Detection of coins ingested by children using a handheld metal detector: a systematic review

J B Lee, S Ahmad, C P Gale

To determine if the use of a handheld metal detector (HHMD) can safely reduce the number of radiographs requested in cases of coins ingested by children, a search was performed to identify prospective studies of the ability of an HHMD to identify the presence or absence of ingested coin in children (17 years or younger). Outcome measures were presence or absence of coin on metal detector screening, and accuracy of coin localisation. Inclusion and exclusion criteria were defined. Mantel-Haenszel (fixed effect model) pooling with 95% confidence intervals (CI) was used to calculate overall sensitivities and specificities. In total, 11 studies met the inclusion criteria. The overall sensitivity of the HHMD at detecting the presence of coins was 99.4% (95% CI 98.0 to 99.9%) and accuracy at localisation was 99.8% (98.5 to 100.0%). The overall specificity of the HHMD was 100% (76.8 to 100%). Use of the HHMD is an accurate, radiation free, and cost effective method of identifying and localising coins ingested by children. An algorithm for investigating children with coin ingestion is proposed.

METHODS
Criteria for selection of studies
Only prospective assessments of the ability of an HHMD to identify the presence or absence of ingested coins in children (17 years or below) were included. Outcome measures had to include either presence or absence of coin on metal detector screening, or accuracy of coin localisation. Case reports, editorials, and opinions were excluded.

Studies were scored for internal and external validity and were excluded if the following criteria were not met. (a) The gold standard (radiograph(s)) was applied in all cases regardless of result. The gold standard investigation was considered to be a chest radiograph as a minimum. Serial radiographs, performed until a coin was located or excluded, were considered an acceptable alternative. (b) The HHMD operator was blinded to the results of the gold standard investigation.

Search strategy

The following journals were hand searched by two authors (JL, CG) for issues covering January 1980–September 2004: Emergency Medical Journal (Journal of Accident and Emergency), Annals of Emergency Medicine, Pediatrics, European Journal of Pediatrics, Academic Emergency Medicine, and Journal of Otolaryngology.

Two authors (JL, CG) independently reviewed the abstracts retrieved from the search and selected which studies were to be included. If there was insufficient information from the abstract to decide, the full version of the paper was requested. Bibliographies of retrieved papers were scanned for further relevant studies.

Abbreviation: HHMD, handheld metal detector
Finally, experts in paediatric medicine, paediatric surgery, radiology, emergency medicine, and otolaryngology were contacted to identify further papers or unpublished data. In the event of disagreement the decision of a third author (SA) was final.

Search results and study quality
The search strategy employed retrieved 1039 citations, of which 12 articles met the criteria for the review. Agreement was total between authors for the 12 studies chosen for inclusion. The quality of included studies was good but this could only be concluded after contact with the authors for six studies, because of inadequate reporting of methodology. All studies were prospective, blinded, and used an appropriate reference test. The study characteristics have been tabulated (table 1).

Data extraction and analysis
Data was independently extracted from the papers by two authors (JL, SA) and doubly entered into Meta-DiSc software (version 1.1.1). Where studies included all types of ingested metal foreign body, only the subset data for coins was used to calculate sensitivity at coin identification, and accuracy of localisation. Only data from studies purely investigating ingested coins was used to calculate specificities. Where studies included patients referred from secondary centres with radiologically proven oesophageal coins, those patients were excluded from the analysis of ability to identify coin presence, but were still included in analysis of accuracy of coin localisation (provided this was confirmed on a second radiograph) as coins could have moved en route. Only data from doctor or radiographer operators, with prior instruction on how to use the HHMD, however brief, was used in the pooled analysis. If studies localising coins used a variety of descriptions of location areas, the areas were dichotomised into abdominal (below the xiphisternum) or non-abdominal (xiphisternum or above).

