# **Martinos Research Facilities**

The MGH Human MRI Core consists of eight advanced Siemens MRI systems devoted exclusively for research, along with associated support facilities including subject care environment (waiting and changing rooms), equipment for cognitive and behavioral testing and Blu-ray/DVD players for subject entertainment within each scanner Bay, Web based portal for scheduling and access to the scanners (and associated SOP’s), and newly arriving 13-C Hyperpolarizer for hyperpolarized 13-C MRI studies. As described below, each of these scanners has unique technical capabilities at or beyond the manufacturers current commercial capabilities, and all are fully accessible to our large and open community of investigators and users from throughout the world - the MGH Human MRI Core services more than 300 active users currently, making it one of the worlds largest and most actively used research dedicated MRI facilities.

**Bay 1: Siemens 3T MRI Skyra with 128ch receive capabilities and 2ch pTx**

This is a Siemens 3T Skyra with 128-channel receive capabilities and 2-channel parallel transmit. The system comes with 128 RF channels, 40mT/m gradients and a 70cm patient bore for improved subject comfort (and mandatory for fetal imaging) and stimulus access. The scanner provides Siemens 32- and 64-channel head coils as well as an assortment of body arrays. Bay 1 also contains an assortment of audio, visual, and sensory stimuli equipment for fMRI studies, including digital high-definition rear projection, audio stimulation, and a subject response device. The stimulus equipment is set up to be run from a PC, a Macintosh, or the user’s laptop computer. Stimuli can trigger or be triggered by the scanner. Bay 1 is also equipped with a state-of-the-art power injector. Furthermore, the system is configured for simultaneous TMS/MRI operation, including a video navigation system for the TMS stimulator.

**Bay 2: Siemens 7T Terra MRI**

This is a 7T MAGNETOM Terra system with a 60-cm bore which has CE and 510(k) approval for clinical use. Secure switch between research and clinical operation can be performed in less than 7 minutes. The system has a gradient strength of 80 mT/m and slew rate of 200 T/m/s, provides passive and active shimming, and is equipped with Tim (Total imaging matrix) technology, which provides up to 64 coil elements and up to 64 receive channels and 8-channel parallel transmit (in research mode), including a Siemens 32-channel head coil. The increased SNR allows for 0.2 mm in-plane resolution to visualize previously unseen structures, 0.14 cm³ voxel sizes for metabolic brain mapping (in research mode) and submillimeter BOLD fMRI precision to visualize sub-cortical activations. The system has multinuclear imaging capability. Bay 2 also contains an assortment of audio, visual, and sensory stimulus equipment for fMRI studies and rear projection, audio stimulation, a subject response device and an eye tracking setup. Stimuli can trigger or be triggered by the scanner. The user may operate the stimulus equipment from a personal laptop computer. Bay 2 is also equipped with a Siemens Syngo workstation for 3D image processing, cardiac evaluation, and quantitative image analysis.

**Bay 3: Siemens 3T Trio MRI**

This is a 32-channel Siemens Tim Trio 3T whole-body MRI scanner with an insertable 36-cm (gradient coil ID) head-only gradient. The whole-body gradient system uses the same gradients as the 1.5T Avanto (45 mT/m strength, 200T/m/s slew rate). It has 32 independent RF receive channels for phased array coils, including a Siemens 32-channel head coil and a home-built 32-channel head coil for the gradient insert. Bay 3 further features an insertable asymmetric head gradient coil (Siemens AC88) that is capable of 60 mT/m and slew rates in excess of 600 T/m/s at a duty cycle of 70%, allowing single-shot 3mm resolution EPI with an echo spacing of 300 µs at a sustained rate of 14 images/second. Bay 3 also contains an assortment of audio, visual, and sensory stimulus equipment for fMRI studies including rear projection, audio stimulation, a subject response device, and an eye tracking setup.

