The Evidence-based Evaluation of Pediatric Abdominal Trauma

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Disclosure
No financial relationships or conflict of interests related to this talk

Objectives

• Epidemiology of pediatric abdominal trauma
• Clinical evaluation for intra-abdominal injury (IAI)
  – History and physical examination
  – Laboratory testing
  – FAST
• Indications for abdominal CT
  – Prior evidence
  – UC Davis pilot study
  – PECARN multicenter study
  • Important sub-analyses

Epidemiology of Pediatric Trauma

• Leading cause of death in children > 1 year
  – 70%: Traumatic brain injury
  – 25%: Thoracic and abdominal injuries
• Preventable traumatic deaths/morbidity due to unrecognized and under-treated IAI
  – Can maintain SBP with ~30% loss of blood volume
• More than 600,000 children with abdominal trauma evaluated in EDs in the U.S. each year

Epidemiology of Pediatric IAI

• Most common mechanisms of injury:
  – MVC, auto vs. pedestrian, falls
• Frequency of injured organs
  – Spleen: 40%
  – Liver: 40%
  – Kidney: 30%
  – Bowel: 15%
• Compared to adults:
  – Larger organs, less abdominal wall protection
  – Pliable chest wall: energy transferred to organs

Epidemiology of Pediatric IAI

• Evaluation particularly difficult in children
  – ~20% of children with IAI and GCS scores of 15 have no apparent abdominal tenderness
  • More later...
  – Much controversy remains over physical exam
• Limited evidence for clinical decision-making
  – 15-25% of children with abd. trauma undergo CT
  – Fewer than 10% of abdominal CTs demonstrate IAI
  – Few patients with IAI require specific therapy
Controversies in Pediatric IAI

- Reliability of the physical examination
- Role of laboratory tests
- Bedside ultrasound (FAST): Utility in children?
- Indications for abdominal CT
  - Abdominal CT is reference standard, but has risks
  - Varying acceptance between specialists in restricting CT for identification of small findings and hospitalizing children with small CT findings

Variation Between Clinicians

- Variation between clinicians in:
  - Limiting CT use (what is acceptable to miss?)
  - Discharging children with small CT findings
- Survey of 636 general EM, pediatric EM, trauma surgeons, and pediatric surgeons:
  - 56% did not feel all with small IAIs need hospitalization
  - 74% would accept not identifying a small IAI not needing intervention in a well appearing child

  *Substantial variation – highlighting the need to define what is a clinically important finding*

Sokolove/Kuppermann/Holmes 2013

Case Presentation

- 10 y.o. female slipped off 6 foot fence, landed on right wrist and shoulder
- Difficulty breathing, R wrist and shoulder pain
- Denies LOC, neck, chest, abd, back pain
- Physical Examination
  - Crying but consolable, BP 100/60, HR 90, RR 20
  - Head/neck/chest/back: atraumatic
  - Abdomen: unclear if tender, but distracted
  - Extremity: right wrist deformity
  - Neuro: GCS 15

Patient History and IAI

- Mechanism of injury
  - Helpful mechanistic injury patterns
    - MVC with lap belt: bowel and mesenteric injuries
    - Handlebar injury: pancreas and duodenum
    - Abuse: liver and spleen
- Chest injury and costal margin tenderness associated with missed IAI
- *Be cognizant of mechanism and ribs!*

Handlebar Injury

Abdominal Examination and IAI

- Abdominal tenderness
  - Increased risk of IAI after adjusting for other findings
  - Adjusted odds ratio = 5.8 (95% CI 3.2, 10.4)
  - Approximately 80% of alert children with IAIs have abdominal tenderness
- Low GCS complicates examination

Taylor 1994; Holmes/Kuppermann 1998; 2002; 09; 13; Adelgais/Kuppermann/Holmes 2014
Seat Belt Injury

- Injury pattern seen in children > adults
- Flexion over lap belt (even w/shoulder harness)
- GI injuries in particular; lumbar spine fracture
- Prospective study after MVC
  - 46/390 with "Seat Belt Sign"
  - 30% (18-46%) with IAI