The authors of one study, Arena et al., reported a 100% sensitivity and specificity using the HHMD on 28 children but could not be contacted. Owing to the inadequate reporting of type of metal objects ingested, data for coins alone could not be extracted, and this paper was excluded. Nine studies

### Table 1: Characteristics of included studies

<table>
<thead>
<tr>
<th>Author, date and country</th>
<th>Patient group</th>
<th>Study type</th>
<th>Reference standard</th>
<th>Outcome measures</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muentener Oi et al, 2004, Germany</td>
<td>65 consecutive children presenting to an ED over 20 months with suspected MFB ingestion</td>
<td>Diagnostic</td>
<td>Serial radiographs (abdomen +/− chest +/− neck)</td>
<td>Presence or absence of MFB on scan. MFB localisation to chest or abdomen</td>
<td>Uzman Tracker IV model. Coins present in 25 patients. 2 false positives</td>
</tr>
<tr>
<td>Scholamon J et al, 2004, Austria</td>
<td>53 consecutive children presenting to an ED with suspected MFB ingestion</td>
<td>Diagnostic</td>
<td>Chest radiograph</td>
<td>Presence or absence of MFB on scan. MFB localisation to chest or abdomen</td>
<td>MVF Proxon model. Coins present in 34 patients</td>
</tr>
<tr>
<td>Younger R et al, 2001, US</td>
<td>26 children referred from EDs with radiologically proven oesophageal coins (at least 6 hours earlier)</td>
<td>Diagnostic</td>
<td>Repeat radiographs of chest and abdomen</td>
<td>Presence or absence of MFB on scan. MFB localisation to chest or abdomen</td>
<td>Garrett Super-Scanner™ model. 1 patient refused 2nd radiograph and was excluded from the study. Coins present in 25 patients</td>
</tr>
<tr>
<td>Gooden E et al, 2000, Canada</td>
<td>10 children presenting to an ED with suspected foreign body ingestion, or transferred from another centre</td>
<td>Diagnostic</td>
<td>Repeat radiographs of chest, neck, and abdomen</td>
<td>MFB localisation to chest or abdomen</td>
<td>Heiman HHMD model. Investigators were not blinded to radiographs of transferred patients. Coins present in 9 patients</td>
</tr>
<tr>
<td>Bassett KE et al, 1999, US</td>
<td>62 consecutive children presenting to an ED with suspected coin ingestion, and 29 children referred with radiographically proven oesophageal coin (at time of referral)</td>
<td>Diagnostic</td>
<td>Serial radiographs (chest +/− abdomen +/− neck)</td>
<td>Presence or absence of coin on scan. Coin localisation to chest or abdomen.</td>
<td>Garrett Super-Scanner™ model. Operators received &lt;1 min of training. Coins present in 54 of the patients presenting directly to the ED. 1 coin not identified in the oesophagus. 1 oesophageal coin incorrectly localised to the stomach area</td>
</tr>
<tr>
<td>Doraiswamy NV et al, 1999, UK</td>
<td>231 children presenting to an ED with suspected MFB ingestion</td>
<td>Diagnostic</td>
<td>Chest radiograph</td>
<td>Presence or absence of MFB on scan. MFB localisation to chest or abdomen</td>
<td>Adams AD 18™ model. Coins present in 146 patients. 8 false positives</td>
</tr>
<tr>
<td>Seikel K et al, 1999, US</td>
<td>176 consecutive children presenting to 2 children’s hospitals with suspected MFB ingestion examined by “inexperienced” scanners, 140 of whom were also seen by “experienced” scanners</td>
<td>Diagnostic</td>
<td>Chest radiograph</td>
<td>Presence or absence of MFB on scan. MFB localisation to chest or abdomen</td>
<td>Garrett Super-Scanner™ model. Coins present in 60 patients. 6 false positives. MFBs were only missed in the inexperienced group</td>
</tr>
<tr>
<td>Tidby B et al, 1996, UK</td>
<td>20 children presenting to an ED with suspected foreign body ingestion</td>
<td>Diagnostic</td>
<td>Serial radiographs (chest +/− abdomen +/− neck)</td>
<td>Presence or absence of MFB on scan. MFB localisation to chest or abdomen</td>
<td>Adams AD 15™ model. Coins present in 8 patients</td>
</tr>
<tr>
<td>Sachetti A et al, 1994, US</td>
<td>23 children presenting to an ED with suspected MFB ingestion</td>
<td>Diagnostic</td>
<td>Chest radiograph</td>
<td>Presence or absence of MFB on scan. MFB localisation to chest or abdomen</td>
<td>Garrett Super-Scanner™ and Enforcer G2™ model. Coins present in 6 patients. Backpacker-2™ model. Coins present in 27 patients. Areas used to document localisation were: above clavicles, substernal, or abdominal Garrett Super-Scanner™ model. Coins present in 11 patients. 1 coin in the rectum not identified. Only the anterior neck, chest, and abdomen were scanned</td>
</tr>
<tr>
<td>Biehler JL et al, 1993, US</td>
<td>19 consecutive children presenting to an ED with suspected coin ingestion and 11 children referred with proven oesophageal coin</td>
<td>Diagnostic</td>
<td>Serial radiographs (chest +/− abdomen +/− lateral chest)</td>
<td>Presence or absence of coin on scan. Coin localisation to chest or abdomen</td>
<td>Garrett Super-Scanner™ and Enforcer G2™ model. Coins present in 6 patients. Backpacker-2™ model. Coins present in 27 patients. Areas used to document localisation were: above clavicles, substernal, or abdominal Garrett Super-Scanner™ model. Coins present in 11 patients. 1 coin in the rectum not identified. Only the anterior neck, chest, and abdomen were scanned</td>
</tr>
<tr>
<td>Ros S et al, 1992, US</td>
<td>14 consecutive children presenting to an ED with suspected coin ingestion</td>
<td>Diagnostic</td>
<td>Chest and abdominal radiographs</td>
<td>Presence or absence of coin on scan. Coin localisation to chest or abdomen</td>
<td>Garrett Super-Scanner™ and Enforcer G2™ model. Coins present in 6 patients. Backpacker-2™ model. Coins present in 27 patients. Areas used to document localisation were: above clavicles, substernal, or abdominal Garrett Super-Scanner™ model. Coins present in 11 patients. 1 coin in the rectum not identified. Only the anterior neck, chest, and abdomen were scanned</td>
</tr>
</tbody>
</table>