**Bay 4: Siemens 3T Prisma MRI**

This is a 3T Siemens Prisma fit, 128-channel whole-body MRI with a two-channel transmit system. The system features the Siemens XR200 gradient system with 80 mT/m gradient strength and 200 mT/m/ms maximum slew rate. Bay 4 is equipped with a full assortment of body imaging coils as well as Siemens 32-channel and 64-channel head-neck coils. Bay 4 is also multi-nuclear capable and an MGH-built 8-channel 31P head array is available. In addition, it contains an assortment of audio, visual, and sensory stimulus equipment for fMRI studies including rear projection, audio stimulation, a subject response device, and an eye tracking setup. Bay 4 has also been configured to allow simultaneous TMS stimulation as well as recording of simultaneous EEG.

**Bay 5: Martinos 7T MRI**

This laboratory supports an ultrahigh-field 7 Tesla whole-body MRI with 70 mT/m (200 T/m/s max slew rate) gradient set (SC72B) and 32 RF receive channels. The 7T whole body magnet (90 cm magnet ID) was built by Magnex Scientific (Oxford, UK). Siemens provided the conventional MRI console, the gradient and gradient drivers, and the patient table. The system is shielded by 460 tons of steel. Integration of these components and the design and construction of RF coils were performed jointly by MGH and Siemens personnel. With its high-performance gradient set, the system can provide better than 100 µm resolution and ultra-fast EPI readouts for reduced image distortion. The system uses a home-built 32-channel or 8-channel head array coil for human imaging. A selection of specialized coils is also available for *ex vivo*MR microscopy as well as primate imaging. The system has multinuclear imaging capability, and coils for 31P and 13C are available. The system has been upgraded by Siemens to contain 8 independent 1kW transmit channels capable of simultaneous parallel excitation with different RF pulse shapes for B1 shimming and/or parallel transmit methods such as transmit SENSE. The 7T scanner environment includes a visual display system and a button box for acquiring subject responses in the scanner. A MedRad power injector is installed in the Bay for the injection of gadolinium contrast agents.

**Bay 6: Martinos 3T MR/PET (head-only)**

The combined MR-PET system (Siemens Medical Solutions) consists of a 3T Siemens TIM Trio 60 cm (RF coil ID) 32-channel whole-body MRI with the BrainPET head camera insert for simultaneous MR-PET acquisitions. The BrainPET prototype is a dedicated brain scanner that has 32 detector cassettes, each consisting of 6 detector blocks, each made up of a 1212 array of lutetium oxyorthosilicate crystals (2.52.520 mm3) read out by magnetic field–insensitive avalanche photodiodes (APDs). The transaxial and axial fields of view are 32 cm and 19.125 cm, respectively. The 3T MR system is equipped with the standard “TIM” 32 RF channel receivers, accommodating up to 32 element array coils.

This system has EPI, second order shimming, CINE, MR angiography, diffusion, perfusion, and spectroscopy capabilities for both neuro and body applications. It uses the same gradients as the 1.5 T Avanto (Bay 2; 45 mT/m strength, 200T/m/s slew rate).

Bay 6 also contains an assortment of audio, visual, and sensory stimulus equipment for fMRI studies including rear projection, audio stimulation, subject response device, and eye tracking setup. The system contains one of the first PET cameras capable of simultaneous PET acquisition during MR acquisition, and is located adjacent to the research cyclotron. The PET system is a head-only insert camera.

**Bay 7: Siemens 3T MMR MR/PET (whole-body)**

The Biograph mMR scanner (Siemens Healthcare Inc.) consists of a 3T whole-body superconductive magnet with active shielding and external interference shielding and a whole-body PET scanner. It is equipped with a gradient system with a maximum gradient amplitude of 45 mT/m and a maximal slew rate of 200 T/m/s. Separate cooling channels that simultaneously cool primary and secondary coils allow the application of extremely gradient intensive techniques. This scanner is equipped with the “TIM” RF coils that were custom designed to minimize the 511 keV photons attenuation. The fully-integrated PET detectors use APD technology and LSO crystals (eight rings with 56 detectors blocks per ring, each consisting of 8×8 arrays of 4×4×20 mm3 crystals read out by a 3×3 array of APDs). The PET scanner’s transaxial and axial fields of view are 594 mm and 25.8 cm, respectively. The Biograph mMR scanner is also located adjacent to the research cyclotron.