Any IAI

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Multivariable Risk Ratio (95% CI)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vomiting</td>
<td>7.42 (0.98-55.8)</td>
<td>0.06</td>
</tr>
<tr>
<td>Hypotension</td>
<td>2.41 (0.13-45.0)</td>
<td>0.01</td>
</tr>
<tr>
<td>GCS score &lt; 14</td>
<td>2.91 (0.59-14.0)</td>
<td>0.01</td>
</tr>
<tr>
<td>Decreased breath</td>
<td>1.61 (0.4-6.4)</td>
<td>0.61</td>
</tr>
<tr>
<td>Evidence of thoracic injury</td>
<td>1.41 (1.1-1.8)</td>
<td>0.02</td>
</tr>
<tr>
<td>Head injury</td>
<td>1.62 (0.20-11.9)</td>
<td>0.61</td>
</tr>
<tr>
<td>Abdominal pain and/or tenderness</td>
<td>3.00 (1.0-8.8)</td>
<td>0.00</td>
</tr>
<tr>
<td>Loss of consciousness</td>
<td>1.01 (1.0-1.0)</td>
<td>0.87</td>
</tr>
</tbody>
</table>

IAI Intervention

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<td>7.32 (0.99-52.2)</td>
<td>0.06</td>
</tr>
<tr>
<td>Hypotension</td>
<td>2.37 (0.11-51.0)</td>
<td>0.01</td>
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<tr>
<td>GCS score &lt; 14</td>
<td>2.81 (0.59-12.6)</td>
<td>0.01</td>
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<tr>
<td>Decreased breath</td>
<td>1.60 (0.4-6.4)</td>
<td>0.61</td>
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Seat Belt Sign

- Of 194 children with SBS, GCS 14-15 and no complaints of abdominal pain and no abdominal tenderness, 11 (6%) had intra-abdominal injuries
Laboratory Testing and IAI

- Multiple laboratory tests have been used to screen children for possible IAI
  - AST, ALT, hematocrit, lipase, amylase, HCO3, UA
- Prior studies: conflicting results, limited in design (sample size, retrospective)
  - *Fundamental question...what is the marginal benefit over physical examination?*

Hematuria

- Gross hematuria: 50% with IAI→ obtain CT!
- Microscopic hematuria
  - Present in 30-40% of children with IAIIs
  - IAI present in ~25% with microscopic hematuria
- *Does microscopic hematuria add marginal benefit to examination as a predictor of IAI?*
  - Physical exam + > 5 rbc/hpf = Sensitivity of 98.6%
  - Many suggested cutoffs for microscopic hematuria
  - Controversy remains owing to conflicting results

Hematocrit

- *Obtaining hematocrit is routine, but is it useful?*
  - Delay between significant blood loss and hematocrit drop (~2 hrs)
- Hematocrit < 30% significant predictor of IAI
  - Large retrospective study
  - Prospective studies
- Dropping hematocrit levels associated with IAI
  - Unclear if serial hematocrit levels are useful screen for otherwise unsuspected IAI
  - Ebert 1941, Taylor 1994, Holmes/Kuppermann 2002

Transaminases

- Several studies show correlation between elevated AST and ALT and hepatic injuries
- Degree of elevation does not correlate with grade of liver injury
- AST >200 or ALT >125 best predictor of IAI
- ALT > AST in face of liver injury suggests injury > 12 hours old

Amylase and Lipase

- Used to identify pancreatic/bowel injuries
- Elevated amylase often salivary
- In pancreatic injury, enzymes increase 24 – 48 hours after the injury
- *Not a useful predictor of IAI in pediatric trauma patients in the ED*

