Image quality and dose evaluation in Pharyngo-Esophageal Foreign Bodies (P-E FB) detection with low-dose CT protocols in a guinea pig

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Aims and objectives

The management of patients with clinical suspicion of Pharyngo-Esophageal foreign body (P-E FB) ingestion traditionally provides: a) clinical examination, b) standard radiographic study of the cervical region in anteroposterior (AP) and latero-lateral (LL) projections, possibly supplemented by a dynamic examination of the upper digestive tract during barium suspension or Gastrografin® swallowing c) esophageal endoscopy with flexible or rigid endoscope in both diagnostic and therapeutic purposes, especially in high criticality situations (risk of perforation and/or aspiration, ingestion of sharp objects or batteries, complete obstruction of digestive tract with inability to swallow). CT is currently a second level radiological examination in the management of patients with suspected P-E FB ingestion. The factor that has severely restricted its use is the unfavorable cost/benefit ratio, in terms of dose-dependent biological damage to patients that often are children or young adults.

The goal of this work, in agreement with the ALARA (As Low As Reasonably Achievable) principle, is to identify the best compromise between image quality and radiation dose in CT scans for P-E FB detection. Generally, testing for image quality and radiation dose, phantoms with different inserts that allow to simulate the different tissues of the human body are used. These phantoms have the obvious limitation of not being anthropomorphic and not allowing the introduction of objects into them: for all these reasons is impossible to simulate a real condition in which a foreign body is surrounded by air and soft tissues. In order to overcome this limitation and to reproduce a real case study we used a guinea pig pet, anatomically very similar to humans.
Methods and materials

It was used a guinea pig (weight: 12 kg; length: 58 cm; chest and neck circumferences: 47 and 37 cm). The size of the pig was chosen in order to be as close as possible to the average adult neck circumference. The guinea pig was intubated into the esophagus with a tracheal tube (length: 34 cm, internal diameter: 8.5 mm). Through the cavity delimited by the tracheal tube a series of 7 P-E FB, with different physical characteristics, dimensions, and radiopacity (Tab. 1) were inserted into the hypopharynx and esophagus. CT scans were performed with OPTIMA CT 660 GE (General Electric®) provided at the Radiology Department of "St. Maria Ca' Foncello " Hospital, Treviso (TV), Italy. The scanning parameters used are listed in Tab. 2.

The P-E FB were positioned at 20 cm depth (measured from the end of the tube). The guinea pig was placed supine on the CT bed in cranio-caudal direction and secured with bands of containment. CT scans were performed at 80Kv with different values of current intensity (10, 20, 30 and 40 mA) for each individual P-E FB. To completely capture the tracheal tube the scans have been set with an extension of 16 cm above and below the center of the scan (Fig. 1).

All images and dose reports were stored digitally.

Were carried out the following assessments: 1) qualitative, by two different observers; 2) quantitative, using the software " Image J®"; 3) dosimetric, compared with the upper gastro-intestinal Rx examination (UG-I X-Ray).

1. Qualitative analysis: a first assessment of P-E FB detection was based on the subjectivity of observer's perception. Two different Radiologist (G.A., S.B.) with different levels of work experience (15 and 5 years respectively) have analysed all images independently.

2. Quantitative analysis: an objective assessment using the " Image J"® software was then assessed. Using a ROI (Region of interest) this software allows to quantify the pixel values in the selected area (Fig. 2). At first it was calculated the mean pixel value of P-E FB (mPV fb). The pixel values belonging to peri-esophageal soft tissues (PV st) were analyzed in order to determine the threshold of detection of P-E FB. The threshold of detection is commonly defined as the average value of the fund plus twice the product of fund standard deviation (#). In this study, the detection limit was deliberately overestimated using the maximum pixel value instead of the mean pixel value of the fund.

\[
\text{Fund (Detection limit)} = PV st (\text{max}) + (# * 2)
\]

The P-E FB is therefore visible if its PVM is greater than the threshold of detection:
Detectability of foreign body = mPV fb - Fund

If the difference is > 0, the P-E FB is discriminated; if not the detail is indistinguishable. These procedures were repeated for each P-E FB and for each CT scan (10, 20, 30 and 40 mA).

