Background

Prostate cancer
- The most common malignancy diagnosed in men
- Prognosis and survival depends greatly upon whether or not skeletal metastases or spread to lymph nodes can be identified at the time of diagnosis

Staging methods
- During staging, the urologist may order a bone scan (BS) and/or a CT scan, which are the most frequently used noninvasive imaging methods
- There are harms associated with both over-imaging and missing a patient with undetected metastases

Problem Statement

- Standard clinical guidelines indicate the need for BS and CT scan only in patients with certain unfavorable characteristics; however, the guidelines vary in their recommendations
- The goal was to determine which patients should receive a BS and/or a CT scan and which patients can safely avoid imaging on the basis of individual risk factors
- The proposed approaches were evaluated in a population-based sample of newly-diagnosed men in the Michigan Urological Surgery Improvement Collaborative (MUSIC) — a physician-led, statewide collaborative including 90% of the urologists in the state

Risk Prediction Models

- Multivariate logistic regression models were fit to determine the probability of a positive imaging test as a function of all routinely available clinical variables in a sample of patients who received an imaging test

Classification Modeling

- Two important challenges: learning from unlabeled data and learning from imbalanced data
- In practice not all patients receive a staging BS or CT scan at diagnosis
- A minority of patients has metastatic cancer
- We propose Cost-sensitive Laplacian Kernel Logistic Regressions (Cos-LapKLR), a spectral clustering based semi-supervised learning approach that accounts for missing labels and class imbalance:
  \[ f^* = \arg \min_{f} \frac{1}{2} \|f\|_F^2 + \gamma \text{Bias-Corrected Error} \]
  where \( f \) is the decision function, \( f(x) = \sum_{x_i \in C} K(x, x_i) \), \( x \) is the number of unimaged patients,
  \( K \) the positive definite kernel function and \( L \) the Laplacian matrix
- In addition to Cos-LapKLR, several other classification models adapted for imbalance data learning were implemented:
  - Cost-sensitive logistic regression and support vector machines
  - Random forests and AdaBoost combined with advanced sampling techniques

Bias-Corrected Guidelines

- The diagnostic accuracy of alternative classification models are systematically biased since they are based on only the imaged patients
- We used an established method to correct for verification bias proposed by Begg and Greens (Stat Med, 1987 6(4):411) to evaluate the performance of the guidelines
- Trade-off curves were created to determine Pareto optimal models based on sensitivity and specificity
- A model is considered dominated if there is another model that has a higher sensitivity and a higher specificity

Patient Centered Criteria

- Two important criteria were considered: expected number of positive outcomes missed and expected number of negative studies
- The published guidelines are very close to the efficient frontier for BS and CT scan while also achieving a missed metastasis rate < 1%

Implementation

- The MUSIC consortium instituted statewide criteria for BS and CT scan, known as the MUSIC Imaging Appropriateness Criteria
- MUSIC set a statewide goal of performing imaging in ≥ 95% of patients that meet the criteria and in < 10% of those that do not

Avoidance of low-value imaging using MUSIC Criteria

- Baseline (2012-2013)
- Post-intervention (Jan-Oct 2015)

- This work has had a significant societal impact by decreasing the chance of missing a case of metastatic cancer and reducing the harm from unnecessary imaging tests
- Our publications were cited in the 2016 NCCN guidelines

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MUSIC Imaging Appropriateness Criteria 2014-2015

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