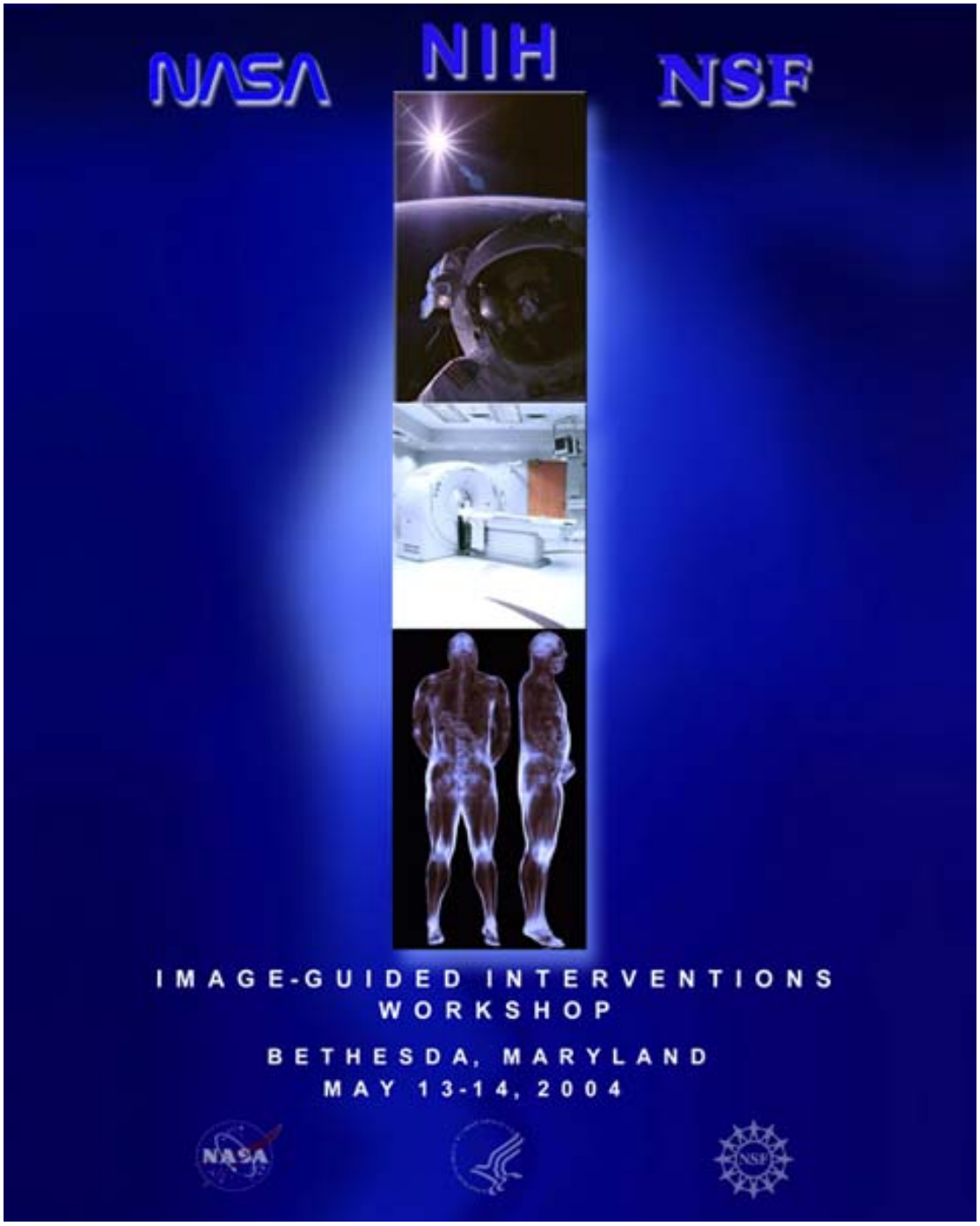
Final Report of the Image-Guided Interventions 2004 Workshop
May 13-14, 2004
Bethesda, Maryland



Report of the NIH/NSF Group on
Image-Guided Interventions
May 13-14, 2004

Sponsored by
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TABLE OF CONTENTS

NOTE: To navigate this WORD document, click on active hyperlinks (colored text) below. Use back arrow [←] in your WORD tools above to return to this table of contents.

EXECUTIVE SUMMARY

NIH/NSF/NASA Workshop on Image-guided Interventions

May 13-14, 2004

Background
The National Institutes of Health (NIH), the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) held a two-day, Image-Guided Interventions (IGI) workshop on May 13-14, 2004, in Bethesda, Maryland. The workshop was convened to review technological advances related to image-guided interventions used for surgery, biopsy, radiation treatment, and other image-guided therapies. The requirements for IGI have been evaluated in the past, including a 2002 workshop sponsored by the NIH and NSF. At this current workshop, recent progress in fields related to IGI was reported by NIH, NSF, and NASA grantees.

Purpose
The purpose of this workshop was to promote interdisciplinary team science, and provide recommendations to ensure that NIH, NSF, and NASA programs address important needs and issues associated with IGI by seeking input from the researchers and developers of image-guided technologies. Specifically, recommendations were solicited regarding: 1) overcoming barriers to collaboration; 2) facilitating interdisciplinary collaborations; and 3) advancing new technologies related to image-guided interventions. For the purpose of the 2004 IGI workshop, IGI was defined as a patient encounter where images are obtained (within or immediately before a procedure) and used for guidance, navigation, and orientation in a minimally invasive procedure to reach a specified target under operator control.

Recommendations
Workshop participants emphasized the need for greater collaboration among disparate disciplines and how Federal agencies might facilitate advances in image-guided technologies. The views and the derivative recommendations contained within this report are solely those of the invited grantee participants and do not reflect existing or contemplated policies and/or activities of any of the sponsoring Federal agencies. Specific participant recommendations are listed below.

- **Interdisciplinary Collaborations and Translational Research**
  - **A Strategic Plan to advance technologies related to image-guided interventions.** The plan, analogous to the NIH Roadmap, should outline specific steps and the timeframe to implement IGI-related recommendations.
  - **Interagency collaboration**. A core interagency team should serve as an ongoing resource to foster interdisciplinary and interagency collaboration.
  - **Interdisciplinary collaboration**. Tangible agency support of interdisciplinary collaborations should be a priority. Funding mechanisms

should encourage multiple principal investigators and interdisciplinary research.

- **Technology Recommendations**
  - **Increase the development and use of semi-autonomous and autonomous devices**. Consistent with the recommendation of the 2002 IGI workshop is the recommendation for the development of surgical robots, biopsy techniques, and other semi-autonomous devices for image-guided interventions.
  - **Heterogeneous data integration/fusion**. Multimodality image fusion, as well as the integration of other data and relevant information is needed for the further development of image-guided interventions.
  - **Real time modeling and 3D imaging.** Image processing requirements include the need for fast-acquisition and display technologies, including new tools for 3D visualization.
  - **Improvements in image acquisition.** Molecular and optical imaging, in particular, are expected to have a profound impact on image-guidance and intra-procedural monitoring.
  - **Platform technologies** for IGI systems should be seamlessly integrated for a wide range of clinical applications.
  - **Image-guided delivery of drugs, genes and therapeutic devices. F**uture developments will enhance the effectiveness of these types of therapies

Advances in tool development that enable minimally invasive procedures have the potential to replace more invasive technologies that are commonly used today. Minimally invasive technologies (those that require a small incision), or alternative treatments such as precisely targeted radiation treatment, will clearly benefit from recommendations to advance IGI. The most significant advantages of IGI are its less invasive nature, as well as greater time efficiency and cost effectiveness. Furthermore, increased precision of IGI may result in fewer complications and less damage to normal tissue.

There is an urgent need for IGI as in conjunction with positive screening tests for cancer, cardiovascular, and other diseases. Medicine is quickly shifting from a model of disease detection to one of disease prevention in asymptomatic at-risk populations, resulting in a critical need for image-guided diagnosis and treatment. A rapid, reliable, and cost-effective means of diagnosing at-risk individuals is needed, and IGI is virtually the only alternative for management of individuals who have a positive screening result but no overt signs of disease.

