A Web-based Computer-aided Diagnosis Tool for Bone Age Assessment: 
Clinical Implementation and Lessons Learned

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Bone Age Assessment

Introduction
Bone Age Assessment (BAA) Computer-Aided Diagnosis (CAD) project goals
digital hand atlas (DHA)
CAD algorithm

Clinical Validation
LAC+USC clinical workflow
graphical user interface (GUI)
radiologist validation

Preliminary Results and Analysis
integration and lessons learned

Future Work
reproducibility at other institutions
Bone Age Assessment (BAA)

- If indicated, a frontal left hand and wrist radiograph is used as a clinically accepted assessment of developmental status via bone growth observations.
- Bone age is utilized in the diagnosis and treatment of:
  - endocrine disorders
  - metabolic related growth abnormalities
  - renal disease
  - obesity
  - skeletal dysplasias
  - orthopedic interventions
Bone Age Assessment – Current Radiologic Workflow

1. Left hand/wrist radiograph


3. Selection of closest match bone age

7 years 10 months
The Digital Hand Atlas (DHA)

- Our group’s effort to update reference normals
- Collected 1,400 normal left-hand images
- Determination of normal by physical examination: Tanner maturity index, height, weight, trunk height, BMI
- X-ray images collected on film and converted to DICOM
- Data collection of normal hand images of both genders
  - Newborn to 18 years old
  - Ethnicities:
    - Asian
    - African American
    - Caucasian
    - Hispanic

*DHA available for viewing online at [http://www.ipilab.org/BAAweb](http://www.ipilab.org/BAAweb)*
BAA CAD System Workflow

- **Programming Language**: MATLAB
- **Platform**: Microsoft Windows XP/2000
- Distal radius analysis has recently been integrated into the algorithm
**BAA CAD Methodology**

- Each region of interest (ROI) has different levels of reliability in different age groups and genders.
- Reliability is defined as how well the extracted features correlate with bone age calculation.

<table>
<thead>
<tr>
<th>Age group / ROI</th>
<th>Phalangeal ROIs</th>
<th>Carpal Bone ROI</th>
<th>Wrist Joint ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 5 (female) 0 – 7 (male)</td>
<td>Feature analysis of epi-metaphysis - NOT Reliable</td>
<td>Size &amp; shape analysis of carpal bones - Reliable</td>
<td></td>
</tr>
<tr>
<td>6 – 13 (female) 8 – 15 (male)</td>
<td>Feature analysis of epi-metaphysis - Reliable</td>
<td>Degree of overlapping of carpal bones - NOT Reliable</td>
<td></td>
</tr>
<tr>
<td>14 – 18 (female) 16 – 18 (male)</td>
<td>Features are - NOT Sufficient</td>
<td></td>
<td>Feature analysis of epi-diaphysis - Reliable</td>
</tr>
</tbody>
</table>
BAA CAD Clinical Validation

• Goals:
  – Design a CAD clinical validation workflow for use in the pediatric radiology section of LAC+USC
  – Design and implement a web-based graphical user interface (GUI)
  – Install a CAD workstation in this clinical PACS environment
  – Validate CAD results with Pediatric Radiologist readings using G&P Atlas

• Result:
  – A web-based BAA CAD system integrated within the clinical PACS workflow of the Los Angeles County General Hospital
Conventional Clinical Workflow:
1) Hand image sent from modality simulator to Gateway.
2) Hand image sent from Gateway to PACS server.
3) PACS workstation query/retrieve hand image from PACS server for review.

With CAD BAA in PACS workflow:
4) Second copy of hand image is sent to CAD server for processing and CAD report is generated and updated on the web GUI at PACS WS
5) Radiologists review CAD results via web browser at PACS WS
6) Readings are captured and stored in BAA CAD server.
CAD Workstation Setup with Clinical PACS

• Hardware
  – PC: Windows 2000/XP/Vista
  – Monitor: 28”, larger and higher definition for image clarity

• Software
  – BAA CAD Program
    • MATLAB: Version 7.0.1
  – Web-based system
    • Apache web server 2.0
    • PHP/MySQL
    • Web browser

• Network Connection
  – Gigabit clinical site internal network, integrated with PACS
  – Static IP
  – AE title and Port No. for DICOM receiver
Current Clinical Validation Workflow

1. **CR** sends a second image copy to the **CAD** server
2. **CAD** server receives the **DICOM** image, performs BAA and records results in database
3. **Web server** looks into database to locate **CAD** result and original image, as well as best-matched **DHA** image (determined by **CAD**)
4. **GUI** displays images and guides radiologist through validation steps
Clinical Validation Workflow – Step 1

1. Radiologist clicks on a patient’s ID number to start the validation process

<table>
<thead>
<tr>
<th>Step</th>
<th>Patient Id</th>
<th>Patient Name</th>
<th>Gender</th>
<th>Ethnicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LACWCH 000001</td>
<td></td>
<td>Female</td>
<td>Black</td>
</tr>
<tr>
<td>2</td>
<td>LACWCH 000002</td>
<td></td>
<td>Male</td>
<td>Caucasian</td>
</tr>
<tr>
<td>3</td>
<td>LACWCH 000003</td>
<td></td>
<td>Female</td>
<td>Black</td>
</tr>
<tr>
<td>4</td>
<td>LACWCH 000004</td>
<td></td>
<td>Male</td>
<td>Caucasian</td>
</tr>
</tbody>
</table>

Patient is anonymized

A username/password system is used to determine a user’s privileges, the worklist, etc.

