Acquisition of Synchrotron Radiation micro-CT images for the investigation of bone micro-cracks

Release 1.10

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May 4, 2011

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Abstract

This paper describes two MicroCT datasets that Creatis has made publicly available to the imaging community. These datasets were acquired using Synchrotron Radiation, have resolutions of 1.4 microns, and size in the range of six Gigabytes. The provided datasets were previously included in a study to develop new 3D imaging methods to analyze physiological microcracks in human trabecular bone at the micrometric scale.

This paper is a pure data contribution. The datasets described here have been made available in the public MIDAS database. Here we describe the content of the files to make easier for others to use this data as input for their own research work. This adheres to the fundamental principle that scientific publications must facilitate **reproducibility** of the reported results.

Contents

1 Introduction

The concept of bone quality is increasingly considered to be an important factor to explain bone fragility in addition to bone mass [9]. Bone quality is defined as a combination of factors that determine how well the skeleton can resist fracture [6]. Among others, such properties include bone microarchitecture, mineralization, bone turnover, the quality of collagen, lacuno-canalicular system and microscopic damage.

Microscopic damage accumulates in bone tissue due to physiological loading and mechanical stress occurring in daily life. Microdamage accumulation has been shown to play a major role in the increased bone fragility associated with aging and osteoporosis [2]. It has been identified in the form of microcracks, whose size, morphology and localization are strongly related to the mechanical constraints applied to the bone [3].

Although many works aiming to study the microdamaging process have been conducted in animal models, recently data have been reported on human bone samples [3]. Moreover, studies on human trabecular bone allow analysis of microarchitecture simultaneously with bone-damaging processes, since the localization, orientation and shape of trabeculae strongly affect the characteristics and nature of this damage [2].

Ideally, bone microcracks should be evaluated in three dimensions with isotropic and sufficiently high spatial resolution. While, contrast agents are being developed for 3D observations with standard micro-CT devices [5], the spatial resolution of these images and the capacity of contrast agents to specifically bind to microcracks are still not sufficient to provide relevant 3D data on microcrack morphology. On the other hand, Synchrotron Radiation Micro-Computerized Tomography (SR μ-CT) possesses significant advantages over standard micro-CT. A synchrotron source provides a high-flux, high- intensity and monochromatic X-ray beam, allowing acquisition of quantitative high-resolution 3D images with a high signal-to-noise ration [8]. SR μ-CT has already been used to study trabecular bone microarchitecture, remodeling and local mineralization [7].

The datasets here introduced make part of a study to develop new 3D imaging methods based on SR μ-CT images to analyze physiological microcracks in human trabecular bone at the micrometric scale. The precision of SR μ-CT in combination with image processing techniques allows to study the morphology of microcracks. For further details on the developed methodology, we refer the interested reader to the publication from Larrue *et al* [4].

2 Acquisition Process

2.1 Sample Preparation

Femoral head trabecular bone compartments were obtained from patients undergoing total hip replacement for osteoarthritis on a study population consisting of an equal number of male and female subjects between

Table 1: Summary of dataset 1 acquisition parameters

Parameter	Value
Monochromator	Multilayered
Energy	24 keV
Pixel size	1.4 μm
Scan time	26 minutes
Count time	0.5 s/projection
Number of projections	1999 over 360°
Optic	magnification 20
Scintillator	YAG Ce 25 μm
Detector	2048 $\times$ 2048 CCD FReLoN HD2k
Size of projections	2048 $\times$ 1440
Number of reconstructed subvolumes	6
Subvolume size	2048 $\times$ 2048 $\times$ 256 (5 subvolumes)
	2048 $\times$ 2048 $\times$ 140 (1 subvolume)

the ages of 77 and 80 years old. Signed informed consent was obtained from all patients. 20 mm thick slices of femoral heads were cut in the traverse plane by surgeons immediately after surgery.

Sample preparation was performed following the guidelines from [1]. Cylinders, 10 mm diameter, were drilled with a diamond threphine from the original slices and cut to a height of 5 mm using a Leica SP1600 Saw microtome. During the cutting procedure, the bone was irrigated with sterile 0.9% sodium chloride at 4°C to limit the-generated damage, remove bone chips, and prevent drying. Next, bone cores were embedded in methylmethacrylate. Finally, pseudo-parallelepiped samples (5x5x10mm) were prepared for SR μ-CT imaging.