Utility of Laboratory Tests in a Multivariate Model

- Prospective observational study of 1,095 children to derive a clinical prediction rule
  - 107 with IAI
- Explicit entry criteria, age <16 years
- 664 with definitive diagnostic tests and remainder with clinical (telephone) follow-up
- Performance of decision instrument:
  - Sensitivity: 98% (95% 93, 100%)
  - NPV: 99.6% (95% 99, 100%)
  - Holmes/Kuppermann 2002
Variables in the Clinical Prediction Rule:
- Low systolic blood pressure
- Abdominal tenderness
- Femur fracture
- Elevated liver enzymes:
  - AST > 200 U/L or ALT > 125 U/L
  - Urinalysis > 5 rbc/hpf
  - Initial hematocrit < 30%

Abdominal Ultrasound (FAST)
- Rapid evaluation at patient bedside
  - Hemoperitoneum (FAST)
- Frequently used in evaluation of adult trauma
- Less frequently performed in pediatric trauma
  - <15% in recent PECARN observational study
  - Same rate as reported in a survey 10 years earlier

Abdominal Ultrasound in Pediatric Trauma
- Not as sensitive as CT for IAI
- Meta-analysis of pediatric trauma studies (*all injury severities, ultrasound experts*)
  - Sensitivity for hemoperitoneum: 80% (76-84%)
  - Sensitivity for all IAI: 66% (56-75%)
  - LR (+): 14.5 and LR (-): 0.36

Abdominal Ultrasound in Pediatric Trauma
- May allow risk stratification for CT scan
  - Best performance in hypotensive children
  - Negative FAST exam *may* decrease abdominal CT in children at low risk (<10%) for IAI
- Clinical implications unclear in children at substantial risk for IAI
  - Ultrasound (+) → Abdominal CT
  - Ultrasound (-) → Abdominal CT
Abdominal Ultrasound in Pediatric Trauma

*Ultrasound should not replace CT, and may or may not confer benefit in initial evaluation*

**Arguments against:**
- Insufficient sensitivity
- Most IAIUs managed non-operatively
- False sense of security
- “Over-triage” to the OR

**Arguments for:**
- Sensitive in unstable pts
- Bedside availability
- May decrease CT use in low risk patients
- “Risk stratification”/CT prioritization

**Methods**

- Single-center RCT
  - Clinical trials registration: NCT01540318
- Approved by UC Davis IRB with Exception from Informed Consent for ED data gathering
  - Consent required for follow-up data
- Study period April 2012 – May 2015
- 40 EM/PEM attending physicians participated
  - FAST credentialed

**Inclusion criteria**

- Age < 18 years with hemodynamically-stable blunt torso trauma resulting from a significant mechanism of injury including any of the following:
  - MVC: >60 mph, ejection, or rollover
  - Automobile vs pedestrian/bicycle: >25 mph
  - Falls >20 feet in height
  - Crush injury to the torso
  - Physical assault involving the abdomen
Methods

Inclusion criteria (cont’d.)

Any of the following:

– Decreased level of consciousness (GCS 9-15) with blunt torso trauma
– Blunt traumatic event with either:
  • Extremity paralysis
  • Multiple long bone fractures
– History and physical examination suggestive of IAI following blunt torso trauma

The Intervention:

• FAST performed by credentialed EM/PEM attending physicians providing care to the patient
• Zonare US machine with low frequency transducers
• Standard FAST protocol:
  – RUQ, LUQ, pelvis and subxyphoid
  – Evaluation solely for fluid
• Images stored for subsequent review
• Clinicians asked re: suspicion for IAI pre- and post-FAST

Outcome measures

1. Abdominal CT rate
2. Rate of missed diagnosis of IAI
   – IAI identified after ED discharge/admission
3. Time to ED disposition
   – ED arrival to discharge/admission orders
4. Changes in suspicion of IAI pre-to post-FAST

