Fractures: give me a break

Mary Clyde Pierce MD
Professor of Pediatrics
Northwestern University Feinberg
School of Medicine

Emergency Medicine,
Lurie Children’s Hospital of Chicago

Medical Director Injury Risk
Assessment and Prevention Laboratory
The most common reason for physician reporting to social services is that the injury and history are not consistent.

What are the guiding scientific principles supporting that determination, and what elements of that determination are objective?
Learning Objectives:

1. Apply simple biomechanics concepts to assess fracture types and clinical characteristics.

2. Be able to use biomechanical principles to determine if the history and injury are compatible.

3. Apply concepts of an injury plausibility model for assessing fractures cases.
Today’s approach

- Fractures: why do they matter and what does the fracture tell us about the environment?
- Bone: what is it?
- Biomechanics: physical laws meet common sense
- Plausible?: moving from possible to plausible
- Cases
Is this story possible?

Is this story plausible?
Injury Plausibility

1. History quality?
2. Injury compatibility?
3. Time congruency?
4. Skin findings?
5. Psychosocial findings?
Fracture morphology

1. Which bone?
2. Where on the bone?
3. Fracture type?
4. Displacement?
5. Acute or healing?
Why do fractures matter?
Fractures are second only to bruising as a presentation of child abuse

Indicate the child is being subjected to extreme and potentially life-threatening violence

In 50% of cases, the fracture is the only finding
Consider: child’s age and level of development

- 80% of child abuse fractures occur in children less than 18 months of age
- 25-50% of fractures in children under 1 yr of age are caused by abuse
- 80% of long bone fractures in children under 1 year of age are caused by abuse
- After the child begins to walk, the % of fractures caused by abuse declines abruptly
- 1/3 of femur fractures in children under 4 yrs are caused by child abuse
Specificity for abuse

- Rib fractures
  - Posterior: PPV 95%
- Classic metaphyseal fxs
  - Most common long bone fx in children who die from abuse
- Scapular fx
- Spinous process fx
- Sternal fx

- Complex skull fx
- Epiphyseal fx
- Vertebral body fx
- Digital fx
- Long bone fx
- Linear skull fx
- Clavicle fx
- SPNBF

High specificity

Moderate and Low specificity
Every fracture is as different as it is similar.

The fracture’s characteristics determine the clinical manifestations.
Fractures can:

- be immediately obvious with swelling, or occult and difficult to identify,
- take a day or 2 to produce painful symptoms, or immediately cause incapacitating pain,
- be very easy to see on xray, or take a few weeks to show up,
- cause immediate inability to walk, or only show up as a mild limp,
- *So what’s the confusion??????*
How much force did it take to cause this fracture?

- Why is this question so difficult to answer?
  - Developing bone changes daily
  - Multiple components to the structure
  - Tissue is anisotropic and viscoelastic
  - Prematurity and nutritional status affects bone quality
Bone: what is it and how does it work?
Scientific picture
Likelihood of Fracture

• Dependent upon:
  • Extrinsic factors (external)
    • the specifics of the event (e.g. fall)
    • loading conditions, direction and rate
  • Intrinsic factors (internal)
    • factors inherent to the bone’s structure, composition and material properties
    • geometry, bone mineralization
Fracture occurrence

- Whether or not the bone fails depends on 3 key factors:
  - the amount of energy available,
  - the direction of the force,
  - the ability of the tissue to respond to the load

- These same factors also determine the specific fracture characteristics (shape/type/degree) also known as fracture morphology
What is fracture morphology?

- Bone:
  - Which bone broke?
  - Where on that bone is the break?
  - Does the bone appear normal?
What is fracture morphology?

- Fracture characteristics
  - The overall type of fracture tells the predominate type of load – which can be tied back to the history
    - Buckle, transverse, spiral, oblique, cml; comminuted?
  - Is there separation of the fracture line? – energy
    - Partial (hairline; greenstick)
    - Complete through and through?
    - Is there angulation or displacement of the fragments?
    - Are there multiple fragments (comminuted)
Concepts

- The biomechanical properties of bone dictate that a particular level of load and a particular mechanism of loading are necessary to cause a particular type of bone fx” *Accidental Injury 2002*

- The fx morphology is a direct reflection of the degree and direction of the forces and the ability of the tissue to resist those forces
Direction of loading: where history meets x-ray

- **Compression** – stress created by “trash compacter”

- **Tension** – stress created by extending or “pulling”

- **Shear** – stress produced when force application is aligned with the surface of an object: *weakest*

- **Bending** – stress created when a force is applied perpendicular to the long axis of an object causing tension on one side and compression on the other – bent in half

