Tutorial on access to, and use of OAI Images

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Overview

- Image Releases: process and nomenclature
- What has been released & What is still to be released
- Types of Images Available:
  - Imaging schedule
  - Exam types (radiographs/ MRI sequences)
- Images on Hard Drives:
  - Barcodes and meta-data to find images
  - Operations Manuals & DICOM Image Release Notes
  - Contents of DICOM headers & images on disk
- Matching Clinical/Demographics to Images:
  - Imaging meta-data, and Barcodes
  - Clinical/Demographic datasets, ‘Search & Browse’, ‘My Cart’
  - Case Study selecting on baseline characteristics
- Exploring existing Biomarkers:
  - Selecting MRIs for examination based on x-ray readings
Process and organization of image releases

- Images received at the Imaging QC Center (Synarc)
  - undergo QC and cleaning
  - sent to the CC in batches as processing completed
- At CC, images undergo further QC checks
  - additional blinding and removal of private DICOM tags
  - packaged for public release
- Images in each release correspond to a designated subset of participants (ppts)
  - 200 ppts (progression/incidence)
  - 160 ppts (progression)
  - “first half” of the cohort (all ppts)
  - “second half” of the cohort (all ppts)
  - 278 ppts (progression, with 18-month interim visit)
OAI Image Release Nomenclature

Image Releases identified by 3 pieces of information:

- **Visit at which images were obtained:**
  - Baseline (0), 12-month (1), 18-month (2), 24-month (3), 30-month (4), 36-month (5), 48-month (6)

- **Group of participants:**
  - 200 progression/incidence (Group A)
  - 160 progression (Group B)
  - “First Half” of Cohort (Group C)
  - Participants with 18-month interim visit (Group D)
  - “Second Half” of Cohort (Group E)

- **Version number of release:**
  - Sequentially numbered beginning with 1
OAI Current Image Releases

- **#1: 0.A.2**
  - Baseline images from Group A participants
  - \((N=200)\) – 2\textsuperscript{nd} version of the release

- **#2: 0.B.2 + 1.B.2**
  - Baseline & 12-month images from Group B participants
  - \((N=160)\) – 2\textsuperscript{nd} version of the release

- **#3: 0.C.1 + 1.C.1**
  - Baseline & 12-month images from Group C participants
  - \((N=2686)\) – 1\textsuperscript{st} version of the release

- **#4: 2.D.1**
  - 18-month interim visit images from Group D
    - \((N=288)\) – 1\textsuperscript{st} version of release
    - Baseline and 12m can be provided (subset of #3)
Current Images Available (O.C.1 & 1.C.1)

1\textsuperscript{st} half ppts
n = 2,691

FU images acquired

MRI: 2,340 (87%)
Knee x-ray: 2,394 (89%)
Both: 2,309 (86%)

BL-FU Images available for release

MRI: 2,328 (86%)
Knee x-ray: 2,206 (84%)
Both: 2,111 (80%)
OAI Future Image Releases

- **#5**: 3.C.1 (Group C 1\textsuperscript{st} half of cohort)
  - 24-month images - release early 2008
  - followed later by: 36-month (5.C.1), 48-month (6.C.1)
  - Groups A and B are subsets of Group C:
    - later images will be in the “C” releases

- **#6**: 0.E.1 (Group E 2\textsuperscript{nd} half of cohort)
  - Baseline images remainder of cohort (N=2110) – mid 2008
  - May be paired with 12-month images (1.E.1)
  - Followed later by 3.E.1, 5.E.1, 6.E.1

- Releases for special groups of participants:
  - Group F (participants with 30-month interim visits)
  - Thigh MRIs
OAI Annual Knee Imaging

- All participants, baseline, 12mo, 24mo, 36mo, 48mo
- Knee Radiographs:
  - *Bilateral Fixed Flexion: baseline and then annually*
- Knee MRI (3T Siemens Trio):
  - *baseline and then annually*
  - *R knee: long protocol, L knee: shorter protocol*