Results

Demographics and Examination

<table>
<thead>
<tr>
<th></th>
<th>FAST (n=460)</th>
<th>No FAST (n=465)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>9.7 ± 5.3</td>
<td>9.7 ± 5.3</td>
<td>0.99</td>
</tr>
<tr>
<td>Sex (male)</td>
<td>286 (62%)</td>
<td>289 (62%)</td>
<td>0.99</td>
</tr>
<tr>
<td>Initial GCS (median)</td>
<td>15 (15, 15)</td>
<td>15 (15, 15)</td>
<td>0.36</td>
</tr>
<tr>
<td>Pediatric Trauma Score (median)</td>
<td>11 (10, 11)</td>
<td>10 (10, 11)</td>
<td>0.65</td>
</tr>
<tr>
<td>Abdominal tenderness</td>
<td>159 (35%)</td>
<td>151 (32%)</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Outcomes

<table>
<thead>
<tr>
<th></th>
<th>FAST (n=460)</th>
<th>No FAST (n=465)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdominal CT rate</td>
<td>241 (52.4%)</td>
<td>254 (54.6%)</td>
<td>-2.2% (-8.7, 4.2)</td>
</tr>
<tr>
<td>IAI rate</td>
<td>24 (5.2%)</td>
<td>26 (5.6%)</td>
<td>-0.4% (-3.3, 2.9)</td>
</tr>
<tr>
<td>Hemoperitoneum rate (on CT)</td>
<td>19 (4.1%)</td>
<td>21 (4.5%)</td>
<td>-0.4% (-3.0, 2.2)</td>
</tr>
<tr>
<td>Missed IAI rate</td>
<td>1 (0.2%)</td>
<td>0 (0%)</td>
<td>0.2% (0.2, 0.8)</td>
</tr>
<tr>
<td>Laparotomy rate</td>
<td>7 (1.5%)</td>
<td>2 (0.4%)</td>
<td>1.1% (0.2, 2.4)</td>
</tr>
<tr>
<td>Hospitalization rate</td>
<td>249 (54.1%)</td>
<td>251 (54.0%)</td>
<td>0.2% (-8.3, 6.6)</td>
</tr>
<tr>
<td>Time to CT (hours)</td>
<td>2.67</td>
<td>2.54</td>
<td>0.13 (-0.18, 0.43)</td>
</tr>
<tr>
<td>Time to ED disposition (hours)</td>
<td>6.03</td>
<td>6.07</td>
<td>-0.04 (-0.47, 0.4)</td>
</tr>
</tbody>
</table>
Changes in Suspicion of IAI due to FAST

Overall, FAST resulted in significantly decreased suspicion of IAI.

<table>
<thead>
<tr>
<th>Pre-FAST</th>
<th>Post-FAST</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1%</td>
<td>&lt;1%</td>
<td>104</td>
</tr>
<tr>
<td>1-5%</td>
<td>1-5%</td>
<td>199</td>
</tr>
<tr>
<td>6-10%</td>
<td>6-10%</td>
<td>64</td>
</tr>
<tr>
<td>11-50%</td>
<td>11-50%</td>
<td>47</td>
</tr>
<tr>
<td>&gt;50%</td>
<td>&gt;50%</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>453</td>
</tr>
</tbody>
</table>

Decreased suspicion post-FAST primarily in those with pre-FAST suspicion of 1-10%

Of the 173 considered to have <1% risk of IAI post-FAST:
- 49 (28%) nevertheless underwent abdominal CT
- 27 of 49 had trauma request as an indication for CT
- 0 of 49 had IAI

Conclusions

- FAST did not decrease CT use compared to controls
  - Trend towards less CT use in children younger than 3 years
- No difference in missed IAI or time to ED disposition
- FAST significantly decreased clinician suspicion of IAI
  - But CT ordering remained substantial in low risk group
- Future research on safely decreasing abdominal CT use in pediatric trauma should include how physicians interpret and apply FAST results, and power studies on younger patients
  - Focus for CT reduction: those with low pre-test probability

CT for Pediatric Trauma

- Gold standard for diagnosis of IAI
  - Excellent sensitivity for solid organ injuries
  - IV contrast needed, but not oral contrast
- Drawbacks and Risks
  - Pharmacological sedation
  - Transfer outside the ED
  - Costs
  - Radiation exposure (500x that of CXR)

Indications for Abdominal CT

What’s the current evidence in children?