Biomedical images enable the interventionalist to look beneath the surface anatomy to visualize the underlying pathology. As a result, images can be used to localize pathology and navigate the anatomy for biopsy and treatment of disease. The recommendations from this workshop are aimed at rapidly accelerating advances in IGI, advancing the early detection of disease, reducing human suffering, and improving human health.

OVERVIEW

INTRODUCTION AND PURPOSE

The National Institutes of Health (NIH), the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) held a two-day, Image-Guided Interventions (IGI) workshop on May 13-14, 2004, in Bethesda, Maryland. The purpose of this workshop was to promote interdisciplinary team science, and provide recommendations to ensure that NIH, NSF and NASA programs address important needs and issues associated with IGI. Input was solicited from the researchers and developers of image-guided technologies, as well as the medical practitioners who will benefit from such technology advances.

Multi-investigator and interdisciplinary collaborations have a number of attractive features (Figure 1). Joint research efforts optimize governmental and nongovernmental funding through leveraged resources and reduced redundancy, as well as through the translation of technology from one application to another. At a time of tremendous pressure on Federal dollars for domestic and international priorities, collaborative research also becomes a necessity.

Figure 1: *Multi-investigator and interdisciplinary collaborations have a number of attractive features. (Figure courtesy of Dr. Dennis Matthews, NSF-CBST-UCD/LLNL)*

Collaborative research poses many challenges. Creating and sustaining collaborations takes precious resources such as time and funding. A common language must be forged among diverse communities to overcome culture and communication differences. Mutually beneficial goals must be identified and promoted to internalize what can be gained, and to justify the investment. Commitment to support the development of collaborative, targeted research must extend beyond initial good intentions or the positive experience of a singular event such as a conference or workshop. Partnerships must be sustained through changes among the parties involved.

For the purpose of this workshop, IGI was defined as a patient encounter where images are obtained (within or immediately before a procedure) and used for guidance, navigation and orientation in a minimally invasive procedure to reach a specified target under operator control (Figure 2). A common requirement for all IGI is a source of images; real-time interactive display linked to the intervention with a means of target definition in the context of real 3-D space (as distinguished from the abstract image space).

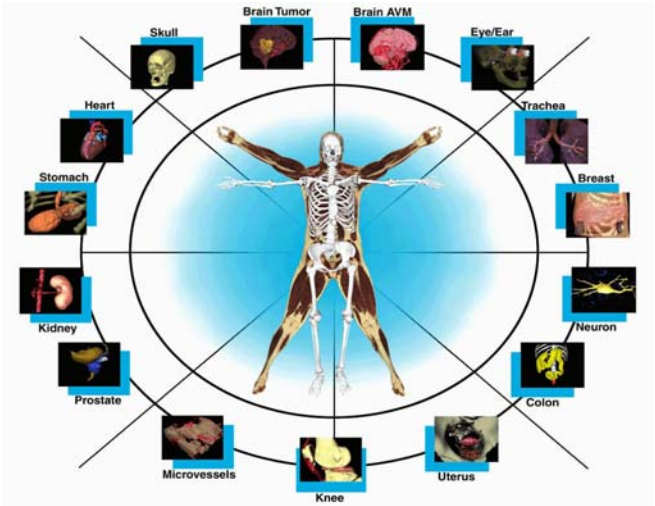

Figure 2: *For the purpose of this workshop, IGI was defined as a patient encounter where images are obtained and used for guidance, navigation and orientation in a minimally invasive procedure. Examples of Image-Guided Interventions include Brain surgery for Epilepsy, Guided Arrhythmia Ablation, Virtual Colonoscopy, Prostate Cancer Treatment, Cochlear Implants (Figure courtesy of Dr. Richard Robb, Mayo Clinic)*

This report identifies the challenges to multi-investigator with interdisciplinary collaborations, as well as potential opportunities for addressing them, from the perspective of IGI grantees attending this workshop. Also, input was sought from the diverse IGI research community in attendance regarding opportunities and directions for significant advances in basic imaging science and engineering related to IGI's role in improving human health.

METHODS

Thirty-five grantees from the three Federal agencies with IGI interests participated in the workshop. In addition, approximately 40 representatives attended from the sponsoring Federal agencies. The workshop consisted of several plenary sessions, small working group sessions, and general discussion sessions. Specifically, the grantees described their research and discussed how interdisciplinary collaborations might be formed and enhanced. Participants also provided their perspectives and recommendations to NIH/NSF/NASA representatives regarding the development of complementary Federal programs to address needs and gaps. IGI grantees provided answers to the following questions in advance of the workshop:

1. What are the challenges and barriers to collaborations among clinicians, engineers, and scientists?

2. How might collaborations among clinicians, engineers, and scientists be facilitated and/or enhanced?
3. What technological advances and requirements can we implement that will significantly advance IGI over the next five to ten years?

These three critical questions formed the basis of discussions within the small working group sessions that were convened following individual grantee presentations. The results of those discussions were presented and refined by the attendees during the general session. Thereafter, the large group synthesized and prioritized the consensus findings.

Following the conference proceedings, a writing group of session leaders and plenary speakers, facilitated by staff from the sponsoring agencies, prepared this written report. The report utilizes: 1) participant responses to the questions; 2) the small working group reports; and 3) the minutes of the general session discussions (including the prioritized lists of findings and recommendations).

While the grantee research presentations were of great interest, the scientific findings presented are not the major focus of this document. In some cases, the technological advances most likely to further image-guided technologies were highlighted by the scientific presentations. Therefore, while those individual reports of scientific activity funded by the sponsoring agencies are not included in this report, they may be found at http://www.nibib.nih.gov/events/IGI2004/. Also available at this site are the plenary session outcomes and this report.

FINDINGS

The workshop findings are organized along the lines of the three critical questions. . It should be reemphasized at this point that the views documented in this section of the workshop report are those of the invited grantee participants and do not reflect existing or contemplated policies of the sponsoring Federal agencies or the agency representatives who were in attendance.

1. What are the challenges and barriers to collaborations among clinicians, engineers and scientists?

There are three main areas that pose a challenge to effective multi-investigator and inter-disciplinary collaboration: resource constraints, institutional issues, and culture/communication.

Funding limitations:
Funding opportunities are a major concern of the research community. It is felt that Grant awards are often too small to encourage researchers to divert core funding towards the effort involved in establishing and continuing inter-disciplinary initiatives, even if such effort ultimately provides substantial return on investment. Grant funding is further

limited by the impact of indirect costs (i.e. subcontractor costs, university overhead rates). In addition, there is also a lack of seed funding for high risk, potentially high benefit collaboration. Time is also a limited resource. The demands of research and medical practice leave little time available for partnership formation. Also, the complexity of a given project may amplify these challenges. Furthermore, academic "credit," traditionally awarded only to the principal investigator, is proportional to indirect costs retained by the institution. Now, at a time when collaboration between and among investigators is essential, this system of academic accounting seems arcane, if not counter-intuitive.

Institutional Constraints

The host institution or organization may pose a barrier to multi-investigator collaboration. There may be constraints due to geographic distances between labs and other facilities. There may be additional institutional barriers to overcome, such as a reluctance to expand a research team, yield control, or acknowledge new ideas and approaches that result from collaboration (Figure 3). Even if there is support for new ideas and direction, institutional inertia may result in lengthy negotiations for terms of agreement and/or implementation delays once an agreement is signed. As organizations and agencies may alter strategic direction, collaborative partnerships may be impacted. Specific issues associated with intellectual property or patient rights may also pose challenges to collaboration.

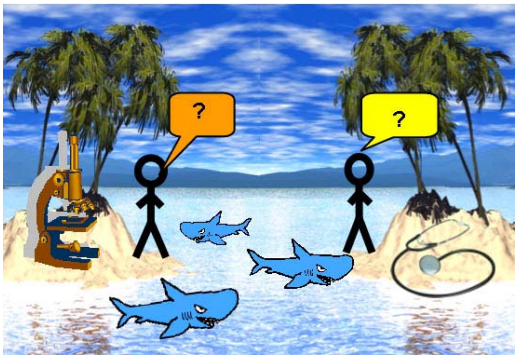

Figure 3: *There may be constraints due to geographic distances between labs and other facilities. There may be additional institutional barriers to overcome, such as a reluctance to expand a research team, yield control, or acknowledge new ideas and approaches that result from collaboration. (Figure courtesy of Dr. Agata Exner, Case* Western Reserve University)

Apart from resource or institutional issues, culture and communication differences also pose significant challenges to effective collaboration.