Bay 7 also contains an assortment of audio, visual, and sensory stimulus equipment for fMRI studies including rear projection, audio stimulation, subject response device, and eye tracking setup.

**Bay 8: Human Connectome Scanner**

Siemens Skyra 3T platform. This is the “Connectome” scanner, which is based on a Siemens Skyra 3T with the 300mT/m SR=200T/m/s “connectome” gradients. The full gradient strength is available for maximum duty-cycle on diffusion images. Since the diffusion pulses and EPI readout have different needs (diffusion pulses need high Gmax and modest slew rate while EPI needs only a ~50mT/m at 200T/m/s slew rate), the combination of 300mT/m and SR=200T/m/s is potent and usable for diffusion imaging without peripheral nerve stimulation. This gradient strength is useful for achieving high b value diffusion imaging in a short echo time (TE). For example, a b =15,000s/mm2 diffusion weighting can be acquired with a TE of about 55ms, compared to 120ms for a conventional 40mT/m scanner. This improves the diffusion images in two ways: First, it shortens the diffusion time and thus reduces blurring of the water PDF. Second, it increases SNR by about 3.5 fold by reducing loss to T2 decay. The system comes with 64 RF channels and a home-built 32- and 64-channel brain arrays available. The bore is reduced to 56 cm to accommodate the bigger gradients and the gradients have a linear region (to 5%) of 20 cm. Bay 8 also contains visual (rear projection) and auditory stimulation setups as well as a triggering interface.

**The Low-field MRI and Hyperpolarized Media Laboratory**

A custom-made 6.5-mT scanner in this laboratory is enabling novel research on spin-polarized materials and their use as magnetic tracers in vivo. The lab is working to develop orientation-variable imaging of human lung function with inhaled hyperpolarized noble gas (3He). This novel open geometry MR technology allows imaging in a variety of orientations (i.e., subject may be standing, sitting, or lying down) and without the limitations of high-field imaging, which exclude subjects with implants, pacemakers, etc. By the process of hyperpolarization, which increases the atomic nuclear spin polarization, the NMR signal of noble gases such as 3He and 129Xe can be increased by four to five orders of magnitude, allowing their detection by low-field MRI scanners. Current research applications include studies of pulmonary physiology, e.g., to map ventilation and pulmonary oxygen concentration as a function of body orientation in the gravitational field.

**Mock Magnet**

The mock magnet is used to acclimate normal and clinical populations (children and adults) to the MRI environment in preparation for participation in MRI studies. The mock scanner is modeled after the Siemens 3T Allegra system in both structure and dimensions. Its parts include an original Siemens patient table, funnel and head coil. Transducers and recordings of scanner noise from the Siemens 1.5T (Sonata) and 3T are used to simulate the vibrations and pulse sequence noises associated with the actual scanning experience. Stimuli may be presented using headphones or a rear projection system; a mirror is mounted on the head coil (as also found in Bays 2, 3 and 4), and a button box is available for responding to stimuli. Potential subjects who are anxious about participating in MRI studies are gradually desensitized to the confined space of an MRI magnet tunnel through a series of training steps. A feedback system to help train subjects to remain still when in the scanner is being developed. The mock scanner is located near the Behavioral Testing Suite, and in close proximity to the 1.5T and 3T magnets.

## **Chemistry & Biomedical Laboratories**

**Cyclotron**

A Siemens Eclipse HP self-shielded 11 MeV cyclotron with single-beam extraction and a four-position target changer (targets currently available: 11C gas target, 18F fluoride water target, 18F F2 gas target, 15O2 target, 13NH3 water/ethanol target).

**Radiochemistry laboratory**

Includes 2 full-sized hot cells and six mini hot cells for automated radiochemistry, a GMP-qualified production facility with an isolator hot cell and a class-100 biosafety cabinet. Several synthesis modules have been installed, including: Explora FDG4 Module, Explora GN Module for general nucleophilic substitution reactions, Sofie Elixys Module, Hydrogen Cyanide Module, and 15O water module. In addition, a GE FxMeI, FxN, and FxM systems are on site and qualified. In addition to capabilities that allow us to work with 68Ga and 64 Cu isotopes.