MFB, metal foreign body.
Detection of coins ingested by children using a handheld metal detector

841

remained for analysis of the ability of the HHMD ability to identify coins, and 11 studies remained for the analysis of its ability to localise coins (table 2). Mantel-Haenszel (fixed effect model) pooling with 95% confidence intervals was used to calculate sensitivities and specificities (fig 1). Handling of zeros was performed by adding 0.5 to zero cell studies. The $\chi^2$ test was performed to assess study heterogeneity. Predictive values, likelihood ratios, and diagnostic odds ratios are not useful in this clinical setting and were therefore not calculated.

RESULTS
The included studies showed no evidence of heterogeneity for sensitivity ($\chi^2 = 8.0, p = 0.43$) or specificity ($\chi^2 = 0, p = 1.0$). The overall sensitivity of the HHMD at detecting the presence of coins was 99.4% (95% confidence interval (CI) 98.0 to 99.9%) and accuracy at localisation was 99.8% (98.5 to 100.0%). The overall specificity of the HHMD was 100% (76.8 to 100%).

DISCUSSION
Most metal detectors work on the basis that metal objects cause a disturbance in an electromagnetic field, passing between a transmitter and receiver, triggering an audiovisual signal. When attempting to identify an ingested metal foreign body with an HHMD, false positive results may be caused by metal implants and wires remaining in situ following thoracic surgery, nearby wall fixtures, trolleys, patient or parental jewellery, metal clasps, zips, buttons, or belt buckles. Ideally, for the scan, a child should wear a gown, and should stand or be held away from walls. The majority of studies identifying ingested metal foreign bodies have effectively employed techniques of vertically scanning the chest from chin to xiphoid, horizontally across the abdomen, and horizontally down the back.