Communication and Culture Barriers

There are distinct professional languages and organizational cultures within the fields of medicine, engineering and technology development, and other research arenas that may inhibit the development of vital communication frameworks. Regarding the development of new knowledge, methods differ substantially between basic and applied sciences. Moreover, the medical need and the drivers for technology development may not be in synch. Doctors may desire simple medical solutions, while engineers may seek elaborate new technology. Conversely, technology development for a specific type of IGI may have near-term feasibility, while a given drug still in clinical trials will likely not enjoy widespread use for the foreseeable future. Research end points and metrics for success may also differ between the scientific and engineering fields of research. These

distinctions between professions are compounded by gaps in communication within an organization, and between organizations. Insufficient cross-discipline training and exposure to other professional environments reinforce professional isolation. Finally, constraints on physician time due to clinical practice responsibilities may prohibit successful collaborations.

The nature of research may be a contributing factor to cultural and communication barriers. Research projects promote individual achievements, not collaborative efforts. This approach rewards the efforts of the individual but does not provide sufficient visibility for group achievements, however justified. As a result, the benefits of collaboration are not made clear and there is a lack of institutional incentives for multi-investigator and inter-organizational group achievement.

There will always be the stunning technological or medical breakthrough by an individual. However, in general, barriers to collaboration result in insular research, which in turn may lead to fewer advances at higher cost.

2. How might collaborations among clinicians, engineers and scientists be facilitated and/or enhanced?

As noted above, there are a number of barriers to collaboration. At the same time, with creative program development and interagency support, most of these challenges and barriers can be overcome or, at the very least, minimized. The initiatives listed below outline methods to overcome these barriers. A key element to the success of any of these initiatives outlined below is the commitment by participants and support by respective agency management. Without this commitment, no initiative to facilitate multi-investigator collaboration can be developed or sustained.

Funding Mechanisms and Foci (Including an Emphasis on Translational Research)

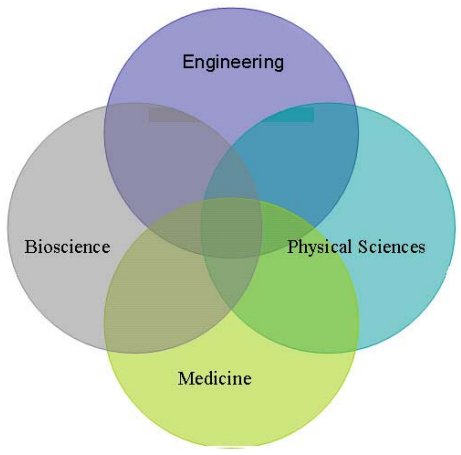

Figure 4: *Interagency bridge grants and joint research initiatives can foster multi-investigator collaboration along targeted research areas and encourage a cross section of researchers from several agencies to participate. (Figure courtesy of Dr. Dennis Matthew)*

Funding mechanisms such as NIH R01 and R21 grants could be supplemented in recognition of collaboration in order to raise the threshold of individual grants, enabling researchers to devote time and effort to forging multi-investigator partnerships without diminishing the core research thrust. This supplemental funding to reward collaborative approaches to a given research effort can be a powerful inducement for the research community to seek collaboration. Alternatively, existing funded research could be supplemented through an expedited process to foster collaborative efforts that might supplement such pre-existing

programs. Absent supplemental funding, the requirement to seek partnerships may appear to be an unfunded mandate, indeed a burden rather than a benefit. Seed money can also support risk-taking to explore high-risk, high-benefit research endeavors. Translational research funding mechanisms should also be promoted and expanded. Apart from additional funding to supplement core research, creative approaches to funding should be encouraged. Interagency bridge grants and joint research initiatives can foster multi-investigator collaboration along targeted research areas and encourage a cross section of researchers from several agencies to participate (Figure 4). Additional innovations that should be considered include an effective mechanism for the consideration of cluster grant applications and "bonus" scoring of applications that prominently feature collaboration among investigators. In addition, issuing specific program announcements and requests for applications that explicitly include interdisciplinary collaboration should be considered. Optimum effectiveness could be attained if these latter program announcements were issued and funded through interagency collaborations. Clearly, such collaborative ventures must be scientifically and technologically rigorous to optimize research goals.

Research resources and infrastructure should be leveraged across agencies. The most obvious area of leveraged research is interagency-supported research initiatives. Joint research grants, memoranda of understanding, and other formalized agreements can be developed with specific and measurable goals in support of each participating agency's strategic objectives.

Academia and industry are significant components to leveraged research efforts. Student research collaboration across agencies should be strongly supported. The importance assigned to industry's role in the transition from research to marketplace, can serve as an inducement for companies to participate in the research phase itself, including the commitment of resources. The Small Business and Innovation Research (SBIR) model should be expanded to include large businesses or graduates from the SBIR program, and a "reverse SBIR" approach fostered, whereby industry efforts may foster new research initiatives. Administrative procedures should be streamlined to maintain and encourage industry support Food and Drug Administration (FDA) participation can simplify the pathway to delivery of medical devices and integrated IGI systems. To leverage the input of physician researchers in collaboration with engineers and basic scientists, consideration should be given to salary support and real-world earning capacity. Agencies should consider fiscal support for infrastructure to facilitate collaborations, including open source software, databases, and mechanisms to reduce geographic and temporal barriers.

Tangible Institutional and Agency Support of Collaboration as a Priority

To overcome institutional barriers, reluctance, or inertia, there must be a core of dedicated individuals at the program level who understand the benefits of multi-investigator collaboration and devote significant time to establishing and sustaining collaboration and partnerships. Each agency must have managers who provide visible support for collaboration. Tangible results in terms of research advances, optimized funding through leveraged efforts, etc., will be the most persuasive metrics for continued

agency support of collaboration, and will be the most effective means of removing barriers and overcoming inertia. Specifically, there must be fiscal reward to the institution in order for collaboration to be seriously viewed as an important objective (this could be accomplished by additional funding to institutions that actively foster collaborative research efforts in order to support the infrastructure necessary for such collaborations). For collaboration to be viewed as a priority there must be academic recognition, opportunity for advancement for co-investigators, and equity among collaborating investigators in terms of interest and contribution for such collaborations to be sustained. (last line deleted as confusing)

Commonality of Communication, Culture, and Knowledgebase

Inter-disciplinary cross-pollination should be actively supported to provide scientists and engineers exposure to other research environments and to help forge greater understanding. Interaction should be on two levels: 1) short-term: individual workshops, meetings and conferences (particularly in support of on-site exposure by varied professional fields), multi-agency tasks targeting specific technical topics, interdisciplinary/interagency training; and 2) longer-term: cross-training for post-doctoral fellows and sabbaticals that immerse the clinician, scientist, or engineer in an alternative professional research environment for extended periods. Where possible, advantage should be taken of agency and/or professional society meetings' geographic proximity.

Formal initiatives include interagency symposia, workshops, specific technical workshops (i.e. IGI, photonics, and nanotechnology), research rotations for physicians, and clinical rotations for PhDs to bring together researchers in a common infrastructure (i.e. Stanford's Bio-X, NASA National Space Biomedical Research Institute, Scripps, Woods Hole Marine Bio-Labs, NIH funded IGI centers). These centers could also be used to host or sponsor individual workshops and conferences. New publications can be developed such as an NIBIB newsletter that discusses new technology being developed by funded researchers, medical technology needs suggested by other NIH institutes, and sections dedicated to collaborative initiatives with other agencies. Conversely, NIH collaborative research efforts might also be reflected in other agency publications. Formal academic initiatives could also be expanded such as MD/PhD programs and specific NIH funded training grants to improve integration of clinicians into basic science and engineering research.

Informal strategies to foster communication include better dissemination of agency Web-sites that are user-friendly. Networking among researchers should include virtual networking and collaboration on refereed (peer reviewed??) journals, including cross-discipline engineering and clinical journals. Sustained dialogue between engineers, basic scientists, and physicians should be strongly encouraged prior to grant submission.