**Analytical chemistry laboratory and a blood analysis laboratory**

Instrumentation in these laboratories includes automated gamma counter and multi-channel radioisotope analyzer along with an analytical HPLC system for quantifying metabolites present in the plasma whether venous or arterial blood draw location.

**Synthetic Chemistry Laboratories**

A suite four laboratories containing 12 fume hoods support chemical synthesis. These rooms consist of modern laboratory space equipped with acid-resistant benches, fume hoods, appropriate shelving and small equipment (glassware, pipettes, rotary evaporator, thermocouple controlled hot-plates, vacuum pumps, manifolds, shakers, analytical balances, pH and conductivity meters, centrifuges, several refrigerators, -20°C freezers, and a -80°C low temperature freezer, drying ovens, etc.). Major equipment in this space includes:

* 1 Agilent 1260 series and 1 Hitachi preparatory scale HPLC, both with UV detection for analysis and purification of new compounds
* FlexChem Hydra96 Liquid dispenser, 24- and 96-well reactor blocks, and a FlexChem rotating oven for parallel synthesis
* PS 3 Protein Technology bench-top peptide synthesizer (Rainin Instruments)
* QuixStand cross-flow benchtop filtration system for purification of synthesized compounds (A/G Technology)
* DuPont RT-6 medium-speed refrigerated centrifuge and benchtop centrifuge CL2 (Thermo Electron)
* Two freeze/dry systems (Freezemobile Sentry 2.0, Freezone Stopping Tray Dryer)
* Emrys Optimizer microwave synthesizer with autosampler
* Parr hydrogenation apparatus
* Two ISCO CombiFlash Companion personal flash chromatography systems with multi-wavelength monitoring

**Analytical Chemistry Laboratories**

These laboratories house an extensive collection of instrumentation to support analysis of chemical and biological samples, including:

* Jeol 500 MHz NMR with 54 mm bore 11.7T vertical bore, actively screened magnet with variable temperature capability. This instrument has 3 RF channels, each with complete waveform shaping capability. Channel 1 is highband, with 1H/19F observe, spinlock and decouple capability (100 W, 455-535 MHz). Channel 2 has broadband observe, spinlock and decouple capability (10-210 MHz, 300 W). Channel 3 is highband, with 1H/19F observe, spinlock and decouple capability (100 W, 455-535 MHz). The probe consists of a 5mm ROYAL HFX, triple-channel NMR probe (1H,19F, and X) with 3G/A\*cm Z gradient, and BB range from 31P to 109Ag. The probe is auto tune/matched and has VT capabilities for operation between -170 to +250°C.The system has a robotic autosampler for automated, unattended use. In addition to the spectrometer workstation, there is a second workstation for off-line processing and analysis.
* Agilent 6310 LC/MSn ion trap mass spectrometer with a complete 1200 series Agilent HPLC (pump, autosampler, diode-arrary detector, , thermostatted column compartment, and vacuum degasser) Agilent 1100 LC/MSD SL quadrapole mass spectrometer system complete with binary pump, autosampler, multi-wavelength detector, thermostatted column compartment, and vacuum degasser)
* Six analytical scale HPLC (Agilent and Hitachi) with autosamplers, solvent degassers, and either multiwavelength or diode array UV detectors, and one HPLC (Agilent 1260 with binary pump, autosampler, multi-wavelength detector, thermostatted column compartment, and vacuum degasser) with an additional fluorescence detector.
* Agilent ICP-QQQ 8800 inductively coupled plasma - triple quadrupole mass spectrometer (ICP-MS) with an autosampler for elemental analysis, and interfaced to a complete 1260 series Agilent HPLC for tandem applications
* Hitachi F7100 spectrofluorimeter with a constant temperature cell holder
* Bruker 1.4 T mq60 Minispec low resolution NMR spectrometer for relaxometric characterization of contrast agents.
* Spectronic BioMate 5 spectrophotometer (Thermo Electron)
* Tecan 200 Pro fluorescence plate reader
* JEOL Accu-TOF 4G-LC Plus Direct Acquisition in Real Time (DART) mass spectrometer
* NuVant EZstat Pro potentiostat for electrochemical measurements
* MPT 798 Titrino equipped with an Orian ROSS Ultra pH electrode and temperature controlled titration vessel and Tiamo software. Hyperquad 2013 software for data analysis