Of the 11 studies included in our final analysis, some are worthy of further scrutiny because they serve to highlight potential limitations of the ability of the HHMD to detect metal foreign bodies. Schalamon et al. correctly identified all 32 coins ingested by children in their study, using an HHMD. However, 8 of 15 non-coin metal foreign bodies were not identified, including two button batteries and a needle. Similar difficulties have been reported by other investigators, and the message appears clear that HHMDs may not be reliable at excluding the presence of metal foreign bodies other than coins. The study of Basset et al. correctly identified 53 of 54 coins but missed one oesophageal coin.

Muensterer et al. 1.0 (0.81–1.0)
Schalamon et al. 1.0 (0.89–1.0)
Basset et al. 0.98 (0.90–1.0)
Doraiswamy et al. 1.0 (0.97–1.0)
Seikel et al. 1.0 (0.95–1.0)
Tidey et al. 1.0 (0.63–1.0)
Sachetti et al. 1.0 (0.71–1.0)
Biehler et al. 1.0 (0.79–1.0)
Ros et al. 0.91 (0.59–1.0)
Pooled sensitivities 0.99 (0.98–1.0)

Figure 1 Sensitivity graph of HHMD at identifying coins ingested by children from included studies.
Statistics can complicate even the most straightforward of matters. Quite simply, of 351 children with radiographically identified coins, only two were not identified by the HHMD, with plausible explanations offered for both. Only one of 417 coins identified was incorrectly localised, by an operator with <1 minute of instruction. Of contacted authors who continue to use the HHMD, none could provide new data because they no longer perform confirmatory radiographs on patients with negative scans or those with positive scans below the epigastrium. Combined, these authors' data represent a period of over 20 years of HHMD investigation of coin ingestion by children in the emergency department. None could recall a complication from a missed coin. Although anecdotal, complications from ingested coins missed by the HHMD must be rare, and have not yet been reported.

Children with coins located at the level of the xiphisternum should have confirmatory radiographs to exclude impaction at the gastro-oesophageal junction, whereas children with coins localised below the xiphisternum can forego radiographic investigation. Accurate localisation of coins to the abdomen is important because such cases can be managed conservatively. We could find only one report of a coin below the diaphragm that required surgical intervention.37 The patient was a 22 year old woman who had ingested an American "penny" 3 weeks earlier. The coin had caused a local reaction in the area of the ileocaecal valve and the resulting 10 cm inflammatory mass had precipitated small bowel obstruction. The reaction was thought to be a consequence of the corrosive effect of gastric acid on this particular coin, the composition of which is 97.5% zinc.

Currently, advice given to parents of children with ingested coins is not standardised. Particularly with infants, they may be advised to examine each stool for the coin. The study of Schalamon et al38 is interesting in this respect. Despite parents of children with proven abdominal coins claiming that every stool was examined for a coin and none found, six of 12 children who returned a week later no longer had radiological evidence of coin presence. The practice of examining stools is messy and unreliable, and may raise anxiety levels when the coin is not seen to pass. As intervention would only be considered in symptomatic patients, advising parents to return if the coin has not passed in a week or two appears futile. There is no cutoff period after which management would change. Therefore, parents should be advised to return only if the child becomes symptomatic (abdominal pain, vomiting, or rectal bleeding).

This review has potential limitations. It is possible that all relevant studies have not been found. The number and range of journals in which similar studies could be published is vast. Logistically, only the journals considered most likely to yield relevant papers were hand searched. Diagnostic studies are considered more prone to publication bias than randomised controlled trials39 and, despite contacting experts, it is possible that negative studies remain unidentified. Of the studies that were included, most documented that consecutive patients were enrolled but few documented the number of eligible children not enrolled, raising the possibility of selection bias. Finally, the ability to detect a coin may be dependent upon the device chosen or the composition of the coin. However, sensitivities of 100% were found with a variety of HHMD models, and no difficulties were found with identification of US, UK, or European coins.