<table>
<thead>
<tr>
<th>Pulse Sequence</th>
<th>Right Knee (mins)</th>
<th>Left Knee (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localizer (3 plane)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>SAG 3D DESS WE (with Cor &amp; Axial MPRs)</td>
<td>10.6</td>
<td>10.6</td>
</tr>
<tr>
<td>COR IW 2D TSE</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>SAG IW 2D TSE (with fat suppression)</td>
<td>4.7</td>
<td>4.7</td>
</tr>
<tr>
<td>COR T1W 3D FLASH WE</td>
<td>8.6</td>
<td>--</td>
</tr>
<tr>
<td>SAG 2D muti-echo (T2 MAP)</td>
<td>10.6</td>
<td>--</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>38.4</strong></td>
<td><strong>19.2</strong></td>
</tr>
</tbody>
</table>
OAI Additional Imaging

- Additional Knee Radiographs:
  - Fluoro-guided L and R knee: Enrollment and annually*
  - Lateral L & R knee: enrollment and 36-month (controls)

- Additional Knee MRI visits:
  - Interim 18-month visit in 287 (unilateral MRI)
  - Interim 30-month visit in ~500 ppts (unilateral MRI)
  - Also with clinical outcomes and biospecimen collection

- Pelvis and Hand Radiographs:
  - Enrollment visit and 48-month visit

- Bilateral Full-Limb Radiograph:
  - 12-month, 24-month or 36-month visit

- Thigh MRI:
  - Enrollment, 24-month and 48-month

* Fluoro in subset of progression subcohort only
OAI Imaging Details

- Imaging Schedule:
  - visits and examination schedules:
    http://www.oai.ucsf.edu/datarelease/DataImaging.asp

- Operations Manuals:
  - detailed information on how the images were acquired
    http://www.oai.ucsf.edu/datarelease/DataImaging.asp

- DICOM Image Release Notes:
  - image releases have a set of notes on the hard drive
  - includes types of images, pulse sequence parameters
  - they are also downloadable at:
    http://www.oai.ucsf.edu/datarelease/DataImaging.asp

- Bilateral Fixed Flexion Knee Radiographs:
  - Synaflexer Frame
    - allows correction for magnification differences between visits
    - allows for assessment of beam angle
OAI - Synaflexer Frame
OAI - Hand and Pelvis Radiographs
OAI – Full Limb and Lateral Knee Radiographs
Osteoarthritis Initiative

OAI - MRI IW TSE Sequences
OAI - MRI 3D DESS Sequence

3D - reconstructed as 0.7mm sagittal slices

MPR Reformats

Osteoarthritis Initiative
OAI - Special Sequences

- **Coronal FLASH Multi-echo sequence for T2 Maps**

Osteoarthritis Initiative
OAI Images on Hard Drives

- Provided by Group (A,B,C, etc)
  - separate folder for each annual visit (0,1,3,5,6)
  - interim visits (2 = 18month, 4=30month)

- Participant ID / Exam Date/ Barcode folders
  - participant ID is UID (7 digits starting with “9”)
  - barcode is UID for a particular radiograph or MR sequence

- Each “barcode” has downloadable imaging meta-data
  - can be used to find out location of images on the hard drives
  - imaging meta-data also has QC ratings for images
  - if we decide current arrangement is stable, we could consider storing folder name in meta-data
  - for 0.A.2, 0.B.2, 1.B.2 you also need the spreadsheets that go with each release to find images on disk

- Each release has DICOM Image Release Notes
DICOM Image Headers

- **Patient ID & Name:**
  - OAI ID (9nnnnnnn), prefixed with “OAI” for Patient Name

- **Study Descriptions:**
  - Visit + Exam Type + Anatomy/Side
    - eg: Enrollment Visit Left Knee MRI
    - eg: 12-month Visit Knee x-ray

- **Series Descriptions:**
  - **MRI:** describes pulse sequence used
    - eg: COR_IW_TSE
  - **X-Ray:**
    - eg: Bilateral Fixed Flexion Knee
    - ONE x-ray image per series and only one series per study

- **DICOM Series identified by Barcode:**
  - Barcode is in “Accession Number” since often easy to search on
Image Acquisition Details

- **DICOM Image Release Notes (DIRN)**
  - give some information on image acquisition
  - some background on what particular type of images can be used for

- **Operations Manuals (OM)**
  - set of instructions on how to perform the acquisition
  - detailed specifics such as:
    - special positioning for knee radiographs
    - internal rotation for pelvis radiographs
    - selection of imaging plane orientation for specific MRI sequences

- **DIRN and OM both downloadable from OAI Online:**
  - http://www.oai.ucsf.edu/datarelease/OperationsManuals.asp
  - one OM for radiography
  - one OM for MRI
  - separate DIRN for each image release
Figure 3.3.1 — SynaFlexer for reproducible feet fixation and knees flexion. The frame is positioned with its anterior wall in direct contact with the bucky, cassette holder or reclining table top such that both knees are centered on the film. With the great toes touching the anterior wall of the frame, both feet are fixed in external rotation by pressing them against the V-shaped support on the base of the frame. Body weight is distributed equally between the two legs. Both knees and thighs are pressed against the anterior wall of the frame in order to fix flexion of the knees. The x-ray beam is angled 10° caudal and centered at the level of the joint line midway between the two knees.
MRI OM Example

Coronal 3D FLASH with Water Excitation (WE)

- Use the 160mm FOV acquisition to fully cover the femoral condyles and tibial plateau.
- Prescription of the Cor 3D FL WE is crucially important. This double oblique acquisition must have both posterior femoral condyles appearing within 2 slices of each other (double bullseye sign).
- Prescription Instructions:
  - Imaging volume is prescribed from the axial localizer with largest femoral condyles, and from mid-joint sagittal and coronal localizers.
  - First, imaging volume (box) is oriented such that the posterior edge aligns with (touches) the posterior femoral condyle surface on the axial localizer. (Figure 1)

Figure 1. Scan Prescription of Coronal 3D Flash

- Next, use sagittal localizer and move the center of the imaging FOV to the tip of the femur in the joint.
- Move top (superior) center of imaging FOV to the center of femoral shaft (diaphysis). The alignment is now correct and results in a line tangential to the posterior femoral condylar surfaces in the axial plane, and parallel to the femoral-tibial axis in the sagittal plane.
- Finally, move (translate only!!) imaging FOV (without changing either alignment axes) such that joint is centered. Check all three localizer planes to ensure that complete coverage of the joint is obtained and aliasing does not obscure structures of interest.

Coronal and Axial Multi-Planar Reformatting (MPR)

- Coronal and Axial MPR of the Sagittal 3D DESS WE do not require further acquisition
- Perform 1.5mm Coronal and Axial MPR reformat

*** Coronal MPR: Ensure that the posterior femoral condyle appear within the first 2 – 3 slices.
*** Axial MPR: Ensure that reconstruction contains both patellar bone and cartilage.
OAI Imaging Meta-Data

- Images of 11,090 Radiographs released
- Images from 61,950 MRI acquisitions released
- Imaging meta-data is provided online:
  - information on who has which types of images at a particular visit
  - if no image, gives you the reason the image isn’t available
  - gives you a QC rating (if selected for visual QC)

<table>
<thead>
<tr>
<th>BL Meta-Data Variable (XR / MR)</th>
<th>Description</th>
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<tbody>
<tr>
<td>ID</td>
<td>Participant's ID</td>
</tr>
<tr>
<td>V00XRCOMP or V00MRCOMP</td>
<td>Was exam completed &amp; available?</td>
</tr>
<tr>
<td>V00XNDREAS or V00MNDREAS</td>
<td>If Not Available, Reason</td>
</tr>
<tr>
<td>V00EXAMTP or V00MEXAMTP</td>
<td>Type of x-ray / MRI sequence</td>
</tr>
<tr>
<td>V00XRDATE or V00MRDATE</td>
<td>Date of exam</td>
</tr>
<tr>
<td>V00XRBARCD or V00MRBARCD</td>
<td>Unique identifier (barcode)</td>
</tr>
<tr>
<td>V00ACCEPT or V00QCRESLT</td>
<td>QC rating</td>
</tr>
</tbody>
</table>
OAI Data, Variables and Documentation

Data & Documentation

OAI has collected both clinical data from forms (questionnaires and examinations) and images from X-RAY and MRI images of joints.