**Radiotracer Development Laboratories**

A suite of three laboratories is specifically designed for the synthesis and radiolabeling of novel imaging pharmaceuticals. These rooms consist of modern laboratory space equipped with acid resistant benches, fume hoods, appropriate shelving and small equipment (glassware, pipettes, rotary evaporator, thermocouple controlled hot-plates, vacuum pumps etc.). Major equipment in this space includes:

* 3 Analytical Radiochemistry HPLCs (2 x Agilent 1100 systems consisting of vacuum degasser, quaternary pump, autosampler, diode array detector, and outfitted with Carroll & Ramsey Associates radiochemical detectors
* 1 Hitachi 7000 series HPLC (equipped with a Packard Flow Scintillation Analyzer) Bioscan AR-2000 radio-TLC Imaging Scanner
* ISCO CombiFlash Companion personal flash chromatography system with multi-wavelength monitoring.
* 2 PET Radiochemistry Hot Cells (1 - Capintec 3 Part Horizontal Door Hot Cell & 1- VonGahlen Single Door Hot Cell)
* Eckert & Ziegler Modular-Lab for automation of carbon-11 and fluorine-18 radiolabeling.
* Perkin Elmer Cyclone Plus Storage Phosphor System with medium format carousel, multi sensitive storage phosphor screens, and tritium sensitive storage phosphor screens.

**Biochemistry Laboratory**

This laboratory contains supreme Air LV Chemical Hoods (3), HPLC system (Lachrom Elite, Hitachi) equipped with Vydac columns and guard columns; BRUKER MQ60 NMR Analyzer mini-spec, BUCH1 Rotor Vapor R-114 and Heating Bath B-481, Mettler Toledo FiveEasy Plus FP20 pH meter, Forma Scientific –80°C Freezers (2), Thermo Scientific -80C Freezer, Forma Scientific –20°C Lab Freezer (2), Forma Scientific Blood Bank Refrigerator, Marvel Industries Freezer (5),) Spectra/Chrom CF-1 Fraction Collector, Mettler Toledo Balance (1), Mettler PM 400 Balance, OHAUS Precision Standard Balance (1), Harris 37°C incubator, GIBSON Energy Saver Refrigerator (1), 4C Cold Room, Savant Integrated Speed Vac System, Savant Refrigerated Vapor Trap RVT4104, GE pump, Edwards pump, Sorvall Legend RT Centrifuge, Beckman Allegra 6R Centrifuge (1), Eppendorf centrifuge 5417C (4);

Eppendorf refrigerated microcentrifuge 5424R, Biofire safe solvent cabinet, a vacuum line, a lyophilizer, Millipore Synergy water purification system and a water bath (Polystat constant temperature circulator, Cole Palmer).

**Cell Culture, Microscopy, Multimodal Microimaging & Macroimaging, and Flow Cytometry Laboratories**

The cell culture facility (Biocontainment Level 2) was established for the culture of normal tissue cultures, tumor cells, production of monoclonal antibodies and cell transfection. In addition, facilities exist for the isolation of primary cells and non-sterile culture conditions. The tissue culture facility consists of two connected rooms (313 and 170 sq.ft) for continuous and primary cultures respectively and equipped with necessary cell culture equipment including NUAIRE Biological Safety Cabinets Class II Type A/B3 (4), Forma Scientific water-jacketed incubators (4), Sorvall TC 6 Centrifuge (2), Forma Scientific –20°C lab Freezer, Marvel Industries Freezer (1), Goldstar 4C Refrigerator(1), Taylor-Wharton Liquid Nitrogen storage tank, Fisher 37 C water bath, phase contrast microscope(Cambridge Instruments, MicroStar IV model 410), Fisher Scientific SpectroMaster (1), and Nikon TMS (2) phase contrast microscopes.

