Heart Disease Program: Diagnosing Shock

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Challenge
- Use the Heart Disease Program (HDP) to diagnose acute shock events in the ICU
- HDP developed over 20 years to diagnose hemodynamic compromise in the wards
- MIMIC data has 30,000 patients many of whom go into shock during stay
- Shock may be from pump failure, sepsis, hypovolemia, toxicity

Heart Disease Program
- Knowledge base -- causal physiologic model
  - hemodynamic function and dysfunction
  - probabilities and constraints (time & severity)
- Input Interface -- menu driven
  - history, exam, and lab data
  - same information a clinician would use
- Differential diagnosis generator -- heuristic
  - hypotheses are complete explanations

HDP Program Structure

Knowledge Base
Patient Specific Model
Input Module
Diagnosis Generator
Differential Diagnosis
HDP Knowledge Base

• About 180 physiologic state nodes
• Covers the common hemodynamic problems
  – infarction, cardiomyopathy, valvular diseases,
    pericarditis, etc.
• Covers diseases influencing hemodynamics
  – renal, hepatic, pulmonary, thyroid, etc.

Knowledge Base

Node: low cardiac-output

severities: 1+ salt&water-retention, 2+ moderately low, 3+ shock
causes:
  low lv-emptying p=1.0 => severity=
  low la-press p=1.0 => severity=
  mitral-regurgitation 2+ & < 1wk p=0.4
  AR, VSD, low lv-compl, low HR
measure:
  orthostatic-bp-change (if >= 2+ p=0.4 else p=0.1)
  or postural syncope (if >= 2+ p=0.1 else p=0.05)
  elevated liver-function-tests (if > 1wk & >= 2+ p=0.3)
  cardiac-index, fatigue, obtundation, acidosis, soft S1,
  extremities

Knowledge Base

ADULT-RESPIRATORY-DISTRESS-SYNDROME
MORTALITY: 1WK
PERSIST: 0
ONSET: IMMEDIATE
SEVERITIES: 1+ (2+ (HIGH PCO2))
  <0.24= SEPTIC-SHOCK (PROB (0.3 => 1+ 0.2 => 2+))
  =0.30> (HIGH PCO2) (PROB (2+ 0.5 => 1+ 0.4 => 2+))
  =0.95> (LOW ARTERIAL-PO2) (PROB ((0.95 (IF OXYGEN-RX 0.8 1.0)) => SEV=))
  =f> (KNOWN-DIAGNOSIS (PROB ARDS 0.5))
  =f> (DYSPNEA (PROB AT-REST 0.9))
  =f> (RESPIRATORY (PROB DISTRESS 0.9))
  =f> (RALES CHEST) (PROBA DIFFUSE 0.5 PART-WAY-UP 0.3 PULM-EDEMA 0.1
          (ELSE NO) 0.1))
  =f> (CXR (PROB PULMONARY-EDEMA 0.8))

Knowledge Base -- Paths

DIABETES (p=.01)
=0.10> FIXED-Coronary-Obstruction (age & sex dept.)
=0.30> HX-MYOCARDIAL-INFARCT
=0.45> DILATED-CARDIOMYOPATHY
=0.80> LOW LV-SYSTOLIC-FUNCTION
=0.80> LOW LV-EMPTYING
=0.80> LOW CARDIAC-OUTPUT
=0.50> HIGH LA-PRESS
=0.70> PULMONARY-CONGESTION
= f> (CXR (PROBA VASCULAR-REDISTRIBUTION 0.4
          CONGESTIVE-FAILURE ((> 2+) 0.6) PULMONARY-EDEMA
          ((> 2+) 0.6) (ELSE NO-PULMONARY-EDEMA) 0.4))
Reasoning Challenges: Time

- MYOCARDIAL-INFARCTION-ACUTE =>
  - ANGINAL CHEST PAIN for 2hrs
- ISCHEMIC-LV-DYSFUNCTION =>
- LOW LV-COMPLIANCE =>
- LOW CARDIAC-OUTPUT =>
- HIGH LA-PRESS =>
- PULMONARY-CONGESTION
  - NOCTURNAL DYSPNEA for 1wk

Severity: Aortic Stenosis

- Mild: SCLEROSIS (mostly murmur)
- Mod: LV-HYPERTROPHY (ekg findings)
- Sev: LIMITED-CARDIAC-OUTPUT, HIGH LA-PRESS, EXERTIONAL-ANGINA
- V Sev: SYNCOPE, LOW LV-SYSTOLIC-FUNCTION, CARDIAC-DILITATION (heart failure, less murmur)

Diagnosis Algorithm

- Input used to generate finding objects
- Probabilities of the paths are computed
- Input is searched for definite consequences
- Abnormal findings are selected
- For each abnormal finding and uncaused node, all diagnostic nodes are found
- Diagnostic nodes are ordered by coverage
- From these, seeds are generated that can cover the findings

Diagnosis Algorithm Example

Nodes and seeds:
- Seeds: d2, d1+d3
- Node inferred true
- Findings
Diagnosis Algorithm, cont’d

For each, a hypothesis is built starting with the cover set and true nodes.