FAQ - frequently asked questions

Clinical

- **Clinical data** - "Getting Started with OAI Data: Overview of Structure, Use, and Conventions", version logic, visit schedule and assessments, variable guides, formats, documentation (includes variable distributions), datasets, and dataset descriptions.

- **Search/browse** - a database of categorized variable documentation displayed longitudinally with links to statistics, comments, and annotated data collection forms.

- **Data collection forms** - annotated pdfs of the questionnaires used for collecting data, including the visit schedule and assessments.

- **Operations manuals** - pdfs of the detailed procedures for collecting data and performing examinations.

- Create a personal cart of variables of interest that can be used 1) to build a custom codebook able to be read offline, and 2) to filter downloadable datasets.

- **DataExplorer** - explore the clinical data online. Generate descriptive statistics, crosstabs, subsetting, frequency distributions and more. This tool requires acceptance of the terms of a Data Use Agreement.

- **Tutorial** - walks you through the variety of tools available for touring and comprehending the clinical data.
Search/Browse “Frequent Knee Pain” @ BL

Select “FKP (by person)” for “My Cart”
# OAI “Shopping Cart”

## Current Cart

### Case Study
Contains 7 item(s)
- **Add Items** | **Jump to Save**
- **Build Codebook** | **Get Datasets**

### Suggested labels shown with a grey background
Ascend up the family tree of form logic from your selected items. Click the ADD link to put them in your cart. They are not included in the item count until you add them.

<table>
<thead>
<tr>
<th>Label</th>
<th>Root</th>
<th>Dataset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass index (calc)</td>
<td>BMI</td>
<td>Physical exam, measurements</td>
</tr>
<tr>
<td>Age (calc, used for study eligibility)</td>
<td>AGE</td>
<td>Subject characteristics, risk factors</td>
</tr>
<tr>
<td>Gender, male or female</td>
<td>SEX</td>
<td>Enrollees</td>
</tr>
<tr>
<td>Right knee baseline radiographic OA (definite</td>
<td>RXXKO</td>
<td>Biomarkers</td>
</tr>
<tr>
<td>osteophytes, calc, used in OAI definition of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>symptomatic knee OA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left knee baseline radiographic OA (definite</td>
<td>LXXKO</td>
<td>Biomarkers</td>
</tr>
<tr>
<td>osteophytes, calc, used in OAI definition of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>symptomatic knee OA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline radiographic knee OA status by person</td>
<td>XRXKO</td>
<td>Biomarkers</td>
</tr>
<tr>
<td>(calc)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequent knee pain status by person (calc)</td>
<td>KSX</td>
<td>Joint symptoms, function</td>
</tr>
</tbody>
</table>

**Dataset(s) for cart:** Biomarkers, Enrollees, Joint symptoms, function, Physical exam, measurements, Subject characteristics, risk factors

[Osteoarthritis Initiative](https://www.oai.ucsf.edu/)
### OAI “My Codebook”

#### KSX (top)

**Label:** Frequent knee pain status per person (calc)  
**Dataset:** Joint symptoms/function [Download](#)  

**Category:** Knee symptoms  
**SubCategory:** Knee pain severity scale  

#### Main Cohort

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Screening</th>
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<tbody>
<tr>
<td>P01KSX (pdf)</td>
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</tr>
<tr>
<td>Calculated</td>
<td>yes</td>
</tr>
<tr>
<td>SAS Format Name</td>
<td>SXBPER</td>
</tr>
<tr>
<td>0: No pain either knee</td>
<td>705</td>
</tr>
<tr>
<td>1: Infreq pain 1 knee, no pain other knee</td>
<td>685</td>
</tr>
<tr>
<td>2: Infreq pain both knees</td>
<td>965</td>
</tr>
<tr>
<td>3: Freq pain 1 knee, no pain other knee</td>
<td>646</td>
</tr>
<tr>
<td>4: Freq pain 1 knee, infreq pain other knee</td>
<td>637</td>
</tr>
<tr>
<td>5: Freq pain both knees</td>
<td>1130</td>
</tr>
<tr>
<td>Missing</td>
<td>28</td>
</tr>
</tbody>
</table>