- **Torsion** – stress resulting from twisting
Piglet study

- To characterize fx morphology resulting from bending and torsional loading in immature bone
- To compare bone strength and energy to failure for transverse / oblique fx (bending loads) & spiral fx (torsional loading) in an in vitro-immature animal model (piglet)
Biomechanical Terms and Concepts

Force-load-stress/strain

- compression
- tension
- bending
- torsion
- shear

Force Animations:

http://www.pbs.org/wgbh/buildingbig/lab/forces.html
Bending Load (injury mechanism)

Pierce, CPEM 2006;7(3)
Emerging Issues and Technology in Child Abuse and Neglect
Torsional Load (injury mechanism)

Pierce, CPEM 2006;7(3)  
Emerging Issues and Technology in Child Abuse and Neglect
Injury causation to mechanism to fracture type

- Injury causation
  - The loading conditions are influenced by
    - How you start
    - How you land
    - What you hit on the way
    - Why you started
  - Fall; running; thrown
  - How far did you fall
  - What stops you
  - Loading conditions leads to a specific injury mechanism at the tissue level
  - Mechanism of failure at the tissue level results in the specific fracture

- Extrinsic (external)
  - Energy
  - force
- Intrinsic (internal)
  - Load
  - stress
Transverse fractures

1. Obvious or subtle?
2. Immediate symptoms or take time to show signs?
3. Easy to see on xray or near invisible?
4. Immediate and complete skeletal compromise with loss of function or still working, just not as well?

Evaluating long bone fractures in children: a biomechanical approach with illustrative cases
Oblique fractures

- Obvious or subtle?
- Immediate symptoms or take time to show signs?
- Easy to see on x-ray or near invisible?
- Immediate and complete skeletal compromise with loss of function or still working, just not as well?

Evaluating long bone fractures in children: a biomechanical approach with illustrative cases
Buckle fracture

- 1. Obvious or subtle?
- 2. Immediate symptoms or take time to show signs?
- 3. Easy to see on x-ray or near invisible?
- 4. Immediate and complete skeletal compromise with loss of function or still working, just not as well?

Spiral fractures

1. Obvious or subtle?
2. Immediate symptoms or take time to show signs?
3. Easy to see on x-ray or near invisible?
4. Immediate and complete skeletal compromise with loss of function or still working, just not as well?

Child Abuse Negl 2004 vol. 28 (5) pp. 505-24
Classic metaphyseal lesion CML), corner, bucket-handle fracture

Biomechanical Investigation of the Classic Metaphyseal Lesion Using an Immature Porcine Model

Angela Thompson
Gina Bartocci
Kim Kaczer
Craig Smalley
Mary Clyde Pierce

OBJECTIVE. The classic metaphyseal lesion is highly associated with abuse in infants. Classic metaphyseal lesions, also referred to as corner or bucket-handle fractures, are fractures through the metaphyseal region of the long bones near the growth plate. Knowledge of the biomechanics and mechanisms necessary to produce a classic metaphyseal lesion may provide insight into the injury causation associated with this unique fracture type. Thus, the purpose of this study was to investigate loading conditions necessary to create a classic metaphyseal lesion using an immature porcine model.

MATERIALS AND METHODS. Twenty-four pelvic limb specimens from 7-day-old and 2-day-old piglets were tested in lateral bending (tension and compression) using an electromechanical
Femur fractures resulting from stair falls: an injury plausibility model

Children’s Hospital of Pittsburgh; U of Pittsburgh School of Medicine; Rehab Science and Technology; Injury Risk Assessment and Prevention Laboratory (iRAP)

Mary Clyde Pierce, Gina Bertocci, BC Deemer, Fernando Aguel, Janine Janosky, Morey Moreland, Danielle Boal, Sandy Herr, Noel Zuckerbraun, Sylvia Garcia, Ev Vogeley
Femur Fractures Resulting From Stair Falls Among Children: An Injury Plausibility Model

Mary Clyde Pierce, MD*†; Gina E. Bertocci, PhD, PE*†§; Janine E. Janosky, PhD¶; Fernando Aguel, BS†¶; Ernest Deemer, MS†¶; Morey Moreland, MD**; Danielle K. B. Boal, MD†§§; Sylvia Garcia, MD*; Sandra Herr, MD*; Noel Zuckerbraun, MD*; and Eva Vogeley, MD*†

Hypothesis

Quantifiable and significant differences exist between cases of inflicted and non-inflicted injuries

1. History quality
2. Biomechanical fracture characterization
3. Time line
4. Other injuries
Injury Plausibility (IP) Model: Category I: history

- Richness and quality of history: is the story detailed, or vague and changing
- History Quality Scale (HQS)
  - initial position
  - dynamics of the fall
  - final position
- Injury reconstruction history
IP Model Category II: *fracture analysis*

- Does the fracture morphology identified on x-ray reflect the biomechanics and biodynamics of the stated cause of injury?
- Does the history allow for the type and magnitude of loading required to cause the observed fracture type?
- Are confounders present that might alter the child’s specific injury threshold?
# IP Model category scores: Witnessed vs. Confessed cases

<table>
<thead>
<tr>
<th>Category</th>
<th>Points</th>
<th>p value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>I History</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All 3 fall components</td>
<td>2 of 3</td>
<td>1 of 3</td>
</tr>
<tr>
<td><strong>II Fracture biomechanics</strong></td>
<td>Direct match</td>
<td>Indirect match</td>
</tr>
<tr>
<td><strong>III Time delay</strong></td>
<td>No</td>
<td>Yes: subtle findings</td>
</tr>
<tr>
<td><strong>IV Additional Injuries</strong></td>
<td>No</td>
<td>1</td>
</tr>
</tbody>
</table>

* Fisher’s Exact
Results: grouped by IP model score

![Graph showing number of patients with different IP scores]

- **Plausible (P)**
  - Score 0: 7 patients
  - Score 1: 10 patients
  - Score 2: 5 patients
  - Score 3: 3 patients
  - Score 6: 1 patient
  - Score 8: 1 patient
  - Score 12: 1 patient

- **Suspicious (S)**
  - Score 0: 2 patients
  - Score 4: 1 patient
  - Score 6: 1 patient
  - Score 7: 1 patient
  - Score 11: 1 patient
Results Category IV: other injuries

Plausible | Suspicious
---|---
0 bruises | 0 bruises
1 bruise | 1 bruise
2 bruises | 2 bruises
3+ bruises | 3+ bruises
Conclusions

• By identifying key features associated with both plausible and abuse cases and by incorporating patient and event specific data for assessment of injury causation, a more objective evidence based model was derived.

• The goal of our stair fall study was to identify distinguishing features for future model development and testing.
Derived a Bruising Clinical Decision Rule (BCDR) by modeling key differences in bruising characteristics in children with abusive and accidental injuries.
BCDR Research Trajectory

Plot: single site, retrospective, PICU-based study

NIH funded multi-center, prospective study

Testing, refining, & validation

Derivation
Fractures can:

- be immediately obvious with swelling, or occult and difficult to identify,
- take a day or 2 to produce painful symptoms, or immediately cause incapacitating pain,
- be very easy to see on x-ray, or take a few weeks to show up,
- cause immediate inability to walk, or only show up as a mild limp,

So what’s the confusion?????
There was a car wreck

The car is totaled

IS THIS POSSIBLE??

Is this PLAUSIBLE is the real Q

You cant say THIS case is plausible until you know the specifics of THIS car wreck
It’s the details of that history and the characteristics of the fracture that determine plausibility.
Injury plausibility

- Was there sufficient energy to explain all the damage?
  - Totaled car but only going 5 mph?
  - Crushed femur but only fell 18 inches

- Does the direction of forces reported in the history match with the type of injury sustained?
  - Bilateral side door damage but said you were rear-ended?
  - Spiral femur fracture with bilateral ear bruising but you said the child was dropped onto their knee

- Do the described events afterward fit with what is possible after the damage has occurred?
  - Said car drove fine afterward but engine is on the ground?
  - Said child was walking fine without pain but the femur has a spike of bone sticking into the muscle and the leg is like a noodle
Identifying which fractures are caused by child abuse

- Required elements to take into consideration:
  1. The history
  2. Fracture characteristics:
     1. The location of the fracture
     2. The type of fracture
     3. Acute or healing?
  3. The mechanism that causes the particular type of fracture
  4. The presence of other injuries - skin
  5. The presence of psychosocial risk factors
  6. Other possible causes
Almost any fracture type can be associated with any history

So the history alone, or the fracture alone can not tell you if the child is at high risk for abuse or not
Injury plausibility

- Fracture type (morphology) matters
- History details matter
- Time line and description of events and behaviors matters
- Skin findings matter
- Psychosocial risk factors matters (real ones that pertain to attitudes about the child etc)
Wow, breaking news: diagnostic tool kit available NOW...offer free while supplies last!!

- The history you obtain is your best tool
- A detailed physical exam is your 2\textsuperscript{nd} best tool
- The best screening tool for risk....is a skilled psychosocial “survey”