- Search for states true no matter which causal paths were chosen for the findings
- Findings and states are sorted by certainty of path
- For each finding, best path is added to hypothesis
- Hypothesis is pruned of unnecessary nodes and paths
- Probability of hypothesis determined
- Differential = hypotheses with \( p > (0.01 \times \text{best}) \)

Evaluation

Evaluation Results

<table>
<thead>
<tr>
<th>Compared to the Final Diagnosis</th>
<th>Sensitivity</th>
<th>Comprehensiveness</th>
<th>Specificity</th>
<th>PPV</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDP &amp; Physician</td>
<td>61.3</td>
<td>65.7</td>
<td>77.0</td>
<td>29.1</td>
<td>30.0</td>
</tr>
<tr>
<td>HDP</td>
<td>53.0</td>
<td>57.3 *</td>
<td>75.6</td>
<td>25.4</td>
<td>32.0</td>
</tr>
<tr>
<td>Physician</td>
<td>34.8</td>
<td>39.0 *</td>
<td>93.9</td>
<td>56.2</td>
<td>56.0</td>
</tr>
</tbody>
</table>

Table 1: Performance (%) compared to the final diagnosis

(* \( p<0.0001 \))

Critique by Physicians

<table>
<thead>
<tr>
<th>Response from the physician about each HDP analysis</th>
<th>First Cohort</th>
<th>Second Cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solves a difficult diagnostic question</td>
<td>0</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>Helpfully guides further investigations</td>
<td>11 (29%)</td>
<td>6 (13%)</td>
</tr>
<tr>
<td>Confirms your opinion</td>
<td>8 (21%)</td>
<td>18 (40%)</td>
</tr>
<tr>
<td>Organizes the data usefully</td>
<td>1 (3%)</td>
<td>7 (16%)</td>
</tr>
<tr>
<td>Suggests additional possibilities/ useful ideas</td>
<td>11 (29%)</td>
<td>12 (27%)</td>
</tr>
<tr>
<td>Not helpful</td>
<td>7 (18%)</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>Total responses/cases analyzed</td>
<td>38/49</td>
<td>45/65</td>
</tr>
</tbody>
</table>

Table 4: Physician’s answers to questions on the critique form completed after the HDP’s diagnosis was returned (% of responses in parentheses)
Diagnosing Shock

- Criteria: Mean BP < 60
  - More than one measurement
  - Therapy instituted (pressor or fluids)
- Extracting data
  - Need snapshot of patient situation (single point diagnosis)
  - All of the findings prior to the incident

Example Case

84yo male with CAD - CABG x5
continuous 7 out 10 shoulder to shoulder chest pain
CRF-HD on T-Th-Sat

On 11/2 at 7pm
Creat 6.6, BUN 48, CK-MB 30, CK 239, WBC 13.5
At 8pm
RR 28, BP mean 52, Temp 101.4
=> Given dopamine

Extraction of MIMIC Data

- Patients: age, sex
- Labevents: BUN, Creat, CK, etc.
- Medevents: IV drugs
- Chartevents: BP, edema, rhythm, etc
- IOevents: fluids, renal function
- Noteevents: nursing notes, ecg, echo, Xray, discharge summary
  - Must be parsed and UMLS concepts translated

Case Data

History
  age: 84 year old
  sex: male
  known-diagnosis: of (1) coronary-heart-disease (2) acute-MI (3) hypertension (4) hypertensive-heart-disease
  [a moderate acute-MI assumed new]

Vital-Signs
  map: 52
  heart-rate: 102
  resp: 28
  temp: 101.4

Routine-Investigations
  EKG: sinus-rhythm
  CXR: (1) generalized cardiac-enlargement (2) pleural-effusion
  blood-chemistry: Na: 135 K: 4.5 BUN: 48 creat: 6.6 Ca: 8.1
  serum-albumin: 3.2
  CBC: HCT: 33 WBC: 13.5
  cardiac-enzymes: increased-CPK-MB
  liver-function-tests: elevated
MYOCARDIAL-INFARCTION-ACUTE (caused by CAD) as indicated by
  known-diagnosis of acute-MI, increased-CPK-MB, FEVER (T: 101.4),
  WBC: 13.5, (but anginal chest-pain at-rest not present)
RENAL-INSUFFICIENCY as indicated by creat: 6.6,
  HYPO ALBUMINEMIA (serum-albumin: 3.2), causing ANEMIA; causing
SALT&WATER-RETENTION causing
  HIGH BLOOD-VOLUME, (but Na: 135); causing CXR: pleural-effusion
DILATED-CARDIOMYOPATHY (caused by HHD) as indicated by
  CXR: generalized cardiac-enlargement; causing
LOW CARDIAC-OUTPUT as indicated by elevated liver-function-tests,
  HIGH HEART-RATE (hr: 102); causing
  TACHYPNEA (R: 28) as indicated by respiratory distress
  LOW BLOOD-PRESS as indicated by map 52
HHD (known diagnosis) (caused by RENAL-VASCULAR-DISEASE)
  as indicated by known-diagnosis of hypertension,
  causing DILATED-CARDIOMYOPATHY; causing
LV-HYPERTROPHY
ANEMIA (caused by RENAL-INSUFFICIENCY) as indicated by HCT: 33
CORONARY-ARTERY-DISEASE as indicated by known-diagnosis,
  causing MYOCARDIAL-INFARCTION-ACUTE; causing
RENAL-VASCULAR-DISEASE as indicated by causing HHD