#### Comments:

<table>
<thead>
<tr>
<th>Var Name</th>
<th>Visit</th>
<th>Comment Title</th>
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<tbody>
<tr>
<td>P01KSX</td>
<td>P01</td>
<td>KSX</td>
</tr>
</tbody>
</table>

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**Osteoarthritis Initiative**
Baseline Demographics:

- Knee Pain Status (KSX) vs Radiographic OA (XRKAO)
- Only in elderly people who aren’t overweight
### Data Explorer Results (Simplified)

#### Table of P01KSX by P01XRKOAA

<table>
<thead>
<tr>
<th>P01KSX</th>
<th>P01XRKOAA</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0: Neither</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1: Right knee only</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2: Left knee only</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>3: Both knees</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>3</td>
</tr>
<tr>
<td>M: Missing</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0: No pain either knee</td>
<td>77</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>124</td>
<td></td>
</tr>
<tr>
<td>1: Infreq pain 1 knee, no pain other knee</td>
<td>52</td>
<td>16</td>
</tr>
<tr>
<td>2: Infreq pain both knees</td>
<td>68</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>3: Freq pain 1 knee, no pain other knee</td>
<td>36</td>
<td>13</td>
</tr>
<tr>
<td>4: Freq pain 1 knee, infreq pain other knee</td>
<td>24</td>
<td>11</td>
</tr>
<tr>
<td>5: Freq pain both knees</td>
<td>33</td>
<td>11</td>
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<tr>
<td></td>
<td>53</td>
<td>167</td>
</tr>
<tr>
<td></td>
<td>584</td>
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</tbody>
</table>
OAI - Matching Clinical Data to Images

- Use “Search and Browse” to identify variables
  - Variable Guide is an off-line alternative
- Add variables to your “Cart”
- Download relevant datasets
  - always make sure you have current ENROLLEES dataset
- Use datasets to find a subset of participants/knees that fit your inclusion/exclusion criteria
  - can use “Data Explorer” to determine approximate #s who match
  - cannot analyze whether particular ppt has particular images
- Download imaging meta-data:
  - merge with clinical/demographic data
  - find who has particular types of images
  - find the “barcodes” (UIDs) and hence folders on disks
  - find QC ratings (or reasons not done)
OAI Images Case Study

- Want to select based on baseline criteria:
  - Gender, Enrollees dataset
  - Body Mass Index, PhysExam00 dataset
  - Age at Enrollment, SubjectChar00 dataset
  - Radiographic Knee OA, Biomarkers00 dataset
  - Frequent knee pain, JointSx00 dataset

- Need to merge based on ID:
  - Remember imaging meta-data is multiple records per participant
  - Enrollees dataset is “master” of who is in study
  - Can merge easily in SAS
  - Import ASCII into database and use “left joins” on ID

- To find relevant variable names/values:
  - Use “Search/Browse” online
  - or Variable Guides offline
OAI Images Case Study

- Choose based on baseline criteria:
  - Female Gender (P02SEX = 2)
  - 22.5 Body Mass Index (P01BMI = 22.5)
  - No Radiographic Knee OA (P01XRKO A = 0)
  - Frequent pain in at least one knee (P01KSX > 2)
  - Older than 60 at Enrollment (V00AGE > 60)

- Gives the following 4 participants:

<table>
<thead>
<tr>
<th>ID</th>
<th>P02SEX</th>
<th>P01BMI</th>
<th>V00AGE</th>
<th>P01KSX</th>
<th>P01XRKO A</th>
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<tbody>
<tr>
<td>9665472</td>
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<td>22.5</td>
<td>68</td>
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## OAI Baseline Imaging Meta-Data

