sent to reading;
7. The lead apron was placed over the pelvic region. Also, 1 new OSL dosimeter were placed in the same position as before (Fig. 11 on page 18).
8. 5 volumetric acquisitions of the left knee (routine lower limb CT of the knee) were repeated (Fig. 10 on page 17), with the same technical parameters of Table 4 on page 19;

To check the image quality the following steps were undertaken:

1. The GAMMEX 464® was positioned in the isocenter to the CT gantry, aligned according to the sagittal, axial and coronal lines (Fig. 12 on page 20);
2. The axial laser was positioned in the indicated module of the phantom (this phantom has 4 modules);
3. The routine abdomen CT examination protocol was used, but with several adjustments for image quality control purposes and there was produced just one slice. This protocol can be seen in Table 5 on page 22;
4. The previous step was repeated, with exactly the same protocol, but adding a sponge over the phantom (to reduce beam hardening artifacts) and with the bismuth protection over the sponge (Fig. 13 on page 21);
5. For each of the other 3 modules of the phantom, the previous steps were repeated;

Images for this section:
**Fig. 1:** Positioning of the plain ionization chamber and OSL dosimeters during the routine head CT examination.

**Fig. 2:** Topogram of routine head CT examination.
Fig. 3: Positioning of the barium, lead and bismuth protections over the lens, thyroid and breast, respectively.

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Table 1: Technical parameters of sequential head CT examination
Fig. 4: Positioning of the plain ionization chamber and OSL dosimeters during the routine thorax CT examination.
**Fig. 5:** Topogram of routine thorax CT examination (focus on the upper range).
Fig. 6: Positioning of the barium, lead and bismuth protections over the lens, thyroid and breast, respectively.
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**Table 2**: Technical parameters of volumetric thorax CT examination.
Fig. 7: Topogram of routine abdomen CT examination (focus on the lower range).
Fig. 8: Positioning of the bismuth protection over breast.
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<td>Exposition Time (s)</td>
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**Table 3:** Technical parameters of volumetric abdomen CT examination.
**Fig. 9:** Positioning of the plain ionization chamber and OSL dosimeter on the pelvic region, during the routine lower limb CT examination.
**Fig. 10:** Topogram of lower limb CT examination (left knee).
Fig. 11: Positioning of the lead apron over the pelvic region.
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**Table 4**: Technical parameters of volumetric lower limb CT examination
Fig. 12: Phantom for image quality control positioned in the gantry.
Fig. 13: Bismuth protection covering the phantom for image quality control.
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<td>Reconstruction Slice (mm)</td>
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<td>FOV (mm)</td>
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**Table 5**: Technical parameters of sequential abdomen CT examination, adapted to image quality control.
Results

General considerations about the results

In order to compare the results measured by both the ionization chamber and the optically stimulated dosimeters (OSL), a conversion from mGy to mSv had to be done, through the quality factor of the x-ray beam (1 in this research).

About the quality control, the phantom GAMMEX 464® was used. This phantom is composed by 4 different modules that allow the evaluation of several aspects of image quality such as hounsfield units (HU) values, low contrast resolution, image uniformity and spatial resolution.

In this research the sensitivity of OSL dosimeters was better for both primary radiation and secondary radiation and, for this reason, only the values obtained with this devices were used.

Dosimetry done in routine head CT examinations

At a depth of 10mm (Hp10), results show that lens was the organ that had received more radiation, 37.854mSv due to the fact that it is exposed to the primary x-ray beam. The barium protection reduced the dose to 36.732mSv.

Thyroid received a dose of 3.568mSv and breast received a dose of 0.792mSv. After protection of lead on thyroid and bismuth on breast the doses received were 2.772mSv and 0.274mSv, respectively. The Fig. 14 on page 27 presents a graph with these values.

At a depth 0.07mm (Hp0.07), results show that lens was the organ that had received more radiation, 35.962mSv due to the fact that it is exposed to the primary x-ray beam. The barium protection reduced the dose to 34.896mSv.

Thyroid received a dose of 3.522mSv and breast received a dose of 0.792mSv. After protection of lead on thyroid and bismuth on breast the doses received were 2.772mSv and 0.554mSv, respectively.

The Fig. 15 on page 27 presents a graph with these values.

Dosimetry done in routine thorax CT examinations

At a depth of 10mm (Hp10), results show that thyroid was the organ that had received more radiation, 18.790mSv due to the fact that it is exposed to the primary x-ray beam. The lead protection reduced the dose to 5.162mSv.
Breast received a dose of 14.410mSv and lens received a dose of 0.676mSv. After protection of bismuth on breast and barium on lens the doses received were 9.540mSv and 0.348mSv, respectively. The Fig. 16 on page 28 presents a graph with these values.

At a depth 0.07mm (Hp0.07), results show that thyroid was the organ that had received more radiation, 17.852mSv due to the fact that it is exposed to the primary x-ray beam. The lead protection reduced the dose to 7.788mSv.