Patient’s gender and ethnicity affects which BAA module will be used to evaluate bone age. Gender is obtained from DICOM header, while ethnicity must be requested by the radiologist from the report.
Clinical Validation Workflow – Step 2

2. Radiologist scrolls through the digitized G&P atlas image to select the closest match to the patient’s image.

3. Radiologist clicks here to continue to step 3.

Hand images are in JPEG format, Javascript is enabled to have functionality such as zoom, pan, window/level, etc.
GUI – Step 3

G&P atlas choice from Step 2 is displayed here

Patient’s chronological age

CAD result is displayed here. The hand image represents the closest-match DHA image (degree of matching is determined by the CAD program).

Clicking on this link will display the CAD reading and the normal development curves.

Radiologist clicks here to complete the validation process. The GUI goes back to the step 1 page to start assessment of another patient.

Please check which image matched your patient the best. If equal check both.

- DHA Image
- GP Image
- Same

Save and Return to Step 1
Clinical Validation Process

- Web-based CAD workstation installed at LAC+USC February 2008
  - Hospital moved to new facility November 2008

- 74 bone age cases collected as of October 2008
  - Image sources
    - direct DICOM sent from CR
    - archived cases burned on CD
  - 33 normal (defined by original radiologist reading)
    - bone age within two standard deviations of chronological age
  - 41 abnormal
    - bone age falls outside of two standard deviations

- Clinical validation:
  - Tested the success rate of CAD program in obtaining a bone age output
  - Compared CAD output with radiologist reading
Clinical Validation – Preliminary Results

- Without an enforcement of hand-scanning protocol, CR hand images differ in finger separation, image angle, right hand instead left, etc.
- Some or all of the above discrepancies affect BAA CAD performance in successfully segmenting and extracting ROIs
- Approximately 47% of hand images yield successful Bone Age CAD results without an imaging protocol

<table>
<thead>
<tr>
<th>Case description</th>
<th>Total cases</th>
<th>Normal cases</th>
<th>Abnormal cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Number of cases</td>
<td>74</td>
<td>33</td>
<td>41</td>
</tr>
<tr>
<td>Success cases</td>
<td>35</td>
<td>16</td>
<td>19</td>
</tr>
<tr>
<td>Unable to detect phalanges</td>
<td>14</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Unable to segment hand and fingers</td>
<td>13</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>CAD Program Crashes</td>
<td>12</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>
Result Analysis

- Web-based BAA CAD is successfully installed in a clinical PACS environment.

- Preliminary validation results show that CAD BAA outputs roughly match radiologist initial readings based on the G&P Atlas:
  - All cases are currently assumed Hispanic, since race is not recorded in retrospective studies, and most patients at LAC are of Hispanic ethnicity.
  - While CAD results tend to follow the trend of radiologist readings, the sample size is not yet large enough to draw definitive conclusions.
  - Normal bone age cases are extracted and plotted to show a better trend of radiologist and CAD bone age readings.
  - Abnormal bone age cases are also collected, however, only normal studies are currently used in evaluating CAD performance since the DHA is a collection of normal cases. Abnormal studies will be included in a future separate CAD performance evaluation.
Results Analysis

• While the sample size is not yet large enough, a general trend of CAD output agreeing with radiologists’ readings closely for younger children but they differ in older children.
  – This may be attributable to the nature of carpal and phalangeal features. Younger children’s bone age features originates from the size and shape carpal bones and epiphysis, while older children’s bone age analysis depends on separation of epiphysis and metaphysis, which is more difficult to assess and has more variability
  – Future work is being developed to refine the algorithm for the distal radius which in the assessment of older children.

• Radiologist preference between the two readings, the final stage of BAA CAD clinical evaluation, are soon to be recorded and evaluated.
Lessons Learned

- **Lesson:** patient positioning is variable leading to cases of unsuccessful CAD analysis
- **Solution:**
  - develop an x-ray template to improve compliant positioning
  - introduce to and educate technologists on a standard hand radiograph protocol
  - improve CAD logic for wrist region

- **Lesson:** case collection does not include all bone age assessments being performed at our institution
- **Solution:**
  - increase awareness and education among radiology and pediatric residents on CAD and project
  - consider inclusion of all left hand pediatric radiographs
  - integrate CAD workstation into primary workflow

- **Lesson:** CAD workstation is not used for all bone age assessment cases and workspace in the new facility is decreased
- **Solution:**
  - streamline GUI to allow fewer steps and produce final report to send to RIS
  - integrate CAD GUI directly into PACS application to eliminate extra physical workstation
  - prefetch images and perform CAD to have results available for review prior to interpretation
Use and Integration at Other Institutions

- The recent move to a new facility has necessitates changes due to:
  - Differing network
  - New modalities (DR) and equipment
  - New personnel
  - Smaller physical workspace
- This recent move and the lessons learned from it are encouraging in that they allow an internal trial to improve the robustness of our system.
- Work is underway to streamline the workflow and integrate the CAD workstation features directly into our PACS.
  - With the proposed improvements, we feel that this bone age assessment CAD can successfully be used at other institutions with differing workflows and clinical settings
  - Efforts are underway to collaborate with other institutions.
Summary

– An updated, ethnically diverse bone age assessment CAD has been developed by IPILab at and is now in the advanced clinical validation stage.

– A web-based GUI has been developed to aid radiologists in comparing CAD bone age results with results from the GP atlas.

– The web-based CAD validation system has been installed in USC+LAC and integrated into the clinical PACS environment.

– Cases collected so far have produced promising results for BAA CAD. Further refinement of the workflow and efforts to implement this tool at other institutions are underway.
Thank you.

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More information available at:
http://www.ipilab.org/BAAweb
http://www.ipilab.org/BAAgraph
http://www.ipilab.org/Research/BAA/BAAindex.php