**Example ID=9665472**

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<th>V00XRCOMP</th>
<th>V00XRSIDE</th>
<th>V00XNDREAS</th>
<th>V00XRDATE</th>
<th>V00XRBARCD</th>
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<td>3</td>
<td></td>
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<td>016600223205</td>
<td>AP Pelvis</td>
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</table>

<table>
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<th>V00MNDREAS</th>
<th>V00MRDATE</th>
<th>V00MRSIDE</th>
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<th>V00MEXAMTP</th>
<th>V00OCRESLT</th>
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<td>L AXIAL MPR</td>
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OAI Baseline Imaging Meta-Data

- **XRAY00** shows that this person has (V00XRCOMP=1)
  - Fixed flexion knee radiograph
  - Right Hand radiograph
  - AP Pelvis radiograph
  - Each radiograph has a date and a unique barcode (V00XRBARCD)

- **MRI00** shows Left Knee MRI sequences not available:
  - V00MRCOMP=0 for all Left Knee sequences
  - 2 sequences were not expected (V00MNDREAS=8)
    ➤ “MRI Sequence Not Expected” (L knee has short protocol)
  - 5 sequences were not done (V00MNDREAS=2)
    ➤ “MRI Stopped at Participant request”

- **MRI00** shows that this person DID have R knee MRI:
  - V00MRCOMP=1 for all Right Knee sequences
  - There is a date for each sequence
  - There is a unique barcode (V00MRBARCD) for each sequence
OAI Images Case Study

- Choose based on baseline criteria:
  - Female Gender ($P02SEX = 2$)
  - 22.5 Body Mass Index ($P01BMI = 22.5$)
  - No Radiographic Knee OA ($P01XRKOA = 0$)
  - Frequent pain in at least one knee ($P01KSX > 2$)
  - Older than 60 at Enrollment ($V00AGE > 60$)

- Include requirement that there is:
  - Baseline fixed flexion radiograph
  - Baseline R knee Sagittal DESS

- Find 2 participants who have images that match:

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run;

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run;

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run;

proc print;
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OAI Biomarkers Datasets

- Clinic Baseline X-ray readings (for whole cohort)
- Central paired knee x-ray readings (Group B, 160ppts):
  - OARSI gradings and K&L Grades at baseline and 12-months
  - identified by V00IMAGESB=1 / V01IMAGESB=1
  - images are in 0.B.2 and 1.B.2 (are also a subset of 0.C.1 and 1.C.1)
- Biomarkers dataset will grow:
  - Joint Space Width measurements (Group B)
  - MRI Readings and/or Cartilage Volumes (Group B)
  - Further analyses of larger groups of participants
  - Any results/readings given back to OAI (eg: Hip-Knee-Ankle angle)
- Matching Paired Readings to Clinical/Demographics:
  - Images analyzed identified by barcode
  - V00XRBCODE / V01XRBCODE in knee x-ray readings
  - Matches to barcode variables in XRAY00 / XRAY01 meta-data
Summary

- Use clinical, demographic, biomarker datasets to select participants or knees
- “Search & Browse” or Variable Guides to explore
- “My Cart”, “My Codebook” to customize
- Download data available as SAS or ASCII
- Imaging meta-data to find who has required images
  - you may only require specific image types
- Request images from Coordinating Center
  - small subsets on UCSF provided hard drives
  - larger releases – requestor provides hard drive
- Future Releases
  - additional visits, “2nd half of cohort”
  - images for specific lists of participants
In Future

- **Further Releases:**
  - additional visits for “1st half” of cohort (Group C)
  - images for “2nd half” of cohort (Group E)
  - thigh MRIs

- **Food for thought:**
  - Images for specific lists of participants
    - selection based on downloadable datasets
    - would be subsets of existing releases
    - about ½ GB per participant per visit
    - requestor keeps track of images already provided
  - Online access to downloadable images
    - about 1TB of data per visit for “1st half” of cohort (Group C)
    - can compress, but only to about 75% of original size