Breast received a dose of 13.690mSv and lens received a dose of 0.694mSv. After protection of bismuth on breast and barium on lens the doses received were 9.062mSv and 0.438mSv, respectively. The Fig. 17 on page 29 presents a graph with these values.

Dosimetry done in routine abdomen CT examinations

In abdomen CT examinations, the dose was checked just at the level of the breast.

At a depth of 10mm (Hp10), results show that breast received a dose of 20.038mSv due to the fact that it is exposed to the secondary x-ray beam. The bismuth protection reduced the dose to 14.128mSv. The Fig. 18 on page 29 presents a graph with these values.

At a depth 0.07mm (Hp0.07), results show that breast received a dose of 20.936mSv due to the fact that it is exposed to the secondary x-ray beam. The bismuth protection reduced the dose to 13.422mSv. The Fig. 19 on page 30 presents a graph with these values.

Dosimetry done in routine lower limb CT examinations

In lower limb CT examinations, the dose was checked just at the level of the female gonads at the pelvis. The examined anatomic part was the left knee.

At a depth of 10mm (Hp10), results show that the pelvic area received a dose of 0.140mSv due to the fact that it is exposed to the secondary x-ray beam. The lead apron protection increased the dose to 0.162mSv. The Fig. 20 on page 30 presents a graph with these values.

At a depth 0.07mm (Hp0.07), results show that the pelvic area received a dose of 0.134mSv due to the fact that it is exposed to the secondary x-ray beam. The lead apron protection increased the dose to 0.166mSv. The Fig. 21 on page 31 presents a graph with these values.

Image Quality control
**Module 1:** Hounsfield units (HU) tolerance values are calculated by the sum and by the subtraction of the standard deviation to the each mean value observed in the region of interest (ROI) evaluated. If the values obtained are included in the indicated tolerance interval, then the HU calibration is acceptable to the evaluated materials. In the Fig. 22 on page 32 we can see that, without protection, poliethilene HU are between -95.28 and -82.06, bone HU are between 866.29 and 878.47, acrilic HU are between 117.55 and 129.27, air HU are between -988.9 and -993.99 and water HU are between -5.3 and 4.64. We can see the acquisition of module 1 without protection in Fig. 23 on page 32, were all the materials have acceptable HU values. In the Fig. 22 on page 32 Fig. 24 on page 33 we can see that, with bismuth protection, poliethilene HU are between -46.89 and -32.73, bone HU are between 855.73 and 873.77, acrilic HU are between 133.73 and 147.77, air HU are between -972.64 and -958.46 and water HU are between 28.6 and 50.26. We can see the acquisition of module 1 without protection in Fig. 23 on page 32 Fig. 25 on page 33, were poliethilene and water does not have acceptable HU values.

**Module 2:** Low contrast resolution is verified if the contrast to noise ratio (CNR) is above 1. This value is calculated by the subtration of the mean HU of ROI A by the mean value of ROI B and then by dividing this result by th standard deviation of ROI B. Without bismuth protection, the CNR is 1.173, which is acceptable, as shown in Fig. 26 on page 34. In Fig. 27 on page 34, we can see the ROI placed in position B. With the bismuth protection, CNR is 0.764, as shown in Fig. 28 on page 35, which is unacceptable. In Fig. 29 on page 35, we can see the ROI placed in position B. Despite the sponge placed between the protection and the phantom, the beam ardening artifacts increased the HU of both A and B ROI placed, which affected negatively the CNR.

**Module 3:** Image uniformity is calculated by checking the mean HU at the ROI placed in the center of the image. The tolerance values are calculated by adding and subtracting 5 HU to that mean. Then, the mean HU values of the for ROI placed at 12 o'clock, 3 o'clock, 6 o'clock and 9 o'clock can be evaluated in order to check if the image is uniforme. Without the bismuth protection, all the HU values are in the tolerance interval. The ROI placement can be seen in Fig. 30 on page 36 and the values can be checked in Fig. 31 on page 37.

With the bismuth protection, none of the HU values are in the tolerance interval. The ROI placement can be seen in Fig. 32 on page 38 and the values can be check in Fig. 33 on page 39 and it shows that the bismuth protection have a negative effect on image uniformity.

**Module 4:** Spatial resolution is verified by simply counting the pair of lines. To have good spatial resolution, 7 pairs of lines should be visible. In Fig. 34 on page 40 (without the bismuth protection) and in Fig. 35 on page 41 (with bismuth protection)
is possible to count 7 pairs of lines, which means that the bismuth protection does not affect negatively the spatial resolution.

Images for this section:

**Fig. 14:** Individual equivalent dose at a depth of 10mm in a routine head CT examination.
Fig. 15: Individual equivalent dose at a depth of 0.07mm in a routine head CT examination.