3. Dose analysis: dose reports of each CT scan were collected in order to compare them with each other and with the traditional X-ray examination of the upper digestive tract (UG-I X-Ray), considered in literature as the "gold standard" in P-E FB detection. Integration with fluoroscopic contrast medium takes place in case of radiolucent, small or even only partially penetrated into the wall of the esophageal lumen P-E FB, but is therefore not necessary when the detail has a high intrinsic radiopacity. CT absorbed dose rate is reported in term of CTDIvol (Computed Tomography Dose Index, volumetric) and DLP (Dose Length Product) for each value of mA.
Table 1: Pharyngo-esophageal foreign bodies (P-E FB) characteristics.

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<table>
<thead>
<tr>
<th>P-E FB</th>
<th>Foreign body</th>
<th>Length (cm)</th>
<th>Width (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N°1</td>
<td>Bolus carneo</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>N°2</td>
<td>Walnut kernel</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>N°3</td>
<td>Walnut shell</td>
<td>1.6</td>
<td>0.6</td>
</tr>
<tr>
<td>N°4</td>
<td>Metamer of mullet</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>N°5</td>
<td>Little sea bass spine</td>
<td>2.2</td>
<td>From 0.4 to 1</td>
</tr>
<tr>
<td>N°6</td>
<td>Flat sea bass spine</td>
<td>3</td>
<td>From 0.6 to 1</td>
</tr>
<tr>
<td>N°7</td>
<td>Chicken bone</td>
<td>4.3</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 2: CT scans parameters.

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Fig. 1: CT scout view of the guinea pig.

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Fig. 2: ROI (Region Of Interest) selections during the quantitative analysis. a) ROI of the foreign body b) ROI of the peri-esophageal soft tissues

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Results

1. **Qualitative analysis:** according to the qualitative assessment of the images all the details are distinguishable at each mA value.

2. **Quantitative analysis:** the quantitative evaluation confirmed only part of the qualitative assessment. In fact, the mPV fb is higher than the Fund just for a few details: detail n°3 (430.00), detail n°4 (810.50), detail n°5 (1078.00), detail n°6 (948.00) and detail n°7 (1291.75).

   For details n°1 (bolus cameo) and n°2 (walnut kernel) the quantitative analysis showed that these P-E FB are indistinguishable at all mA values, even at 40 mA. Detail n°3 (walnut shell) is detectable at 30 mA and 40 mA. The detection of the others P-E FB is shown at 10 mA.

3. **Dose analysis:** the absorbed dose rate for UG-I X-Ray is 4.33 mGy (Tab.3). The absorbed dose rate for CT scan is 0.20 (10 mA), 0.40 (20 mA), 0.60 (30 mA), 0.80 (40 mA) mGy (Tab.4).
Table 3: Upper Gastro-intestinal X-Ray (UG-I X-Ray) absorbed dose rate.

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<table>
<thead>
<tr>
<th>Projection</th>
<th>Dose (μGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pharynx A-P</td>
<td>140</td>
</tr>
<tr>
<td>Pharynx A-P enema</td>
<td>140</td>
</tr>
<tr>
<td>Pharynx L-L</td>
<td>140</td>
</tr>
<tr>
<td>Pharynx L-L enema</td>
<td>140</td>
</tr>
<tr>
<td>Esophagus Obl</td>
<td>348</td>
</tr>
<tr>
<td>Esophagus L-L</td>
<td>348</td>
</tr>
<tr>
<td>Additional X-Ray exposure</td>
<td>3075</td>
</tr>
<tr>
<td>Total (μGy)</td>
<td>4331</td>
</tr>
</tbody>
</table>

Table 4: CT absorbed dose rate. CTDIvol: Computed Tomography Dose Index, volumetric DLP: Dose Length Product

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Conclusion

Our study has shown that a low-dose CT protocol, optimized for the anatomical region and diagnostic question, results in a substantial dose saving than traditional X-ray examination: the CT total absorbed dose is about 20 times lower than UG-I X-Ray with the low-dose CT protocol at 10 mA.

It has also been shown that dose reduction with low-dose CT protocol it's not associated with a reduction in diagnostic capability.

Further advantages due to CT scan are the reduction in time, very useful especially in pediatric patients and generally uncooperative, and the possibility of multiplanar reconstructions by post-processing that allows to significantly increase the diagnostic accuracy.

According to these results is therefore possible to envisage new guidelines for P-E FB detection, with a low-dose CT as a first-level technique.
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