In line with most electrical items, the cost of HHMDs has reduced over the years. Schalamon et al39 demonstrated a sensitivity of coin identification of 100% with an HHMD purchased for £15 in a tool shop (2004) while the Garrett Super-Scanner®, used in most studies,39 22 23 26 is available on the internet for $149 (£87) at the time of writing. Running costs are dependent only on battery costs. Departmental variation and recent conversion to PACS makes costing of radiographs difficult. Figures of £22, £26, and £30 for lateral neck, chest, and abdominal radiographs, respectively, have been quoted in the literature.23 37 Thus, it would take only four cases (based on the cost of a single radiograph) of ingested coins excluded by a HHMD to cover the initial cost of the device, with all subsequent negative scans or scans localising coins to the abdomen representing direct savings. Few UK studies have documented the incidence of children presenting to the emergency department with suspected coin ingestion. Doraiswamy et al38 noted 124 in 18 months in Glasgow. By comparison, Tidey et al23 noted only 13 in 1 year in Brighton, but acknowledged that the majority would have been seen at the local children’s hospital.

The benefit of reduced patient time spent in the department for those foregoing radiological investigation will be obvious not only to the child and parents, but to all facing the number of children exposed to potentially harmful ionising radiation as the main advantage of the HHMD. A telephone and internet survey of UK emergency consultants conducted by us in October 2004 revealed that of the 50 departments sampled, only five possessed a metal detector (unpublished data). The commonest reasons given for not using a HHMD were cost and doubt over its accuracy. This

Table 2 Extracted data from included studies examining the ability of the handheld metal detector to identify and localise ingested coins in children

<table>
<thead>
<tr>
<th>Authors</th>
<th>Coins correctly identified</th>
<th>Coins <em>missed</em></th>
<th>Coins correctly localised to chest or abdomen</th>
<th>Coins incorrectly localised to abdomen</th>
<th>MFBS correctly excluded</th>
<th>False positives for an ingested MF</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muensterer CJ et al</td>
<td>25</td>
<td>0</td>
<td>25</td>
<td>0</td>
<td>22</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schalamon J et al</td>
<td>32</td>
<td>0</td>
<td>32</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bassett KE et al</td>
<td>53</td>
<td>1</td>
<td>81</td>
<td>1</td>
<td>8*</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doraiswamy NV et al</td>
<td>146</td>
<td>0</td>
<td>138</td>
<td>0</td>
<td>48</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seikai K et al</td>
<td>50</td>
<td>0</td>
<td>50†</td>
<td>0†</td>
<td>1†</td>
<td>6†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tidey B et al</td>
<td>8</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sachetti A et al</td>
<td>11</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birkler JL et al</td>
<td>16</td>
<td>0</td>
<td>21</td>
<td>0†</td>
<td>3*</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ross S et al</td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>0</td>
<td>3*</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gooden E et al</td>
<td>–</td>
<td>–</td>
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<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Younger R et al</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>351</td>
<td>2</td>
<td>417</td>
<td>1</td>
<td>101 (14%)</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Studies investigating suspected coin ingestion only; † only data for localisation to the chest was collected; N/A, data could not be extracted from paper and author could not be contacted.
view may have been based upon the historically higher costs of the HHMD and wide confidence intervals around sensitivity values published in small studies. Evidence has now been presented to challenge both points.

In fig 2, we present a proposed algorithm for the investigation of a child with a suspected ingested coin.

**CONCLUSION**

The HHMD is accurate, radiation free, and cost effective at identifying and localising coins ingested by children. The use of a HHMD by all UK emergency departments is overdue. Personnel who operate the device should have a demonstration and practice session before use, and be alerted to possible causes of false negative and false positive results.

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REFERENCES