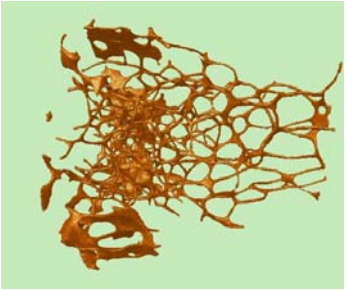
THE SKYSCAN 1172 MICROCT INTRODUCTION



Principles of operation: Briefly, the system obtains multiple x-ray "shadow" transmission images of the object from multiple angular views as the object rotates on a high-precision stage. From these shadow images, cross-section images of the object are reconstructed using a modified Feldkamp cone-beam algorithm, creating a complete 3D representation of internal microstructure and density over an investigator-selected horizontal region in the transmission images. Micro CT has revolutionized the field of tissue biology and materials science because it offers the ability to obtain in-depth quantitative data on the 3D structure of bone, teeth, cartilage, lung, microvasculature and other soft tissues, as well as composite materials, fuel cells, rocks, and more. MicroCT has become the gold standard for the assessment of microarchitecture and composition of structures in general.

It really represents 3D microscopy, where very fine scale internal structure of objects is imaged non-destructively. No sample preparation, no thin slicing - a single scan will image your sample's complete internal 3D structure at high resolution, plus you get your intact sample back at the end!

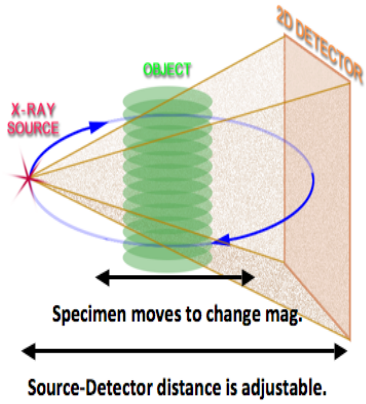
General description of instrument:

The Skyscan 1172, 50mm FOV (image field width) is a desktop *ex vivo* microCT specimen scanner. This instrument has a fully distortion-corrected 11Mp X-ray camera that is a 12-bit cooled CCD fiber-optically camera coupled to scintillator. The X-ray source is 20-100kV, 10W, with a <5µm spot size. The detail detectability is 1µm at highest resolution to 25µm. Importantly, the Skyscan 1172 has an innovative dynamically variable acquisition geometry that provides the shortest scan times possible at any magnification (adaptive geometry features explained more fully below). Cross-section images are generated in a wide range of formats up to 8000 x 8000 pixels. The maximum object size is 50mm in diameter or height. Reconstruction can be performed using either a single PC or using the cluster of 4-PCs in the core facility to enhance post-scan reconstruction times. Importantly, the Skyscan 1172 has PC windows based software for 2D/3D image analysis, bone morphometry and realistic visualization, making it accessible for use on investigators' home and laboratory computers.

Specific features of the Skyscan 1172, 50mm FOV

a. ADAPTABLE GEOMETRY GIVING VARIABLE RESOLUTION CHOICES AND VARIABLE SPECIMEN PLACEMENT FROM SOURCE: The Skyscan 1172 has automated-changeable specimen placement and variable specimen magnification for scanning (*adaptive geometry*). This state of the art architecture, in which both the sample stage and the x-ray camera (the detector), can be moved either closer or further away from the source, as needed, allows us to meet higher and lower magnification (resolution) and size needs of the investigator and specimen, respectively. This feature allows for high-performance capabilities for the bone biology and materials science users, and users investigating microvasculature, in our research community at Temple University as it has a nominal resolution (pixel size) of lower than 1 µm. However, this flexible geometry design also allows a user to reduce the performance of the instrument to 25 µm pixel size (it has 1-25 µm variable pixel sizes capacity).