The microscopy facility consists of a dedicated room (193 sq. ft.) equipped with a Nikon Eclipse TE2000-S fluorescence microscope with flow chamber and LiveCellTM capability, and a Nikon Eclipse E400 microscope. All fluorescence microscopes are connected to computers with software for image processing). This laboratory has additional lab space for tissue processing and histology.

The multi-modal microimaging facility is equipped with a SPECTRAMAX DROP Absorbance reader with SpectraDrop Micro-Volume Starter Kit and SoftMax Pro software(Molecular Devices, Sunnyvale, CA), which is capable of reading a wide range of formats including dual-mode cuvette port and 6-384 microplate reading capability. Endpoint, kinetic, spectrum and area-well scanning read types and PathCheck® allow homogeneous and heterogeneous microplate assays to be performed. In addition, the facility is equipped with a HITATCHI F-7100 Fluorescence Spectrophotometer.

Flow cytometry services are available through the MGH Ragon Research Center at MGH. The facility contains two FACScalibur machines dedicated to research for flow cytometry analysis that are available 24 hrs a day, and in addition offers a FACS sorting service with dedicated technical staff. Full training is provided to any investigator within the Martinos Center by fully trained technical staff within the AIDS research center.

**Molecular Biology Laboratory**

This facility is fully equipped for isolation, purification and production of DNA, cloning, DNA transfection and gene therapy investigations. The laboratory is equipped with NUAIRE Biological Safety Cabinet Class II Type A/B3 (2), VWR Scientific Low temperature Incubators (2), Perkin-Elmer DNA Thermocylcer 480 (2), VWR Scientific Transilluminator, SpectroLine UV Transilluminator Select Series, Bio-Rad Sub-Cell-GT, and a Whirlpool microwave.

**Biochemistry Laboratory in Building 149**

Additional wet lab space in Building 149 contains two fume hoods, a refrigerator/freezer, a –80°C low temperature freezer, a fire-safe solvent cabinet, centrifuges, vacuum line, lyophilizer, table-top surgical microscope, ultrafiltration apparatus, deionized water supply and laboratory bench space.

**Animal Surgery Laboratories**

The Martinos Center has three dedicated areas for animal surgery and scanning preparation. Room 137 is equipped with 3 workbenches, 2 independent inhalation anesthesia systems capable of using Halothane or Isoflurane, floor-standing Zeiss operating microscope, table-top operating microscope, Radionics bipolar coagulator, Ivy Systems physiologic monitor capable of monitoring blood pressure, temperature, and heart dynamics. This unit also has a built in pulse oximeter, Instrumentation Lab blood gas analyzer, and 2 temperature controlled water blankets. Room 94T is equipped with 1 workbench, 1 inhalation anesthesia system capable of using Halothane or Isoflurane, floor standing Zeiss operating microscope, temperature-controlled water blanket. Room 1067 is dedicated to large animal surgery and prep and is equipped with 1 workbench, an operating table, an inhalation anesthesia system capable of using Halothane or Isoflurane and a temperature controlled water blanket.

**Transcranial Magnetic Stimulation Facilities**

Stereotactically navigated transcranial magnetic stimulation (TMS) can stimulate the cerebral cortex noninvasively at precisely defined areas or to interrupt neuronal networks at specific locations and latencies, and when combined with simultaneous EEG / fMRI and DSI tractography can be used as an exceptionally powerful test bed for specific hypotheses regarding structural and functional connectivity. The Martinos Center TMS Lab is equipped with two MagPro X100 w/ MagOption stimulators, multiple MagPro (including MRI-compatible and liquid-cooled) coils, Nexstim eXimia Navigated Brain Stimulation (NBS) frameless neuronavigator, and Nexstim eXimia EEG system comprising 60 EEG and 6 EMG channels. The laboratory is inside a Braden Shielding electrically shielded room. Computer-controlled visual, auditory, and somatosensory stimulation systems as well as behavioral response monitoring are available in the laboratory. Our comprehensive analysis software suite allows integration of TMS, EEG/MEG/EMG, MRI, and fMRI data. The TMS laboratory is located within the Harvard Catalyst CTSC Biomedical Imaging Core (see below, co-located with the imaging laboratories above), which is equipped to support clinical and pharmacological studies and experiments that require advanced physiological monitoring.