Fig. 16: Individual equivalent dose at a depth of 10mm in a routine thorax CT examination.
**Fig. 17:** Individual equivalent dose at a depth of 0.07mm in a routine thorax CT examination.
**Fig. 18:** Individual equivalent dose at the breast level, with a depth of 10mm, in a routine abdomen CT examination.

![Graph showing individual equivalent dose](image)

**Fig. 19:** Individual equivalent dose at the breast level, with a depth of 0.07mm, in a routine abdomen CT examination.
**Fig. 20:** Individual equivalent dose at the pelvic level, with a depth of 10mm, in a routine lower limb CT examination.
Fig. 21: Individual equivalent dose at the pelvic level, with a depth of 0.07mm, in a routine lower limb CT examination.

<table>
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<td>Bone</td>
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<td>872,38</td>
<td>866,29 - 878,47</td>
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<td>Acrylic</td>
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Fig. 22: HU values obtained with module 1 without protection.
**Fig. 23:** Module 1 and respective ROI without protection.

**Fig. 24:** HU values obtained with module 1 with protection.
Fig. 25: Module 1 and respective ROI with protection.

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Fig. 26: Contrast to noise ratio without bismuth protection.
Fig. 27: Placement of ROI B, without bismuth protection.

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<th>Evaluation</th>
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<td><strong>B</strong></td>
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Fig. 28: Contrast to noise ratio with bismuth protection.
Fig. 29: Placement of ROI A, without bismuth protection.
Fig. 30: Placement of the 5 ROI in the phantom, without the bismuth protection.
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**Fig. 31:** Values of the 5 ROI in the phantom, without the bismuth protection.
Fig. 32: Placement of the 5 ROI in the phantom, with the bismuth protection.
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<tr>
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**Fig. 33:** Values of the 5 ROI in the phantom, with the bismuth protection.
Fig. 34: Module 4 of the phantom, without the bismuth protection.
**Fig. 35:** Module 4 of the phantom, with the bismuth protection.
Conclusion

In routine head CT examinations, to use the barium lens protector, allowed a reduction in the radiation dose of only 3% at a depth of both 10mm and 0.07mm (Fig. 36 on page 43 & Fig. 37 on page 44, respectively). In the same examination, for a depth of 10mm the use of lead thyroid protection allowed a decrease in dose of 22% and the use of bismuth breast protection allowed a reduction in breast of 65%. For a depth of 0.07mm the use of lead thyroid protection allowed a decrease in dose of 21% and the use of bismuth breast protection allowed a reduction in breast of 30%.

In routine thorax CT examinations, for a depth of 10mm (Fig. 38 on page 45), the use of thyroid lead protection allowed the reduction of 73% in dose, the bismuth breast protection allowed the reduction of 37% in breast dose and the use of barium lens protection allowed the reduction of 49% in lens dose. At a depth of 0.07% (Fig. 39 on page 46), the use of thyroid lead protection allowed the reduction of 56% in dose, the bismuth breast protection allowed the reduction of 34% in breast dose and the use of barium lens protection allowed the reduction of 37% in lens dose.

In routine abdomen CT examinations, for a depth of both 10mm (Fig. 40 on page 46) and 0.07mm (Fig. 41 on page 47), the use of bismuth breast protection allowed a reduction of 36% in breast radiation dose.

In pelvic region, the radiation dose has increased by 16% for a depth of 10mm and in 24% for a depth of 0.07mm, because the lead apron was placed just in the front of the anthropomorphic phantom, which increased the pelvic radiation dose due to the considerable backscattered radiation caused by the lead in the apron, towards the measuring devices. A limitation arose, because there was no more OSL dosimeters available for this research. However it is important to share this information, because future researches on this theme, should place lead aprons all around the patient before access the secondary radiation.

As for image quality, the results were not so encouraging, since the use of bismuth shield decreased the image quality regarding the calibration of HU values, low contrast resolution and image uniformity. Despite the results demonstrate that the protections are very useful in dose reduction, they have negative effects when intended to reduce primary radiation on the patient.

Images for this section:
Fig. 36: Percentage of reduction on individual equivalent dose in a routine head CT examination at a depth of 10mm.
Fig. 37: Percentage of reduction on individual equivalent dose in a routine head CT examination at a depth of 0.07mm.
**Fig. 38:** Percentage of reduction on individual equivalent dose in a routine thorax CT examination at a depth of 10mm.

**Fig. 39:** Percentage of reduction on individual equivalent dose in a routine thorax CT examination at a depth of 0.07mm.
Fig. 40: Percentage of reduction on individual equivalent dose in a routine abdomen CT examination at a depth of 10mm.
Fig. 41: Percentage of reduction on individual equivalent dose in a routine abdomen CT examination at a depth of 0.07mm.
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**Images for this section:**
Fig. 42: Health School - University of Algarve
References

The Bibliographic references used during the development of this research were, by alphabetic order:


