**Document Overview**

This document is meant to provide an overview of using the OGO Python scripts for performing opportunistic CT screening. The opportunistic screening pipeline includes image segmentation, internal density calibration, bone mineral density (BMD) analysis, finite element (FE) model generation, FE model post-processing, and results tabulation. Each of these steps will be discussed below and how to implement the analyses. This bone analysis pipeline is set up to analyze abdominal CT scans, which includes the right proximal femur, left proximal femur, right pelvis, left pelvis, sacrum, L5 vertebra, L4 vertebra, L3 vertebra, L2 vertebra, and L1 vertebra. All CT scan images can be performed using DICOM or NIFTI file formats. For purposes here, we use the NIFTI file format, as it is a single image file, rather than a directory of multiple files. All example analyses use images from the OGO\_Example\_Data directory included with the analysis scripts.

Included in the OGO Python scripts are some additional scripts for performing QCT phantom-based density calibration, where different scripts are for different calibration phantoms. These details are at the end of this document.

**Relevant File Naming in Example Images**

*OGO\_Abdomen\_Example.nii* – This is an example abdominal CT scan, converted to NIFTI format from a DICOM image sequence.

*OGO\_Abdomen\_Example\_PERI\_CORR.nii* – This is the segmentation MASK image, where each different label is a specific bone and a value of 0 is the background.

*OGO\_Abdomen\_Example\_IC\_MASK.nii* – This is the internal density calibration MASK image, where each different label is a specific region-of-interest for the calibration and a value of 0 is the background.

**Step 1: Image segmentation to identify bone of interest**

Image segmentation can be performed using a number of different tools. For purposes here, we use manual image segmentation in ITK-SNAP. The main necessary component is to stay consistent with the proper bone labels (see included labels text file: ‘Bone\_ITKSNAP\_Labels.txt’). These bone labels are used for all analyses when applying the MASK image.

|  |  |
| --- | --- |
| **Label Value** | **Description** |
| 0 | Clear Label |
| 1 | Femur Right |
| 2 | Femur Left |
| 3 | Pelvis Right |
| 4 | Pelvis Left |
| 5 | Sacrum |
| 6 | L5 |
| 7 | L4 |
| 8 | L3 |
| 9 | L2 |
| 10 | L1 |
| 11 | Background |
| 255 | Label 255 |

A picture containing monitor, screen, computer, sitting

Description automatically generatedAbove is an example screenshot of ITK-SNAP in which the right proximal femur, left proximal femur, and L4 vertebra are segmented (using the example datasets). The output of the image segmentation is provided in NIFTI file format. Output: *OGO\_Abdomen\_Example\_PERI\_CORR.nii*

**Step 2: Internal density calibration**

The internal density calibration step uses the OGO script *ogo\_internal\_calibration.py*. This script reads in the base image and the internal density calibration MASK image. The internal density calibration MASK image (*OGO\_Abdomen\_Example\_IC\_MASK.nii*) is currently generated in ITK-SNAP by manual segmentation, using the provided label files (*Internal-Calibration\_ITKSNAP\_Labels.txt*).

|  |  |
| --- | --- |
| **Label Value** | **Description** |
| 0 | Clear label |
| 1 | Adipose |
| 2 | Air |
| 3 | Blood |
| 4 | Cortical Bone |
| 5 | Skeletal Muscle |

A screen shot of a computer

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Above is an example screenshot of the region definitions using ITK-SNAP. From ITK-SNAP, save the calibration mask as *\*\_IC\_MASK.nii* (i.e., *OGO\_Abdomen\_Example\_IC\_MASK.nii*).

The internal calibration script is run from a terminal. Activate your analysis environment and change to the OGO script directory. To run the internal calibration, use the command prompt as follows:

$ python ogo\_internal\_calibration PATH/TO/OGO\_Example\_Data/OGO\_Abdomen\_Example.nii PATH/TO/OGO\_Example\_Data/OGO\_Abdomen\_Example\_IC\_MASK.nii

OUTPUTS:

A screenshot of a cell phone

Description automatically generated1. *\*\_IntCalibParameters.txt* – Text file containing all of the internal density calibration parameters, as seen below.