**Explanation of Findings**

LOW CARDIAC-OUTPUT explained by LV-HYPERTROPHY
  known-diagnosis of coronary-heart-disease and MI-ACUTE
  explained by CORONARY-ARTERY-DISEASE
HCT: 33 explained by ANEMIA or unaccounted
  HYPERTENSIVE-HEART-DISEASE explained by RENAL-VASCULAR-DISEASE or
  known diagnosis
known-diagnosis of hypertension and DILATED-CARDIOMYOPATHY explained by
  HYPERTENSIVE-HEART-DISEASE
map 52 explained by LOW BLOOD-PRESS
respiratory distress explained by TACHYPNEA (R: 28)
HIGH HEART-RATE (hr: 102) explained by LOW CARDIAC-OUTPUT
  elevated liver-function-tests explained by NONCARDIAC-LIVER-INVOVLEMENT,
  SPLANCHNIC-CONGESTION or LOW CARDIAC-OUTPUT
CXR: generalized cardiac-enlargement explained by LV-HYPERTROPHY or
  DILATED-CARDIOMYOPATHY
creat: 6.6, HYPO ALBUMINEMIA (serum-albumin: 3.2) and ANEMIA explained by
  RENAL-INSUFFICIENCY
known-diagnosis of acute-MI, inc-CPK-MB, FEVER (T: 101.4) and WBC: 13.5
  explained by MYOCARDIAL-INFARCTION-ACUTE

**Differential**

<table>
<thead>
<tr>
<th>Hypotheses of differential, by relative probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative prob:</td>
</tr>
<tr>
<td>1.0 0.6 0.3 0.1</td>
</tr>
</tbody>
</table>

| MYOCARDIAL-INFARCTION-ACUTE | X | X | X | X |
| RENAL-INSUFFICIENCY          | X | X | X | X |
| SALT&WATER-RETENTION         | X | X | X | X |
| HIGH BLOOD-VOLUME            | X | X | X | X |
| DILATED-CARDIOMYOPATHY      | X | X | X |
| LOW CARDIAC-OUTPUT          | X | X | X |
| LOW BLOOD-PRESS             | X | X | X |
| ANEMIA                      | X | X | X |
| NONCARDIAC-LIVER-INVOVEMENT   | - | - | - |
| CORONARY-ARTERY-DISEASE     | X | X | X |
| SPLANCHNIC-CONGESTION       | - | X | - |

**Data Extraction Challenges**

- No nursing notes prior to event
- Extraction from ECG, echo, X-ray
- ECG: Consider anteroseptal myocardial infarct => <MI>
- Echo: Moderate AS. => nothing
  - Mild PA systolic hypertension => <HTN>
- X-ray: bilateral pleural effusions => <pl eff>
Extraction Needs

- Context specific abbreviations
  - AS in an echo is aortic stenosis (MR, MS, etc)
- More extensive possible and negatives
  - consider
  - cannot be completely excluded
- Section specific interpretation
  - Indication, Findings, Impression

Challenges of Diagnosis

- One shot diagnosis ignores important data
- Response to therapy
  - Fluid may improve CO or cause pulm edema
- Rate of change of parameters
  - Rapid changes => acute cause
- Past diagnoses
  - Chronic pathologies remain

Interpreting Data

- Mapping Findings
  - Edema “legs 4mm” => moderate pedal edema
  - Edema “firm distended” => ??
- Mapping Diseases
  - Myocardial Infarction => MI
  - Anteroseptal Myocardial Infarction => MI

Idea

- Use MIMIC data to learn a better diagnosis program, using the HDP as the structure for inference
  - Extend the HDP model to cover the additional therapies used in the ICU
  - Improve the mapping between concepts in HDP and those in notes
  - Extend HDP to handle therapy response and finding changes
Extracting Cases from MIMIC

- Identify events in case
  - Often signaled by change in therapy
- Divide by organ system involvement
- Determine diagnosis
  - Usually as “Discharge Diagnosis” in DS
  - May be acute on chronic

Learn a Better HDP

- Use the cases to refine the HDP probabilities
- Learn classes of disease with distinct presentations => extend model
- Validate model against additional MIMIC cases