REVISED CURRICULUM FOR BIOMOLECULAR IMAGING AND BIOPHYSICS PH.D. PROGRAM

Introduction and Rationale

The Ph.D. Program in Biomolecular Imaging and Biophysics was formed because of changes in the curriculum to realign the former Medical Biophysics program with the many recent innovations in research in biomedical imaging, as well as its increasing importance to basic and translational research. These changes were approved in 2004, and the first student was recruited that year. To emphasize these changes a request was made in 2006 for an official change in the program name to ***Biomolecular Imaging and Biophysics***. Additional modest changes to the curriculum were approved in 2007 to accommodate the alignment of this and other School of Medicine Ph.D. programs as part of the Indiana University School of Medicine Biomedical Gateway (IBMG) program.

The revised program was launched with emphasis on imaging at the molecular and cellular scales, but the program did not have a large complement of faculty in the areas of *in vivo*/molecular imaging (imaging modalities typically associated with medical diagnostic imaging). The increased involvement of recently hired Radiology and Radiation Oncology faculty is the catalyst for this curricular revision. Moreover, the IUSM has an ongoing interest in promoting *in vivo*/molecular imaging as an area of strength, and existing faculty already constitute a sufficient base for this program. However, we will continue to recruit interested faculty from IUSM, the Sciences, and Engineering to participate in this program. This illustrates how this program is very much an interdisciplinary program that invites participation from other IUPUI faculty. In the past, faculty from Science (Biology, Physics, Chem.) and Engineering have participated in the program.

This program is one of the ten-degree granting programs participating in the IUSM open enrollment system, the Indiana University School of Medicine BioMedical Gateway (IBMG) program. The sharing of resources under this program has allowed the IUSM to strengthen its recruiting of quality graduate students. The IBMG system has also improved the attractiveness of the IUSM graduate program to potential students by offering students more choices and greater flexibility in their degree programs. The increased profile of the research and graduate programs of the school is consistent with the IUPUI goal to increase research output and the IU life sciences initiative.

Under the IBMG program, incoming students join a common first-year community and take a core first semester curriculum in basic biomedical science. In the second semester, students choose modular courses to track towards their specific areas of interest. The curriculum also includes professional skills, experimental design, career development activities, and ethics. First-year students have the freedom to choose laboratories from any of the 10 Ph.D. programs for their required 3 research rotations. At the end of the year, students choose a mentor laboratory and join the Ph.D. program from which they will ultimately receive their degree. The IBMG program at the IUSM better reflects the interdisciplinary nature of modern biomedical research.

We are now at a point where it is opportune to incorporate the full range of biomedical imaging approaches into the program. This will significantly strengthen the program by:

1) expanding the faculty, training opportunities and course offerings in imaging;
2) bringing extensive opportunities for translational research in diagnostic imaging within the compass of the program, consistent with the aims of the Indiana Clinical and Translational Sciences Institute (CTSI) and the campus emphasis in translational research;
3) enhancing opportunities for student-centered research collaborations between faculty in different areas of imaging;
4) Providing a critical mass of faculty and students to ensure a vibrant program.

The revised curriculum presented here will provide a rigorous curriculum that is designed to be flexible enough to allow students to tailor the coursework to their needs, but will ensure that all students receive a core foundation covering the fundamentals of imaging in all modalities. Students will also take foundational courses in biomedical science as part of the IBMG curriculum common to all School of Medicine PhD students.

Proposed Curriculum

Required Courses ***35 credits***

** indicates courses required for all IBMG students*
†indicates revised course syllabus
§indicates new course

G715 Biomedical Science I – Biochemical Basis of Biological Processes (3 cr)*
G716 Biomedical Science II – Molecular Biology and Genetics (3 cr)*
G717 Biomedical Science III – Cellular Basis of Systems Biology (3cr)*
Total: 9 cr
G718 Research Rotations (3 x 2 cr = 6 cr)*
G655 Research Communications Seminar (1 cr.)*
G505 Responsible Conduct of Research (1 cr.)*
G855 Experimental Design and Biostatistics (1cr.)*
G733 Introduction to Biological Microscopy (2 cr) *†*
G719 Survey of Radiologic Imaging Modalities (1 cr) *§*
G722 Fundamentals of X-Ray and PET Imaging (1 cr) *§*
G723 Fundamentals of Magnetic Resonance Imaging (1 cr) *§*
G613 Image Processing for Biological and Biomedical Applications (3 cr) *§*
A611 Seminar in Biomolecular Imaging (2 semesters) (2 x 1cr = 2cr) *§*
XXX First Year Spring Elective (1 cr)
Total: 20 cr

6 credits from the following:
G614 Methods in Biological Microscopy (3 cr) *§*
G734 Theory and Principles of Optical Microscopy (3 cr) *†*
G730 Quantitative Modeling for Functional and Molecular Imaging (2 cr)
G738 Advanced Topics in CT (2 cr)
G739 Advanced Topics in PET (2 cr)
G740 Advanced Topics in MRI (2 cr)
G742 Advanced Topics in Neuro MRI (2 cr)
Total: 6 cr

Independent Research **55 credits**

Total Minimum Credits **90 cr**

Sample Curriculum Sequence (First 2 years)
Two sample sequences are presented, depending on the Students Research interests.

a) Concentration in Biological Microscopy

First Year

Fall Semester

G715 Biomedical Science I – Biochemical Basis of Biological Processes (3 cr)*
G716 Biomedical Science II – Molecular Biology and Genetics (3 cr)*
G717 Biomedical Science III – Cellular Basis of Systems Biology (3 cr)*
G718 Research in Biomedical Science (1st Rotation) (2 cr)
Total: 11 cr

Spring Semester

G655 Research Communication Seminar (1 cr)*
G718 Research in Biomedical Science (2nd Rotation) (2 cr)*
G718 Research in Biomedical Science (3rd Rotation) (2 cr)*
G733 Introduction to Biological Microscopy (2 cr)
G719 Survey of Radiologic Imaging Modalities (1 cr) *§*
G722 Fundamentals of X-Ray and PET Imaging (1 cr) *§*
G723 Fundamentals of Magnetic Resonance Imaging (1 cr) *§*
XXX First Year Spring Elective (1 cr)
Total: 11 cr

Summer
G614 Methods in Biological Microscopy (3 cr) *§*
Total: 3 cr

Second Year

Fall Semester

G505 Responsible Conduct of Research (1 cr.)*
G855 Experimental Design and Biostatistics (1cr.)*
G734 Theory and Principles of Optical Microscopy (3 cr) *†*
G613 Image Processing for Biological and Biomedical Applications (3 cr) *§*
A611 Seminar in Biomolecular Imaging (1 cr) *†*
Total: 9 cr

Spring Semester

A611 Seminar in Biomolecular Imaging (1 cr) *†*

Required Courses ***35 credits***

b) Concentration in Molecular/In Vivo Imaging

First Year

Fall Semester

G715 Biomedical Science I – Biochemical Basis of Biological Processes (3 cr)*
G716 Biomedical Science II – Molecular Biology and Genetics (3 cr)*
G717 Biomedical Science III – Cellular Basis of Systems Biology (3 cr)*
G718 Research in Biomedical Science (1st Rotation) (2 cr)
Total: 11 cr

Spring Semester

G655 Research Communication Seminar (1 cr)*
G718 Research in Biomedical Science (2nd Rotation) (2 cr)*
G718 Research in Biomedical Science (3rd Rotation) (2 cr)*
G733 Introduction to Biological Microscopy (2 cr)
G719 Survey of Radiologic Imaging Modalities (1 cr) *§*
G722 Fundamentals of X-Ray and PET Imaging (1 cr) *§*
G723 Fundamentals of Magnetic Resonance Imaging (1 cr) *§*
XXX First Year Spring Elective (1 cr)
Total: 11 cr

Second Year

Fall Semester

G505 Responsible Conduct of Research (1 cr.)*
G855 Experimental Design and Biostatistics (1cr.)*
G613 Image Processing for Biological and Biomedical Applications (3 cr) *§*
G739 Advanced Topics in PET (2 cr)
A611 Seminar in Biomolecular Imaging (1 cr) *†*
Total: 8 cr

Spring Semester

A611 Seminar in Biomolecular Imaging (1 cr) *†*
G740 Advanced Topics in MRI (2 cr)
G742 Advanced Topics in Neuro MRI (2 cr)
Total: 5 cr

Required Courses ***35 credits***

*Students in the MD/Ph.D. combined degree program may substitute courses from the medical (MD degree) curriculum for IBMG biomedical science courses.

Students may count the Biomedical Science I, II, III courses (9 credits) towards an appropriate minor such as Life Sciences.

Subsequent Semesters: Remaining elective coursework for major and minor, research credits (balance of remaining credits for total of 90 credits). Students majoring in the Biomolecular Imaging and Biophysics program are expected to choose a biomedical science minors. Examples of the typical minors are (but not limited to):

Life science minor
Diabetes and obesity minor
Cardiovascular science minor
Cancer biology minor

The flexibility of the "life science" minor also permits a student to take courses from other IUPUI Schools such as Science or Engineering to compose this minor. Students that have specific interests in other areas will be free to explore available minors in those areas. Students will be required to register for Seminar in Biomolecular Imaging (A611) until they have completed their qualifying exam and advanced to candidacy. Students will be required to achieve at least a 3.00 GPA overall in didactic coursework to remain in good standing.

Candidacy/Qualifying Exam

Submission of a written research proposal in the area of the candidate's proposed dissertation research (in NIH grant format) to the advisory committee, followed by an oral presentation and defense of the proposal to the committee, during which the committee shall examine the candidate in knowledge in the field of imaging, biophysics and in the field covered by the minor.

New or Revised Courses Required for the Program

A611 Seminar in Biomolecular Imaging (1 cr per semester) (Name change for A611)
Day

Regular attendance and participation in designated seminar series presenting cutting edge research emphasizing imaging.

G733 Introduction to Biological Microscopy (2 credits) (expansion of current G733 to 2 credits)
Atkinson and staff

The course will be divided equally between lecture time and demonstration sessions covering the basics of light and electron microscopy, emphasizing approaches commonly used in contemporary biomedical research. Topics to be covered include: basic light microscope design, resolution limit of conventional light microscopy, contrast generation
in transmitted light microscopy, fluorescence and fluorescence microscopy, confocal and multiphoton microscopy, FLIM, TIRF, fluorescent probes for biological microscopy, using

FRET in biological microscopy, electron microscopy, preparation of biological samples for electron microscopy, image processing.

G614 Methods in Biological Optical Microscopy (3 credits) (new syllabus for existing G614)
Dunn and staff

This is an intensive 2-week summer experience offering hands-on training in all aspects of modern optical microscopy. Students will prepare specimens and collect images using the full range of optical microscopes available on campus. Students will be guided in the application of image methods for image processing, rendering and quantitative analysis. Topics to be covered include, preparation and labeling of fixed tissue samples, live cell imaging, epifluorescence imaging, FRET, imaging calcium, pH, membrane potential etc., FLIM, TIRF, confocal and multiphoton imaging.

Prerequisite – G733 or equivalent background

Theory and Principles of Optical Microscopy (3 credits) (new syllabus for existing G734)
Day and staff

Rigorous treatment of the fundamental principles underlying optical imaging methods. The course will combine didactic lectures, problem sets, discussions and review of relevant research literature. Topics to be covered include: interaction of light and matter, optics, physico-chemical properties of fluorophores (organic, biological, semiconductor), multiphoton excitation, fluorescence lifetime measurements, fluorescence correlation spectroscopy, super-resolution methods.

G719 Survey of Radiologic Imaging Modalities (1 cr) (new course)
Liang and Hutchins

A survey course of the main in vivo imaging modalities, including positron emission tomography (PET), x-ray computed tomography (CT), and magnetic resonance imaging (MRI). Basic physics principles of image generation are discussed. Fundamentals of performance and measurables for diagnostic medical imaging equipment are discussed.

G722 Fundamentals of X-Ray and PET Imaging (1 cr) (new course):

Liang, Yoder and Hutchins
Basic physical principles underlying x-ray and nuclear medicine imaging methods, including data acquisition, image formation, and data analysis. Scanner design and engineering are also discussed.

G723 Fundamentals of MRI (1 cr) (new course):
Dydak, Lin and Bansal

Physics and techniques of magnetic resonance imaging (MRI) and spectroscopy (MRS), emphasizing techniques employed in biomedical applications.

G613 Image Processing for Biological and Biomedical Applications (3 cr) (new syllabus for existing G613)
Shen and staff

Mathematical foundations and practical techniques for digital manipulation of images. Topics include image acquisition reconstruction, post-processing, visualization, and commonly used semi-quantitative and quantitative data endpoints. The course will provide an integrated view across all imaging modalities including both in vivo/molecular imaging and microscopy.

G730 Quantitative Modeling for Functional and Molecular Imaging (2Cr) (new course):
Hutchins and staff

Introduce biological background and theoretical strategies of mathematical models of kinetic modeling in PET, CT, and MRI. Topics include the derivation and implementation of the model equations, and methods for testing and validating new models and model variations.

G738 Advanced topics in CT (2 cr) (new course):
Liang and staff

(Permission of instructors required). In-depth working knowledge of X-ray computed tomography (CT) for graduate students who are interested in principle and application of CT in Medical Physics. The course focuses on the CT system design, image artifacts, and recent advances in CT technology. Review of CT applications in cardiovascular and other diseases.

G739 Advanced topics in PET (2 cr) (new course:
Yoder and Hutchins

(Permission of instructors required.) This course will cover advanced research applications of PET techniques. Topics include critical analyses of overall study design, methodology, and scanner instrumentation for both small animal and human PET studies.

G740 Advanced topics in Magnetic Resonance (2 cr) (new course)
Lin, Dydak and Bansal

(Permission of instructors required). Advanced 1H magnetic resonance imaging (MRI) methods and their applications, localized magnetic resonance spectroscopy (MRS), non-proton MRI and MRS.

G742 Advanced topic in Neuro MRI (2 cr) (new course)
Shen and staff

Permission of instructors required. (1) Physical principles of Neuro MRI: Basic biophysics of MR, Imaging formation, MR contrast and mechanism, artifacts and noise, Neuro MRI acquisition. (2) Neuro Physiology in MR imaging: Neuroanatomy primer, Neuronal to Hemodynamic activity, Neuro functional organization. (3) Neuro MRI data analysis:

preprocessing and data quality, issues in experimental design, spatial and temporal noise, statistical review for neuroimaging.