Inference Model for Acute Lung Injury Detection in the ICU

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Abstract:
Acute Lung Injury (ALI) is a devastating complication of acute illness and one of the leading causes of multiple organ failure and mortality in the Intensive Care Unit (ICU). The detection of this syndrome is limited due to the complexity of the disease, insufficient understanding of its development and progression, and the large amount of risk factors and modifiers, and delayed radiographic results [1]. In this paper, we propose a novel detection framework for ALI that encompasses physician’s experience, knowledge of pathophysiology, results of clinical trials and patient data. It involves three complementary techniques, namely, rule-based Fuzzy Inference Systems, Bayesian Networks, and Finite State Machines. The proposed application was validated on Electronic Medical Record (EMR) data for 600 patients from Mayo Clinic (300 ALI and 300 Controls) and it attained sensitivity in the range of 72.3-92.3% and specificity in the range of 60-80.3% depending on the technique used, as opposed to the 30% sensitivity by bedside clinicians [2].

Methods:
The knowledge sources which involve physicians’ experience (heuristics), results of clinical trials (odds ratios), knowledge of pathophysiology (causal relationships) and patient data serve as the foundation for the proposed ALI detection application. Mathematical approaches were selected based upon the knowledge provided. Heuristics were naturally translated into fuzzy logic, odds ratios into probabilistic relationships, and causal relationships into state flow diagrams. Thus, three complimentary algorithms namely, a rule-based Fuzzy Inference System (FIS), Simplified Bayesian Network (SBN), and Finite State Machine (FSM) are used to perform inference on ALI detection. Figure 1 shows a schematic representation of the ALI detection framework.

Introduction:
Acute Lung Injury (ALI) and its more severe form Acute Respiratory Distress Syndrome (ARDS) are devastating acute illnesses leading to multi-organ failure and long term decline in quality of life. In the US, ALI and ARDS afflict 200,000 patients/year (a prevalence of 5%-10% in ICU) contributing to 40% in-hospital mortality and 3.5 million hospital days.

According to the American-European Consensus Conference (AECC), the ALI definition is based on radiological assessment of bilateral infiltrates and PaO2/FiO2 ratio thresholds [3]. Only 30% of ALI patients are recognized by bedside clinicians due to the complexity of the disease, insufficient understanding of its development and progression, late symptom onset, delayed radiographic results, and the large number of risk factors and modifiers [2]. Thus, an advanced clinical decision support system for ALI detection in real time holds significant value for the clinical world.

Results and Discussion:
The ALI detection framework was tested on the ICU patient data obtained from Multidisciplinary Epidemiology and Translational Research in Intensive Care (METRIC) consisting of 300 confirmed ALI patients (cases) and 300 confirmed non-ALI controls. Each of the three algorithms, FIS, SBN, and FSM, gives an ALI detection score every time a new data record of a patient is presented. The detection score for the FIS and SBN algorithms is a number between 0 and 1 while the FSM output is either 0 or 1. Sensitivity of each algorithm will be evaluated by testing...
with the 300 confirmed ALI patients while specificity will be tested with the 300 confirmed non-ALI patients.

We evaluate each method individually first and then as an ‘AND’ combination via Receiver Operating Characteristic (ROC) curves. We choose a window and a number of minutes within the window where the detection score needs to stay above a threshold. Figure 2 shows the results for a window of 240 min and a time of 60 min, i.e. each detection score needs to stay above a threshold for 60 min in any 240 min window in order to declare the presence of ALI and Table 1 shows the sensitivity, specificity, negative predictive value (NPV), positive predictive value (PPV) for the different algorithms and their combinations. The NPV and PPV are calculated assuming an ALI prevalence of 10%.

The ROC for the ‘AND’ combination was evaluated by varying the thresholds for the SBN and the FIS independently while the FSM threshold was fixed at 60 min (i.e. the FSM had to be ‘1’ for any 60 min during the 240 min window). As seen from Figure 2 and Table 1, the ‘AND’ combination of the three different algorithms provides better ALI detection compared to individual algorithms. In addition, the ROC curve shown in Figure 2 rises quickly in the bottom left corner, indicating that for lower values of sensitivity, the approach makes little to no false positive errors, which is of great importance to the experienced clinician to weed out those who look like the ALI patient but do not have ALI. This is again apparent in Table 1 where the PPV is higher for the ‘AND’ combination as compared to the individual methods.

Many factors contribute to the decisions that a physician makes in the ICU. Physicians’ reasoning is a combination of knowledge sources, such as prior experience, published literature, and understanding of pathophysiology. Thus, in order to replicate this decision making, for the purpose of analysis, we take an ‘AND’ combination of the three algorithms and not surprisingly, this combined algorithm achieves better performance and is more robust than any of the individual algorithms.

Table 1: Sensitivity and Specificity for ALI Detection (with window = 240 min and time = 60 min)

<table>
<thead>
<tr>
<th></th>
<th>SBN</th>
<th>FIS</th>
<th>FSM</th>
<th>AND</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity (%)</td>
<td>72.3</td>
<td>76.3</td>
<td>92.3</td>
<td>78.0</td>
</tr>
<tr>
<td>Specificity (%)</td>
<td>69.3</td>
<td>71.7</td>
<td>60.0</td>
<td>80.3</td>
</tr>
<tr>
<td>NPV (%)</td>
<td>95.7</td>
<td>96.5</td>
<td>98.6</td>
<td>97.1</td>
</tr>
<tr>
<td>PPV (%)</td>
<td>20.8</td>
<td>23.0</td>
<td>20.4</td>
<td>30.6</td>
</tr>
</tbody>
</table>

Conclusion:
In conclusion, we have shown a proof-of-concept framework for the detection of ALI, validated on Electronic Medical Record (EMR) data, with 85% sensitivity and 72% specificity as opposed to a sensitivity of 30% in the current clinical setting. In order to ensure the robustness of the inference model for ALI detection, we intend to further validate the model with data from a multi-center trial. As part of our future work, we plan to investigate the model’s ability to detect ALI before the clinical detection time in order to support accurate and early identification of patients with or at risk of ALI. Early detection of ALI will enable clinicians to develop novel treatment and prevention strategies to improve patient outcomes. We intend to extend this work to detect other organ failures, such as acute kidney injury (AKI).

References: