Is i2b2 for you?
Monitoring and Evaluation of Urban Health Outcomes using Open-source Population Health Software

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The “EcoSystem”

• BMC is largest safety net provider in New England
• Nearly all CHCs are FQHCs
• EHR-based care
  • BMC since 1999
  • CHCs since 2003
A Vision

- Data is open - privacy is protected
- Researchers focus on the question - not the query
- Researchers ask complex clinical research questions *themselves*
- Data is standardized so the same question can be asked at multiple sites
- 10 hypotheses -> 1 great question
i2b2

- “Informatics for Integrating Biology with the Bedside”
- Open-source software based on the MGH Research Patient Data Repository (RPDR)
- Collection of modules or “cells” constitute the i2b2 “hive”
  - De-identified clinical data repository
  - Data linked to standardized vocabularies
  - Query and analytic tools
  - Two applications: web-client and Workbench (java)
i2b2 Key Concepts

- Data integration and mapping
  - Disparate data mapped to common format
- Master Patient Index (MPI)
  - Data for individuals linked
- De-identification
- Patient sets
  - Outcomes measured via nested queries that identify populations
Enterprise-wide repurposing and distribution of medical record data for research

i2b2 Hive

Use of medical record data in clinical studies focused upon genomics and pharmacology
i2b2 Core Data Elements

- Patients
- Observations (Facts)
- Concept Libraries (Ontologies)
Massachusetts Health Disparities Repository (MHDR)

Staging Area
- Functions:
  - MPI linkage
  - Data cleaning
  - Standardization (LOINC, CPT, RxNorm, ICD9, SNOMED CT)

Clinical Data
- Data:
  - Demographic
  - Insurances
  - Services
  - Medications
  - Problems
  - Labs
  - Clinical Observations
- Sites:
  - Boston Medical Center
  - Dorchester House MSC
  - Codman Square HC
  - Healthcare for the Homeless
  - Greater Roslindale MDC
  - Whittier Street HC
  - Mattapan CHC
  - South End CHC
  - South Boston CHC
  - Uphams Corner CHC

Database
- BMC-i2b2
  - People (1.4+ mil)
  - Facts (1+ billion)
  - Concepts
- Tools
  - Query Cell
  - HOME Cell

BMC-i2b2
- BMC only
- Web accessible
- Aggregate data
- No additional IRB

MHDR
- BMC + CHCs
- RDP access (with SAS, STATA)
- HOME Cell and data extracts
- IRB approval required
Patient Sets Example

MHDR Individuals

Age 45-64

1+ Primary Care Visit

Ever Diagnosed with Essential HTN
### Billing Data – Site 2

<table>
<thead>
<tr>
<th>MRN</th>
<th>Visit_date</th>
<th>Location</th>
<th>Dx1</th>
<th>Dx2</th>
<th>CPT1</th>
<th>CPT2</th>
<th>PrimIns</th>
</tr>
</thead>
<tbody>
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<td>125.8</td>
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<td>90213</td>
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<td>70</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### i2b2 Repository (de-identified data)

#### Patients

<table>
<thead>
<tr>
<th>ID</th>
<th>Birth_Date</th>
<th>Sex_Cd</th>
<th>Race_Cd</th>
</tr>
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<tbody>
<tr>
<td>12</td>
<td>11/07/2000</td>
<td>M</td>
<td>B</td>
</tr>
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</table>

#### Observation_facts

<table>
<thead>
<tr>
<th>ID</th>
<th>Concept_Cd</th>
<th>Start_Date</th>
<th>Value</th>
<th>Location_Cd</th>
<th>End_Date</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Site1</td>
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<td>Dx</td>
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<td>125.8</td>
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<tr>
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<td>90124</td>
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</tr>
<tr>
<td>12</td>
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<td>90254</td>
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<td></td>
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<tr>
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</tr>
<tr>
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<td>PediPulm</td>
<td>2/22/2010</td>
<td>Site2-PediPulm</td>
<td>Site2</td>
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<td>Dx</td>
<td>2/22/2010</td>
<td>123.4</td>
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<td></td>
</tr>
<tr>
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<td>Hct</td>
<td>2/22/2010</td>
<td>11.1</td>
<td>Site2</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>MCV</td>
<td>2/22/2010</td>
<td>70</td>
<td>Site2</td>
<td></td>
</tr>
</tbody>
</table>
Value considerations

- i2b2 uses standard coding systems (ontologies) like ICD9, ICD10, LOINC, RxNorm, SNOMED-CT
- Observations have five main components: Pt ID, start/end dates, concept ID, and value
- Concepts with the same code can mean different things
Choose value of Diabetes mellitus (Test:ICD9:250)

Searches by Lab values can be constrained by the highflow flag set by the performing laboratory, or by the values themselves.

- No Value
- By Value

OK Cancel
Choose value of Diabetes mellitus (Test:ICD9:250)

Searches by lab values can be constrained by the high/low flag set by the performing laboratory, or by the values themselves.

- No Value
- By Value

Please select a value:
- ADMITTING
- PRIMARY
- PROBLEM
- SECONDARY
i2b2 Compatible Data

- Demographics
- Problems/Diagnoses
- Medications
- Clinical Observations
- Procedures
- Laboratory Data
- Genomic Data
- Much more...
i2b2 and Health Services Research

- i2b2 excels at cohort identification
- Lacked functionality to describe clinical processes and outcomes over time
- Outcomes research possible with:
  - New ontologies
  - New data (GIS, services, insurance, etc)
  - Temporal modeling of facts as exposures and outcomes
New MHDR Ontologies

Administrative:

• **Clinical Services** (e.g. GIM, Pediatrics)
  • By location and specialty
  • Coding: custom ontology

• **Insurance** (e.g. BCBS, Medicaid)
  • By payer type (e.g. Commercial, Medicaid)
  • Coding: Custom

Clinical:

• **Vital Signs** (e.g. Blood Pressure, Growth)
  • Coding: SNOMED-CT
New Ontologies

Coding:
- Custom
- SNOMED-CT

GIC and Insurance

Vital Signs
- Coding: SNOMED-CT

Substance Use
- Coding: Custom

Coding: Census - Zip Code - Custom
The HOME Cell

A new i2b2 Health Outcome Monitoring and Evaluation (HOME) Cell to model and assess relationships between:

• *any* exposure fact(s)
• *any* outcome fact(s)
• *many* temporal relationships
• stratified by *any* i2b2 query population
• during discrete reference intervals
Enterprise-wide repurposing and distribution of medical record data for research

i2b2 Hive

Use of medical record data in clinical studies focused upon genomics and pharmacology

Health Outcome Monitoring and Evaluation (HOME)
HOME Cell Components

• **Baseline query** from i2b2 Query Cell

• **Constraints:**
  • **Occurrence**: temporal relationships between facts
  • **Value**: extends occurrence constraint to specify numeric values/ranges
  • **Age**: models subject’s age at time of fact
  • **Strata**: i2b2 queries define sub-populations
  • **Reference interval**: period (month, year, date interval) to optionally further constrain data
HOME Cell Example:
Hypertension Control 45-64 Years Old
### Initial Query

**Query Tool**

#### Query Name: HL 1-4 pop

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dates</strong></td>
<td><strong>Dates</strong></td>
<td><strong>Dates</strong></td>
</tr>
<tr>
<td><strong>Occurs &gt; 0x</strong></td>
<td><strong>Occurs &gt; 0x</strong></td>
<td><strong>Occurs &gt; 0x</strong></td>
</tr>
<tr>
<td><strong>Exclude</strong></td>
<td><strong>Exclude</strong></td>
<td><strong>Exclude</strong></td>
</tr>
</tbody>
</table>

- **Group 1**:
  - FAMILY MEDICINE
  - GENERAL MEDICINE

- **Group 2**:
  - Essential hypertension

- **Group 3**:
  - Blood Pressure

**Analysis Types**

- Patient List
- Number of patients
- Vital Status
- Race
- Age
- Gender
- Find Line

**Previous Queries**

- [HL 1-4 pop (03-15-2012)]
- [HL 1-4 pop (03-15-2012) (Badger)]
- [Warfarin (04-14-2012) [Badger]]
- [Warfarin 1 (04-04-2012) (Badger)]

**Run Query Above**

**Patients returned:** 6066
Strata Queries
Denominator Population
Numerator Population
### Strata Query List

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Male</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Female</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Health Safety Net</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Medicaid</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Self Pay/Uninsured</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Commercial/Private</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Black</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>White</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Female: Black</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Mixed: Black</td>
<td></td>
</tr>
</tbody>
</table>
Display/Execute: Percent

- **Outcome**: Percent
- **Interval**: Year
- **Date range**: 01-01-2004 to 12-31-2010

Save Query:
- **Name**: HomeQueryName
Sample Result Set

<table>
<thead>
<tr>
<th>Interval</th>
<th>Strata</th>
<th>SD</th>
<th>SN</th>
<th>SN/SD</th>
<th>SN/SD</th>
<th>SN/SD</th>
</tr>
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<tbody>
<tr>
<td>2004</td>
<td>Male</td>
<td>4421</td>
<td>2325</td>
<td>52</td>
<td>2</td>
<td></td>
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<tr>
<td>2005</td>
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<td>5271</td>
<td>2974</td>
<td>56</td>
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<tr>
<td>2006</td>
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<td>5645</td>
<td>3273</td>
<td>57</td>
<td>2</td>
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<tr>
<td>2007</td>
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<td>6058</td>
<td>3655</td>
<td>60</td>
<td>2</td>
<td></td>
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<tr>
<td>2008</td>
<td>Male</td>
<td>6580</td>
<td>3984</td>
<td>60</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>Male</td>
<td>7329</td>
<td>4485</td>
<td>61</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>Male</td>
<td>7992</td>
<td>4989</td>
<td>62</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Strata Denominator Count

Strata Numerator Count

Proportion
HOME: Blood Pressure Control for Persons Over 18 with Essential Hypertension
I2b2 + HOME ?
Note: This map shows the number of people, by census tract of residence (2008-2011), who had at least one visit to an MHDR clinical center from 2005-11. Census tracts with fewer than 20 patients are not included.
Percent of patients with any BHN Contact during 2011-2014 by Zip Code of residence 2011-2014*

East Boston (EB) - 65%  
(no local EHR data)

South Boston (SB) – 63%  
South End/Chinatown (SE) – 84%  
Roxbury (RX) - 71%  
North Dorchester (ND) - 100%  
South Dorchester (SD) - 91%  
Mattapan (MT) - 95%  
Roslindale (RS) - 45%  
Hyde Park (HP) - 65%

* % of patients with address zip code noted at least once 2011-2014 divided by 2010 US Census count for that area
Note: Number of people, by census tract of residence (2008-2011), who had at least one visit to the clinical center from 2005-11.
Cardiovascular Health and Disparities: Boston, 2005-2011

Preliminary findings prepared by William G. Adams, MD\textsuperscript{1,2}, Nancy Kressin, PhD\textsuperscript{3,4}, Cathryn Byrne-Dugan, MD/MPH\textsuperscript{5}, and Aaron Legler, MPH\textsuperscript{4}.

\textsuperscript{1}Department of Pediatrics, \textsuperscript{2}BU-Clinical and Translational Sciences Institute, \textsuperscript{3}Department of Medicine, \textsuperscript{4}Health Disparities Research Program, Boston University School of Medicine/Boston Medical Center
**Note:** Percent of patients with essential HTN whose latest systolic BP was < 140 and diastolic BP was < 90 during each year for each center.
Blood Pressure Control by Sex-Race
Boston, 2005-2011

Note: Percent of patients with essential HTN whose latest systolic BP was < 140 and diastolic BP was < 90 during each year for patients of differing race and/or sex.
Blood Pressure Control by Census Tract
Boston, 2011

Note: Percent of primary care patients with essential HTN whose latest systolic BP was < 140 and diastolic BP was < 90 by census tract. Patients were assigned to a tract if they had at least one address listed in the tract during 2008-2011.
Blood Pressure Control Rates by Census Tract
Boston Medical Center, 2010-11

Note: Percent of primary care patients with essential HTN whose latest systolic BP was < 140 and diastolic BP was < 90 by census tract. Patients were assigned to a tract if they had at least one address listed in the tract during 2008-2011.
Lipid Screening by Center
Boston, 2005-2011

Note: Percent of patients (male ≥ 35 years old or female ≥ 45 years old) with a primary care visit during the year and at least one lipid screening test (HDL, LDL, or Total Cholesterol) within 2 years preceding or 60 days following the visit for each Center.
Lipid Control for High Risk CVD Patients by Center Boston, 2005-2011

Note: Percentage of high risk CVD patients (≥ 20 years old) with a primary care visit during the reference year who had controlled lipid levels (HDL >50 in females, HDL >40 in males, or Total Cholesterol <200) stratified by CHC.
Adult Obesity by Sex-Race
Boston, 2005-2011

Note: Percent of patients with a primary care visit at 18-65 years old during the reference year who had a BMI ≥30 by race and gender
Note: Percent of patients with essential HTN whose latest systolic BP was < 140 and diastolic BP was < 90 during each year for patients of differing race and/or sex.
Note: For patients who were seen at each Center during 2010-2011, percent of patients with a primary care visit at 3-18 years old during the reference year who had a recorded BMI %’ile by Center.
Childhood Obesity by Sex-Race Boston, 2009-2011

**Note:** Percent of children with a primary care visit at 3-18 years old during the reference year who had a BMI Percentile ≥ 95’tile by race and/or sex.
Note: Patients with a primary care visit during the reference year who were ≥18 years old at the time of the visit, were screened for cigarette use, and reported being a smoker by CHC
Passive Cigarette Exposure in Children by Sex-Race
Boston, 2005-2011

Note: Children with a primary care visit during the reference year who were 0-12 years old at the time of the visit, screened for passive exposure, and reported smoking in the home by race and/or sex.
Percent of Asthma Patients with Assessment of Daytime or Nighttime Symptoms by Center*

- BMC
- CHC1
- CHC2
- CHC3
- CHC4
- CHC5
- CHC6
- CHC7

*EHR Asthma Form Added
Distributed HOME Project

- 5 Collaborating i2b2-enabled CTSAs
- Comparative effectiveness evaluation of medications for hypertension, hypercholesterolemia, childhood asthma, diabetes

- Boston University
- Univ. of Massachusetts
- Univ. of Cincinnati
- Univ. of Alabama at Birmingham
- Univ. of Washington

www.dhome-project.net
Research Objectives

• Describe variation in cardiovascular outcomes (hypertension, dyslipidemia, diabetes) over time in 5 CTSA i2b2 instances distributed across U.S.

• Assess within medication class outcome differences (comparative effectiveness) for commonly used medications (anti-hypertensives, statins, oral hypo-glycemics)
Approach

• Bi-monthly web-based teleconferences
• Shared ontology development (BP, BMI, medications)
• Technical collaborations between sites and from Recombinant/Deloitte
• Shared query development
• Distributed query execution with centralized aggregate data sharing
Definitions – BP control

Denominator:

- At least one primary care visit in reference year
- At least one systolic and diastolic BP that followed a diagnosis of essential hypertension during year
- Separate HOME Cell queries for all combinations of BMI (< 30, 30+) and Age (< 65, Age 65+) during reference year

Numerator

- Most recent systolic BP during year < 140
- Most recent diastolic BP during year < 90

Strata: Race, Gender
Percent of Patients with Essential Hypertension and Controlled BP*

<table>
<thead>
<tr>
<th>Site</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMC</td>
<td>24,930</td>
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<tr>
<td>UAB</td>
<td>15,393</td>
</tr>
<tr>
<td>UC</td>
<td>19,435</td>
</tr>
<tr>
<td>UMASS</td>
<td>16,144</td>
</tr>
<tr>
<td>UW</td>
<td>8,913</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>84,815</strong></td>
</tr>
</tbody>
</table>

* n = number of patients for most recent year
Percent of Patients with Essential Hypertension and Controlled BP on Most Recent Test

<table>
<thead>
<tr>
<th>Site</th>
<th>n</th>
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<tbody>
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<td>24,930</td>
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<td>UC</td>
<td>19,435</td>
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<tr>
<td>UMASS</td>
<td>16,144</td>
</tr>
<tr>
<td>Total</td>
<td>60,509</td>
</tr>
</tbody>
</table>
BP Control for Patients with Essential Hypertension by Gender and Site
BP Control for Patients with Essential Hypertension by Race and Site
### Logistic Regression Models for BP Control 2006-2012*

**BMC** (90481 controlled, 53869 not controlled)  
**UCinn** (39434 controlled, 18880 not controlled)  
**UMass** (48679 controlled, 20770 not controlled)

<table>
<thead>
<tr>
<th></th>
<th>BMC</th>
<th>UCinn</th>
<th>UMass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Odds ratio (95% CI)</td>
<td>p-value</td>
<td>Odds ratio (95% CI)</td>
</tr>
<tr>
<td>Year overall</td>
<td>1.01 (0.96, 1.05)</td>
<td>0.81</td>
<td>0.79 (0.62, 1.01)</td>
</tr>
<tr>
<td>2007 vs. 2006</td>
<td>1.01 (0.97, 1.06)</td>
<td>0.53</td>
<td>1.03 (0.82, 1.30)</td>
</tr>
<tr>
<td>2008 vs. 2006</td>
<td>1.07 (1.03, 1.12)</td>
<td>0.002</td>
<td>1.03 (0.82, 1.29)</td>
</tr>
<tr>
<td>2009 vs. 2006</td>
<td>0.98 (0.94, 1.02)</td>
<td>0.28</td>
<td>1.02 (0.81, 1.28)</td>
</tr>
<tr>
<td>2010 vs. 2006</td>
<td>1.01 (0.97, 1.02)</td>
<td>0.56</td>
<td>NA</td>
</tr>
<tr>
<td>Asian vs. White</td>
<td>1.12 (1.04, 1.19)</td>
<td>0.002</td>
<td>0.99 (0.83, 1.20)</td>
</tr>
</tbody>
</table>

|                          | Odds ratio (95% CI)         | p-value                    | Odds ratio (95% CI)         | p-value                    | Odds ratio (95% CI)         | p-value                    |
| Black vs. White          | 0.70 (0.68, 0.72)           | <0.0001                    | 0.65 (0.63, 0.68)           | <0.0001                    | 0.79 (0.73, 0.86)           | <0.0001                    |
| Hispanic vs. White White  | 0.99 (0.96, 1.03)           | 0.80                       | 0.72 (0.52, 0.99)           | 0.046                      | 1.10 (0.99, 1.23)           | 0.06                       |
| Obese vs. Not            | 0.84 (0.83, 0.86)           | <0.0001                    | 0.83 (0.80, 0.86)           | <0.0001                    | 0.82 (0.79, 0.85)           | <0.0001                    |
| Female < 65 vs. Male 65+ | 1.53 (1.47, 1.58)           | <0.0001                    | 1.07 (1.01, 1.14)           | 0.02                       | 1.26 (1.19, 1.34)           | <0.0001                    |
| Male < 65 vs. Male 65+   | 1.18 (1.14, 1.22)           | <0.0001                    | 0.93 (0.88, 0.99)           | 0.02                       | 1.00 (0.94, 1.06)           | 0.99                       |
| Female, 65+ vs. Male 65+ | 0.90 (0.87, 0.94)           | <0.0001                    | 0.91 (0.86, 0.97)           | 0.005                      | 0.84 (0.79, 0.90)           | <0.0001                    |

* Limited to comparisons with significant findings
BP Control for Patients with Essential Hypertension by Medication Class at BMC

- BMC - ACE: Black
- BMC - Diuretic: Black
- BMC - ACE: White
- BMC - Diuretic: White
MySCILHS Telephony

- Leverage experience with data-driven telephony to support IVR REDCAP
  - “self-service questionnaires”
  - Local and cloud-based options
  - TTS (Susan) and ASR
  - Staff make contact and obtain consent
- Majority of call via IVR
  - Scalable
  - IRB- and patient-friendly
IVR Strengths

• Conversational
  • Bidirectional
  • Speech-based

• Accessible
  • Ubiquitous technology
  • Available everywhere
  • Lower literacy requirements

• Adaptive
Conclusions

• Powerful tool for exploratory analyses
• “Rapid”, distributed queries are feasible and informative
• The outcomes evaluated are not improving nor are racial gaps narrowing
• Multi-variate approach particularly promising/important (strata enhancement work ongoing)
Word of caution...

- Numerous opportunities for “epidemiologic malpractice”
- Lots of cheese
- Plenty of holes...
- New ways of thinking and data management required (not always easy)
- Lots of work to do with Epic
A Novel Approach

• Data is open - privacy is protected
• Focus is on measurement - not SQL
• Researchers can ask complex questions *themselves* - quickly
• CER, HSR, *and* QI supported by a common framework
• Analytic software is interoperable
• Logic is transparent *and* portable
Additional projects/activities

- BMC Cancer Registry Integration
- BP Normalization and Care
- VVV in BP, lipid, and Hgb1C
- Sickle Cell QI (children and adults)
- Sickle Cell BH
- Community-based smoking cessation
- Pneumonia rates in PCV vaccine era
- HPV vaccination
- Algorithms for Personalized Decision Making
- ePROS – psychotropic medication use in kids
- ePROS – on-off-label safety
- PCORI-CDRN (SCILHS)
- Tele-REDCAP
- Insurance switching
- Vital Village – geographic health effects
Future Plans

• Spread i2b2 web-client access to BUMC research community
• Expand functionality of Strata tab and query code to support multivariate, aggregate data generation
• Provide a web-based version of the HOME Cell
Coming soon…
Massachusetts Health Disparities Repository (MHDR)

Staging Area

Functions:
- MPI linkage
- Data cleaning
- Standardization (LOINC, CPT, RxNorm, ICD9, SNOMED CT)

Clinical Data

Data:
- Demographic
- Insurances
- Services
- Medications
- Problems
- Labs
- Clinical Observations

Sites:
- Boston Medical Center
- Dorchester House MSC
- Codman Square HC
- Healthcare for the Homeless
- Greater Roslindale MDC
- Whittier Street HC
- Mattapan CHC
- South End CHC
- South Boston CHC
- Uphams Corner CHC

BMC-i2b2
- BMC only
- Web accessible
- Aggregate data
- No additional IRB

i2b2

Database
- People (1.4+ mil)
- Facts (1+ billion)
- Concepts

Tools
- Query Cell
- HOME Cell

MHDR
- BMC + CHCs
- RDP access (with SAS, STATA)
- HOME Cell and data extracts
- IRB approval required