- No single-center study has identified criteria that identify all IAIIs with great confidence
- Most pediatric studies small, retrospective, not adjusted for all important variables
- More recent data starting to clarify best approach...multicenter data was needed!
Indications for Abdominal CT

- Variables in the Clinical Prediction Rule:
  - Low systolic blood pressure
  - Abdominal tenderness
  - Femur fracture
  - Elevated liver enzymes:
    - AST > 200 U/L or ALT > 125 U/L
    - Urinalysis > 5 rbc/hpf
    - Initial hematocrit < 30%

Validation of Clinical Prediction Rule

- Prospective, observational study of 1324 children to validate the prediction rule
- Children < 18 years, all imaged with CT
- ED physician documented patient history and physical examination before CT scan
- 157 (14%) with IAs

**Validation of Clinical Prediction Rule**

- Sensitivity: 95% (95% CI 90, 98%)
- Specificity: 37% (95% CI 34, 40%)
- PPV: 20% (95% CI 17, 23%)
- NPV: 98% (95% CI 96, 99%)
- 8 missed pts; 1 non-therapeutic laparotomy (serosal tear and mesenteric hematoma)

*The prediction rule requires further refinement/validation in multicenter setting...*

Ongoing PECARN Research Development

- Patient safety and error reduction
- Quality of PEM care
- Evaluation of head trauma
- C-Spine immobilization
- Steroids in acute bronchiolitis
- The burden of mental illness and psychiatric emergencies in PED
- RCT of fluids for DKA
- Magnesium for sickle cell pain
- Therapeutic hypothermia in pediatric cardiopulmonary arrest
- Diagnostic categorization of illnesses and injuries in the PED
- Management of status epilepticus
- Evaluation of abdominal trauma
- Screening for alcohol abuse
- Probiotics for AGE
- Knowledge translation of TBI rules
- RNA transcription biosignatures to diagnose febrile infants

PECARN Clinical Prediction Rule

- Prospective multicenter study 2007 - 2010
  - < 18 years with blunt abdominal trauma
  - Clinical data recorded before abd CT (if done)
  - Follow-up obtained on all patients:
    - Discharged patient: Telephone follow-up
    - Admitted patients: medical record review
- Primary outcome: IAI requiring therapy (IAI<sub>AI</sub>)
  - Recursive partitioning analysis
  - 761 (6.3%) with IAI and 203 (1.7%) with IAI<sub>AI</sub>

Holmes/Kuppermann 2009

Pediatric Emergency Care Applied Research Network (PECARN)

Supported in full by Project #U01 MC00001-01 from the Maternal and Child Health Bureau, Health Resources and Services Administration, Department of Health and Human Services

Holmes/Kuppermann 2009
Prediction Rule for IAI (n=12,044)

7/17/2017

1,963 patients
112 (5.7%) IAI

GCS < 14
826 patients
38 (4.6%) IAI

Abdominal tenderness
2,532 patients
36 (1.4%) IAI

Thoracic trauma
955 patients
6 (0.6%) IAI

Abdominal pain
305 patients
36 (11.8%) IAI

Breath sounds
34 patients
1 (2.9%) IAI

Emesis
395 patients
2 (0.5%) IAI

1,234 CT scans (25%)

1,963 patients
112 (5.7%) IAI

No

Sensitivity = 197 / 203 (97.0%; 95% CI 93.7, 98.9%)
Specificity = 5,028 / 11,841 (42.5%; 95% CI 41.6, 43.4%)
PPV = 197 / 7,010 (2.8%; 95% CI 2.4, 3.2%)
LR- = 0.07 (95% CI 0.03, 0.15)

PECARN Prediction Rule for IAI

<table>
<thead>
<tr>
<th>Number</th>
<th>%, (95% CI)</th>
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<td>Sensitivity</td>
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<td>Specificity</td>
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<td>PPV</td>
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<td>LR (-)</td>
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IAI Not Identified by the Rule