2.*\*\_IC\_K2HPO4.nii* – K2HPO4 bone equivalent density calibrated image in NIFTI format. This file is used for BMD analysis and FE model generation.

**Step 3: Integral BMD analysis for a specific bone**

All integral BMD analyses are performed using the density calibrated image (*OGO\_Abdomen\_Example\_IC\_K2HPO4.nii)* and the bone mask image (*OGO\_Abdomen\_Example\_PERI\_CORR.nii)*. These analyses are performed using the *ogo\_bmd\_analysis.py* script in the command prompt. Example command lines are:

1. Integral BMD analysis of right femur:

$ python ogo\_bmd\_analysis.py /Path/to/OGO\_Example\_Data/OGO\_Abdomen\_Example\_IC\_K2HPO4.nii /Path/To/OGO\_Example\_Data/OGO\_Abdomen\_Example\_PERI\_CORR.nii --mask\_threshold 1

2. Integral BMD analysis of left femur:

$ python ogo\_bmd\_analysis.py /Path/to/OGO\_Example\_Data/OGO\_Abdomen\_Example\_IC\_K2HPO4.nii /Path/To/OGO\_Example\_Data/OGO\_Abdomen\_Example\_PERI\_CORR.nii --mask\_threshold 2

3. Integral BMD analysis of L4 vertebra:

$ python ogo\_bmd\_analysis.py /Path/to/OGO\_Example\_Data/OGO\_Abdomen\_Example\_IC\_K2HPO4.nii /Path/To/OGO\_Example\_Data/OGO\_Abdomen\_Example\_PERI\_CORR.nii --mask\_threshold 7

OUTPUT:

1. \*\_RT\_FEMUR\_BMD\_RESULTS.txt; \*\_LT\_FEMUR\_BMD\_RESULTS.txt; OR \*\_L4\_BMD\_RESULTS.txt – Text file containing the integral BMD analysis for the specific bone, as shown below.

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**Step 4: FE model generation**

The provided OGO scripts will generate an FE model in either a sideways fall on the hip (for proximal femurs) or a vertebral body compression (for lumbar vertebra). The scripts expect a K2HPO4 density image, so if using a HA density image some conversion equations will require adjustment to properly generate the FE model. For the sideways fall models, PMMA caps are added to the femoral head and greater trochanter. For the vertebral compression models, PMMA caps are added to the inferior and superior vertebral body faces.

Sideways fall models are generated using the *ogo\_sideways\_fall\_fe.py* script, and vertebral compression models are generated using the *ogo\_l4\_compression\_fe.py* script. There are multiple optional arguments for each model as well. Example command lines are:

1. Right proximal femur sideways fall model:

$ python ogo\_sideways\_fall\_fe.py /Path/To/OGO\_Example\_Data/OGO\_Abdomen\_Example\_IC\_K2HPO4.nii /Path/To/OGO\_Example\_Data/OGO\_Abdomen\_Example\_PERI\_CORR.nii --mask\_threshold 1 --femur\_side 2

OUTPUT: *\*\_RT\_FEMUR\_SF.n88model*A screenshot of a computer

Description automatically generated

2. Left proximal femur sideways fall model:

$ python ogo\_sideways\_fall\_fe.py /Path/To/OGO\_Example\_Data/OGO\_Abdomen\_Example\_IC\_K2HPO4.nii /Path/To/OGO\_Example\_Data/OGO\_Abdomen\_Example\_PERI\_CORR.nii --mask\_threshold 2 --femur\_side 1

OUTPUT: *\*\_LT\_FEMUR\_SF.n88model*

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Description automatically generated

3. L4 vertebral compression model

$ python ogo\_l4\_compression\_fe.py /Path/To/OGO\_Example\_Data/OGO\_Abdomen\_Example\_IC\_K2HPO4.nii /Path/To/OGO\_Example\_Data/OGO\_Abdomen\_Example\_PERI\_CORR.nii --mask\_threshold 7

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Description automatically generatedOUTPUT: *\* \_L4\_FE.n88model*

**Step 5: Solve FE models**

All FE models can be solved in FAIM (> v8.0) using standard solving methods.