Technology dissemination and awareness should be promoted through open-source software, databases, and related infrastructure. Ad hoc interagency and interdisciplinary teams can be organized to develop standards for data reporting and other recommendations to foster standardization where appropriate.

These efforts require careful planning in order to minimize any negative impacts of time commitment in support of meetings, special tasks, training, or detail assignments (researcher exchanges may be a good forum for quid-pro-quo sharing of workload). Without careful planning, researcher participation in short- or long-term initiatives may be viewed by agency management as a threat to the achievement of core research objectives.

It is also important for each investigator to be able to publish in the literature that is complimentary to but apart from each respective discipline's usual journals. However, in order for this to occur the stigma of publishing outside of one's discipline must be overcome and permission should be given for cross-publishing studies in clinical, engineering, and basic science journals.

A final recommendation to promote interdisciplinary research collaboration is to recognize and reward such collaborative programs, initiatives, and research accomplishments at the institutional and agency levels. Such recognition sends a powerful message that agency management values the benefits of interagency and multi-investigator collaboration and shared research efforts. Examples might include academic advancement, "credit" for all significant collaborators as principal investigators, indirect funding credit to all significant collaborators, and recognition on subsequent grant applications as a previously-funded (established) investigator.

Creation of a common vision and culture should also mitigate concerns over the pursuit of "technology in search of a use" as well as "clinical needs in search of a solution that already exists." Finally, an environment of collaboration should facilitate the translation of technologies pertinent to a given clinical area as well as address other areas of clinical utility not originally anticipated.

3. What technological advances and requirements can we implement that will significantly advance image-guided interventions over the next five to ten years?

Although the attendees' responses to this last query were greatly influenced by each researcher's specific area of expertise, certain themes emerged. Reponses from the workshop participants are divided into three

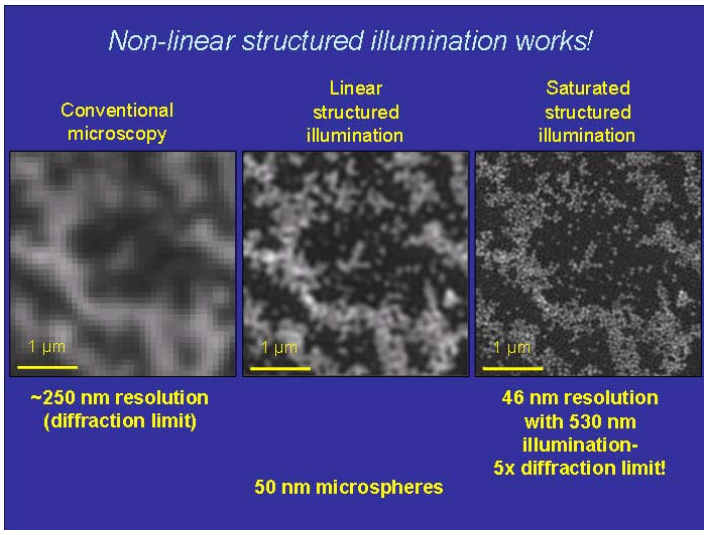

Figure 5: *High-resolution images for IGI will come from a variety of image modalities. Increase Resolution Imagery by Illumination (Figure courtesy of Dr. Dennis Matthews, NSF-CBST –UCD/LLNL)*

categories: 1) Image devices and image acquisition, 2) Image processing and data modeling, and 3) Interventions and other IGI advances.

Advances in Imaging Devices and Image Acquisition

Future IGI will incorporate real-time, multi-scale, 3-D imaging for guidance. High-resolution images for IGI will come from a variety of image modalities (Figure 5). Improvements in technologies include optical coherence tomography (OCT), local coils for MRI, UHF ultrasound, spectroscopic imaging, and endovascular imaging. Other improvements in imaging technologies poised to impact IGI include spectral domain OCT, OCT microscopy, improved fluorescent biomarkers, and multi-photon microscopy.

Low-cost, smaller scale devices will provide greater portability and widespread usage. Intelligent change detection will be provided through the application of imaging or sensor devices that enable detection of significant biological changes, quantifying, for example, bone loss or treatment response. Other advances in early detection (e.g., precancerous targets), monitoring and intervention at molecular level will profoundly impact IGI technologies and their effect on healthcare outcomes. These advanced detection and imaging techniques will provide new knowledge for small probes or catheters, laser and Radio Frequency (RF) ablation, coagulation, Micro Electro Mechanical Systems (MEMS) cutting and manipulation, US disruption, and placement of therapeutic implants (e.g., electrodes, sustained on demand drugs).

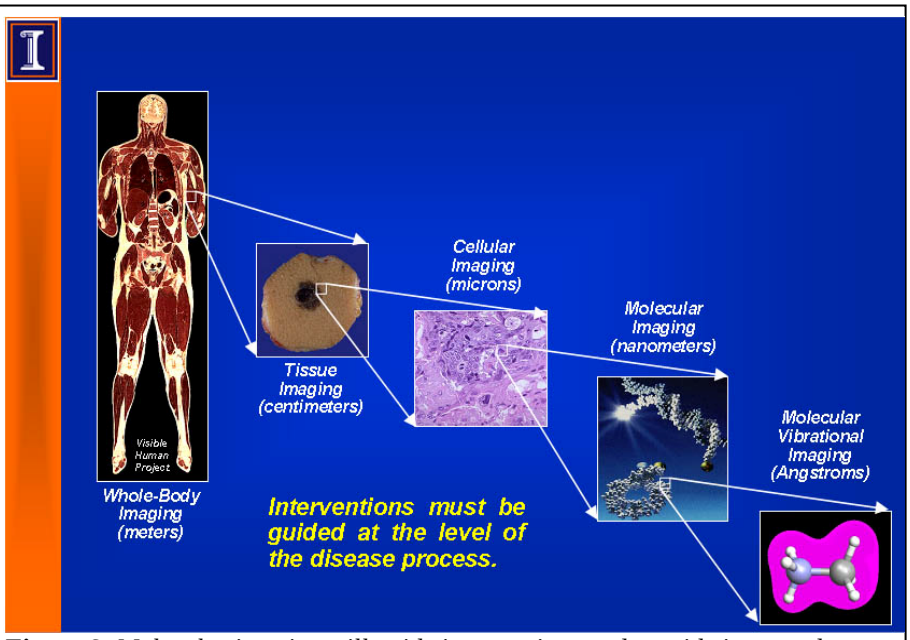

Figure 6: *Molecular imaging will guide interventions and provide improved target specificity. Optical Coherence Tomography (OCT) for Surgical Diagnosis Guidance, and Interventions (Figure courtesy of Dr. Stephen A. Boppart University of Illinois at Urbana-Champaign)*

Molecular imaging will guide interventions and provide improved target specificity (Figure 6). Advances in molecular imaging and imaging agents will be provided by improved dyes, signaling agents (probes), contrast agents, smart targeting molecules, fluorescent biomarkers, and novel markers.

Interventions and Other IGI Advances

Advances in IGI will be associated with greater use of semi-autonomous and autonomous devices. Consequently, several questions arise. For example, what will be the advantages of these semi-autonomous or autonomous devices, and how can the introduction of useful devices into mainstream medicine be accelerated? In other words, what is the IGI strategic plan that will make this happen? What are the most opportune procedures or studies that can be done to demonstrate the utility of these devices? The answers to these questions could be used to guide technology development.

IGI advances require the encouragement of core technology development of devices like MEMS, field programmable gate arrays (FPGAs), labs-on-a-chip, and other "smart devices" for intervention (e.g., sensor, imager, actuator in one, devices that provide important ancillary data such as temperature and pH). Furthermore, it is clear that advances in haptics and remote manipulation will play an important role for image-guided interventions. The measurement and understanding of human factors will be a critical element, as will the education and training of referring and practicing physicians.

Image Processing and Data Modeling

Heterogeneous data integration is used to combine knowledge from data that are acquired from disparate sources. Biomedical data that could be integrated for IGI applications might include patient medical records, multimodal images, genomic data, and other symbolic information. Image co-registration and innovative methods for display of integrated images will be critical to advancing IGI (Figure 7). Deformable image registration techniques will be invaluable for the deformation and co-registration of atlases and patient-specific images. Deformable registration and other advanced image processing and segmentation algorithms are also critical to the future of IGI. Image-based modeling and simulations will help predict outcomes of image-guided procedures. Tissue and biomechanical models will provide additional information for treatment planning and outcome prediction. A major area of potential opportunity lies in the integration of physiological and anatomical data in the planning, guidance, monitoring, and follow-up of IGI in many clinical conditions.

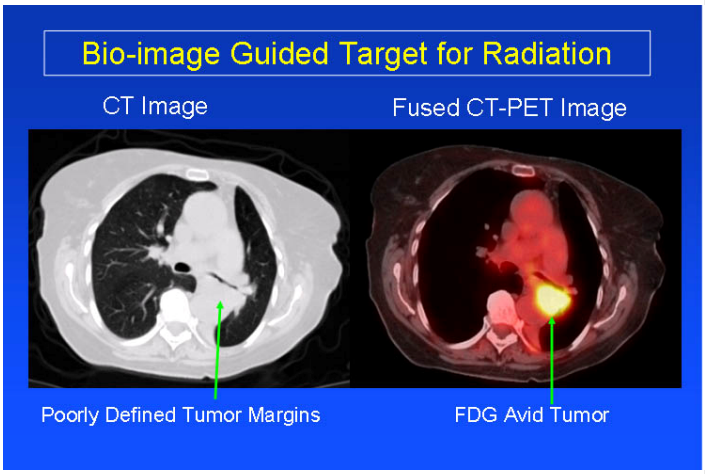

Figure 7: *Image co-registration and innovative methods for display of integrated images will be critical to advancing IGI. (Figure Courtesy of Dr. Noah Choi)*

Finally, biomedical and imaging informatics will play an important role for IGI in the future through software quality control as well as data standards and integrated imaging and interventional systems. Support of knowledge bases will not only bridge the multiple disciplines involved in IGI, but will also facilitate continued collaboration among federal agencies such as the NIH, NSF, NASA and the Department of Defense (DOD).

DISCUSSION

There is remarkable congruity among the findings related to all three questions posed to this group of researchers. In part, this congruity might be attributable to the methods used in the organization and facilitation of the workshop and breakout sessions. For example, the breakout sessions were organized to create a diverse mixture of basic scientists, engineers, clinicians, experienced investigators, newly funded investigators, and investigators funded through each of the sponsoring agencies. Staff members from the sponsoring agencies served as facilitators and moderators. Alternatively, one might argue that this congruity was achieved at the expense of diversity of potential attendees of the workshop. Specifically, the investigators in attendance were not fully representative of all the agencies or the various funding mechanisms that currently support IGI research. As well, researchers and clinicians who do not have current federal funding were not included among the participants. Nevertheless, the original premise for this workshop was to include only currently funded investigators from the sponsored organizations, specifically only investigators funded through certain funding mechanisms.

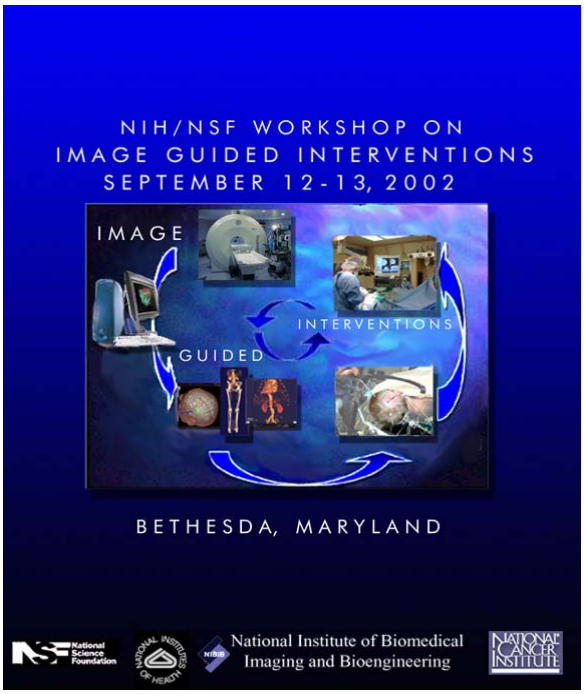

Figure 8: *Furthermore, the outcomes of this workshop are also congruous with the published proceedings from the NIH/NSF Workshop on Image Guided Interventions held in September 2002 http://www.nibib1.nih.gov/events/IGI2002/IGIWorkshop2002_FINALReport.doc.*

Despite these potential shortcomings, it is also interesting to note the congruity of ideas generated at this workshop with those of a previous multi-disciplinary conference focused on the creation of a Cardiovascular and Interventional Radiology Research and Education Foundation (CIRREF) strategic plan for oncologic IGI held in September of 2002, sponsored by the National Cancer Institute (NCI), NIBIB, American Chemical Society (ACS), American Association of Physicists in Medicine (AAPM),

American College of Radiology Imaging Network (ACRIN), and the CIRREF, and published in Journal of Vascular Interventional Radiology (JVIR) (J Vasc Interv Radiol 2004; 15:7-12). Furthermore, the outcomes of this workshop are also congruous with the published proceedings from the NIH/NSF Workshop on Image Guided Interventions held in September 2002 http://www.nibib1.nih.gov/events/IGI2002/IGIWorkshop2002_FINALReport.doc (Figure 8). Interestingly, some of the themes and ideas from this workshop are also congruous with general concepts from symposia and workshops unrelated to IGI such as BECON/BISTIC 2004 symposium entitled, "Biomedical Informatics for Clinical Decision Support: A Vision for the 21st Century" held on June 21-22, 2004 at the Natcher Conference Center, NIH, Bethesda , Maryland (for further information please see http://www.becon.nih.gov/symposium2004.htm) and the "Interagency Workshop On Research At The Interface Of The Life Sciences And Physical Sciences" held on May 10, 2004 (for further information please see http://www.nibib1.nih.gov/events/interagency/interagencyreport.pdf). Therefore, it is unlikely that the potential confounding variables such as the organization, facilitation, and attendee bias were significant effectors of the general themes and ideas generated.

One might ask what is new and different this time? First, the previously cited meeting related to oncologic IGI was specifically focused on that clinical area only. Second, that meeting was heavily focused on clinical needs assessment and the translation of technology into clinical applications. Third, the September 2002 meeting sponsored by the NSF and NIH was related to IGI technology. While this meeting was influenced by clinical needs to some extent, it was highly directed toward future technologies in imaging as used for guidance and monitoring. This current workshop provided a nexus of ideas ranging from early technology through translational efforts, from developing FDA indications to validating clinical utility from the perspective of basic and clinical scientists. Furthermore, this current workshop was not disease- or organ-system specific.

Another salutary outcome from this workshop is the identification of very specific barriers and challenges coupled with strategies to overcome them. The list of potential technological advances critical to the future growth and clinical application of IGI is also more specific than those previously generated.

However, all of these specific ideas will still be for naught without mechanisms to ensure their pursuit as appropriate. In this light, another basic idea that was mentioned with regard to overcoming barriers as well as technological advances was the creation of an IGI strategic plan. This idea was also highly rated as a "missing but necessary infrastructure for IGI" in the previously cited JVIR article authored by Rundback, et al. Such a strategic plan could be very useful in ensuring that continued progress is made, as it would contain not only a cohesive plan for forward movement, it would also ensure periodic assessments.

Another common area among the findings from this workshop and the previous workshops is the relative lack of prioritization among the ideas generated. A strategic plan could also serve to resolve this lack of prioritization.

Figure 9: *Image-Guided Interventions: It Takes a Village… First, the major stakeholders should be represented in the creation and/or review processes including, but not limited to, the investigator communities, (e.g., basic scientists, engineers, clinicians with representation from academia and industry), Federal and non-Federal agencies and foundations (e.g., NSF, NASA, NIH, FDA, CIRREF and American Heart Association), and advocates from target patient populations..(Figure courtesy of Dr. Richard Robb, Mayo Clinic)*

The generation of a strategic plan for IGI research initiatives could be crafted through a number of mechanisms. However, for such a strategic plan to have credibility, several attributes of the creative process should be strongly considered. First, the major stakeholders should be represented in the creation and/or review processes including, but not limited to, the investigator communities, (e.g., basic scientists, engineers, clinicians with representation from academia and industry), Federal and non-Federal agencies and foundations (e.g., NSF, NASA, NIH, FDA, CIRREF and American Heart Association), and advocates from target patient populations (Figure 9). Specifically, it will be important to ensure that representatives from the broad IGI research and clinical community participate in the strategic plan creation process. Second, the process should be facilitated to ensure a timely completion of the work product. Third, there should be a mechanism to ensure the plan remains a "living document," as this field is rapidly evolving and today's vision of the future may very well become yesterday's news. Based on these prerequisites, it may be useful to have a smaller representative group involved in the initial creation of a draft proposal with a larger, more expansive group involved in the refinement and validation processes.

A common thread on the topic of barriers and challenges pertains to funding mechanisms that are not in alignment with the concept of "team science." Team science in the corporate world is often possible, as the outcome of the team work is shared in all respects including intellectual property, cash flow, credit, and advancement. A system that recognizes only single PI status, even for projects that demand high-level, high-intensity collaboration among diverse disciplines does not foster team science. Also, the grant review and funding processes discourage multiple simultaneous, yet potentially linked, applications from fostering team science. Finally, the lack of coordination among granting agencies and study sections with regard to an overarching objective that might require varying levels of novelty and complexity is almost guaranteed to thwart team science. This issue must be resolved at a level greater than any individual investigator, institution, or agency. One potential mechanism for solving this is to make advances in IGI and minimally invasive therapies a focus for a "team science pilot initiative." In addition to funding an expansive, overarching goal that requires multi-disciplinary team science, such a pilot initiative could be used by the various funding agencies to work through the details of novel referral, review, funding, and oversight processes that might be inherent in the sponsorship of large team science initiatives. In other words, perhaps it

makes sense for this important area of IGI to become a test bed for the NIH concept of novel approaches to foster team science, potentially in conjunction with other Federal, non-Federal, and private funding sources.

Another theme that emerged to overcome barriers and challenges is the need to create a common culture among the diverse investigator communities and funding agencies with interest in IGI. The creation of a common culture is an effort that can be facilitated by Federal agencies. For example, Federal agencies can convene groups to address specific issue such as standards, nomenclature, quality assurance mechanisms and measurements. However, this matter also demands the active participation of professional organizations (e.g., societies, colleges, academic institutions, centers of excellence, resource centers, conference organizers, and industry). In fact, many of these entities have actively maintained inter-disciplinary barriers and rivalries for a variety of reasons that are beyond the scope of this document. An open and frank dialog is necessary to better understand if facilitating a common culture to advance the field of IGI is even possible and if so, what specific tactics should be employed. Such an open and frank dialog could also be facilitated by Federal agencies through the sponsoring of focused workshops and panels. Such workshops should have consistent, longitudinal representation of the involved communities in order to facilitate a convergence of interests about the field in general and the overarching goal of creating a common culture over time.

The fundamental outcome of the workshop is that a very specific set of recommendations and next steps should be vigorously pursued. For this to occur it will be necessary to achieve unprecedented cooperation and coordination among the concerned Federal agencies. A proposed set of recommendations and next steps immediately follow.

RECOMMENDATIONS AND NEXT STEPS

The recommendations and next steps are tied to the previously reported findings and discussion. In many instances the recommendations are related to specific findings and/or constellations of findings. In such instances, the recommendations are grouped thematically.

Theme I: A Strategic Plan is Needed for the Field of Image-Guided Interventions.
The creation and adoption of a strategic plan for the field of IGI that has broad acceptance within the research and clinical IGI communities is a high priority to foster timely advancement within this field. This strategic plan should be a "living document" coupled with a periodic review and update mechanism. The strategic plan should also contain within it the identification of several IGI "Grand Challenges" that should serve to spark inter-agency and multi-investigator collaborations coupled with appropriate funding mechanisms to support work of such overarching importance. The Strategic Plan itself as well as the Grand Challenges should contain goals or outcomes as well as intermediate checkpoints or benchmarks that are timed.

Specific Recommendations:

Near term:

- Convene an expert panel to create the first draft of the IGI Strategic plan through an iterative process that will involve pertinent concerned agencies, researchers, clinicians, representatives of industry, and patient communities.
- Identify IGI Grand Challenges together with intermediate accomplishments that will serve as measurable checkpoints and potentially as funding objectives.

Mid- or Longer term:

- Create a mechanism for periodic review, refinement, and dissemination for progress reports and revisions/updates to the Strategic Plan and its Grand Challenge.

Theme II: Facilitate Interagency and Multi-investigator Collaborations.
While there was overall consensus among workshop participants that collaboration, ranging from individual researcher to inter-agency collaboration, is needed to optimize capabilities and advance mutual research goals, barriers must be addressed for successful collaboration to take place. Attendees also indicated there must be clear, measurable follow-through and implementation for there to be any long-term benefits attributed to the workshop. Specific barriers of note are addressed in several of the subsequent themes, however, an overarching issue that was raised time and again relates to tangible evidence that such collaborations are valued and that the agencies themselves demonstrate collaborative behaviors. The workshop participants repeatedly stressed that

authentic interagency collaboration with effects tangible to the investigator community would be most welcomed. Currently, interagency collaboration is a small portion of individual agency budgets. The reader is referred to the report of the May 10, 2004, workshop on interagency collaboration ("Research at the Interface of the Life Sciences and Physical Sciences"); for further information please see http://www.nibib1.nih.gov/events/interagency/interagencyreport.pdf).

Specific Recommendations:

Near term:

- Establish and maintain a robust, core interagency team that will serve as an ongoing resource to foster inter-disciplinary and inter-agency collaboration within the field of IGI. A nascent group has already been established and should be nurtured and expanded.
- This inter-agency IGI group should continue to build on its ongoing activities but should also coordinate with follow-up activities related to the May 10, 2004, Interagency Workshop "Research at the Interface of the Life Sciences and Physical Sciences".
- The inter-agency group should collaborate within the field of IGI to make the strong case that IGI should be considered as a "team science pilot initiative." The pilot initiative should include a prerequisite review and funding mechanisms, an appropriate budget with specific funds identified to support collaborative activities, and the necessary infrastructure (see subsequent recommendations relative to resources).

Mid- or Longer term:

- Identify and fund, through specific program announcements, one or more pilot projects. The projects must include collaborative team science and will contain a specific funding mechanism to facilitate such collaborative research. The projects must also contain measurable outcomes that provide data on the value-added of the collaboration(s) to the projects. These pilot projects should be identified from among those contained within the aforementioned Strategic Plan and/or the Grand Challenges.

Theme III: Resources Allocated to IGI Collaborations Must Be Appropriate in Scope and Mechanism.

Resources are a critical element to achieve individual and interagency collaboration. Resources include time commitment and other forms of in-kind as well as financial resources in support of grant research. Furthermore, there must be specific and tangible recognition of the costs inherent in collaboration above and beyond the "science" itself. Some of these costs are start-up as the culture of team science must first be inculcated in the communities involved. Some of the costs are related to remodeling the current structure of grant funding and "credit" within the grantee recipient communities.

Specific Recommendations:

Near term:

- The interagency IGI group should work with existing "team science" workgroups to reinforce proposed efforts to nurture collaborations and the

proposed solutions to the existing barriers to inter-disciplinary collaborative research.

Mid- or Longer term:

- Interagency bridge grants should be generated for multi-investigator collaboration along targeted research areas.
- Proposal scoring criteria should include collaboration as a positive factor in grant and other funding consideration. Scoring must still ensure proposals maintain high quality.
- Explore enhancements to present grant funding mechanisms (e.g., NIH's R01 and R21 grants), raising grant thresholds to enable researchers to devote part of their grant dollars/time to research collaboration where appropriate.
- Provide seed money in support of high-risk, potentially high-benefit research projects. Multi-agency funding of such ventures can reduce individual agency risk.
- Funding mechanisms must allow and encourage multiple PIs in appropriate projects.
- Administrative burdens should be minimized which will also reduce the burden on resources. For example, collaboration with the FDA can help to simplify the translation of medical devices/IGI systems (also see Theme VI) for specific clinical applications and streamline the addition of subsequent clinical applications.
- Specific funds to support the collaborative aspects of a project. In addition, establish alterations in/improvements to grant review mechanisms. Finally, the matter of institutional accounting (for direct funds, indirect funds and intra-institutional contracts and collaborations) and "credit" for PI status must be addressed. The reader is also referred to the report of the 2003 Bioengineering Consortium (BECON) Symposium on Team Science (http://www.becon2.nih.gov/symposia_2003/becon2003_symposium_final.pdf.). The NIH has at least two working groups following up on the outcome of this symposium including the BECON Subcommittee on Interdisciplinary Research and Team Science (BSIRTS). The IGI inter-agency group should coordinate with other NIH groups, including BSIRTS, with activity in this area.
- The attendees were especially intrigued by the presentation focused on Team Science and believe that IGI could provide a high priority area for implementing a Team Science initiative. Specifically, collaborative IGI research on one or several of the previously identified Grand Challenges could be used to work through the issues stemming from the program announcement, review, funding, accounting, PI status, among others, that are recognized barriers to the pursuit of team science. These barriers are recognized across all NIH institutes and centers. An IGI pilot project could help to address many of the key concerns and move the general concept of team science forward into reality.

Theme IV: Specific Strategies to Overcome Institutional Barriers to Collaboration Should Be Implemented.

Institutional barriers to collaboration exist including geographic distances, historical, potentially unsupportive infrastructure, and inertia. These will remain impediments unless targeted strategies to overcome these barriers are identified and implemented.

Specific Recommendations:

Near term:

- Develop an informal survey to solicit input to identify specific institutional barriers to collaborative team science at each investigator's specific site and identify solutions to address these identified barriers.

Mid- or Longer term:

- Through the IGI interagency group, assess ways to improve communication among facilities such as laboratories that are geographically distant from one another and to enhance collaboration of facilities located near one another.
- Studies should be undertaken to identify issues associated with patient data rights and commercial intellectual property rights and how to address these issues.

Theme V: Specific Strategies to Overcome Cultural and Communication Barriers to Collaboration Should Be Implemented.

Communication and cultural differences hinder effective inter-disciplinary and interagency collaboration. There are communication issues between scientific, clinical, and engineering disciplines, between researchers aligned with academia and industry, among researchers within an organization, and between organizations. Individually and collectively, these issues hamper effective collaboration.

Specific Recommendations:

Near term:

- Implementation of a specific, user-friendly IGI Website that would contain pertinent information to all IGI communities including a communication function that would bring interested parties together. This Website could also be used to post and thereby facilitate the coordination of annual meetings and workshops sponsored by professional organizations and representatives from the various IGI research communities. Such a website could be established and funded by a variety of entities and coordinated by a variety of mechanisms.
- The participants found the May 13-14, 2004 IGI PI Workshop to be worthwhile. These participants believed that subsequent annual workshops would be beneficial, although recommendations were made for potential improvement of both format and content that should improve the return on investment for continuing to hold this meeting on an annual basis. The attendee roster could be broadened to include IGI PIs funded by additional Federal and non-Federal grantors. This annual IGI PI meeting should continue to be held.

Mid- or Longer term:

- Continue discipline-specific interagency workshops and conferences that include breakout group sessions on intra-and inter-organization communication and collaboration.
- Promote open source software, databases, and related support consistent with BECON/BISTIC findings.
- Encourage agency management to recognize and reward group efforts, within an agency and between agencies.
- Explore greater visibility for research co-PIs (also see recommendations related to funding and "team science" above).
- Encourage researchers to explore a broader range of professional publications for their research.
- Through the use of interagency team(s), support standard data reporting and other efforts to standardize communication where appropriate.
- Partnerships with industry should be encouraged (also see Theme VI).
- Provide individual growth opportunities through inter-agency detail assignments, for specific tasks or longer term (6 months to a year) agency researcher exchange programs.
- Create interagency "student and researcher exchange" programs, for a discrete task or for a longer term detail.

Theme VI: Academic and Industry Collaborations Should be Encouraged.

The participants provided many examples of gaps in the discovery, development, and dissemination cycle of IGI-related science and technology related to the interface between academia, and industry and especially at the critical nexus of regulatory interactions. Mechanisms to facilitate these relationships and interactions should become a focus of specific strategies including, but not limited to, the potential of specific program announcements and requests for proposals.

Specific Recommendations:

Near term:

- Ensure the dissemination of existing program announcements that might be useful to support such activities.
- Expand disease and/or institute-specific announcements to include broader objectives by issuing companion announcements from additional funding agencies.
- Engage the FDA in discussions to identify potential mechanisms to facilitate the critical bench-to-bedside translation.

Mid- or Longer term:

- Potentially issue IGI-specific funding announcements related to facilitating the translation of early technology to clinical delivery through phased awards.
- Partnerships with industry are to be encouraged through joint endeavor agreements, memoranda of understanding, or other cooperation documents.

- Administrative burdens should be minimized which will also reduce the burden on resources. An example is that collaboration with the FDA to simplify the translation of medical devices/IGI systems for specific clinical applications and streamline the addition of subsequent clinical applications.

Theme VII: Critical Informatics Infrastructure Should Be Created to Facilitate More Effective IGI Therapies.

Global access to complex data sets is critical in many aspects of medical practice, among them IGI. However, the demands of real time interactive data are significant. It is important that ongoing efforts relative to global access to such complex data include the consideration of the needs important to IGI. The reader is also referred to the report of the 2004 BECON-BISTIC Symposium ((http://www.becon2.nih.gov/symposium2004.htm.

Specific Recommendations:

Mid- or Longer term:

- Informatics needs relative to IGI should be incorporated within the proposed IGI strategic plan.

Theme VIII: Specific Image-Guided and Interventions Technology Objectives Are Critical to the Future Advancement of IGI Therapies.

While a complete compendium of the prioritized research advances considered critical to the advancement of IGI will likely await the completion and validation of an IGI strategic plan, certain areas of focus are strongly suggested by the proceedings and outcome of this workshop. These suggestions are cataloged herein for inclusion in the strategic plan and for potential funding announcements. Furthermore, as certain of these recommended areas of focus are or might become areas of focus for funding, the aforementioned Web-site and other mechanisms should be used to alert the various research communities of potential funding announcements relative to these topics.

Specific Recommendations for image-guided interventions technology research relevant to the field of IGI include:

- Real-time, multi-scale three dimensional imaging.
- Deformable single modality image mapping.
- Greater non-anatomic target specificity (e.g., molecular or physiological imaging).
- Multi-modal (heterogeneous) data fusion; including both imaging and non-imaging (e.g., physiological) data fusion in real-time.
- Image-based modeling available in real-time.
- Development, optimization, and validation of autonomous and semi-autonomous IGI devices.
- IGI should seamlessly integrate into a wide range of applications in the form of platform technologies.

- IGI systems for clinical applications in the delivery of drugs, genes and therapeutic devices.

CONCLUSION:

The field of IGI is at a critical juncture and would benefit greatly from interdisciplinary and interagency collaboration. However, such collaboration will require resources and facilitation. In order to ensure effective utilization of these resources, an IGI Strategic Plan including prioritization and checkpoints would be useful, but should be reflective of and created by the broad IGI research and clinical community. Novel funding mechanisms and revision of existing funding and review mechanisms will be helpful in order to facilitate such collaborations. IGI could function as a transagency test bed for such revised and/or novel mechanisms. Ongoing efforts to create a common culture among researchers and funding agencies with interest in IGI are necessary and should be supported. This report outlines in detail the specific strategies and tactics that the workshop attendees suggest to accomplish these outcomes.

APPENDIX I. WORKSHOP AGENDA

IGI Workshop
Thursday, May 13, 2004

OPENING REMARKS/PURPOSE OF MEETING (Washington Room)

7:00 – 8:00 AM	**Breakfast**
8:00 – 8:10 AM	**Welcome and Introduction of Staff** *Dr. John Haller,* *National Institute of Biomedical Imaging and Bioengineering,* *NIH*
8:10 – 8:25 AM	**Image-Guided Interventions: Definition of IGI & Purpose of Workshop** *Dr. Gary Dorfman,* *National Cancer Institute,* *NIH*
8:25 – 8:35 AM	**Collaboration Models for Similar Research Thrust and Agenda** *John Emond,* *National Aeronautic and Space Administration*

PLENARY PRESENTATIONS (Washington Room)

8:35-9:20 AM	**Image-Guided Interventions: It Takes A Village...** *Dr. Richard Robb, Scheller Professor in Medical Research* *Professor of Biophysics and Computer Science* *Director, Mayo Biomedical Imaging Resource,* *Mayo Clinic*
9:20-10:05 AM	**Applications of Biophotonics to Bioscience and Medicine** *Dr. Dennis Matthews, Director of Center for Biophotonics Science & Technology, University of California, Davis*
10:05-10:25 AM	**Break**
10:25-11:10 AM	**Optical Imaging for Human Exploration and Supporting Research** *Dr. DeVon Griffin, Glenn Research Center, NASA* *Bioscience and Engineering Institute,*

University of Michigan

11:10-11:30 AM **Interdisciplinary Research: The NIH Road Map Perspective**
Dr. Belinda Seto, Deputy Director
National Institute of Biomedical Imaging and Bioengineering,
NIH

11:30-11:45 AM **Group Photo**

11:45-12:00 PM **Pick up Lunch**

12:00-12:45 PM **Working Lunch**

Engineering Research Center for Subsurface Sensing and Imaging Systems
Dr.Badri Roysam,, Rensselaer Polytechnic Institute

12:45-1:00 PM **Instructions for Breakout Groups**

BREAKOUT SESSION 1: GRANTEE PRESENTATIONS

1pm-4:00 PM **RED Breakout Group (Washington Room)**
Facilitators: Richard Robb and John Haller
Assistant: Theresa Smith

Red Group: James Beach, George May, Noah Choi, David Dickensheets, Agata Exner, David Liang, Michael McConnell, Janelle Molloy, Kishwer Nehal, Peter Ramadge, Douglas Robertson, Badri Roysam, Allen Tannenbaum

GREEN Breakout Group (Georgia Room)
Facilitators: DeVon Griffin and John Emond
Assistant: Elijah Weisberg

Green Group: Mehran Armand, Vadim Backman, Stephen Boppart, Gabor Fichtinger, Kenneth Hoffman, Ioannis Kakadiaris, George Ojemann, Azhar Rafiq, Stephen Rudin, Oskar Skrinjar, John Triedman

BLUE Breakout Group (Connecticut Room)
Facilitators: Dennis Matthews and Bruce Hamilton

Assistant: Yantian Zhang

Blue Group: Darryl Bornhop, Frank Bova, Richard Boyle, Pierre Dupont, Daniel Hammer, David Huang, Robert Labadie, Robert Mah, Lev Perelman, Nirmala Ramanujam,

Each Grantee gives a 10 minute Presentation with 5 minute discussion of ongoing research

2:30-2:45 PM **Break**

2:45 – 4:00 PM **Grantee presentations** (Continued)

4:00-4:15 PM **Break**

BREAKOUT SESSION 2: DISSCUSION GROUPS

4:15-5:30 PM **RED Breakout Group (Washington Room)**
Facilitators: Richard Robb and John Haller

Red Group: Same participants as above

GREEN Breakout Group (Georgia Room)
Facilitators: DeVon Griffin and John Emond

Green Group: Same participants as above

BLUE Breakout Group (Connecticut Room)
Facilitators: Dennis Matthews and Bruce Hamilton

Blue Group: Same participants as above

3 minute presentation by each grantee answering the following questions (one minute per slide per question)

1. How to facilitate collaborations among clinicians, engineers and scientists like ourselves?
2. What are the barriers for collaborations?
3. What technological advances and requirements can we implement that will significantly advance image-guided interventions in the next 5-10 years?

5:30 PM **Adjourn**

Friday, May 14, 2004 IGI Workshop

COLLABORATION MODELS (Washington Room)

7:00-8:00 AM	**Breakfast**
8:00-8:30 AM	*Dr. Pettigrew, Director NIBIB*
8:30-9:15 AM	**Breakout Groups finalize slides summarizing Breakout Session 2 Discussion** **RED Breakout Group (Washington Room)** *Facilitators: Richard Robb and John Haller* **Red Group**: Same participants as above **GREEN Breakout Group (Georgia Room)** *Facilitators: DeVon Griffin and John Emond* **Green Group**: Same participants as above **BLUE Breakout Group (Connecticut Room)** *Facilitators: Dennis Matthews and Bruce Hamilton* **Blue Group**: Same participants as above
9:15-10:15 AM	**Presentations Summarizing Breakout Session 2** *Breakout Facilitators* (Three ten minute summaries of break out group's discussions with group discussion)
10:15-10:30 AM	**Break**
10:30 -10:50 AM	**NIH/NASA/NSF Presentations on respective programs**
10:50-11:10 AM	**Panel Question/Answer for the Federal Agency Representatives**

MEETINGS WITH AGENCY REPRESENTATIVES

11:10 – 11:30 AM	**Closing remarks and Adjournment** **Evaluation of meeting and feedback from participants**
11:30 – 12:30 PM	**Individuals and/or small groups meet individually with agency representatives to discuss potential collaborations**

BREAKOUT GROUPS AT A GLANCE

RED BREAKOUT GROUP: WASHINGTON ROOM
Facilitators: Richard Robb and John Haller
Assistant: Theresa Smith

RED GROUP: James Beach, George May, Noah Choi, David Dickensheets, Agata Exner, David Liang, Michael McConnell, Janelle Molloy, Kishwer Nehal, Peter Ramadge, Douglas Robertson, Badri Roysam, Allen Tannenbaum

GREEN BREAKOUT GROUP: GEORGIA ROOM
Facilitators: DeVon Griffin and John Emond

Assistant: Elijah Weisberg

GREEN GROUP : Mehran Armand, Vadim Backman, Stephen Boppart, Gabor Fichtinger, Kenneth Hoffman, Ioannis Kakadiaris, George Ojemann, Azhar Rafiq, Stephen Rudin, Oskar Skrinjar, John Triedman

BLUE BREAKOUT GROUP: CONNECTICUT ROOM
Facilitators: Dennis Matthews and Bruce Hamilton
Assistant: Susan Autry Conwell

BLUE GROUP: Darryl Bornhop, Frank Bova, Richard Boyle, Pierre Dupont, Daniel Hammer, David Huang, Robert Labadie, Robert Mah, Lev Perelman, Nirmala Ramanujam,

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Appendix III : Background Information

Questions

1. How to facilitate collaborations among clinicians, engineers and scientist like ourselves?

2. What are the barriers for collaborations?

3. What technological advances and requirements can we implement that will significantly advance image-guided interventions in the next 5-10 years?

Charge To Speakers, Session Facilitators and Participants

The NIH, NSF and NASA are seeking recommendations from the research community regarding advances needed in image-guided (IG) procedures, as well as recommendations regarding basic imaging science, engineering and medicine as they relate to IG therapies, minimally invasive treatments, IG biopsies, and IG surgical procedures.

Speakers:

1. Please use POWERPOINT only. Your presentation time is 45 minutes for the plenary session and 10 minutes for the breakout session 1. Suggested maximum number of slides is 5. Presentations should specifically relate to your research for the funded grant that you have been asked to present.
2. The three questions for the session 2, discussion groups should be presented in 3 minutes or less.
3. NIH, NSF and NASA request a copy of your POWERPOINT slides for the workshop notebooks and associated websites. Please do not include proprietary information you do not wish made public.

Breakout Session Facilitators

1. One of the two facilitators may present three POWERPOINT slides each that address the topic of the breakout session and ask specific questions for the purposes of stimulating a discussion and developing recommendations to NIH, NSF and NASA.

2. Following breakout session 2, one of the two facilitators will provide a 10 minute summary presentation to all workshop participants, summarizing the discussion and recommendations of their particular breakout session. (NIH, NSF and NASA staff will assist in preparing summary slides).

Participants Changing Sessions

1. The breakout session participants for all 3 breakout sessions have been identified in advance and assigned a session room and color. We will consider a *limited number* of participants' requests to attend a different session, and this request should be made to Theresa Smith during the first morning of the workshop.