Skyscan Object (specimen) rotates between a static x-ray source and the detector.



b. HIGH SAMPLE THROUGHPUT DURING RECONSTRUCTION. This design/feature also allows for faster reconstruction of the scans than many instruments as we have a cluster of 4 PC linked into the system.

c. GOOD MAXIMUM SIZE CAPACITY. The 1172 model has an 11 Megapixel X-ray camera to allow maximum scanning versatility, with an image field width of 50 mm (in dual image camera shift modes). Taller samples can be scanned using oversized scanning mode since the software has the ability to merge images (''stitching"). This feature also allows for automatic batch scanning of a column of smaller samples. We also have an X-Y stage option that allows for 5mm travel in the X-Y direction to improve centering of the object in the field of view. These options are key for our users who will have specimens of varied shapes and sizes.

d. VARIABLE FILTER CHOICES. We currently have two filter choices (2 built-in filters that can be placed by software commands into 3 positions) that allow for scanning of high density tissues (e.g. bones, which need filters to correct beam hardening artifact) or low density tissues (e.g. lung, which need a thin filter or no filter at all) as needed.

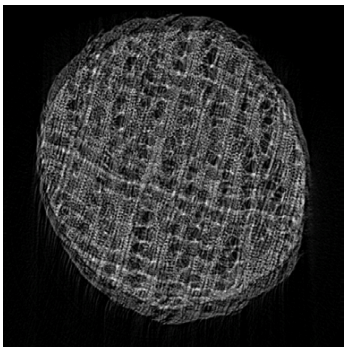
e. PC BASED SOFTWARE WITH SITE-LICENSE FOR USE IN HOME LAB COMPUTERS AND FREE UPDATES AT NO COST. Post scan analysis software runs on PCs running Windows. We have a university site license so that all users can install the software on their own home lab computers for post scan analyses.

<u>Specifications for the Skyscan 1172</u>

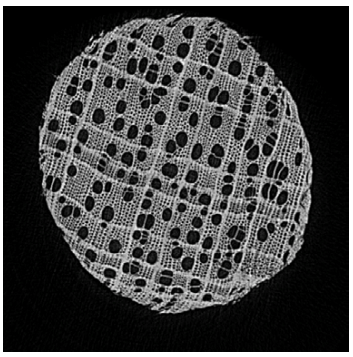
Detail detectability:	<1 μm
Low contrast resolution (10% MTF):	5 μm
Pixel size at maximum magnification:	0.7 μm to 25 μm Continuously variable from <1μm to 25 μm. Gives flexibility to choose based on tissues and user needs.
X-ray source:	Sealed microfocus X-ray tube, air cooled, >10,000h lifetime; Spot size <5μm @ 4W, 20-100klV, 0-250 μA (10W max). Variable X-ray energy range from 20-100kV without a reduction in spot size, which improves contrast for low-density samples (lung, liver, etc). Both camera and sample can be moved closer to source to achieve this variation or alteration in contrast, as needed for the density of the specimen.
X-ray detector (camera):	11 Megapixel (4000X2300) 12-bit digital CCD-camera (50mm field of view). Can be moved closer to specimen to improve resolution.
Corrections	Thermal drift corrections – a source spot correction

Example of images with thermal drift correct:

Uncorrected



Corrected



The scan of a toothpick in the Skyscan-1172, voxel size 0.5 um, showing movement artifacts and the effects of applying the correction. The scan was over 360 degrees so the movement artifacts, from source spot thermal movement, manifest as image doubling.

Radiation Safety:	<1 mSv/h at any point of the instrument surface. Low x-ray dose exposure - to the specimen only. Source completed shielded, protecting the user.
Specimen Holder:	Metal base with flexible construction using Styrofoam and Parafilm to allow for use of varied shaped/sized specimens. This allows us to scan up to 25 mm tall specimens in normal mode and up to 50 mm in offset mode.
Filters:	Automatic filter changer (3 positions) for beam-hardening compensation and multi-energy scanning. Bracket for additional filters that can be inserted manually. Has 5 filters: 0.5mm AI, 1.0mm AI, 0.5mm AI/40 μm CU, 0.25 mm CU. These adaptive filter choices reduce beam-hardening artifact when scanning bone, but allows for removal when soft tissues must be scanned.
Maximum Object Size:	25 mm in diameter for standard scan 50 mm in diameter for scan with camera offset Taller samples can be scanned by stitching (oversized scanning mode)
Computer for system control:	Workstation with Dual Intel Xeon 3.6 GHz, 4GB RAM; internal DVD-Writer, 250 GB HDD, Digital Frame Grabber for 10mP X-ray camera, Analog Frame Grabber for color visual camera on the object stage, Microsoft Windows-XP Professional.
Reconstruction:	Cone-beam volumetric (Feldkamp algorithm)
Reconstruction Time:	6.8 sec per cross-section 1K x1K pixels (0.9^o steps). Multi-PC Cluster option is requested for faster time.
Data Management:	Throughput for microCT imaging depends on scan time, reconstruction time and post-scan processing, if that work has to be performed on the same system. Increasing the resolution of scans can potentially lengthen this time. Since the Skyscan software allows multi-tasking (see below) the average reconstruction time of Skyscan is 15 min to 1.5 hour.
Multi-Tasking reconstruction:	On-line reconstruction – reconstructions can be conducted simultaneously while scans are conducted. Software also allows image reconstruction on a cluster of PCs, which speeds reconstruction considerable (see below).
PC Cluster for reconstruction:	A cluster of 4 dual processor computers with Dual Quad Core Processors with 2 GB of RAM are networked to one host computer.
Size of desktop case:	1250 x 690 x 360 mm
Weight:	240 kg (550 lbs) including host computer
Operating conditions:	100-130V AC, 4A, -10^oC to $+50^oC$

Image Acquisition/Management:	Image quality is artifact free with appropriate beam-hardening corrections for correct reconstructions and a thermal correction feature to reduce shift over time. Operation and scanning is straightforward and user-friendly. The internal analog video camera is most useful for visualization of the specimen, source and camera while the case is closed. One can positively ensure that the specimen is oriented correctly and does not touch the source or the camera during its rotation (useful for scanning large objects, e.g. scapula), thus allowing for safe positioning with maximum resolution for any specimen. Can capture 2400 slices in a single scan with no stitching necessary. Operates in batch mode: i.e. automated image acquisition and reconstruction, which leads to significant savings in personnel time. 24-hr/7 day operation (can be unattended for specimen scanning).
Image/Data Archival:	Files are saved to a regular PC. Can be transferred to laboratory PC's for post-processing analysis. Terabyte drives are recommended for archiving of files as they are quite large.
Image Output:	"bmp" and "tiff" files that can be opened by Macs and PCs in order to visualize individual scans. 3D models can be saved in a variety of outputs including "avi" files that allow 3D models to be opened on Macs and PCs.
Image Analysis Software Tools:	Ease of use, great access. Complete image analysis and visualization tools, data and image management tools. Post processing software = *CTAn, CTVol, CTVox, Data Viewer*; runs on high memory capacity PCs. Not limited to the system computer. *Site license is part of the package. Each investigator can have a copy of each software package for their laboratory, enhancing investigator efficiency. Free updates of the software are available for the life of the instrument.
Morphometry Software:	*CTAn (CT analyzer), CTVol (3D animation), CTVox (for volume rendering)* runs on PCs. Irregular regions of interest (ROIs) are allowed. Users are not limited to pre-defined ROIs. Users can draw these ROIs themselves, which is critical for analyzing trabecular bone architecture in small samples, e.g. mouse bones. Operates in batch mode: i.e. automated analysis of multiple chosen image files which leads to significant savings in personnel time. 24h/7 day operation scan and analysis can be performed unattended. Features include, but are not limited to: zoom, distance, contouring, automatic/manual gray scale adjustments, intensity based thresholding, region based segmentation (geometric and/or conforming ROIs, cut/paste options, morphing, density

measurements (Density, Hounsfield units, Linear Attenuation Coefficient), masking, histograms. Software can be easily adapted to 2D rod and plate models, and/or 3D morphometric analysis.

Data Output: *Two types of standardized output methods*: Standard materials science measures, and standard set of morphometric measures for bone.

3D Imaging Rendering and Visualization: *CTVol (CTvolume)* allows automatic or manual 3D rendering, animation, transparency, multiple color capacity, and making movies. *CT Vox* allows for volume rendering.