2.2 Imaging

Images were acquired on the SR μ-CT setup developed on beamline ID19 at the European Synchrotron Radiation Facility (ESRF), Grenoble, France [10]. Samples were attached on stands adapted to the rotation stage and were placed as close as possible to the camera to limit phase contrast. Crystal monochromators were used to select a single X-ray energy, set to 24 keV. The X-ray beam transmitted through the sample was acquired on a detector made up of a YaG scintillator screen, an optical lens and a 2048 $\times$ 2048 CCD FReLoN camera. Due to limited beam height at the selected energy, only a 2048 $\times$ 1440 ROI was used on the detector. Since pixel size was set to 1.4 μm, the field of view in the sample was of 2.8 $\times$ 2.8 $\times$ 2.0 mm^3. The sample was positioned to allow imaging of its central core, thus excluding imaging of microdamage in the sides of the specimen.

For each sample, 1999 radiographs were taken at different angles. A Filtered Back Projection algorithm was used to obtain a reconstructed 3D volume. Due to the large size of the reconstructed data, the resulting 3D volume was partitioned into 6 different subvolumes. Table 1 presents the main parameter values used in the image acquisition protocol. Further details on the complete protocol can be found in [4].

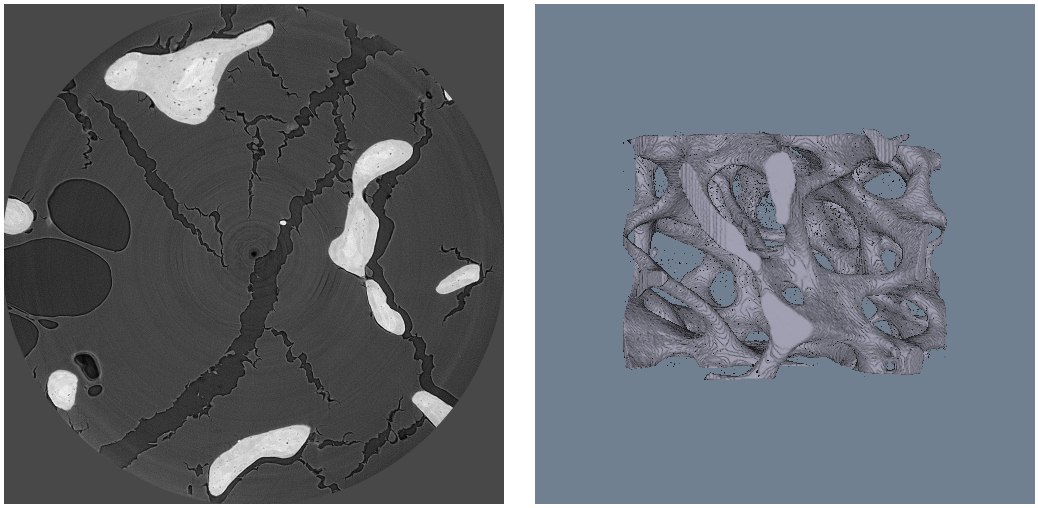

Figure 1: Left. Middle slice from the original float image. Right. Volume rendering of the dataset.

3 Dataset Description and Location

We have contributed to the MIDAS Database with two datasets (denoted as Dataset 1 and 2) that have been used for bone microcrack analysis. In the following, we give a short description of each dataset and we provide its location in the MIDAS Database.

3.1 Dataset 1

Dataset 1 represents the original data obtained after tomographic reconstruction using the acquisition parameters described in Table 1. Its size is around 22 Gb. This dataset is named

- hunc34_14_a_float.mhd (MD5 key: 99e79bce9fa42cf114fa7d2c5b8f2f89).
- hunc34_14_a_float.raw (MD5 key: 37eb40f1b587af0023eb1bf5535b5f12).

Figure 1 presents an example of a slice extracted from the original image and a volume rendering of the complete dataset.