**Behavioral Testing Laboratory**

The behavioral testing suite, located on the second floor of Building 149, provides a quiet and controlled environment for neuropsychological testing, developing and piloting behavioral paradigms, and running pre- and post-scan experiments with children and adults in human studies. It consists of two testing rooms with one-way mirrors (rooms 2236, 2234), separated by a control room (room 2235), which may also serve as an observation station or additional testing space. Each of these rooms is equipped with PC and Macintosh computers and a button-press response box (with millisecond accuracy). These response boxes are identical to those used in the MR research bays, allowing for portability of the paradigms developed in the behavioral setting. Auditory stimuli may be presented via speakers in sound-field or over headphones. A digital audio tape recorder, microphone, touch-screen monitor, video projector and projection screen are also available for stimulus presentation and/or recording subject responses. Transfer of experimental paradigms and data backup may be accomplished with removable media.

**Biomaterials Laboratory**

This laboratory, physically integrated within the High Field Spectroscopy room, contains a Carver (Wabash, IN) 25 ton microprocessor-controlled hydraulic press, a Spex Industries (Edison, NJ) cryogenic grinder, and a computer controlled Lindberg/Blue M (Watertown, WI) 1200 °C 3 inch tube furnace, which are used for preparation and analysis of biomaterial specimens and implants. A special MRI-compatible furnace, capable of 950 °C operation within the 4.7 T magnet, equipped with a quadrature birdcage RF coil, was engineered and fabricated in the Biomaterials Laboratory for in situ studies of high temperature materials processing.

**Histological Analysis Lab**

This laboratory is equipped with a Canon digital camera, camera stand and tripod for photographing blockface images prior to sectioning. For tissue sectioning, this laboratory is equipped with a Leica 2000R microtome for cutting frozen sections. A histological staining area, immunocytochemical reagents, image analysis and stereology (MicroBrightField Bioscience, Inc.) equipment are available for quantitative analyses. Other resources include a Nikon 80i microscrope (with fluorescence and brightfield functions) (MVI, Inc, Avon MA) with motorized stage, to complement the stereology software (MicroBrightField Bioscience, Inc.). A Li-Cor Oydessy Infrared Imaging System (Licor Biosciences, Lincoln NE), located in Dr. Brad Hyman˙s laboratory is available to Center investigators, for digitizing histological sections.

**Electronics and Machine Shops**

Instrumentation for design, construction and repair activities is distributed among three locations: (1) Bay 2/Bay 3/High Field Laboratory; (2) Bay 4/Bay 5/9.4 T Lab; and (3) Photon Migration Lab. The shops are equipped with tools for working with electronic circuitry, fiber optics and mechanical devices; equipment for fabrication of printed circuit boards; instrumentation for electronic testing and measurement of digital, analog, and RF circuitry (power supplies, voltmeters, R/L/C meter, RF power meter, oscilloscopes, gaussmeters, RF sweepers, an analog impedance meter, a digital impedance analyzer, and 5 HP RF network analyzers); and machine tools (drill presses, belt sander, grinder, band saw, 13 inch lathe, small milling machine). A stock of materials, hardware and electronic components is maintained. Machine tools are available to carry out complete computer-assisted design and fabrication of probes, animal carriers, gradient coils, etc. In addition to these resources, we have access to the MGH machine shop. Design and simulation tasks are supported within the Center with Windows 2000-based multiprocessor workstations running Remcom (State College, PA) BioPro 5.2 FDTD software for simulation of electromagnetic fields, Electronics Workbench Multisim 2001 (Toronto, Canada) for simulation of electrical networks, and IMSI TurboCad (Novato, CA) for mechanical design.