**Step 6: FE model post processing**

The Pistoia criterion failure load script from FAIM can be used to estimate the FE model failure load. A critical strain value should be 0.011 and a critical volume value of 7.0% should be used to estimate the failure load.

**Step 7:** **Tabulate the BMD and FE Pistoia failure load values in the directory**

Typically, multiple models are all solved at one time in large batches. The following scripts will tabulate either the integral BMD or FE estimate failure loads of all the models in the specified directory.

1. Tabulate all integral BMD values for the right proximal femur:

$ python ogo\_bmd\_tabulate.py --bone 1 /Path/To/Results/Directory

2. Tabulate all integral BMD values for the left proximal femur:

$ python ogo\_bmd\_tabulate.py --bone 2 /Path/To/Results/Directory

3. Tabulate all integral BMD values for the L4 vertebra:

$ python ogo\_bmd\_tabulate.py --bone 4 /Path/To/Results/Directory

4. Tabulate all FE estimate failure loads for the right proximal femur:

$ python ogo\_fe\_pistoia\_tabulate.py --model 1 /Path/To/Results/Directory

5. Tabulate all FE estimate failure loads for the left proximal femur:

$ python ogo\_fe\_pistoia\_tabulate.py --model 3 /Path/To/Results/Directory

6. Tabulate all FE estimated failure loads for the L4 vertebra:

$ python ogo\_fe\_pistoia\_tabulate.py --model 6 /Path/To/Results/Directory

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Description automatically generatedOUTPUT: *RT\_FEMUR\_BMD\_Results.txt; LT\_FEMUR\_BMD\_Results.txt;* OR *L4\_SPINE\_BMD\_Results.txt*

**Additional QCT density calibration methods**

Density calibration phantoms are the gold standard to perform QCT analysis but are generally limited to a research-based setting. Additional scripts are included to create a density calibrated image for some additional calibration phantoms including:

* Mindways Model 3 CT phantom
* Mindways Model 3 CT phantom asynchronous calibration
* B-MAS200 phantom

Adding other density calibration phantoms is relatively trivial and can be done by modifying one of these mentioned scripts.

**1. Mindways Model 3 CT phantom**

The calibration mask image is generated using ITK-SNAP and the provided labels file (*Mindways\_Model3\_Phantom-Calibration\_ITKSNAP\_Labels.txt*). Place regions on the calibration rods as depicted below and save file as *\*\_PC\_MASK.nii*.

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Generate the density calibrated image using the script *ogo\_mindways\_model3\_phantom\_calibration.py*.

$ python ogo\_mindways\_model3\_phantom\_calibration.py /Path/To/OGO\_Example\_Data/OGO\_Abdomen\_Example.nii /Path/To/OGO\_Example\_Data/OGO\_Abdomen\_Example\_PC\_MASK.nii

OUTPUTS:

1. *\*\_PhanCalibParameters.txt* – Text file containing the density calibration parameters

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Description automatically generated

2. *\* \_PC\_K2HPO4.nii* – Image file of the K2HPO4 density calibrated image.

All other analyses are the same as previously stated.

**2. Mindways Model 3 Asynchronous calibration**

The calibration mask image is generated using ITK-SNAP and the provided labels file (*Mindways\_Model3\_Phantom-Calibration\_ITKSNAP\_Labels.txt*). Place regions on the calibration rods as depicted below and save file as *\*\_AC\_MASK.nii*.

Generate the density calibrated image using the script *ogo\_mindways\_model3\_asynchronous\_calibration.py*.

$ python ogo\_mindways\_model3\_asynchronous\_calibration.py /Path/To/CT\_Scan.nii /Path/To/AsynchronousScan.nii /Path/To/AsynchronousScan\_AC\_MASK.nii

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Description automatically generatedOUTPUTS:

1. *\*\_AsyncCalibParameters.txt* – Text file containing the asynchronous calibration information

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Description automatically generated

2. \*\_AC\_K2HPO4.nii - Image file of the K2HPO4 density calibrated image.