<table>
<thead>
<tr>
<th>Age</th>
<th>Mech</th>
<th>Clinical</th>
<th>Injury</th>
<th>Rx</th>
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<tbody>
<tr>
<td>2yr</td>
<td>Auto-Ped</td>
<td>Hematuria</td>
<td>Renal</td>
<td>Blood Rx</td>
</tr>
<tr>
<td>2yr</td>
<td>Fall</td>
<td>↑ LFTs</td>
<td>Liver, GI</td>
<td>IV fluid</td>
</tr>
<tr>
<td>16yr</td>
<td>MCA†</td>
<td>Femur Frx, hematuria</td>
<td>Spleen, GI</td>
<td>Angio</td>
</tr>
<tr>
<td>17yr</td>
<td>MVC</td>
<td>ETOH, hematuria</td>
<td>Spleen, Renal</td>
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All 6 patients with hemoperitoneum...

Back to our Case...

- 10 y.o. female slipped off 6 foot fence, landed on right wrist and shoulder
- Difficulty breathing, R wrist and shoulder pain
- Physical Examination
  - Crying but consolable, BP 100/60, HR 90, RR 20
  - Head/neck/chest/back: atraumatic
  - Abdomen: unclear if TTP but distracted
  - Extremity: right wrist deformity
- Neuro: GCS 15

Labs and Radiology

- Hematocrit: 34%
- Urinalysis: no hematuria
- ALT: 250 U/L
- CXR: normal
- Right shoulder: normal
- Right wrist: angulated ulna/radius fracture
Summary

- High risk physical examination findings for IAI
  - Low GCS: unable to evaluate if at risk for IAI
  - Abdominal wall trauma: contusion/abrasion/seat belt sign
  - Abdominal tenderness
- High risk laboratory findings for IAI
  - Elevated AST/ALT
  - Hematuria: especially gross hematuria
  - Low hematocrit: <30%

Questions?
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@nkuppermann

A Multicenter Study of the Risk of Intra-Abdominal Injury in Children After Normal Abdominal Computed Tomography Scan
Results in the Emergency Department

Benjamin T. Kuppermann, MD, MPH; Alexander C. Bengoa, MD; Eric H. Lo, MD, MPH; Kathleen Alejandro, MD; Michael Yuh, MD; Stephen M. Blumenberg, MD; Kimberly B. Ophir, MD; Peter C. Srinivasan, MD; David H. Wlices, MD; Michelle L. Wills, MD; Nathan Kuppermann, MD, MPH; James F. Holmes, MD, MPH; for the Pediatric Emergency Care Applied Research Network

“The negative predictive value of CT for any intra-abdominal injury was 99.6% (3,803/3,819; 95% CI 99.3% to 99.8%); and for injury undergoing acute intervention, 99.8% (3,813/3,819; 95% CI 99.7% to 99.9%).

Conclusion: In a multicenter study of children evaluated in EDs after blunt torso trauma, intra-abdominal injuries were rarely diagnosed after a normal abdominal CT scan result, suggesting that safe discharge is possible for the children when there are no other reasons for admission.

A Cost-effectiveness Analysis Comparing a Clinical Decision Rule Versus Usual Care to Risk Stratify Children for Intraabdominal Injury After Blunt Torso Trauma
Daniel K. Kuppermann, MD, MASS, Zhuo Yang, MSc, John A. Clark, MSc, Nathan Kuppermann, MD, MPH, and Jeffrey Low, MD, MPH

Results: Using a hypothetical cohort of 1,000 children with blunt torso trauma, the base case model projected that the implementation of the CDR would result in 0.50 additional missed IAIs, a total cost savings of $54,527, and 104 fewer abdominal CT scans compared to usual care. The usual care strategy would cost $108,110 to prevent missing one additional IAI. Findings were robust under multiple sensitivity analyses.

Conclusions: Compared to usual care, implementation of the CDR in the evaluation of children with blunt torso trauma would reduce hospital costs and abdominal CT imaging, with a slight increase in the risk of missed IAI.