**RF Electronics Laboratory**

The RF coil laboratory consists of a ~500 ft2 area with 6 RF compatible work benches and 5 RF network analyzers; this space includes an electronics store-room for maintaining an extensive supply of RF parts and tools. The laboratory has a circuit board milling machine for creating circuit boards and coil layouts. There is also a 3D printer capable of making head-shaped models and helmet designs out of ABS plastic from CAD files generated from MRI volume scans (Dimension SST-1200). Additional equipment includes and RF spectrum analyzer, oscilloscopes (including a 1GHz BW digital scope), RF frequency synthesizers, and common electronics measurement and test devices.

# **Computational Resources**

**Computing Facilities**

The Center’s IT infrastructure consists of over 300 Linux workstations and 150 Windows and Macintosh desktops in offices and labs owned by individual research groups. There is a server farm with over 25 Linux servers that handles central storage, email, web, print, specialized processing and other shared services. The overall storage capacity of the center, including disks in local workstations and central storage, exceeds 2 petabytes.

The Center has a 126-node computing cluster for batch analysis jobs. Each node consists of two Quad Core Xeon E5472 3.0 GHz CPUs with 32GB of RAM, which together equal a total of 1024 compute cores available for batch jobs. Each node is connected by both a 1 GBit/s Ethernet link and a 20 GBit/s DDR Infiniband backplane. The Infiniband connection is used by parallelized jobs using MPI (message passing interface) to utilize multiple cores.

A 1.8 Petabyte storage cluster was installed and went online in May 2010. This storage cluster uses IBM DCS9900 storage arrays with 1200 SATA hard disks. The array controllers connect via redundant Fibre-Channel fabric to nine IBM HS22 Blade Servers running RedHat Enterprise Linux and the GPFS cluster file system. The 126-node computing cluster accesses the storage directly via GPFS client software while the rest of the workstations in the center use NFS. Backup is provided using a IBM TS3500 Tape Library with 1760 Cartridge Slots and four LTO-4 tape drives.

The IT facilities are supported by a small IT staff comprising one full-time PhD-level manager, who directs two full-time system administrators and a part-time support technician. The Center also has three full-time programmers who support in-house-developed software for data analysis and management. Available commercial software includes AVS (Advanced Visual Systems, Waltham, MA), MATLAB (The MathWorks, Natick, MA) and MEDx (Sensor Systems, Sterling, VA) for general-purpose computation, simulation and image analysis; and XWIN-NMR (Bruker BioSpin), Origin (OriginLab Corp., Northampton, MA), Nuts (Acorn NMR, Livermore, CA) for analysis of NMR spectra and the Siemens IDEA development environment for pulse sequences and image reconstruction software (Siemens, Erlangen, Germany). A substantial level of internal software development for image and data analysis is ongoing, using LAMP, C, C++, Java, FORTRAN, Ruby, Python, Perl and TCL/TK.

For high-performance image reconstruction the center is equipped with a custom-designed ScaleMP vSMP computer equipped with sixteen 8-core Xeon E5472 and 1TB shared RAM. In April 2013 the Center added a Dell PowerEdge R910 server with four 10-core Intel Xeon E7-4850 processors and 1TB of quad ranked, DDR3 RAM. The center also has three Dell PowerEdge R910 with four 8-core Intel Xeon X7560 processors and 256GB of RAM.

**Advanced Computational Image Processing and Analysis Center**

The Advanced Computational Image Processing and Analysis Center (ACIPAC) is a satellite of the Martinos Center on the MIT campus, established in collaboration with the MIT Artificial Intelligence (AI) Laboratory. The closely affiliated ACIPAC has extensive resources and expertise for solving practical image processing and analysis issues relevant to biomedical imaging. This Center is an important bridge to affiliated MIT research community, and allows MIT students a direct avenue to engage in biomedical imaging research at the Martinos Center.

**Education Area**

This area includes a conference room, audio-visual laboratory (equipped with computers, TV monitors, VCRs, carousels, teaching files and tapes), staff offices and general desk space for graduate students, postdoctoral fellows and junior faculty.