The images in 1 were generated respectively with the commands

```
./ImageReadRegionOfInterestWrite hunc34_14_a.mhd  ReadWriteTest_hunc34_14_a_Slice.png 800 0 0
```

```
ImageSurfaceDisplay hunc34_14_a.mhd 128 -Screenshot Rendering3D_hunc34_14_a.png
```

3.2 Dataset 2

Due to the large size of the originally reconstructed volumes, datasets are typically rescaled from floating point accuracy (32 bits per pixel) to an unsigned char pixel type (8 bits per pixel). Such rescaling reduces the image size to approximately 6 Gb. Dataset 2 is the rescaled version of the dataset introduced in Section 3.1 This dataset is named

- hunc34_14_a.mhd (MD5 key: 90fad9dcd3b376933ebf71e751755074).
- hunc34_14_a.raw (MD5 key: 079f4b9022045db8eae5d9ca54e66db2).

3.3 Datasets Location

The datasets are in the MIDAS Database
http://www.insight-journal.org/midas/community/view/33
and, more particularly, under the Creatis collection: http://hdl.handle.net/1926/1750
The datasets can be directly accessed through the following address:
http://insight-journal.org/midas/item/view/2486

4 Licensing

Along the spirit of contributing to the progress of the field, Creatis is generously making these dataset publicly available under the terms of the Open Data License. http://www.opendatacommons.org/licenses/by/

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4.1 Attribution

In order to satisfy the Attribution requirement of the license, when using these data, please acknowledge Creatis using the following text

```
This data was provided by Team 7 (responsible F. Peyrin) at Creatis laboratory.
The data was acquired with funds from the ESRF long term project entitled
'Synchrotron radiation micro-CT for the investigation of bone quality'.
```

5 Conclusions

This paper has described two datasets that have been made publicly available through the MIDAS Database. The first dataset (22 Gb volume) is directly provided by the reconstruction program, while the second (6 Gb volume) is the obtained result after rescaling to 8 bits. These datasets were previously used in the analysis of microcrack morphology through 3D image processing techniques. We refer the interested reader to the previous work [4] on microcrack detection for further details.

6 Contact

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References

[1] CM Davies, DB Jones, MJ Stoddart, and Archer CW Richards RG. Koller K, Smith E. Mechanically loaded ex vivo bone culture system 'Zetos': systems and culture preparation. *European Cells & Materials*, 11:57–75, 2006. 2.1

[2] N. L. Fazzalari, J. S. Kuliwaba, and M. R. Forwood. Cancellous bone microdamage in the proximal femur : Influence of age an osteoarthritis on damage morphology and regional distribution. *Bone*, 31:697–702, 2002. 1

[3] P. Fratzl. Bone fracture: When the cracks begin to show. *Nature Materials*, 7:610–612, 2008. 1

[4] A. Larrue, A. Rattner, Z. Peter, C. olivier, N. Laroche, L. Vico, and F. Peyrin. Synchrotron Radiation micro-CT at the micrometer scale allows analyzing the three-dimensional morphology of microcracks in human trabecular bone. *PlosOne*, page In press, 2011. 1, 2.2, 5

[5] H. Leng, X. Wang, R.D. Rossa, G.L. Niebura, and R.K. Roeder. Micro-computed tomography of fatigue microdamage in cortical bone using a barium sulfate contrast agent. *Journal of the Mechanical Behavior of Biomedical Materials*, 1(1):68–75, 2008. 1

[6] A. Licata. Bone density vs bone quality: What's a clinician to do? *Cleveland Clinic Journal of Medicine*, 76(6):331–336, June 2009. 1

[7] S. Nuzzo, F. Peyrin, P. Cloetens, J. Baruchel, and G. Boivin. Quantification of the degree of mineralization of bone in three dimension using synchrotron radiation microtomography. *Medical Physics*, 19(11):2672–2681, 2002. 1

[8] M. Salomé, F. Peyrin, C. Odet, A.-M. Laval-Jeantet, P. Cloetens, J. Baruchel, and P. Spanne. A synchrotron radiation microtomography system for the analysis of trabecular bone samples. *Medical Physics*, 26:2194–2204, 1999. 1

[9] Ego Seeman. Bone quality: the material and structural basis of bone strength. *Journal of Bone and Mineral Metabolism*, 26(1):1–8, 2008. 1

[10] T. Weitkamp, P. Tafforeau, E. Boller, P. Cloetens, J.-P. Valade, P. Bernard, F. Peyrin, W. Ludwig, L. Helfen, and J. Baruchel. Status and evolution of the ESRF beamline ID19. In *ICXOM20: the*

20th International Congress on X-ray Optics and Microanalysis, volume 1221 of *AIP Conference Proceedings*, pages 33–38, Karlsruhe, Germany, 2010. 2.2